REVISITING GORDION'S PEBBLE MOSAIC PAVEMENT: EVALUATING RE-BACKING TECHNIQUES AND INVESTIGATING ALKALI-SILICA REACTION

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Dedication

To my wife,

whose support sustains me and

who inspires and motivates me every second of every day...

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Chapter 1: Introduction

The Megaron 2 Pebble Mosaic

The Megaron 2 mosaic is an interior pavement that was discovered at the archaeological site of Gordion near Yassihöyük in Western Turkey. Dated to the 9th c. B.C.E., the pavement is the earliest known decorative floor mosaic in the world.¹ The mosaic pavement originally measured approximately 32' x 35' and was composed of white, dark red, and dark blue-grey pebbles in a mud clay bedding. As described by Rodney Young, the director of excavations at Gordion at the time,

...they were small and oval or almond-shaped, their maximum length only two to three centimeters (one to one and a half inches). The binding material, whatever it had been, had lost its cohesiveness and many of the pebbles were loose, which made the cleaning of the floor difficult in the extreme. Dark red, dark blue, and white pebbles were used, with an occasional yellow one or gray where patches or repairs had been made later.²

The pebbles were uncut and arranged to form a random assortment of geometric patterns

around an off-center hearth, approximately 6.5' wide. The patterns are generally believed to have

been adapted from Phrygian textiles and appear to be common patterns that, as Young notes, "can

be matched at Gordion on the engraved bronze work, the inlaid wooden furniture, and the painted

pottery of the same period."³ Furthermore, Young asserts that,

The general effect is that of a rich oriental rug or carpet, giving a strong impression of color with little emphasis on overall design. Most of the simple geometric motives moreover are of a sort easily and endlessly produced in the weaving of textiles.⁴

¹ Dating for the mosaic has been determined contextually based on the approximate date of 800 B.C.E. for a major fire that burned much of the Citadel Mound. The burial of Megaron 2 and subsequent reconstruction of the site above this level suggest a 9^{th} c. B.C.E. date for Megaron 2 and the mosaic.

² Young 1965, 10.

³ Ibid. 12

⁴ Ibid. 13.

While the Megaron 2 mosaic is not the only pebble mosaic from this period at Gordion, it is certainly the most complete and decorative and represents the earliest known attempt to engage with a pavement as a form of art.⁵

Brief historical review. The mosaic was created sometime during the Early Phrygian Period of Gordion which lasted between approximately 900 and 800 B.C.E.⁶ The original location of the mosaic was in the main room of Megaron 2 (Figs. 1.1 and 1.2). Archaeological evidence shows that a fire destroyed much of Gordion's citadel mound around 800 B.C.E. The condition of the mosaic at the time of discovery showed evidence of damage and possible ancient repairs. It is unknown when the damage or repairs occurred or what initiated them, but based on the city-wide rebuilding campaign after the fire, it is likely that the repairs occurred before the fire since the entire complex was intentionally buried and rebuilt over. Evidence for these repairs are circumstantial and were suggested by Young as a way to explain small inclusions of yellow and gray pebbles that are anomalous to the overall mosaic.⁷

⁵ Young notes that all of the rooms in Megaron 2 (called the West Phrygian House in his 1957 published Preliminary Report) were paved with pebble mosaics (Young 1957, 322).

⁶ Sams and Voigt 2011, 155.

⁷ Young 1965, 12.



Figure 1.1. Aerial view of the Gordion Archaeological Site with Megaron 2 highlighted (Digital Gordion: Iron Age Gordion – Early Phrygian Gordion, http://sites.museum.upenn.edu/gordion/history/ironage?start=1).



Figure 1.2. The Megaron 2 mosaic in situ after discovery in 1956.

Excavation. When the mosaic was discovered in 1956, it was completely uncovered and documented with photographs and a nine foot by nine foot watercolor by the site's field artist, Jonathan Last (Fig. 1.3). Although the watercolor is extremely detailed, comparisons to photographs and the existing panels prove that it is not entirely accurate. Young's field notes, excavation reports, and other publications discuss the design and materials of the mosaic, place it within a greater context of the megaron and the citadel, and discuss its role in the historical development of mosaic pavements.⁸ At the end of the excavation season, the mosaic was reburied, likely until a plan for its removal could be devised.⁹

⁸ Young 1957; Young 1965.

⁹ Young comments on the burden archaeological mosaics impose on excavators, saying that "Mosaics cannot in good conscience be simply ripped up to get them out of the way..." and "Lifting them is likely to be expensive, the work of trained experts who are seldom available nearby" (Young 1965, 4).



Figure 1.3. Jonathan Last watercolor (Gordion Archive, University of Pennsylvania Museum of Archaeology and Anthropology).

Conservation. During the mid-20th century, it was common practice for archaeological mosaics, particularly those that were deemed historically or artistically valuable, to be removed, or "lifted," from their original location and brought to museums for conservation and display.¹⁰ Techniques could vary, but generally if the mosaic was large, it would be cut into sections and each section lifted up and out with a portion of its bedding mortar. Alternative methods of detaching and "rolling" a mosaic pavement on a roller were also developed, especially when the mosaic was large and intact.¹¹ In 1963, the Megaron 2 mosaic was re-exposed, divided into 33 separate panels, and lifted. Young explains briefly that the decision concerning which portions of the mosaic to lift was based on the degree of preservation.¹² There is no written documentation of the process, but according to color photographs recently provided by the late Crawford Greenwalt, the panels were faced with a gauze-like textile and unknown adhesive, cut, and lifted in sections.¹³ Because the pebbles were originally set into a clay bedding, the weak bond strength of the clay allowed the lifting process to occur with relative ease, especially compared to the more common classical method of lime-based bedding mortars. Photographs reveal, however, that numerous pebbles remained behind in the ground as the textile facing with adhered pebbles was lifted. This was probably due to insufficient adhesion of the facing to the irregularly surfaced pebbles. The lifted pebbles were then placed face down on boards and re-backed with reinforced cement mortar poured directly in contact with the pebbles.¹⁴ This re-backing system was used frequently on archaeological mosaics at numerous sites from at least the 1930s until the 1970s when it was determined that reinforced cement mortars were detrimental to the safety of the mosaics.

¹⁰ See Chapter 3, pp. 21-22.

¹¹ For detailed descriptions of the lifting processes, see ICCROM 1983, 20-27.

¹² Young 1965, 12. There is no record of any discussions concerning this or why the mosaic was not left in place.

¹³ For images of the lifting process, see Thompson 2011, 115-118.

¹⁴ Little information regarding the composition of the backing is available, with Young simply noting that they were "mounted on cement slabs" (Young 1965, 12).

After re-backing, the cut panels were brought to the nearby dig house for temporary storage before presumably being moved to someplace more secure. However, for an unknown reason, the panels remained in the courtyard of the dig house for at least 20 years, many upright and exposed to the weather (Fig. 1.4). During this period, many panels cracked and possibly lost pebbles. It is also possible that damage to the pebbles from alkali silica reaction (ASR) could have begun at this time as well (see Chapter 4). In 1983, the Gordion Museum was established and sometime after this, the panels were finally moved and set into their current partial outdoor display.¹⁵



Figure 1.4. Gordion dig house with mosaic panels outdoors, 1968 (Gordion Archive, University of Pennsylvania Museum of Archaeology and Anthropology).

Existing conditions of the mosaic. The current state of preservation of the Megaron 2 mosaic is due to a variety of factors, including: their condition upon discovery, the lifting process, treatments performed before and after lifting, the significant amount of weathering endured between lifting and resetting in the museum, and eventual installation. The mosaic panels are now

¹⁵ The date of installation is not precisely known.

exhibited in an outdoor, below grade display at the Gordion Museum, located just outside of the main citadel mound (Fig. 1.5). Portions of the mosaic and the majority of the original clay bedding still remain on site, having been reburied after the mosaic's removal from the site. The display at the museum is covered by a corrugated metal shelter and contains limited signage. Fortunately the panels were dry set on sand on a concrete pad with a cementitious mortar topping.¹⁶ According to the 2013 Lifting Report that described the existing assembly of the mosaic panels, the concrete rudus is approximately 3"-4" thick and the embedded ferrous reinforcement is approximately 1/8" in diameter. The thickness of the bedding layer is not identified, but based on a drawing made by conservator Elisa del Bono and photographs of panel #7 after it was lifted, there is very little space between the base of the pebbles and the level of the reinforcement.¹⁷ In addition, according to the excavation photos and the Last watercolor, the panels were not set in precisely the same configuration as found on site. The overlay in Figure 1.6 shows those panels that correspond to locations on Last's watercolor. Nearly all of them have been moved or rotated to fit the watercolor with the exception of five panels could not be located. Because the panels are isolated from one another by areas of loss from the cutting, any actual connection to one another is lost (Fig. 1.7).

In 2010, a comprehensive documentation campaign and condition assessment was completed for the mosaic by University of Pennsylvania graduate student Elizabeth T. Thompson. This assessment was performed on site and included a thorough mechanical cleaning of the mosaic surface and the preparation of an ortho-rectified photographic plan as a base map.¹⁸

The assessment was a forensic reading of existing conditions which not only identified the conditions but also discerned the phases in which they occurred. The extent of these

¹⁶ The dry set display allows for drainage below the panels.

¹⁷ del Bono 2013, 2.

¹⁸ Thompson 2011.

conditions vary from panel to panel; however they can all be divided into three categories based on the history of the mosaic from its original construction to its museum installation. The ancient conditions are those that already existed at the time of discovery of the mosaic and include: *concrete fill, cavity, and deteriorated pebbles.* The recent conditions are those that occurred between excavation and movement to the museum and include: *over-grout, lacunae, dimensional loss, exposed rebar, deteriorated pebbles, detached pebbles, and cracks.* The present conditions are those that developed after the panels had been installed in the museum and include: *microflora, moisture staining, and guano.*¹⁹

The cementitious mortar backing that was applied in 1963 is particularly responsible for several of the recently identified conditions. During the original backing process, some of the cement migrated through lacunae or areas of loss and resulted in the over-grout condition on the surface. The extended period that the panels were exposed to weathering between 1963 and installation in the museum caused deterioration of the cement through wetting/drying and freeze/thaw cycles and resulted in the exposure and corrosion of the ferrous reinforcement. This has led to cracking and spalling, both damaging the pebbles. The application of the cement has also potentially initiated a chemical reaction called alkali-silica reaction (ASR) that occurs between the alkaline cement paste and reactive silica in the pebbles. This can result in the micro-cracking of the pebbles, as well as their loosening and eventual loss. The description of alkali-silica reaction and its potential in the Megaron 2 mosaic are discussed further in Chapter 4.

¹⁹ Ibid., 22-29.



Figure 1.5. Current display of the mosaic at the Gordion Museum (Courtesy of Meredith Keller, 2013).





Figure 1.7. Photomontage of the existing mosaic display (Architectural Conservation Laboratory).

Chapter 2: Research Problems

Subtopics

This thesis is comprised of several primary subtopics that will inform the final conservation plan. It investigates the existence of alkali-silica reaction between the cement backing and the original mosaic pebbles that could potentially cause micro-cracking and loss of the pebbles. In addition, it explores methods for safely and effectively removing as much of the cementitious backing and replacing it with a lightweight, strong and stable support. Each of these subtopics contains multiple variables that need to be addressed. They are described briefly below.

Alkali-silica reaction. One of the primary research questions that this thesis attempts to resolve is whether alkali-silica reaction (ASR) has previously occurred or is now able to occur. Alkali-silica reaction occurs when particular types of reactive silica are introduced to an alkaline environment. This causes the development of a hygroscopic gel that expands in the presence of water. This expansion puts internal pressure on the cement microstructure and the silicate components.²⁰ In a mosaic, this pressure has the potential to result in both cracking within the system as well as the loosening of the embedded surface stones. Due to the potential for reactivity of silica in all three types of pebbles present in the Megaron 2 mosaic and its physical connection with the alkaline cement, it is possible that ASR has already occurred, forming the expansive gel. This investigation will be performed through petrographic microscopy of original pebbles in order to visualize characteristic micro-cracking or the presence of the gel. This will be discussed further in Chapter 4.

Backing removal and replacement. The use of a reinforced cementitious mortar to back the lifted mosaic panels was a typical treatment beginning in the middle of the 20th century. More recently, however, conservation professionals have recognized numerous problems with this

²⁰ Thomas 2011, 1-5.

technique including the loss of original materials through the removal of bedding layers, added weight, deterioration processes associated with the cement and corrosive iron rebar, and physical and chemical incompatibility between the cement backing and the original materials. As a result of this, removal of the re-backing has become common practice and new, more effective backing materials and methods have been developed. The Megaron 2 mosaic is one of these that has endured cementitious re-backing and is in need of treatment to protect it from ongoing deterioration and to mitigate poor display practices.

In order to neutralize some of the conditions that exist due to the presence of the cement, as much of it must be removed as possible. However, since the pebbles are bedded directly into the cement, it would be extremely dangerous and difficult to remove it all. Therefore, techniques for the removal of the backing and the cementitious over-grout that do not damage the pebbles must be determined. Techniques derived from previously published mosaic conservation treatments, as well as from the construction industry, have been assessed based on criteria developed for this project. This will be discussed further in Chapter 5.

Re-backing. With the removal of the cement backing, a new lightweight system more chemically and mechanically compatible with the pebbles is needed. Backing options were selected from the recent published mosaic conservation literature and several different assemblies were tested. This will be discussed further in Chapters 7 and 8.

Facing. During the removal of the cementitious backing and the application of a new support, the pebbles must be secured with a compatible and reversible facing system. The facing used during the original lifting did not appear to be sufficient and resulted in the loss of pebbles. The new facing system has been determined through a review of published mosaic conservation literature and assessment based on specific criteria. This will be discussed further in Chapter 6.

Pebbles and tesserae. The vast majority of previous conservation efforts on mosaics have focused on tessellated mosaics due to their overwhelming majority in the corpus. While much of the material and procedural precedent is applicable to the Megaron 2 mosaic, the fact that its decorative surface is composed of irregular, natural pebbles rather than uniform, purposecut tesserae presents a specialized case which renders some of the treatment methods challenging, particularly for facing the mosaic and removing the backing and over-grout. These procedures require the adaptation of traditional mosaic conservation materials and techniques to suit this atypical, but not entirely unique, situation. These treatments will then be able to serve as a model for the future conservation of other pebble mosaics.

Justification and Hypothesis

The Megaron 2 mosaic from Gordion is the oldest known mosaic pavement and as such, has intrinsic historical value. However, the current state of preservation of the mosaic is primarily the result of post-excavation lifting, backing, and display campaigns between 1963 and the mid-1980s. This, in combination with over 20 years of outdoor storage, has caused numerous deteriorative conditions to develop. The mosaic's physical and aesthetic integrity was compromised by its removal from the site and the replacement of the original clay bedding layers with reinforced cement. The only authentic components of the mosaic are the remaining pebbles comprising portions of the original geometric designs. The pebbles and panels are in danger of further deterioration through weathering, displacement during mechanical cleaning, and possible alkali-silica reaction. The geometric designs are now difficult to interpret due to the loss of many of the original pebbles, the misalignment of the panels, their isolation by significant sections of lacunae, and the presence of cementitious over-grout. These conditions have created a critical situation that must be remedied to protect this historically significant mosaic. By removing the thick reinforced concrete backing and cementitious over-grout and replacing it with a more

compatible, lightweight backing system, it will be possible to re-situate the panels in their correct configuration, re-integrate portions of the original design, and allow for more options in the conservation, interpretation, and protection of the mosaic.

Chapter 3: Literature Review

The conservation of archaeological mosaics can essentially be divided into three categories: the conservation of mosaics in situ, the conservation of mosaics ex situ, and the reconservation of previously lifted mosaics. The first category deals with those archaeological mosaics which exist *in situ*, or in the same location in which they were discovered. The state of preservation of these mosaics varies widely, from intact or nearly intact, to severely deteriorated. Each site presents different challenges to conservators because the factors that determine the mechanisms of deterioration and treatment possibilities are so diverse. Their current state of preservation is dependent on numerous factors including their condition upon discovery, treatment after discovery, and degree of continued exposure to the environment.

The second category includes recently excavated mosaics which, for a variety of reasons, were removed and in most cases conserved *ex situ*, or away from their original context. While once more popular, this procedure is no longer advocated based on the notion that preservation of context is just as important as the conservation of the original fabric of the mosaic. The decision to remove a mosaic and conserve it ex situ is only valid when all other conservation options are deemed impossible.

The third category refers to those archaeological mosaics that have previously been cut and lifted from their original context before being conserved. The methods of removal and their fate after removal differ on a case-by-case basis. The majority of these mosaics receive some degree of conservation treatment after their removal, although their current state of preservation depends on a variety of factors, including their condition upon discovery, the method of lifting, treatments performed before and after lifting, and where and how they have been exhibited or stored. Since the subject of this thesis is a lifted mosaic that was previously conserved ex situ, this review of the published literature will focus primarily on the third category.²¹

This literature review is subdivided into seven topics, all relevant to the conservation of the Megaron 2 mosaic from Gordion. These topics have been identified in order to guide the conservation of the Megaron 2 mosaic in light of changing theoretical and practical approaches. The topics considered are the value of archaeological mosaics, standardization of the field, the need for documentation, lifting justification and techniques, recognition of problems with previous treatments, re-conservation with new materials and techniques, and the conservation of pebble mosaics.

The Value of Archaeological Mosaics

The utilitarian and artistic dichotomy of decorative mosaic pavements places the field of mosaic conservation between two schools of thought. The primary difference between the two lies in the historical and interpretive values given to the mosaics.²² As a pavement, mosaics were once functional centerpieces of ancient buildings. And although the more decorative pavements were meant to be conspicuous displays of art in the homes of wealthy elite, they were still walked on and used as pavements.²³ This architectural aspect of mosaics lends itself more to the field of architectural or archaeological site conservation, where treatments are generally performed in situ on (mostly) immovable components. However, as much as ancient mosaic pavements were utilitarian, they were also considered works of art. And it is this aspect that led archaeologists, and later conservators, to treat them as individual objects, whereby they were removed from the

²¹ A literature review of in situ mosaic conservation is part of the ongoing MOSAIKON Initiative by the Getty Conservation Institute. To date, comprehensive reviews have been completed for "Inventories and Official Corpora of Mosaics," "Protective Shelters for Archaeological Sites," and "Reburial and Protective Covering of Mosaics." Forthcoming are reviews of "Causes of Deterioration," "Treatment and Maintenance," and "Training and Awareness," although a preliminary installment of literature concerning deterioration and treatments of in situ mosaics was published in Ben Abed, et al, 2008.

²² The value of cultural objects goes beyond that of just historical and interpretive but in terms of conservation methodologies, justification primarily arises from these. The range of values of cultural objects that is most often referenced is that specified by Alois Reigl (Reigl 1903).

²³ Ling 1998; Dunbabin 2001; Clarke 1991.
open archaeological site and better preserved and displayed in a museum environment, often on the wall rather than as conceived on the floor.²⁴ The treatment of archaeological mosaics until the third quarter of the 20th century preferenced the artistic design and often sacrificed secondary borders and the mosaic's support layers during removal. Without consideration for a more architectural approach to mosaic conservation, the tesserae were often torn from the bedding layers in a violent and traumatic process, leaving behind or losing valuable interpretive features and, in many cases, the tesserae.²⁵

This was the case for the Megaron 2 mosaic from Gordion. As the earliest known mosaic pavement in the world, it would have also been considered an extraordinary work of art during its period of creation and use in the 9th century B.C.E., suggested by the rarity of other examples found elsewhere. The published research on the Megaron 2 mosaic is surprisingly sparse. Mosaic surveys and ancient art and archaeology texts mention it in passing as the earliest mosaic pavement but then skip forward to more "disciplined" examples of the late fifth and early fourth centuries B.C.E. in Greece.²⁶ The combination of the lack of historical contextualization of the mosaic, its disconnection from the site, and the current difficulty in interpreting the disjointed panels makes new research into the mosaic very challenging.

Standardization of the Field

Through the middle of the 20th century, the preservation of archaeological mosaics primarily served to save only the decorative surfaces. Mosaics were routinely torn from the ground because of the inability to treat them in situ and/or the desire to display them in a more controlled setting.²⁷ For example, some of the earliest mosaics to be lifted were from the late 18th and early 19th century excavations at Pompeii where the more interesting portions of mosaics, the

²⁴ Podany 2006; Dunbabin 2001; de Guichen and Nardi 2006.

²⁵ Bassier 1978; Podany and Matheson 1999.

²⁶ Ling 1998; Dunbabin 2001; Pedley 2011.

²⁷ Lavagne 1978.

decorative *emblemata*, were separated from the surrounding pavement and cut out of the multilayered mortar bedding layers.²⁸ The rest of the pavement that surrounded the *emblemata* were often mosaics as well, although since they were deemed less remarkable (i.e., not figural), they were left in situ and frequently deteriorated.²⁹ European museums are full of disembodied mosaic pavements from this era that now lack any connection to their original context and often no longer contain any evidence of their original setting or construction.³⁰

With the formation of the International Committee for the Conservation of Mosaics (ICCM) in 1977, professional practice in mosaic conservation changed and in the last 35 years it has strived to develop standards for treatment programs that include better documentation and decision-making processes. This began with the ICCM's detailed descriptions of conservation processes including different lifting, backing removal, and re-backing methods in their 1983 publication of *Mosaics No. 2: Safeguard.*³¹ Later publications recommended conservation in situ in order to avoid the damage and interpretive issues that arise from the removal of mosaics from their original context. Several articles have noted this shift in published techniques from lifting to in situ conservation.³² Entire conferences have been organized around in situ conservation in order to make it more feasible and effective. These conferences have established procedural criteria for the conservation of in situ mosaics.³³ These include accommodations for the preservation of original fabric (Rome, 1978), the need for detailed documentation (Rome 1978; Soria 1986; Nicosia 1996; Arles 1999; Hammamet 2005), recommendations for future research (Soria 1986; Nicosia 1996; Arles 1999; Hammamet 2005), and the need to evaluate

²⁸ Wohlgemuth, 66.

²⁹ Ibid. 7

³⁰ Podany, 115-119.

³¹ Mora 1983. This publication also contains cost comparisons and mechanical property comparisons of various materials.

³² Roby 2002; de Guichen and Nardi 2008; Piqué 2008.

³³ ICCM 2013.

previous and current practice (Hammamet 2005). Many of the recommendations can be adapted for ex situ conservation as well. These conferences established, above all, that in situ conservation should be the first approach with removal only to be considered if the former is not possible.³⁴ The published proceedings of the conferences have become the foundation scholarship for the field.

However, this does not mean that mosaics are no longer being lifted from sites, even when the sites themselves are not threatened. Although methods of conserving mosaics in situ have developed significantly since 1977, there are still deteriorative conditions and treatment questions that are unresolved and often result in the lifting of mosaics. The recent literature review of in situ deterioration and treatments for mosaics has made it clear that these unresolved issues are being explored and it is the hope of the Getty Conservation Institute that by "identifying new trends and areas in need of further research" with their multi-subject literature review, it will be possible to "enhance the conservation of ancient floor mosaics."³⁵ The review of deterioration and treatments concluded that although there has been "progressive developments in methods and approaches to the preservation of mosaic pavements on archaeological sites over the past four decades," there is still a "lack of diagnostic studies" of deterioration mechanisms or the "evaluation of [treatment] efficacy over time."³⁶ Until these research paths are further examined, lifting and conservation ex situ will remain a viable option for the preservation of archaeological mosaics.

The Need for Documentation

Before the formation of the ICCM, documentation of treatments was not customary. Since mosaics were still viewed as objects, they were catalogued as such and although their

³⁴ Ibid.

³⁵ Roby and Demas, i.

³⁶ Piqué, et al., 33.

removal from the site was more difficult than for unattached artifacts, the process was rarely documented.³⁷ When conservation treatments were performed, there was no system in place to communicate the treatment's success or failures to other conservators in similar situations.³⁸ Since 1977, documentation has become paramount as part of the excavation and conservation process of archaeological mosaics. The first ICCM conference included in their field-wide goals "the encouragement of the documentation of specific cases of destruction, salvage, and restoration."39 Since then, documentation of archaeological mosaics has expanded to include the "recording of data produced by mosaic conservation" by each country involved in the field (Soria 1986), the "quantification of the area and state of preservation of mosaics on each site" (Nicosia 1996), "complete documentation prior to intervention" and "documentation of all interventions" (Arles 1999), and the establishment of "systematic standards and protocols to facilitate decision making" and "strategies that permit improved sharing of information" (Hammamet 2005).⁴⁰ By increasing the frequency and quantity of information being documented as well as the availability of this information, the ICCM hopes to create an environment where mosaic conservation is not isolated to a single mosaic or site but is part of a larger problem-solving entity that results in more effective practice.

The majority of these documentation initiatives pursued by the ICCM have generally been adopted by mosaic conservators with the exception of the establishment of "systematic standards and protocols to facilitate decision making." Few of the published studies contain criteria for conservation treatments or testing of materials and procedures. Instead, many of the treatments appear to follow and repeat previous ones without questioning the appropriateness and

³⁷ Zachos 2008; Bethell 2008.

³⁸ de Guichen and Nardi 2006

³⁹ ICCM 2013.

⁴⁰ Al Muayyad Al-Azm 2008.

differences between situations. It is important to consider the differences in each case and determine the particular criteria by which to select appropriate treatments.

For the Megaron 2 mosaic, the pavement's discovery was relatively well documented with notes, photographs, and even a detailed watercolor rendering.⁴¹ However, when the mosaic was finally prepared for lifting in 1963, only limited photographs and a simple lifting plan was used as documentation.⁴² No notes about materials, procedures, or problems were made. A hypothesized description of the process was possible through the recent discovery of photographs taken during the lifting and evidence observed on the actual panels.⁴³ What is known is that the mosaic was cut into 33 distinct panels, which, as noted above, were selected based on the degree of preservation.⁴⁴ However, due to the mosaic's already deteriorated condition at the time of its discovery, it is more likely that the rationale for the panel selection was to lift a combination of the most interesting and the most intact portions.

This situation was common for the pre-ICCM era of mosaic conservation. However, since 1977, the frequency and quantity of documented mosaic conservation techniques has increased exponentially. In fact, the majority of published articles and case studies detail the conservation procedures and include condition assessments, materials, techniques, and results.⁴⁵ Even the fact that case studies are routinely published is an advancement in conservation documentation and communication. As suggested by the ICCM Conference in Hammamet, Tunisia in 2005, mosaic conservation professionals have also begun to evaluate their decisions as well as the performance of their treatments.⁴⁶ These evaluations have become part of the published corpus and allow for more transparency in the practice. With more documentation and

⁴¹ Young 1857.

⁴² Darbyshire and Pezzati 2013.

⁴³ Thompson 2010, 18.

⁴⁴ Thompson suggests that the panels were a "sampling" of the "most interesting and isolated geometric shapes and pattersn," which could have been a secondary justification (Thompson 2010, 18).

⁴⁵ Wihr 1978; Vincent 2008; Tsu, et al. 2008; Demas 2008.

⁴⁶ Uprichard, et al. 2000; Demas, et al. 2008; Bakirtzis, et al. 2008; Kökten 2008; Severson 2008; Tülek 2008.

transparency, the field can become standardized in a way that allows decision-making processes to be calculated and evaluated against existing empirical data.

Lifting Justification

The Megaron 2 mosaic is one of many cases in which previous conservation treatments have led to critical situations in need of new conservation campaigns. Justification for the removal of mosaics from their original context was made on a case-by-case basis, although there are common reasons that are often cited. Before the 20th century, the removal of mosaics was performed primarily due to the desire to display them as part of the collection of "objects" discovered at a site. As noted above, these were often the more decorative examples. A more altruistic justification for the removal of mosaics was to protect them. Before the insistence of the ICCM that all efforts should be made to conserve mosaics in situ and the development of in situ conservation techniques, nearly all of the discovered mosaics that exhibited some degree of deterioration or threat of deterioration or theft were removed. This was seen as the best, and sometimes only, solution.⁴⁷ However, the mosaics were not always immediately treated or placed in appropriate storage.

Lifting process. The process of mosaic removal from archaeological sites has changed very little since its inception so it is possible to hypothesize some of the details for the Megaron 2 mosaic. Lifting is a three step process intended to remove the surface design thought to be in danger of deterioration if left in situ. Since lifting includes the removal of most, if not all, of the bedding material, the first step involves facing the mosaic in order to protect the valuable tesserae and allow the surface to act as one homogeneous layer. Facings include a flexible cover material and an adhesive to bind it to the surface. These materials are often porous textiles such as cotton gauze or muslin that will allow the adhesive to attach to both the mosaic substrate and the facing.

⁴⁷ Bassier 1978; Mora 1983; Severson, et al. 2000; Podany 2002; de Guichen and Nardi 2006; Roby 2006; Piqué, et al. 2008; Kökten 2008; Dominguez-Bella, et al. 2008; Erdek 2008.

Often, several layers of facings are used to provide a more rigid surface with the outer layers consisting of more durable porous textile materials such as jute or burlap. Since the facing is supposed to be temporary, the adhesives used for facing are generally soluble in either water or weak solvents.⁴⁸ The original facing materials for the Megaron 2 mosaic are unknown.

The second step is the actual removal of the tesserae. This process changes depending on the size of the mosaic to be lifted. For smaller mosaic panels, or when larger mosaics are cut into separate, smaller panels, they are often lifted by excavating beneath the mosaic and carefully chiseling out the bedding layers before poles or other rigid supports (often wood) are slid underneath the mosaic.⁴⁹ This process is also used when attempting to retain portions of the bedding layers. For larger mosaics, the tesserae are often purposefully separated from the bedding layers so that the mosaic can be rolled around a wooden cylindrical support. During this process, nearly all of the bedding layers are mechanically chiseled off of the back of the tesserae to ensure a smoother and more uniform roll.⁵⁰ For the Megaron 2 mosaic, a hybrid process seemed to have been performed. As Thompson notes, photographs of the process show a long piece of wood nailed to the edge of the facing used as a handgrip for pulling the mosaic back as the remnants of the weak clay bedding layer was mechanically removed.

The final step in the lifting process represents the re-backing of the tesserae. Generally, the tesserae transfers are laid on their face while the remaining bedding material is mechanically removed.⁵¹ The weak clay bedding layer that originally supported the Megaron 2 mosaic was likely very easily removed. Earlier accounts suggest that the tesserae were also sometimes ground down to ensure a flat surface for re-backing, although this does not seem to be a common

⁴⁸ Wihr 1978; Bradley, et al. 1983; Stanley-Price 1991; Roby 1995; Severson, et al. 2000; Tsu, et al. 2008.

⁴⁹ Wihr 1978; diagram: Mora 1983; Podany 2002; Tsu, et al. 2008; Dominguez-Bella 2008; Erdek 2008.

⁵⁰ Wihr 1978; diagram: Mora 1983; Stanley-Price 1991; Severson, et al. 2000; Podany 2002; Demas, et al. 2008; Severson 2008.

⁵¹ Mora 1983; Stanley-Price 1991.

practice.⁵² Since at least the 1930s, re-backing was primarily performed with reinforced cementitious concrete.⁵³ The idea was to provide as much rigidity to the tesserae as possible and concrete was an obvious solution. In addition, Portland cement and rebar were inexpensive and easily obtainable materials in nearly every country where ancient mosaics were discovered and the process for pouring the new backing was simple. The mosaic would be laid upside down in a wooden form and an initial layer of concrete was poured on the back of the tesserae. The ferrous reinforcement was then laid down and a final layer of concrete (usually approximately three inches thick) was poured. Once the concrete had cured, the panels were flipped and the facing materials were removed. The Megaron 2 mosaic went through this same re-backing process. The new reinforced concrete backing had thin gauge (~1/8" diameter) reinforcement applied in a grid pattern bound together with wire.

Although lifting has become less common of a practice since the standardization of the field and the recommendations of the ICCM, it is still a viable conservation technique, particularly for mosaics where no other course of action will ensure their preservation. And while techniques have been refined and materials for facing and re-backing have been researched and assessed, the process of lifting a mosaic is unavoidably violent and always causes damage.⁵⁴

Recognition of Problems with Previous Treatments

Reinforced concrete. Very few other backing materials were considered until the 1970s when problems with the reinforced concrete were recognized. Although reinforced concrete was acknowledged as a heavy and cumbersome material, its ease of application and wide availability of materials meant that its use was widespread. After the establishment of the ICCM allowed for greater interaction and sharing of knowledge concerning mosaic conservation, it became clear

⁵² Mora, 32.

⁵³ Hafez 1978; Barnes 2006; Tsu, et al. 2008.

⁵⁴ Sweek, et al. 2000; de Guichen and Nardi 2006; Demas, et al. 2008.

that various problems associated with reinforced concrete backings were extensive.⁵⁵ First of all, although heavy and rigid, concrete is actually a fairly brittle material that can frequently crack, especially during repeated movement of the panels. The most omnipresent issue was the deterioration of the entire assembly due to the expansive corrosion of the iron reinforcement. In theory, the elevated alkalinity of the concrete should prevent the oxidation of the iron, although over time carbonation of the concrete drops the pH closer to neutral which allows oxygen in the environment and moisture to attack the iron. As the iron oxidizes, corrosion products form around it, causing expansive pressure to crack and break apart the concrete. The loss of physical integrity of the bedding layers leads to the damage and deterioration of the tesserae.

This condition occurs primarily when the mosaics are stored outside of a climatecontrolled environment. It is likely that since the majority of mosaics that were lifted by the middle of the 20th century were moved to museums, this issue was not as prevalent. Once lifting and reinforced concrete re-backing became standard procedure for the majority of excavated mosaics, whether they were going to be displayed in a museum or placed in storage, this condition was more frequently noticed.⁵⁶ In addition, soluble salts intrinsic in the Portland cement binder of the concrete can often migrate vertically, especially if the mosaic goes through wetting and drying cycles. However, this condition is not often mentioned and the removal of the concrete backing would end its occurrence.⁵⁷

Storing mosaics outside of climate-controlled settings also creates other modes of deterioration. Often, mosaics are moved to uncontrolled spaces for temporary storage while they await either further conservation treatments or transport to a more secure environment. Due to unforeseen circumstances, some mosaics are never treated or moved to their final destinations.

⁵⁵ Mosaic conservator Kent Severson says, "One of the primary goals of the International Committee for the Conservation of Mosaics (ICCM) since its inception has been the elimination of ferroconcrete (steel-reinforced concrete) backing from mosaic conservation practice (Severson 2008).

⁵⁶ Bassier 1978; Roby 2010; Tsu, et al. 2008; Vincent 2008; Zachos 2008; Zizola 2008; Senet 2008.

⁵⁷ Uprichard, et al. 2000; Podany 2002.

This was the case with the Megaron 2 mosaic, whose panels languished outdoors, lying against the side of the Gordion dig house for over 20 years, where they were exposed to weathering which has caused many of the existing deteriorative conditions. This is an extreme case where poor planning and extenuating circumstances lead to the failure to properly store and protect the mosaic panels. Other instances include mosaics being left untreated after lifting and being stored without re-backing or the removal of the supposedly temporary facing. Without backings or more secure facing solutions, the tesserae can come unglued and lost. Eventually, catastrophic incidents or "excavation" of these storage facilities bring renewed attention to the mosaics which may result in their full conservation and more appropriate storage.⁵⁸

Revisiting treatments. With the establishment of in situ conservation and the development of more appropriate and compatible treatments, the problems associated with lifting are occurring less and less. However, there is still a major backlog of lifted mosaics in improper storage conditions that require the attention of conservators. Recently, the Getty Conservation Institute has begun to focus part of their MOSAIKON initiative on the location, inventory, and assessment of previously lifted mosaics. In cooperation with the International Center for the Study of the Preservation and Restoration of Cultural Property (ICCROM), they are "training museum personnel in methods for inventory, condition survey, and risk assessment for collections of lifted mosaics in storage."⁵⁹ This project, in addition to the increased sharing of knowledge between conservators, should provide a structured platform to save these threatened mosaics before damage becomes irreparable.

Alkali-silica reaction. A deteriorative condition that is much less understood or investigated with respect to concrete backings of mosaics is alkali-silica reaction (ASR). ASR is a

⁵⁸ Severson, et al. 2000; Uprichard 2000; Nardi 2002; Severson 2008; Roby 2010; Frankovic 2008; Al Muayyad Al-Azm 2008.

⁵⁹ <u>http://www.getty.edu/conservation/our.projects/education/mosaikon/mosaikon.component3.html</u>

chemical process that occurs when certain types of silica react with hydroxyl ions in the pore solutions of an alkaline material to produce a gel between the two materials. This gel is expansive in the presence of moisture (in both liquid and gaseous phases) and can cause damage to both the silicate material and the alkaline material.⁶⁰ ASR has most widely been studied as it relates to industrial concrete where the reactive silica naturally exists in the aggregate and the gel is formed between the aggregate and the alkaline cement.⁶¹ This causes characteristics cracking of the concrete and micro-cracking of the aggregate. The majority of research dedicated to ASR has been to define it and prevent it through the proper selection of aggregates, rather than mitigate it once it is observed.⁶²

In mosaics, ASR could occur when tesserae contain reactive silica, are re-backed directly into a concrete bedding layer, and the entire system is exposed to moisture. Because all three of these factors must exist in order for ASR to occur, the problem has rarely been encountered. The types of stones used in ancient mosaic pavements were often calcitic, meaning marble or limestone, which is not reactive, rather than silicate stones. In addition, since the mosaic tesserae are not completely bounded by the alkaline cement, as aggregate is, the characteristic ASR deterioration patterns would not be as severe or visible. The expansion of the formed gel would however more likely cause loosening and loss of the pebbles or tesserae, rather than just cracking, which may be misattributed to other conditions. Finally, without more macromorphological evidence such as the characteristic cracking of the concrete, ASR may go unnoticed. The evidence of ASR in mosaics would likely be in the form of micro-cracking. Micro-cracking is only perceptible through microscopic examination. These examinations are not routinely performed on mosaics and when they are, it is more often for petrographic identification of the

⁶⁰ Diamond 1975; C-SHRP 1996; ASTM STP169D-EB 2006; Smaoui 2006; Ichikawa and Miura 2007; Giaccio, et al. 2008.

⁶¹ Diamond 1975.

⁶² C-SHRP 1996; ASTM STP196D-EB 2006; ASTM C-1260-07 2007; Fournier, et al. 2010.

tesserae than for diagnosis.⁶³ Also, evidence of micro-cracking is not necessarily evidence of ASR since micro-cracking can occur due to numerous different causes.⁶⁴ Evidence of the gel may be observed through the same analytical microscopy techniques or through chemical treatments.⁶⁵ However, neither method is absolutely reliable since the gel is notoriously difficult to detect with either system.

Re-Conservation with New Materials and Techniques

With the realization in the 1970s that the concrete re-backing that had been used for over 40 years was, in fact, deleterious to the long-term preservation of lifted mosaics, conservators began to look into new technologies. These technologies came from both other conservation fields and other industries. From archaeological object and paintings conservation came the use of epoxies and other adhesives for backings and from aerospace and marine industries came extremely lightweight yet rigid backing systems such as structural honeycomb panels.

Backing removal. The process for re-conservation of inappropriately conserved mosaics is informally standardized, although techniques and materials change in each situation. Basically, the mosaics are faced with a textile adhered to the surface in order to secure the pebbles during the violent mechanical removal of the backing. This is the same first step as with the original lifting and materials for this have not changed much. Some testing has been published on the efficacy of various adhesives, although materials seem to be chosen more by empirical experience rather than testing.⁶⁶ Once the mosaic has been faced, it is flipped and the backing material is mechanically removed. The actual practice of this step is dependent on numerous considerations including location, availability of technology, and backing material. In most cases, particularly

⁶³ Stanley-Price 1991; ASTM STP169D-EB 2006; Dekayir, et al. 2008; ASTM C1723-10 2010; Thomas, et al. 2011.
⁶⁴ With respect to the Megaron 2 mosaic, if micro-cracking were visible, it could be evidence of ASR, although it could also have been caused due to thermal shock from the large fire that occurred around 800 B.C.E., due to various deterioration mechanisms resulting from the extended weathering period between its lifting and its installation in the museum, or due to shrinkage of the concrete leading to buckling of the panel (Mora 1983).

⁶⁵ Natesaiyer 1989; C-SHRP 1996; Ichikawa and Miura 2007; Giaccio 2008.

⁶⁶ Arslanoglu and Tallent 2003; Arslanoglu 2004; Thuer 2011; Bosetti 2012.

when performed on or near an archaeological site, this is performed by hand with hammers and chisels or simple pneumatic chisels and saws.⁶⁷ Recently, in museum contexts, experimentation with this process has led to the use of digitally-driven machinery.⁶⁸ The degree to which the backing is removed is dependent on the decision of the conservator. There are no standards for this decision, although case studies suggest that the more backing material that can be removed, the better.

Re-backing. Once the backing material is removed to the desired level, the new backing is applied. Re-backing materials are also highly variable. The informal standard for this has become lightweight honeycomb sandwich panels, most often of aluminum. Numerous case studies have shown the prolific use of this technology beginning in the 1960s with its introduction by Rolf Wihr and Claude Bassier.⁶⁹ This material was adapted from the aerospace industry and represents a highly rigid, chemically stable construction that is lightweight, easily shaped, and able to be attached by various means. The disadvantages of this material include a high cost, poor to no availability in many countries with mosaics, and incompatibility with some materials.⁷⁰ Due to these disadvantages, alternative backing materials are still being investigated, including modified epoxy resins and mortars.⁷¹ Even new ways of adapting cements to be less deleterious have been explored.⁷²

Conservation of Pebble Mosaics

The main difference between the Megaron 2 mosaic and the majority of other lifted mosaics is the nature of its tesserae. Strictly speaking, the stone units that make up the mosaic's

⁶⁷ Wihr 1978; Lodge 1981; Munday 1986; Nardi 2002.

⁶⁸ Snow, et al. 2011; Tsu, et al. 2008.

⁶⁹ Bassier 1978; Lodge 1981; Mora 1983; Stanley-Price 1991; Uprichard 2000; Nardi 2002; de Guichen and Nardi 2006; Demas, et al. 2008; Vincent 2008; Tsu, et al 2008; Erdek 2008.

⁷⁰ Barnes 2006.

 ⁷¹ formulation: Bassier 1978; Bradley 1983; Mora 1983; Munday 1986; Nardi 2002; Macchiarola and Fiorella 2008.
 ⁷² Severson 2008.

surface are not tesserae. Tesserae are purpose-cut, usually cubed, stone pieces used in mosaics.⁷³ They provide a relatively flat and uniform surface. Instead, the Megaron 2 mosaic surface is made of small, uncut, naturally rounded pebbles of various shapes. The irregularity of the pebble surface likely had several implications for the lifting process. First of all, since there were more crevasses between the pebbles than on tessellated mosaics, the facing may not have been as effective. As Thompson noted,

small gaps in between the pebbles reveal the white muslin-indicating places that may have once had pebbles. Further proof can be found by looking at the ground directly below the lifted designs in the early photographs; it is possible to see loose pebbles in the stirred-up soil.⁷⁴

The unevenness of the pebbles and lack of a uniform adherence of the facing likely allowed for the movement of the poured cementitious slurry or "grout" between and even on top of the pebbles. This has partially led to the condition identified as over-grout.

The ratio of pebble mosaics to tessellated mosaics treated in the published conservation literature is extremely low. Besides the work regarding the Megaron 2 mosaic, only one other publication deals with a pebble mosaic.⁷⁵ Other pebble mosaics have been treated, such as those from Pella and Olynthus, which were lifted from the site and moved to their respective museums, although the treatment programs have not been published.

⁷³ The Getty Art & Architecture Thesaurus Online defines tesserae as "small, squarish pieces of colored marble, glass, stone, or tile used in making mosaics," although the fact that they were purposefully cut into particular shapes for the mosaic is important and differentiates this type of mosaic construction (opus tessellatum) from the pebble type exhibited by the Megaron 2 mosaic.

⁷⁴ Thompson, 19.

⁷⁵ Gallone Galassi 1987.

Chapter 4: Alkali-Silica Reaction

Definition of Alkali-Silica Reaction

Alkali-silica reaction (ASR) is a generative hygroscopic reaction between highly alkaline materials, usually alkaline pore solution of Portland cement, and particular kinds of potentially reactive silica, usually in the form of concrete aggregates. The alkaline solution is composed of hydroxyl ions (OH) and according to Diamond, "the fundamental cause of alkali-silica attack is the elevated hydroxyl ion concentration produced in pore solutions of concretes made with cements rich in sodium and potassium."⁷⁶ This solution attacks the silica to form alkali silicates which creates a hygroscopic gel that absorbs moisture and expands (Fig. 4.1).⁷⁷ This expansion is the primary cause of deterioration from ASR and when it occurs within a bound system such as between the cement paste and bound aggregate in concrete, it causes micro-cracking of the siliceous aggregate phase and often micro- and macro-cracking of the overall concrete (Figs. 4.2 and 4.3). Thus, the three necessary and sufficient conditions for ASR to occur are: presence of reactive silica, presence of an alkaline solution, and presence of moisture. If either of the first two is removed from the equation, there will be no reaction at all. If moisture is removed, the primary reaction cannot be sustained nor will the hygroscopic gel expand.⁷⁸

⁷⁶ Diamond 1975, 334. The alkaline pore solution is generally composed of hydroxyl ions (OH⁻) rather than any kind of alkali metal cations.

⁷⁷ The chemical equations are provided in Swamy 1992 and Ichikawa 2007, and a very detailed explanation of the alkali-silica reaction chemistry is in Diamond 1975.

⁷⁸ Thomas, et al. 2007, 18.



Figure 4.1. Diagram of ASR reaction (adapted from Thomas, et al. 2007, 8).



Figure 4.2. Micro-cracking of concrete aggregate caused by ASR (Thomas, et al. 2013, 13)



Figure 4.3. Macro-cracking of concrete caused by ASR (Thomas, et al. 2011, 45)
Potential for Alkali-Silica Reaction in the Megaron 2 Mosaic

ASR has not previously been examined in relation to archaeological mosaics. In fact, nearly all of the published scholarship on ASR has been driven by the examination of the reaction as a deterioration mechanism in industrial concrete. While this study focuses on ASR as it relates to one particular mosaic, the potential for ASR in archaeological mosaics is present wherever the three necessary and sufficient conditions are met.

This investigation of ASR in the Megaron 2 mosaic follows the two different tracks. First, it attempts to identify evidence of the formed hygroscopic gel and possible resulting microcracks through petrographic thin-section and microscopic surface analyses of pebble samples. In this way, it may be possible to determine if ASR has previously occurred in the mosaic. Secondly, the pH and salt anion analyses of samples of the cement backing will help to determine if it is possible for ASR to occur now. The presence of ASR could have two potential consequences for the Megaron 2 mosaic. If the pebbles are sufficiently bound within the cement, expansion of the hygroscopic gel could cause the characteristic micro-cracking and lead to the fracturing of the pebbles at the interface between the pebbles and the cement. Several of the pebble samples collected in 2010 display surface fracturing, although the cause is not certain (Fig. 4.4). Other potential causes of fracture could be thermal shock from the fire prior to reburial or mechanical damage from excavation, lifting, and weathering outdoors prior to reinstallation. The other response from the potential formation of the hygroscopic gel could be detachment of the pebbles from the cement bedding. Pop-outs are known from ASR-infected industrial concrete where the aggregate components are not sufficiently bound.⁷⁹ Again, some of the collected pebble samples are intact which may be the result of this pop-out effect or from mechanical causes (Fig. 4.5).



Figure 4.4. Examples of fractured pebbles from the Megaron 2 mosaic.

⁷⁹ Swamy 1992, 25.



Figure 4.5. Examples of popped-out pebbles from the Megaron 2 mosaic.

Necessary and Sufficient Conditions

Each of the three necessary and sufficient conditions for ASR can be examined further to better understand whether or not the reaction has previously occurred or has the potential to occur in the Megaron 2 mosaic. Once the potential of these conditions is verified, the testing program will serve to confirm or disprove its occurrence.

Reactive Silica. The silica (SiO_2) component for ASR to occur in this case is intrinsic in the mineralogy of the pebbles that make up the surface stones of the mosaic. According to Thomas, et al., although numerous types of minerals have been identified as containing the required type of reactive silica, the degree of reactivity between mineral types is also dependent on the quantity of the reactive silica in the minerals and sometimes the quantity of reactive silica in contact with the alkaline pore solution.⁸⁰ Testing standards have been developed to discover potential reactivity, although empirical evidence from ASR-affected industrial concrete has

⁸⁰ Thomas, et al. 2013, 17-18. Thomas, et al. provide a table of identified minerals that contain the necessary reactive silica.

identified numerous reactive minerals.⁸¹ A brief list of minerals with reactive silica suggests that the more irregular the molecular structure of the mineral, the more likely it is to be reactive. For example, many of these identified minerals have an amorphous structure, such as opal and various glassy minerals, or fibrous, fractured, or strained micro- or cryptocrystalline structures such as chert and some forms of quartz.⁸²

The identification of the pebbles as chert (red), metaquartzite (white), and a volcanic mineral in a matrix of glass (blue-grey) indicate that they all likely contain the necessary reactive silica for ASR to occur.⁸³ Metaquartzite and chert have been reported as being present in numerous examples of industrial concrete-related ASR and volcanic glass has also been identified as causing the reaction.⁸⁴

High Alkalinity. The alkalinity of the cement paste changes as the calcium hydroxide reacts with carbon dioxide in the atmosphere to produce calcium carbonate. This reaction, known as carbonation, removes hydroxyl ions from the pore solution in the cement, dropping its alkalinity. Freshly mixed Portland cement generally has a pH of approximately 12.5 due to the dissolution of hydroxyl ions in the water, although it can be even higher.⁸⁵ The rate of carbonation is dependent on several factors including the density and porosity of the cement and its moisture content. Once carbonation has completed, the pH of the cement levels out at near neutral, or pH 7. Carbonation has numerous implications for the behavior of cements and concretes. In addition to reducing the potential for ASR, the reaction results in the decrease of the porosity of the cement, making it stronger. However, in reinforced cements and concretes, the

⁸¹ ASTM C289-07: Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method); ASTM C1260-07: Standard Test Method for Potential Alkali-Reactivity of Aggregates (Mortar-Bar Method); ASTM C227-10: Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar Bar Method); ASTM C1567-13: Standard Test Method for Determining Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method).

⁸² Thomas, et al. 2013, 16.

⁸³ These identifications were originally made by Thompson in 2011 and further confirmed by Victoria Pingarron-Alvarez in 2013.

⁸⁴ Metaquartzite and chert: Carse 1996; volcanic glass: Swamy 1992.

⁸⁵ Grubb, et al. 2007, 79.

reduction of the pH level exposes the reinforcement to potential oxidation. ASR also contributes to the lowering of the cement's alkalinity. As the silica dissolves during the reaction, the concentration of hydroxyl ions and thus the pH, is reduced.⁸⁶

The pH level of the cement pore solution necessary to induce ASR is dependent on the type of reactive silica present. Chert and volcanic glass, for example, are generally unreactive below a pH of 12.5.⁸⁷ This means that with respect to the Megaron 2 mosaic, since the pebbles were embedded directly into the cement, the pH level of the freshly mixed Portland cement at the time of re-backing likely had a pH sufficient to induce ASR with the silica in those three types of pebbles.

Cement pH Analysis. Due to the reduction of the pH from carbonation, it is unlikely that the pore solution in the cement is currently able to react with the silica.⁸⁸ In order to confirm this, it is important to ascertain the alkalinity of the mosaic's cement bedding through pH testing. According to Diamond, "the pH...is a measurement directly reflecting OH ion activity in solution."⁸⁹ As such, a pH measurement will also determine the progress of carbonation by qualitatively establishing the amount of hydroxyl ions in the pore solution.⁹⁰ The following test was performed on a sample of the concrete rudus from Panel #10, collected in 2010, a sample of the surface cement around Panel #7, and a sample of the surface cement between Panel #7 and an adjacent panel.⁹¹

Testing Standard. This pH test is based on a 2007 article that assessed multiple standardized procedures for the pH testing of concrete. The article compared ASTM C25-06,

⁸⁶ Prezzi 1997, 11.

⁸⁷ Hime 2013; No information for the pH level necessary to for metaquartzite to react has been found.

⁸⁸ Carbonation may also have limited the potential for ASR in 1963 since surface carbonation occurs immediately after pouring.

⁸⁹ Diamond 1975, 341.

⁹⁰ There are other tests to determine the extent of carbonation in a cement sample. However, these require fresh breaks in the samples perpendicular to known exposed surfaces. The samples collected from the mosaic in Gordion are random fragments with no known orientation.

⁹¹ The latter two samples were collected in the summer of 2013.

ASTM F710-05, and ICRI guideline No. 03740. The results established recommended test procedures for both field and laboratory concrete pH measurements. This procedure tests the pH of a solution of distilled water and powdered cement sample. In this way, the test is able to measure the overall pH of the sample dissolved in a neutral solvent.

Materials. This pH test procedure uses both an electronic pH measuring device as well as test strips as secondary confirmation. The materials necessary for the procedure include:

- OAKTON[®] Multi-Parameter PCSTestr[™] 35 to electronically measure pH and temperature of the solution.
- HANNA[®] instruments Checker[®] Portable pH Meter for confirmation of the electronic pH reading.
- MICROESSENTIAL LABORATORY pHydrion[®] Papers 1-12 for pH test strip reading.
- Fisher Science Education Buffer Solutions (pH 4.00, 7.00, 10.00) for calibrating the electronic testing instruments and confirming the accuracy of the test strips.
- 10 mL of fresh distilled water at a temperature of $72\pm2^{\circ}$ F for dissolving the test sample.
- Whatman[®] Grade No. 4 filter paper for filtering the dissolved test sample.
- Agate mortar and pestle to grind the sample to a fine powder.
- Fisher Scientific[™] Traceable[™] Digital Hygrometer/Thermometer for measuring the ambient temperature and humidity of the room in which the test is being performed.
- Two 20 mL glass beakers for mixing the test sample and solvent, and for filtering the sample mixture.
- Glass stirring rod for mixing the test sample and the solvent.

Test Procedure. According to the 2007 article, the testing procedure should proceed as follows:

- 1. Calibrate the electronic meters according to the manufacturer's directions for pH with each of the buffer solutions.
- 2. Rinse all labware in distilled water.
- 3. Weigh approximately 5 g. of each test sample and grind it into a fine powder with the agate mortar and pestle.
- 4. In a 20 mL glass beaker, mix the test sample with 10 mL of distilled water with the glass stirrer.
- 5. Filter the test mixture using the filter paper.
- 6. Insert the pH meters, one at a time, into the test mixture. Read the pH and temperature to one decimal place.
- 7. Insert the test strip into the test mixture. Compare the resulting color change to the pH color standard on the container.
- 8. Record the ambient temperature and humidity.

Results. The results of the pH tests showed that all three of the cement samples collected from Gordion are only slightly alkaline. The cement sample from the rudus of panel #10 has a pH between 8 and 9 while the surface cement samples from around the panel have a pH around 9 (fig. 4.6).⁹² This result is unsurprising since the carbonation of the cements since 1963 and approximately 1983, respectively, would have dropped the pH significantly from its likely original level around pH 13. These pH results, although technically alkaline, are not high enough to cause ASR. It should be noted that the cement rudus sample from panel #10 would not have been in direct contact with the pebbles, and therefore, would not have contributed to ASR between the cement and the pebbles. This test only served to show that a representative sample of concrete from the original 1963 backing has carbonated sufficiently to significantly lower its pH.

⁹² See Table A.1 for detailed testing data.



Figure 4.6. Results of the pH strip test on all cement samples.

Soluble Salt Content and Identification. This test should be performed in order to determine, in a semi-quantitative manner, the type and quantity of salts in the concrete. Research has shown that the presence of chloride salts can accelerate ASR in higher temperatures. In fact, sodium chloride (NaCl) can cause an increase in the hydroxyl ion concentration in the pore solution.⁹³ In addition, since a portion of the concrete cannot be removed without severely risking the safety of the pebbles, it will be important to determine how the cement bedding will continue to perform. In this case, the existing quantity of salts should be known so that appropriate remediation techniques can be considered.

Testing Standard. The soluble salt content and identification procedure was developed by A. Elena Charola. It calculates the amount of soluble salts by dissolving them in water and separating them through filtration. The soluble salt solution can then be analyzed using semiquantitative test strips to identify and grossly quantify various types of salt anions.

⁹³ CSHRP 1996, 2.

Materials

- Agate mortar and pestle for grinding the sample.
- Watchglass or suitable sample holder.
- Laboratory oven set to 140°F for drying the sample.
- Laboratory scale for weighing the sample.
- Desiccator for cooling the sample and preventing moisture gain.
- Two 250 mL glass beakers for mixing the test sample and solvent, and for filtering the sample mixture.
- Distilled water in which to dissolve the sample and rinse the graduated cylinder.
- A glass stir rod to mix the sample and distilled water.
- Whatman[®] Grade No. 4 filter paper for filtering the dissolved test sample.
- 250 mL glass graduated cylinder.
- Merck EM Quant[™] chloride, sulfate, and nitrate/nitrite commercial anion test strips.
- Pasteur pipette for dropping the solution on the test strips.

Test Procedure⁹⁴

Soluble salt content

- 1. Grind approximately 10 g. of the sample in an agate mortar until a uniform coarse powder is obtained.
- 2. Weigh the sample holder.
- 3. Place the sample into the sample holder and reweigh.
- 4. Dry the sample for at least 2 hours and weigh it, repeating this step until the difference in weight of two consecutive weighings is less than 0.01% of the weight of the sample. The resulting difference is the moisture content absorbed during grinding.

⁹⁴ See Appendix B (B.1-B.5) for testing images.

- 5. Place the sample into a 250 mL glass beaker and add 100 mL of distilled water.
- 6. Stir the mixture with a glass stir rod periodically for 1 hour.
- 7. Leave the suspension to settle overnight.
- 8. Weigh the filter paper.
- 9. Filter the suspension through the filter paper into a 250 mL graduated beaker.
- 10. Transfer the solution into a 250 mL graduated cylinder, rinsing the out the beaker with distilled water, at least three times, each time with a small amount of water.
- 11. Take the volume to a round number.
- 12. Weigh a watchglass.
- 13. Transfer the filter paper with the solid onto the watchglass and reweigh it.
- 14. Place the filter paper and watchglass into the oven for approximately 24 hours.
- 15. Place the sample and watchglass into a desiccator to cool.
- 16. Weigh the sample.
- 17. Return the sample to the oven for at least another 2 hours and repeat the previous 2 steps until the difference in weight of two consecutive weighings is less than 0.01% of the weight of the sample.

Semi-quantitative analysis of anions present in the sample

- 18. With a Pasteur pipette, place drops of the solution onto the test strips.
- 19. Once the color has developed, compare the color to the standards on the container.

Results. The soluble salt analysis was performed as both a quantitative assessment to determine the percentage of soluble salts in each sample through dissolution of the salts and filtration, as well as a semi-quantitative analysis of several individual anion concentrations with test strips. The quantitative analysis determined that the cement rudus of panel #10 has approximately 4.5% soluble content while the surrounding surface samples have between 4.15%

and 4.88% soluble content.⁹⁵ The soluble fraction can consist of a variety of salt anions and in each of the samples is generally consistent with the allowable concentration of soluble anions in mixtures of Portland cement.⁹⁶ The semi-quantitative analysis assessed the concentration of specific salt anions in each cement samples. The analysis was performed with test strips that determined ranges of nitrate, nitrite, chloride, and sulfate anions. The results indicated that there were not significant concentrations of any of these salt anions in the cement.⁹⁷

The implications of these results for the mosaic are that there is not a sufficient concentration of soluble salts, particularly chloride salts, to cause the chloride-induced increase of hydroxyl ions in the cement's pore solution. In addition, the unremarkable concentration of salts in the cement backing suggests that damage caused by the crystallization of soluble salts through wetting and drying cycles is also unlikely.

Presence of Moisture. The third necessary and sufficient condition for ASR is the presence of moisture. As noted above, sufficient moisture is necessary for both the primary chemical reaction to occur and for the hygroscopic gel to expand.⁹⁸ Moisture has been a consistent problem for the mosaic since it was lifted. When the panels were freshly backed with the cement, they were left outdoors, exposed to two decades of precipitation and atmospheric moisture. The current display at Gordion has been shown to be insufficient at preventing the access of moisture to the mosaic and as long as moisture is present, the potential for damage from ASR exists.⁹⁹

⁹⁵ See Table A.2 for detailed testing data.

 $^{^{96}}$ ASTM Standard C150/C150M-12: Standard Specification for Portland Cement notes that a standard composition of Portland cement likely has approximately 3.0% of soluble sulfates in the form of sulfur trioxide (SO₃). The other 1.5% is likely small amounts of soluble chloride, nitrate, or nitrite salts (ASTM C150/C150M-12, 2).

⁹⁷ See Table A.3 for detailed testing data and figures B.6-B.23 for testing images.

⁹⁸ According to Thomas (2013, 29), the internal relative humidity of the cement matrix must be above 80% for the reaction to proceed.

⁹⁹ Thompson 2011, 31.

Although concrete samples were taken from the mosaic in 2010 and 2013, they were not properly stored in a metal container to enable a moisture content analysis to be performed. The visible presence of moisture on the mosaic and conditions such as micro-flora suggest the continued access of moisture and a moisture content analysis on freshly sampled or properly stored concrete would likely confirm this.

Visual Evidence of Alkali-Silica Reaction

The standard method for determining if ASR has occurred involves optical or scanning electron microscopy. These technique allows for the assessment of samples that may have been affected by ASR through the visualization of micro-cracks and gel rings.¹⁰⁰ With stereomicroscopy, the topography of the surface of the pebbles can be examined and with polarized light microscopy (PLM), the tomography of the samples through petrographic thinsections can be examined.¹⁰¹

Petrographic thin-section analysis. The petrographic analysis for ASR was performed on thin-sections of each type of pebble that retained the most bedding cement. These were selected because if ASR had occurred, the most likely evidence would be visible along the interface of the cement embedment zone identified by the cementitious residues still visible on certain collected pebbles.¹⁰² The pebbles were sent to National Petrographic Service, Inc. for the preparation of the thin-sections. Based on recommendations from John Walsh of Highbridge Materials Consulting, Inc., the thin-sections were impregnated with blue epoxy in order to better visualize the evidence of ASR through both PLM and ultraviolet microscopy (UV).¹⁰³

¹⁰² The over-grout, although cementitious, would likely not contain enough alkaline pore solution to initiate ASR because of its thinness.

¹⁰⁰ Winter 2009, 110.

¹⁰¹ Scanning electron microscopy is also able to be performed on both thin-sections and sample surfaces.

¹⁰³ John Walsh, personal correspondence, 25 February 2014; A thin-section of each pebble type was prepared in 2011 without the blue epoxy and these have been examined as well.

Testing Standard. The petrographic analysis follows ASTM Standard C856-13: Standard Practice for Petrographic Examination of Hardened Concrete. According to the standard, the procedure can be used to "establish whether alkali-silica reaction has taken place, what aggregate constituents were affected, what evidence of the reaction exists, and what were the effects of the reaction on the concrete."¹⁰⁴ Although the standard was created to identify the presence of ASR in concrete, the procedures and characteristics should be similar when examining the pebble samples.

Materials. The following materials and equipment were necessary to complete the petrographic analysis of the pebbles for ASR:

- One petrographic thin-section of each pebble type
- Leica MZ16 stereo microscope with 3.5x-57.5x magnification
- Leica KL2500 LCD ring lamp
- Nikon Optiphot 2-POL Polarizing Microscope with 40X to 1000X magnification
- Nikon Alphaphot-2 YS2 Polarizing Microscope with 40X to 1000X magnification
- Nikon G-1B ultraviolet filter block¹⁰⁵

Test Procedure. ASTM Standard C856-13 provides numerous characteristics of ASR that

can be identified through research and visual examination of petrographic thin-sections through a

petrographic microscope. These include:

- Does the aggregate contain particles of types known to be reactive (chert, novaculite, acid volcanic glass, cristobalite, tridymite, opal, bottle glass)?
- If quartzite or any of those listed above, are there internal cracks inside the periphery of the aggregate?

¹⁰⁴ ASTM Standard C856-13, 5.

¹⁰⁵ The G-1B ultraviolet filter block has an excitation filter wavelength of 541-561 nm, a dichromatic mirror cut-on wavelength of 565 nm, and a barrier filter wavelength of 590 nm.

- Has the aggregate been gelatinized so that it has pulled off during sectioning leaving only a peripheral hull bonded to the mortar?
- Cracks that appear to be tensile and to narrow from the center toward the border of the particle are evidence of ASR.¹⁰⁶
- ASR gel (Na₂O·K₂O·CaO·SiO₂) has an index of refraction of between 1.46 and 1.53 and appears as white, yellowish, or colorless; viscous, fluid, waxy, rubbery, or hard; in voids, fractures, exudations, and aggregate.¹⁰⁷

The thin-sections were taken longitudinally, in order to sample areas that were above and below the cement interface. In this way, it would be possible to compare the conditions of potentially ASR-affected areas with those that could have been deteriorated by other factors, such as thermal shock or mechanical damage.

The standard also suggests the use of ancillary analytical techniques to assist in identifying the presence of ASR. Most notably, it suggests the use of scanning electron microscopy to visualize the topography and tomography of a sample and identify areas where aggregate micro-cracking has occurred. It also details a chemical test with uranyl-acetate that can cause ASR gel to fluoresce under UV light. However, as a derivative of uranium, uranyl-acetate is slightly radioactive and the method for using it does not always produce successful results because other, non-ASR related components in the samples can also fluoresce when stained with the solution.¹⁰⁸

Although the standard does not specifically note the use of UV microscopy outside of the uranyl-acetate procedure, since the thin-sections have been impregnated with a blue epoxy, it was possible to find an UV wavelength that can cause the blue epoxy to fluoresce helping to visualize

¹⁰⁶ Ibid.

¹⁰⁷ The standard also notes that gel rims produced by ASR can be masked by weathering-induced rims (ASTM C856-13, 12).

¹⁰⁸ Natesaiyer and Hoover 1989.

micro-cracking. With the G-1B UV filter, the blue epoxy fluoresced bright red and enabled the visualization of contrasts between the pebble matrix and empty space.

Results. The ASTM standard used for this procedure was designed to detect ASR in petrographic thin-sections where both the cement matrix and bound aggregate are visible. Since the pebbles are isolated outside of their bedding, the microscopic analysis was performed on the thin-sections of the pebbles alone. Also, because the pebbles were sampled over three and a half years ago, if ASR had occurred, there would likely be no residual ASR gel on the surface of the pebble. The only possible evidence could be micro-cracking on the surface or within the pebble.

Answering the questions posed by the ASTM standard was the first step in the microscopic analysis of the thin-sections. The first two questions are the only ones that can be answered in the affirmative. The mosaic pebbles are made of chert, metaquartzite, and a volcanic mineral in a glass matrix; and evidence of cracks and fissures are clearly visible in each of the thin-sections, particularly in UV light. This investigation paid particular attention to areas where cement residue still remained at the edge of the thin-section, indicating this was the section of the pebble that had been bedded in the cement. This was done in an effort to compare the embedded surface with the exposed surface of the pebbles and to possibly identify micro-cracking that could be specific to the regions potentially affected by ASR. However, it is not entirely clear what the causes of the micro-cracking are. It is not localized to the areas with cement residue, suggesting that either ASR is not the cause or not the only cause. Neither is it localized to the original above ground area of the pebbles, suggesting that thermal shock from the 800 B.C.E. fire or subsequent mechanical damage could have caused cracking throughout the pebbles.

In the chert thin-section, UV microscopy clearly shows the red-fluorescing epoxy within cracks at an area where the surface interfaces with cement residue (fig. 4.6), However, higher magnification examination in plain polarized light (PPL) shows that this is likely due to natural

crystallization (fig 4.7). Additional micro-cracking is also visible in areas without noticeable cement residue (figs. 4.8 and 4.9). These cracks appear to emanate from the edge of the pebble, narrowing as they penetrate deeper.

The metaquartzite thin-section exhibited the highest frequency of micro-cracking throughout the thin-section. These micro-cracks were particularly visible on the edge of the sample and were not particular to areas with or without cement residue. In fact, the metaquartzite thin-section appeared to have the least cementitious residue of all three even though it had the most cracking. Because of the highly translucent nature of the metaquartzite, these cracks were best visualized under UV and cross-polarized light (XPL) (figs. 4.10 and 4.11).

The volcanic glass thin-section also shows micro-cracking in areas that both do and do not interface with cement residue. These cracks narrow as they spread from the edge of the pebble and there does not appear to be a difference in the crack patterns between the two locations (figs. 4.12-4.15).



Figure 4.7. Photomicrograph of chert thin-section in UV light (40X).



Figure 4.8. Photomicrograph of chert thin-section in PPL (100X).



Figure 4.9. Photomicrograph of chert thin-section without cement residue in UV light (100X).



Figure 4.10. Photomicrograph of chert thin-section without cement residue in PPL (100X).



Figure 4.11. Photomicrograph of metaquartzite in UV light (40X).



Figure 4.12. Photomicrograph of metaquartzite in XPL (100X).



Figure 4.13. Photomicrograph of the volcanic glass at interface with cement in UV light (40X)



Figure 4.14. Photomicrograph of the volcanic glass at interface with cement in PPL (100X).


Figure 4.15. Photomicrograph of the volcanic glass without cement residue in UV light (100X).



Figure 4.16. Photomicrograph of the volcanic glass without cement residue in PPL (100X).

Surface petrographic analysis. Since micro-cracking due to ASR would also likely be visible on the surface of the pebbles, this was also examined on all of the pebbles. The surfaces more clearly show the interface and limit of the cement residue than the thin-sections, making it more possible to compare damage between the two areas (figs. 4.16 and 4.17). However, micro-cracks are not as easily identifiable because light is not being transmitted through the cracks as it is in the thin-sections and the cracks can be camouflaged by the surrounding pebble matrix (figs. 4.18 and 4.19). In addition, aberrations that appear to be cracks could be naturally occurring fractures.

The majority of the surface anomalies that appear to be cracks are visible in the area that would have been above the cement bedding, distinguishable because there is little to no cement residue. This is unsurprising because the cement residue can hide the surface of the pebble and make cracks difficult to see. Several of the sample pebbles exhibit longitudinal crack patterns and surface discoloration extending from the top of the pebble towards the interface with the cement (figs. 4.20 and 4.21).¹⁰⁹ Both of these are likely the result of thermal shock and can be attributed to the 800 B.C.E. fire. None of the surface cracks are contained completely within the area with cement residue and it is likely that none of these cracks originate there either. The visibility of these cracks was enhanced by completely submerging them in distilled water (figs. 4.22 and 4.23).

¹⁰⁹ The top of the pebble is determined by the point which is furthest from any cement residue and would have represented the surface of the mosaic.



Figure 4.17. Metaquartzite sample clearly showing where it was bedded in the cement (reflected light, 5X).



Figure 4.18. Volcanic glass pebble sample clearly showing where it was bedded in the cement (reflected light, 5X).



Figure 4.19. Volcanic glass pebble with micro-cracks that are camouflaged by the surrounding pebble matrix (reflected light, 5X).



Figure 4.20. Higher magnification showing camouflaged micro-cracks (reflected light, 20X).



Figure 4.21. Cracking pattern and discoloration extending from the top of a volcanic glass pebble (reflected light, 5X).



Figure 4.22. Longitudinal cracking extending from the top of a chert pebble (reflected light, 5X).



Figure 4.23. Cracking pattern and discoloration of a volcanic glass pebble made more visible by submersion in distilled water (reflected light, 5X).



Figure 4.24. Longitudinal cracking of a chert pebble made more visible by submersion in distilled water (reflected light, 5X).

Discussion

ASR requires three specific conditions to be met for it to occur: the presence of reactive silica, an alkaline environment, and the presence of moisture. The previous petrographic identification of each of the pebble types has shown that reactive silica is present in the system. All three pebbles – chert, metaquartzite, and a volcanic mineral in a matrix of glass – contain the reactive silica. The other two conditions, however, are more variable and determine whether or not it has been possible for ASR to have occurred in the past or if it is possible to occur in the future.

Previous occurrence of ASR. The potential for previous occurrence of ASR in the Megaron 2 mosaic is difficult to identify. The quantification of moisture at the time of the original application of the cement in 1963 is not possible to determine. However, since the mosaic panels were left outdoors for approximately 20 years, it is possible to assume that significant quantities of water came into contact with the mosaic. This would almost certainly be enough moisture to catalyze and sustain the reaction if there was sufficient alkalinity. Since the presence of moisture is also causing additional conditions to develop, serious consideration must be taken to either move the mosaic to an indoor, climatically controlled environment, or to design a new shelter and display that more effectively prevents the access of moisture to the mosaic.

The immediate carbonation of the surface of the cement embedment would have resulted in a drop in the surface pH below the catalytic threshold for ASR. However, the generally slow rate of carbonation (approximately 0.01 in./0.5 yr.) means that even at the shallow depths of bedding, the pH could have remained above the threshold while the panels remained outdoors at the dig house. Based on this fact, it is possible for ASR to have previously occurred between the cement and the surface pebbles of the Megaron 2 mosaic.

The petrographic examinations were inconclusive. Although micro-cracking was visible in each of the samples, it is not possible to declare without doubt that the cracks were caused by the compressive pressure from expanding ASR gel. The thin-section analysis showed microcracking in several areas of the examined pebbles, in association with cement residue and in areas without it. The surface examination of the pebbles showed visible cracking, mostly in the regions without cement residue. These cracks most likely occurred from thermal shock from the ancient fire, and could have been exacerbated by mechanical damage during lifting, moving, installation in the museum, or cleaning, Because of the localized nature of the cracks outside of the area with cement residue, it is unlikely that they were caused by ASR.

Further analysis is necessary to discover if any of the micro-cracking was caused by ASR. The pebbles should be cleaned of the cement residue with a dilute solution of acetic acid and examined again through the stereo microscope.¹¹⁰ Scanning electron microscopy (SEM) is able to more clearly visualize the topography of a sample by scanning the surface with electrons and analyzing the back-scattered electron image. This results in a detailed topographical map of a surface that uses gray values to exhibit a high resolution, two dimensional image. SEM can be performed on the surface of the pebbles, meaning that cracks that are difficult to see through optical microscopy would be much more discernible.

The pebbles should also be analyzed categorically. They should be sorted by type and examined for patterns of cracking within each group. In addition, they should be examined by panel position, to determine locational patterns of damage. This could also reveal evidence of how the mosaic was affected by the ancient fire and whether or not the micro-cracking noticed on some of the pebbles could be more concretely identified as a result of thermal shock, thereby discounting their occurrence from ASR.

Potential occurrence of ASR. The most conclusive test that suggests that ASR cannot occur is the relatively neutral pH of each sample. Freshly poured Portland cement generally has a

¹¹⁰ The dilution of acetic acid should be between 2% and 10% v/v and will be determined through empirical testing.

pH of 12-13 which immediately begins to drop due to carbonation. The fairly neutral pH of the ground samples, particularly of the rudus of one of the panels, confirms the fact that the pH is too low for ASR to occur, regardless of the reactivity of the pebbles or the moisture content.

Chapter 5: Cement Reduction

Reinforced Concrete

The lifting and re-backing of the mosaic panels with reinforced concrete in 1963 has been the root of numerous problems and deteriorative conditions for the Megaron 2 mosaic. This situation is not unique to the Gordion mosaic, as many lifted mosaics between the 1920s and 1970s were re-backed with cement mortars or concrete. The damage and continuing deterioration of these treatments have been well-documented for numerous mosaics and the 2011 condition assessment of the Megaron 2 mosaic clearly demonstrates each phase of damage before and during lifting and after reinstallment.

In order to mitigate the damage caused by the concrete backing and ensure that the mosaic is protected from further damage and made lighter for reinstallation, it is necessary to remove as much of the old backing as possible without damaging or losing the surface stones. Since the pebbles are bedded directly into the cementitious mortar, it will be very difficult, if not impossible to remove all of the mortar without damaging the pebbles. Therefore, it is likely that the uppermost zone of bedding mortar will need to remain. By removing and replacing the concrete support with a more stable, lightweight, and reversible backing system, the panels can be handled more easily for installation and traveling and will be less at risk from damage.

Criteria for Removal Methods. In order to safely remove the concrete backing without damaging or dislodging the pebbles, it is necessary that the techniques and tools used for removal conform to the following criteria.

Precision. According to the brief technical evaluation of the current backing system, it appears that the pebbles are bedded into a very shallow cementitious layer, most likely a cement slurry that was poured over the back of the pebbles after they were lifted. The narrow ferrous reinforcing bars were then laid into this slurry very close to the surface and the thicker 3"-4"

concrete support was then poured over this contained by wooden forms. Since it is necessary to remove the ferrous reinforcing bars which are within 1/8" of the bottom of the pebbles, it will be important to employ a technique for cutting the concrete down to the reinforcing bars without cutting into the bedding layer and possibly damaging or dislodging the pebbles.

Pebble safety. Since the pebbles and their configuration are the only remaining original components of the Megaron 2 mosaic, it is of utmost importance that these are protected from damage, displacement, or loss. Since the concrete cannot be removed without mechanical means, this damage can come from cutting too deep into the cement bedding and hitting the bottom of the pebbles as well as vibration or physical shock from the cutting process. Any tools and techniques used to remove the backing should not cause sufficient vibration to fracture or dislodge the pebbles.

Working time. With 33 panels to conserve, it is important that any technique used to remove the concrete can be performed efficiently in a relatively short period of time.

Cost and availability. Any of the tools used must be relatively inexpensive and either able to be procured in Turkey or easily transported there from the United States. This includes any replacement parts such as new blades or grinding discs as well as self-contained dust collecting grinders that are recommended given the associated health issues with silicate dusts and the museum environment.

Assessment of Published Case Studies. Selection of methods for backing removal was informed by an assessment of previously used techniques found in the published mosaic conservation literature as well as from current practices in the construction industry literature.

Conservation Techniques. The mosaic conservation case studies that describe the techniques and tools used to remove cementitious mortars and concrete all include mechanical methods, usually with more than one tool. Often, the removal is performed in at least two steps

with bulk removal of the support first followed by finer removal at the mosaic interface.¹¹¹ Since these case studies all concern tessellated mosaics, they are often able to remove all of the cement from the back of the surface stones. This is because the facing can be more secure on a uniform surface and the old support can be ground or cut down to the planar underside of tesserae. Certainly, the more of the old support that is removed and the closer the tools come to the actual underside of the mosaic, the more risky the process is.

Bulk removal. For the first step which removes the bulk of the 'rudus,' tools that are able to remove a large amount of material are selected. Various types of saws or grinders are usually used for this procedure, although more sophisticated techniques have been developed and tested in controlled laboratory settings. For example, the conservation team at the Yale University Art Gallery adapted a Computer Numeric Control (CNC) milling device to control the pattern and depth at which the grinding bit removed the concrete from the back of an ancient tessellated mosaic from Jordan.¹¹² Another example, reported by Tsu, et al., used a large gantry to maneuver a track saw at the desired depth.¹¹³ While these two procedures are sensitive to the particular details of size, shape, and depth of backing of each mosaic, they are very expensive and not readily available technologies for widespread use or in the field. The handheld saws and angle grinders are more susceptible to user error, although there is also a greater measure of control with smaller hand-held units that can be easily adjusted to only cut to certain depths.

The gross removal of the bulk of the backing is often performed by scoring the cement with a saw followed by grinding or chiseling away the cut areas by hand. This allows for more control of how much material is being removed. For this process, it is important to gauge the depth of the reinforcement and the surface stones and to cut down to a safe level. Although the

¹¹¹ Lodge 1981; Bradley 1983; Munday 1986; Price 1991; Cassio 2002.

¹¹² Snow 2011.
¹¹³ Tsu, et al. 2008, 111-112.

ferrous reinforcement in the Megaron 2 mosaic is very narrow and can likely easily be cut with a saw, its proximity to the pebbles requires that the cutting or scoring stop at the upper level of the reinforcement, which can then be removed in a separate operation.

Fine removal. Once the bulk of the backing has been removed, more sensitive techniques are necessary to remove material nearer the surface stones. In published accounts, various tools have been used to achieve this, including pneumatic styluses, microdrills, microchisels, and air vibrators.¹¹⁴ These pneumatic and automatic tools remove very little material at a time but are much more controllable and sensitive. With tools such as these, it is possible to remove the cement to the level of the reinforcement, then level the cement once the reinforcement has been removed.

Construction Industry Techniques. Since cement and concrete are also used extensively in construction and industrial settings, it is possible to examine industrial removal processes as well, to determine an appropriate course of action for the Megaron 2 mosaic. However, since industrial techniques are not specifically calibrated to the needs of mosaic conservation, it is important to consider all of the advantages and disadvantages as they would relate to a mosaic.

The industrial concrete removal techniques are often performed to remove damaged sections from deteriorative conditions such as ASR and corroding reinforcement. The International Concrete Repair Institute's (ICRI) Technical Guidelines provide suggested methodologies for cutting concrete. For removing corroded reinforcement, the ICRI recommends exposing and undercutting using any number of cutting methods such as "hydro-demolition, hydro-milling, and electric, pneumatic or hydraulic impact breakers."¹¹⁵ This, however, is not possible for the Megaron 2 mosaic since the reinforcement is too close to the pebbles. The ICRI recommends using hydrodemolition processes due to potential negative effects from mechanical

¹¹⁴ Bradley 1983; Munday 1986; Cassio 2002.
¹¹⁵ International Concrete Repair Institute 1995, 921-923.

impact techniques like chiseling and sawing. Hydrodemolition uses high-pressure water to cut through concrete and is used for both gross and localized removal. With this method, vibration is minimal and embedded elements remain undamaged.¹¹⁶ However, hydrodemolition consumes an enormous amount of water, does not result in a uniform surface, usually requires large format equipment, and creates a large quantity of refuse slurry that must be disposed of responsibly.¹¹⁷

The ICRI Guideline states that mechanical techniques use impact to "fracture and split the coarse aggregate, and create micro-fractures in the substrate. As a result, the ability of the fractured substrate to provide a durable bond with the repair material is compromised" (fig. 5.1).¹¹⁸ The vibrations caused by impact are transmitted through the reinforcing bars and can result in additional cracking. In the Megaron 2 mosaic, this could dislodge or crack the pebbles or shatter the rest of the cement.

¹¹⁶ International Concrete Repair Institute 2004, 927.
¹¹⁷ Ibid., 929.
¹¹⁸ International Concrete Repair Institute 1995, 921-923.



Figure 5.1. Damage created by chipping hammer (ICRI 2004, 927).

Discussion. Neither mechanical nor hydrodemolition methods are perfect solutions for removing the cement from the Megaron 2 mosaic. Mechanical methods could result in the cracking of the cementitious grout and possible dislocation of the pebbles, while hydrodemolition uses too much water and the waste products may be difficult to manage. In this case, the mechanical methods are more appropriate, if performed carefully. The techniques that have previously been used for removal of cement and concrete backings from mosaics should be used for the Megaron 2 mosaic. In particular, the rudus should be scored with a depth-controlled circular saw to cut to a depth of approximately 1" above the reinforcing bars. The cement between the score lines can then be chipped away manually with a hammer and chisel or ground down with an angle grinder set with a dust collector. Once the bulk of the rudus has been removed, more precise, fine techniques using low vibration grinding and cutting tools, such as a Dremel or other microabrasive apparatus, should be used to remove the concrete until the level of the reinforcement is reached. The reinforcement should then be lifted, not cut, out of the cement

and voids left by the reinforcement filled with lime mortar. The lime mortar can be reinforced with polypropylene fibers or mesh to instill rigidity in the panels before re-backing.¹¹⁹ If any of the pebbles are exposed, no more concrete should be removed from that area. When a uniform surface is reached, any dust or particulates should be brushed and vacuumed from the surface and the surface should be washed and allowed to dry in preparation for re-backing.

Over-Grout

Numerous panels exhibit some degree of over-grout on the surface, a condition that, according to Thompson, "is characterized by a very thin slurry of cementitious material, covering large areas of pebbles."¹²⁰ This condition was caused by the leakage of the cementitious grout from the back onto the surface of the mosaic through existing lacunae and cracks in the mosaic as well as poor execution of the present museum installation. While it has been determined that ASR is not a concern between the pebbles and the cement, the biggest problem with the over-grout is the fact that it obscures the original design and hinders the interpretation of the mosaic. The removal of over-grout is necessary for the increased interpretation of the mosaic.

¹¹⁹ Published research on the use of polypropylene reinforcement of mortars and cements can be found in Shoenberger 1992, Brown 2002, Ahmed 2006, Izaguirre 2011, Bagherzadeh 2012, and Di Bella 2014.

¹²⁰ Thompson 2011, 25.



Figure 5.2. Over-grout covering a large area of the pebbles on panel #3 of the Megaron 2 mosaic (courtesy of Meredith Keller, 2013).

Criteria for Techniques. The same criteria used for the removal of the cement backing should be considered for the removal of the over-grout. In fact, since the over-grout must be removed completely from the surface of the pebbles, it is important to be even more precise and careful during its removal so as not to damage or dislodge the pebbles. This condition has not been discussed in other mosaic conservation case studies and may be unique to the Megaron 2 mosaic due to its nature as a pebble mosaic and the circumstances of its backing and display installation. However, the careful fine working techniques used for the rudus can also be used for the over-grout, although to reduce vibration so close to the pebbles, a more controlled mechanical method, possibly coupled with chemical means is recommended. Thompson notes that some light probing was performed on the over-grout with a scalpel and dental picks which was partially effective at removing the over-grout, although more powerful techniques such as a Dremel or

other microabrasive apparatus may be necessary for the removal of the over-grout within the interstices of the pebbles.¹²¹

Selected Techniques for Empirical Testing

Based on a review of published literature for cement and concrete removal, both in the field of mosaic conservation and the construction industry, the following methods are recommended for the removal of the cementitious mortars on the Megaron 2 mosaic.

- Bulk cement rudus removal: Cross-cut with circular saw to a depth of approximately 1" • above the reinforcing bars and mechanically removed with an angle grinder.¹²²
- Fine cement rudus removal: *Carefully removed with low vibration grinding or cutting* ٠ tools such as a Dremel or other microabrasive apparatus.
- Over-grout removal: Carefully remove mechanically with a scalpel or with a low • vibration grinding or cutting tools such as a Dremel or other microabrasive apparatus.¹²³

 ¹²¹ Thompson 2011, 26 f.n. 7.
 ¹²² A more controlled removal system using a variable speed CNC router that may avoid damage or loss of the pebbles from percussive stresses is also currently being investigated.

¹²³ The over-grout can likely be softened with diluted acetic acid or distilled water to aid in removal.

Tool	Application	Precision	Pebble Safety	Working Time	Cost	Availability
Hammer and Chisel	Bulk Removal	Moderate	Low	Moderate	Low	High
Pneumatic Hammer	Bulk Removal	Moderate	Low	Moderate	Moderate	Moderate
Masonry Saw	Bulk Removal	Low	Low	Low	High	Moderate
Traveling Wet Saw	Bulk Removal	Low	Low	Low	High	Low
Angle Grinder	Bulk Removal	Low	Low	Moderate	Moderate	High
CNC Milling Machine	Bulk Removal	High	High	Low	High	Low
Dremel	Fine Removal	High	High	High	Moderate	High
Pneumatic Stylus	Fine Removal	High	High	High	Moderate	High
Scalpel	Over-grout Removal	High	High	High	Low	High

Table 5.1. Cement Reduction Criteria

Chapter 6: Facing

The first step in the re-backing of a mosaic is to temporarily secure the surface tesserae or pebbles in order to prevent any loss and fragmentation during the often aggressive re-backing operation. This process, known as facing, generally utilizes a flexible membrane such as fabric or paper and a reversible adhesive applied to the "face" of the mosaic. A similar procedure is used during the lifting of mosaics as well. When the Megaron 2 mosaic was lifted in 1963, sections were cut and faced with muslin and glue in order to pull the selected pebble designs up and out of the clay bedding. The facing was not completely effective in securing all of the pebbles within a design panel, causing lacunae within the panels as they were lifted.¹²⁴

The most common way to secure the mosaic surface is through the attachment of a flexible facing material, usually a textile, with a strong but easily reversible adhesive. The facing material provides a singular, cohesive surface for the discrete pebbles or tesserae and allows for the adhesive to bind them to a common support. A variety of materials have been used to face mosaics and a review of documented treatments confirms that although the materials may be different, the critical properties required of any effective facing are the same.¹²⁵ These properties represent the criteria by which to select facing materials. For the Megaron 2 mosaic, facing materials vary slightly from the majority of the published case studies due to the surface anomalies of the pebbles rather than purpose-cut tesserae. The relatively flat and uniform surface of a tessellated mosaic allows for the use of a variety of facing materials that may not be effective when used on the more irregular surface of a pebble mosaic. The high frequency of peaks and valleys on a pebble mosaic surface require a highly flexible yet strong material to provide the necessary coverage to secure the pebbles.

 ¹²⁴ See Thompson 2011, 116-118 for photographs of the lifting process.
 ¹²⁵ Thuer 2011.

Criteria for Materials

Based on research of published conservation treatments describing facing procedures for mosaics and related works, all of the noted materials were assessed based on the specific properties necessary for this project. Because the facing material and adhesive perform different functions in the facing system, they were each assessed separately. The facing materials for the Megaron 2 mosaic should satisfy the following criteria.

Facing Textile

Flexibility. Since the irregular surface of the pebbles makes it difficult to achieve uniform adhesion of the facing, the facing textile should be strong but flexible enough to penetrate all of the crevasses between the pebbles. This problem was recognized during the 2013 field season at Gordion when one of the panels was lifted. The conservation team used Hollytex, a non-woven, synthetic polyester fabric which was too stiff to be easily and effectively formed over the curvature of the pebbles and did not provide a sufficiently secure attachment (Fig. 6.1). Fortunately, this facing was applied as more of a precaution in order to protect the pebbles during the process of lifting the panel which generally did not put any physical stress or pressure on the pebbles. However, without uniform adhesion, pebbles can loosen, particularly during the flipping of the panel and cement backing removal process.



Figure 6.1. Frank Matero applying Hollytex and Aquazol 200 as a facing material to panel #7 in 2013 (photo courtesy of Meredith Keller, 2013).

Porosity and wetability. The facing textile must have sufficient porosity to allow a liquid adhesive with a moderate viscosity to both 'wet' it and transfer through it, adhering the textile to the pebble and cement surface. However, it should be tightly woven enough to conform as a protective and unifying surface atop the pebbles.

Ability to be cut/shaped. Each of the 33 panels has different dimensions and therefore the facing needs to conform to the shape of each panel. The facing textile should be able to be easily cut with scissors or a knife and should not unduly fray or shed excessive fibers.

*Cost and availability.*¹²⁶ Since all 33 panels must be faced prior to re-lifting and rebacking, it is necessary to consider the quantity and cost of the materials necessary for the comprehensive treatment. The facing materials must either be procured in Western Turkey, if possible, or transported there, which would increase the cost. During the upcoming 2014 summer field season in Gordion, only two of the panels are slated to be re-backed; however, eventually

¹²⁶ This criterion applies to all of the materials, tools, and equipment necessary to conserve the mosaic panels.

the others will need to be faced, re-lifted, and re-backed. It is therefore important to select facing materials that are both effective and economically and geographically feasible.

Adhesive

Stability. The stability of an adhesive is determined by its ability to resist change to its chemical and mechanical properties due to various interferences, including chemical interaction with other materials and the environment. The facing adhesive should be chemically stable so as not to produce an undesired or deteriorative reaction with the mosaic and should resist chemical alteration through temperature change or environmental contact.¹²⁷ Although facing is a temporary process, sufficient time can elapse to cause damage if the adhesive becomes corrosive or more permanent over time.

Adhesive Bond Strength. The adhesive used in the facing should be strong enough to adhere the facing to the pebbles but weaker than the adhesive strength between the cement matrix and the pebbles. If excessive tensile or shear stress were imparted on the facing, the adhesion of the facing rather than the adhesion of the pebbles and cement should fail. Given the thickness and rigidity of the panels, the facing in this case is strictly superficial in that it is meant to protect and cohere the pebbles in place during lifting and backing removal.

Reversibility. The facing is meant to be temporary, only remaining applied during the process of cement removal and re-backing. Once the re-backing is completed, the facing should be removed with no residual damage to the pebbles or cement. In addition, the facing adhesive should be easily removable with the application of a non-toxic solvent.

¹²⁷ Environmental contact includes oxidative processes and chemical interaction with atmospheric moisture.

Glass Transition Temperature (T_g).¹²⁸ Once the adhesive has cured, its strength generally remains constant unless an outside influence interferes.¹²⁹ One intervention that is particularly effective at reducing the bonding strength of an adhesive is heat, which can cause the hardened adhesive to revert back to an amorphous and weak material. The temperature at which this reversion occurs is called the glass transition temperature. Any adhesive that is selected for use must have a T_g that is higher than the maximum annual temperatures in Yassihöyük, Turkey, which is approximately 100°F (38°C).

Toxicity. Since the panels have fairly sizable dimensions, a large quantity of adhesive will be necessary to face all 33 of them.¹³⁰ In order to protect the health and safety of the conservators applying the adhesives, it is important to consider the toxicity of the adhesive components (adhesive and solvent). Therefore, an adhesive and solvent mixture that is non-toxic or minimally toxic should be selected.

Cost and Availability. See above, facing material criteria.

Assessment of Published Case Studies.

The selection of an appropriate facing for the Megaron 2 mosaic included a review of the mosaic conservation literature to determine the range of facing materials that have previously been used. The published treatment reports rarely include evaluation of the facing treatments and it is not always possible to determine whether or not they were effective.¹³¹

Facings for mosaics are generally composed of two different layers, performing different functions. The primary facing, which is the layer that is in direct contact with the mosaic, is

¹²⁸ This criterion also applies to the backing adhesives; Climatic information taken from the Turkish State Meteorological Service (http://www.mgm.gov.tr/en-US/forecast-cities.aspx). Since no climatic data for Yassihöyük is available, this data is for Ankara, which is approximately 60 miles northeast of Yassihöyük.

¹²⁹ This is certainly dependent on the type of adhesive, as some can cross-link with age, although none of the adhesives proposed in this project are prone to cross-linking.

¹³⁰ The panels range from approximately 3.75 ft.² (panel #9) to 32 ft.² (panel #10).

¹³¹ One caveat with this analysis is that the literature appears to demonstrate that mosaic conservators often select treatments based on the fact that conservators before them have done this and perhaps not because they have been particularly effective. Therefore, the published reports should be treated as a base of knowledge from which to initiate a study, rather than a compendium of best practices.

usually, a lightweight, porous material such as cotton gauze. This ensures that the adhesive and facing materials become a single, solid layer that is adhered to the mosaic surface. The primary facing can be composed of numerous layers of the same material embedded in the adhesive. A secondary facing material that is heavier, stiffer, or more tightly woven such as muslin or burlap is often applied atop the primary layer as additional support.¹³² The secondary facing layer provides additional rigidity and protection for the mosaic surface.

Primary facing material. According to the published literature, many treatments used some sort of cotton gauze or thin, porous, cotton fabric as the primarily facing material.¹³³ Synthetic or non-woven textiles are rarely used because of their general inflexibility and relatively low porosity. The cotton fabric allows the adhesive to flow through it and make contact with the substrate while maintaining contact with the facing. The lightweight and exceptional malleability of cotton gauze makes it easily formable to suit any surface.¹³⁴ In addition, cotton is highly available and cost effective. The generally loose weave of cotton gauze may be problematic with smaller pebbles, causing the pebbles to penetrate through the cotton, although this could be remedied with multiple layers of the primary facing. The cotton can have a tendency to fray at the edges when cut but this can be avoided by overlapping the selvage at the edges for reinforcement Also, the cotton has a low tensile strength and may tear under relatively low stress.

A more tightly woven, although still porous, textile such as silk crepeline can also be considered as a highly effective primary facing material. The tighter weave would allow the crepeline to form a better surface than cotton gauze and it frays less when cut. However, it is more expensive and generally less available than cotton, having to be sourced from specific

¹³² Barov 1983, 169.

¹³³ Bradley 1983, Frankovic 2008, Vincent 2008, Tsu, et al. 2008; There is no standard terminology for these materials, so different accounts note the use of cotton scrim, cotton gauze, scrim cloth, and cheesecloth when referring to the use of cotton textiles as facing materials.

¹³⁴ Barov notes that "Because of its flexibility, [cotton gauze] wraps the exposed tesserae surfaces and grouting in between..." (1983, 169).

conservation or quilting vendors. It also has the propensity to tear under low tensile stresses.¹³⁵ Crepeline has not previously been used for mosaic conservation, although it has found application as a backing for the conservation of textiles.¹³⁶ Both cotton gauze and crepeline will be tested empirically on replica panels before use on the Megaron 2 mosaic to determine which performs the best, and how many layers would be most suitable.

Secondary facing material. The secondary facing layer's primary functions are to provide a stronger, more rigid support for the surface stones and to protect them from mechanical damage. This facing is often composed of one or more layers of heavy and stiff, or more tightly woven textiles. Previous mosaic conservation projects have used burlap or tightly woven muslin for this layer.¹³⁷ Burlap is a woven, natural vegetal fiber fabric made from the skin of the jute plant. The burlap is not readily formable to suit uneven surfaces, although the secondary facing material does not need to be as malleable as the primary. Burlap's loose weave means that it is highly porous and allows for a more cohesive bond with the adhesive and the primary facing. Burlap is highly fibrous and can be messy when cut, applied, and removed. It is also highly acidic and has the tendency to bleed when wet.¹³⁸

Muslin, on the other hand, is generally much lighter weight than burlap and is more tightly woven. It is a cotton fabric that is available in a variety of weights. It is more malleable and can conform to any remaining uneven surfaces after the primary facing. It has also been used as a primary facing material, although its tight weave is less desirable in that application. In order to achieve the high strength and rigidity required of a secondary facing, multiple layers of relatively heavy weight muslin can be used. As with the primary facing materials, both burlap and

¹³⁵ Cotte 2007, 5.

¹³⁶ Éri 2009.

¹³⁷ Vincent 2008, Tsu, et al. 2008.

¹³⁸ Lord and Lord 2001, 203.

muslin will be tested empirically for performance and procedure before application on the Megaron 2 mosaic.

An additional layer can also be considered for the further protection of the pebbles. This layer, made of dense, but soft foam such as polyurethane memory foam, would act as a cushion support when the panel is inverted to perform the cement removal and re-backing. This foam can conform to any undulations of the faced surface. While the memory foam should be a temporary cushioned bed, consideration must be given to the pH and degradation products of the foam, as these can cause considerable damage if left unmonitored for too long. The polyurethane memory foam has a relatively neutral pH but is susceptible to thermal and moisture-induced degradation. Therefore, the mosaic should only be set on the foam for a limited period of time and the temperature and moisture should be monitored.

Facing adhesives. Adhesives for facings are far less predictable. They vary between natural and synthetic polymers, and aqueous and non-aqueous emulsions and solutions. As with the facing materials, few of the published treatment reports evaluate facing adhesives and there does not seem to be any pattern to their use. Instead, it is likely that adhesives were previously chosen based on their effectiveness in other applications or in other mosaic conservation projects.

The natural adhesives are proteinaceous glues such as animal bone glue or rabbit skin glue. These generally have too low of a T_g to be functional in the summer, are susceptible to micro-organism growth, and become brittle after drying.¹³⁹ Upon drying, protein glues also have the tendency to shrink, which could result in damaging tensile stresses on the surface.¹⁴⁰ They have previously been used for mosaic facings, although this is likely due to their ease of reversibility with cold water, low expense, and wide availability.¹⁴¹ The most common synthetic

¹³⁹ Arslanoglu 2003, 13.
¹⁴⁰ Schellmenn, N.C. 2007, 62.
¹⁴¹ Barov 1985; Severson 2000; Vincent 2008.

adhesives used for facings have been polyvinyl acetates (PVAs). PVA is a synthetic vinyl resin with thermoplastic properties and when used as an emulsion, is suspended in water. After drying, however, PVA emulsions are not soluble in water, but require organic solvents, such as acetone, ethanol, and toluene, for removal. Due to PVA's low T_g (32-68°F); need for organic solvents; and relatively low viscosity, even at high solid concentrations, PVA emulsions are not appropriate for this facing adhesive. Traditional, non-emulsified PVA resin adhesives also have too low of a T_g and require organic solvents for removal.¹⁴² Barov, determined that PVA emulsions were not a successful facing adhesive due to their poor fabric to stone adhesion.¹⁴³

For this project, two different facing adhesives will be tested on replica mosaic panels: methylcellulose and Aquazol[®] 200, both soluble in water and alcohol. Both adhesives conform to all of the required critical properties. Aquazol[®] 200 was used to face one of the Megaron 2 panels in 2013. The adhesive's effectiveness was not clearly determined because the facing material, Hollytex, was too stiff. Although both adhesives are primarily soluble in water, neither loses their critical properties when dissolved in alcohol, which can be used to speed up evaporation and drying of the adhesive.¹⁴⁴

According to the studies by Arslanoglu, Aquazol[®] is a "poly(2-ethyl-2-oxazoline) or PEOX, a tertiary amide polymeric material based on the monomer 2-ethyl-2-oxazoline."¹⁴⁵ The Aquazol[®] 200 version is the mid-range molecular weight (MWT) of the adhesive. The higher MWTs have better bond strength and the lower MWTs penetrate better. Aquazol[®] 200 is often chosen because of its moderate strength and penetration ability.¹⁴⁶ It is thermally stable and has been tested via artificial aging and found to be temporally stable as well. It is pH neutral, nontoxic, and has a relatively high adhesive bond strength at low concentrations. In alcohols, it has a

¹⁴² Smith 1989, 50-51.

¹⁴³ Ibid., 171.

¹⁴⁴ Arslanoglu 2003; 2004.

¹⁴⁵ Arslanoglu 2003, 12.

¹⁴⁶ The difference between MWTs is the length of the polymeric chain (Arslanoglu 2004, 10.).

low viscosity, making it easy to apply as a mosaic facing adhesive. Although Arslanoglu's testing of Aquazol[®] was performed for its use as a consolidant or film in paintings conservation, many of the properties can be transferred to mosaic conservation. For example, during testing, Aquazol[®] appeared to be less brittle than animal glues, was readily removable in various alcohols and acetone, and dried quickly.¹⁴⁷ Its T_g is approximately 155°F, well above the ambient summer temperatures in Turkey.¹⁴⁸

Methylcellulose, on the other hand, is an organic adhesive formed from cellulose fibers, which dissolve readily in numerous solvents, including water and various alcohols. It is a cellulose ether made from glucose, swelled and decrystallized with sodium hydroxide.¹⁴⁹ It has been used often in paper and textile conservation, although not previously for mosaic conservation.¹⁵⁰ While it should bond well to the textile facing materials, its bonding ability to the pebbles and cement could be a concern. Although it is a weaker adhesive than Aquazol[®], it is thermally and environmentally stable, pH neutral, and non-toxic. Methylcellulose is less expensive and has wider availability than Aquazol[®] but has a lower T_g of approximately 98°F that could make it problematic in the Turkish summer. Also, when dissolved in water, methylcelluose is particularly susceptible to biological attack.¹⁵¹

Both of these adhesives will be tested for ease of application, bonding ability, and reversibility.¹⁵²

Selected Materials for Empirical Facing Tests

Primary facing material: Cotton cheesecloth and crepeline. Both are thin, extremely •

flexible textiles. The cotton cheesecloth is more porous and less expensive but may be

¹⁴⁷ Arslanoglu 2003, 13-16.
¹⁴⁸ Ibid., 12.

¹⁴⁹ Smith 1989, 21.

¹⁵⁰ Indictor, et al. 1975; Hofenk-de Graaff 1981; Baker 1982; Verdi, et al. 1984.

¹⁵¹ Guru, et al. 2012, 961.

¹⁵² Originally, the adhesive criteria included minimal water use out of concern for ASR, but since that has been ruled out, an aqueous solution can be used.

susceptible to fraying or stretching. The crepeline is more expensive but resists fraying and may form a tighter surface over the pebbles.

- Secondary facing material: *Muslin and burlap*. Both are sufficiently heavy and strong but with enough flexibility to conform to remaining undulations of the primary facing. The muslin is more tightly woven and resists fraying and shedding better than the burlap but the burlap is less expensive and more porous to allow for better flow of adhesive between theweave.
- Cushioned bed: *Slow-Recovery Super-Cushioning Polyurethane Foam*. This foam performs well up to 120°F and is reusable, although should be monitored during use for degradation.
- Facing adhesive: *Methylcellulose and Aquazol*[®] 200. Both adhesives are soluble in water and non-toxic solvents, and are thermally and environmentally stable. Methylcellulose is less expensive and more readily available, but has a low enough T_g to be problematic if exposed to high ambient temperatures and has a much lower bioresistivity than Aquazol[®]. Aquazol[®] has a higher bond strength and T_g but is more than twice the cost of methylcellulose.

Facing Material	Application	Flexibility	Porosity/Wetability	Shape/Cut-ability	Tensile Strength	ЪĦ	Weight
Cotton	¢			-	,	-	•
Gauze/Cheesecloth	Primary	High	High	Moderate	Low	Neutral	Low
Ē	£	11.11		1	F	Slightly	F
Japanese Faper	Frimary	Hign	Moderate	HIGN	LOW	Alkaline	LOW
Crepeline	Primary	High	Moderate	High	Low	Neutral	Low
Hollytex	Primary	Moderate	Low	High	High	Neutral	Low
Muslin	Secondary	Moderate	Moderate	Moderate	High	Neutral	Moderate
Hessian (Burlap)	Secondary	Low	High	Low	High	Acidic ⁴	Heavy
Facing Material	Cost	Availability					
Cotton							
Gauze/Cheesecloth	Low	High					
Japanese Paper	Moderate	Moderate					
Crepeline	Moderate	Moderate					
Hollytex	Moderate	Moderate					
Muslin	Low	High					
Hessian (Burlap)	Low	High					

Table 6.1. Facing Textile Criteria

¹ ASTM 1919, 406 ² Nicholson and Page 1988 ³ Murphy and Rempel 1985 ⁴ Lord and Lord 2001, 203

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		Adhesive Bond		Glass Transition				
Adhesive	Stability	Strength	Reversibility	Temp. (T_g)	рН	Toxicity	Bioresistivity	
Animal Glue	High	$High^{1}$	High	N/A	Neutral ²	Low	Low	
PVA Emulsion	High	$High^3$	Low^4	Between $32-68^{\circ}F^{5}$	Slightly acidic ⁶	Low	High	
Acrylic Resin ⁷	High	High	High	Approximately 104°F ⁸	Slightly acidic ⁹	Low	High	0
Methylcellulose	High	Low^{10}	High	Approximately 98°F ¹¹	Neutral ¹²	Low	Low	
Aquazol	High	Moderate ¹³	High	Approximately 155°F ¹⁴	Neutral	Low	High	
Adhesive	Shrinkage	Cost	Availability					-
Animal Glue	High	Low	High					
PVA Emulsion	Moderate	Moderate	Moderate					
Acrylic Resin	Low	Moderate	Moderate					
Methylcellulose	Moderate	Low	High					
Aquazol	Low	Moderate	Moderate					
⁴ Pearson 2003, 483.								
² Pearson 2003, 483.								
3 Cmith 2012 55								

Table 6.2. Facing Adhesive Criteria

³ Smith 2013, 55. ⁴ Ibid., 50. ⁵ Ibid., 51. ⁶ Ibid., 53. ⁷ Acryloid B-72. ⁸ Smith 2013, 67. ⁹ Ibid., 66. ¹⁰ Ibid., 26. ¹⁰ Ibid., 26. ¹¹ Guru, et al. 2012, 961. ¹² Smith 2013, 26. ¹³ Arslanoglu 2003, 12. ¹⁴ Arslanoglu 2003, 12.

Chapter 7: New Backing

As already described in Chapter 3, the use of a reinforced cement backing such as applied to the Megaron 2 mosaic, was common at many archaeological sites in the 1960s. Over time, these backings have caused major problems that have led to the advanced deterioration and loss of the original mosaic designs. Presently, there is a growing concern for the removal of these incompatible and deleterious backings and major mosaic conservation consortia like the International Committee for the Conservation of Mosaics and the Getty Conservation Institute are engaged in discussions and research into developing criteria and techniques for more appropriate backing solutions. This project aims to contribute to that research by generating criteria for the rebacking of a pebble mosaic and assessing previously completed treatments via these criteria.

Criteria for Materials

The Megaron 2 mosaic has particular needs that require the identification of specific criteria for the selection of a new backing system. These requirements are first to ensure the structural support of the mosaic panels and allow for their repositioning in a newly reconfigured space; second to prevent further deterioration and loss of the pebbles, and third to easily allow compensation between the original panels in their new setting. In addition, the re-backing must be lightweight, non-corrosive, and of relatively low cost.

Backing material. The materials that replace the cement backing should possess the following properties:

Rigidity. The only positive property of the current cement backing is that it is extremely rigid and prevents structural warping or displacement of the pebble surface. This aspect must be retained by any new backing material.

Weight reduction. The existing backing weighs approximately 150 pounds per cubic foot.¹⁵³ This means that for the Megaron 2 mosaic panel that was lifted in 2013, the 3'x5'x4" panel #7 weighs approximately 560 pounds. The weight of each panel must be reduced significantly in order to allow ease in future lifting and moving.

Moisture resistance. The panels are currently displayed outdoors, approximately 3' below the surrounding ground level, it is likely that moisture in some form will continue to reach the mosaic until a more permanent display solution is determined (Fig. 7.1). Moisture infiltration of the display has caused the deterioration of the cement on the surface which has led to the exposure, corrosion, and deterioration of the ferrous reinforcement in the backing.¹⁵⁴ Moisture has also resulted in the development of biological growth on the surface of the mosaic and the corrosion of the reinforcing bars. The new backing should be resistant to deterioration by moisture and not contribute to potential moisture-related deteriorative processes.

 ¹⁵³ Hassoun and Al-Manaseer 2012, 64.
 ¹⁵⁴ Thompson 2011, 27.



Figure 7.1. The existing mosaic display demonstrating the depth of the mosaic below grade (Courtesy of Meredith Keller, 2013).

Ductility. Ductility is a material's ability to resist fracture under tensile stress. The cement that forms the existing backing for the mosaic panels is a brittle material, meaning that under stress, it has the tendency to break, rather than deform. A new backing material should be ductile rather than brittle so that it sufficiently resists fracturing under stress.

Ability to be shaped/cut. All 33 of the panels are different dimensions and as such, it is important that the new backing assembly can be shaped to fit each panel. This will also ensure that the panels will still fit in the display when rearranged to more accurately represent the original design. The materials used for the backing must be able to be easily shaped or cut with non-specialized cutting equipment. Since all of the conservation work will be performed on site, it is necessary for whatever materials and equipment needed for cutting, shaping, and applying the backing be easily obtained in Western Turkey or easily transported to the site.

Compressive strength. Once the cement backing has been removed, the panels will weigh significantly less than they do now. However, it is still necessary to consider the forces imparted by the mass of the pebbles, remaining cement, and gravity. Any new backing material must be able to withstand and distribute these forces so as not to buckle or warp under compressive loads.

Coefficient of thermal expansion. Since the new backing material, adhesive, and residual cement of the mosaic will all coexist in a bound system, it will be necessary to understand how all of these materials expand and contract with changes in temperature and relative humidity. In a bound system, if one of the materials expands and contracts more than others, cracking and loss of structural stability from elevated shear stress can occur. It is important to find backing materials with similar coefficients of thermal expansion to ensure that as they expand and contract with changes in temperature, they do so at a similar rate.

Adhesive. The second component of the backing system is the adhesive used to bind the backing to the mosaic. The selection of an appropriate adhesive is important because it bridges the existing mosaic materials with the new backing. Many of these criteria are consistent with those required of the facing adhesives.¹⁵⁵

Adhesive bond strength. An appropriate adhesive should have a bond strength lower than the cohesive strengths of the two adherends: the new backing material and the mosaic matrix. This mechanical property will be discussed further in Chapter 8.

Chemical Stability. It is important to identify any potential chemical interaction between all of the components in the re-backing system. The existing cement backing can potentially lead to deleterious alkali-silica reaction between the pebbles and the cement. The selected backing and adhesive should not chemically react with the mosaic, ensuring that no deteriorative chemical

¹⁵⁵ See Chapter 6 for a description of glass transition temperature, minimal water use, and toxicity.
effects occur and the bond between the backing system and the mosaic can be easily reversed, if necessary.

Reversibility. As with any conservation treatment, the application of the new backing should be reversible with little or no residual effect to the mosaic. The existing cement backing is somewhat irreversible, meaning that the cementitious grout that was used after lifting surrounded and replaced the original clay matrix. While this hard mortar can be reduced, it cannot be totally removed completely without damaging the pebbles.

Isolating Layer. In order to ensure the reversibility of the new backing, it may be necessary to include an isolating layer between the mosaic and the backing adhesive. This layer will function to allow the release of the adhered rigid support due to its solubility in selected solvents. The criteria for the isolating layer are similar to those of the backing adhesive, with the exception of the need for enhanced reversibility.¹⁵⁶

Assessment of Published Case Studies

Many of the case studies of mosaic conservation projects detail the materials and techniques that were used but do not discuss the criteria for their selection.¹⁵⁷

Discussion of backing materials. During the case study review, it became clear that three particular backing systems have been used most frequently for mosaic re-backing: epoxy resins, mortars and modified cements, and honeycomb panels. Each of these materials has been used in various iterations, with different formulations and different honeycomb materials. All of these treatments attempted to create a rigid, lightweight support for a mosaic and some were more

¹⁵⁶ Some additional mechanical procedures may also be necessary to remove it safely from the mosaic.

¹⁵⁷ Where properties were tested or cited, this information is noted.

successful than others. Table 7.1 displays how each of these treatments have or would perform based on the criteria described above.¹⁵⁸

Epoxy resins. In the 1980s, many re-backing projects used various epoxy resins with secondary solid supports to create a lightweight backing system. It was determined early on that the epoxy resins on their own were not rigid enough to support the mosaics, which were often stripped of their bedding matrix. Blackshaw and Cheetham evaluated the use of foaming epoxy resin for a mosaic backing; however, in order for the resin to be rigid enough on its own, it would have to be inordinately thick.¹⁵⁹ Most resins require secondary supports, which are generally steel, usually as an embedded mesh or frame. In addition, the epoxy resins often had to be bulked with another material to have a suitable strength to weight ratio. This bulking additive often came in the form of vermiculite.¹⁶⁰ Epoxy resins are also generally difficult to remove. Two projects have included reversibility testing for epoxy resin backings and found that while the resins themselves were "practically non-toxic," they required moderately toxic solvents, none of which completely removed the adhesive.¹⁶¹ Residues had to be removed mechanically.¹⁶² The lack of inherent rigidity of the epoxy, the need for an additional reinforcement, and the low degree of reversibility makes epoxy resins alone unsuitable for the Megaron 2 mosaic backing.

Modified mortars and cements. Reinforced mortars and especially concrete, were once popular materials for re-backing but have now largely been recognized as an inappropriate method due to its inherent brittleness, susceptibility to moisture-related deteriorative conditions such as the corrosion of iron reinforcement and the crystallization of soluble salts, different coefficients of thermal expansion between the cement matrix and the reinforcing members, issues

¹⁵⁸ Information pertaining to these criteria that were included in the original case studies has been footnoted in Table

¹⁵⁹ Blackshaw and Cheetham 1982, 73.

¹⁶⁰ Stout 1969 identified the vermiculite as kaolin with expanded mica, 167; Bradley 1983, 161-162; Munday 1986, 54. ¹⁶¹ Blackshaw and Cheetham. 73-74.

¹⁶² Ibid., 71-72; Bradley 1983, 165-166.

with reversibility, and extreme weight.¹⁶³ However, mortar backings do have the benefit of being highly cost effective and can be compatible with original backing materials due to similarities in porosity and composition. Because of this, several conservators have attempted to restructure mortars and cements to have a higher strength to weight ratio, be more moisture-resistant, and be more chemically unreactive. In particular, such projects have used glass in some form or another as a weight-reducing, inert additive that could replace traditional metal reinforcement.

In one such project, Robert Vincent used granular expanded glass as an additive in a lime mortar that essentially functioned as a leveling layer between a new lime mortar bedding layer and an aluminum honeycomb panel. The glass was used primarily to reduce the weight of the backing system.¹⁶⁴ A more principal use of a glass additive to a cement backing was investigated by Severson and Fullick, who tested the use alkali-resistant glass fiber reinforced cement (GFRC) as the singular backing material. According to their report, the glass fibers function as the reinforcement in the cement without the problems of rusting and expanding or differential thermal expansion like iron reinforcement. The backing also has a higher strength to weight ratio than traditional reinforced cements and can be applied thinner and lighter.¹⁶⁵ Although Severson and Fullick's tests appeared to be successful, they did examine issues of reversibility and soluble salt content. However, they suggested that an intervening barrier between the mosaic and the GFRC could provide a solution for both problems.¹⁶⁶ Unexplored issues such as brittleness of the cement, chemical compatibility with the tesserae, and the necessary use of large quantities of water make this solution less attractive for the Megaron 2 mosaic.

Honeycomb panels. The most common backing solution, particularly in the beginning of the 21st century, has been honeycomb panels adapted from the aerospace and marine engineering

¹⁶³ Severson and Fullick 2008, 312.

¹⁶⁴ Vincent 2008, 105.

¹⁶⁵ Severson and Fullick 2008, 312.

¹⁶⁶ Ibid., 317.

industries. Honeycomb was first introduced to the field of mosaic conservation by Claude Bassier in 1978.¹⁶⁷ The panels are composed of hexagonal cells of various materials, particularly aluminum, polypropylene, and paper dipped in phenolic resin (Fig. 8.2). Aluminum honeycomb is the most commonly used panel for mosaic conservation and has empirically become the field's standard backing material. It is typically applied to the backs of mosaics as a sandwich assembly, with flat sheets adhered to the honeycomb core. These sheets, or skins, increase the rigidity of the panels and maintain the lightweight nature of the honeycomb by preventing the intrusion of adhesives or other materials into the core cells.¹⁶⁸ They also provide a uniform surface for adhesion. Traditionally, these skins have been in the form of aluminum or fiberglass, although other skins, such as non-woven polyester and plywood, are available as well.

Honeycomb panels have been adapted for mosaic conservation for several reasons. First of all, they have an extremely high strength to weight ratio. Even the thinnest panels have the compressive strength comparable to much thicker slabs of reinforced concrete. With the addition of the skins, they are also very rigid, protecting the mosaic surfaces from warping. The aluminum, polypropylene, and phenolic cores are all generally moisture and mildew resistant, highly ductile, and are relatively easy to cut. They are corrosion resistant, and compatible with a variety of adhesives. The biggest drawbacks to honeycomb backings are their cost and availability. The cores range from \$1.50 to \$20.00/sq. ft. depending on the type of core and the skin.¹⁶⁹

For the Megaron 2 mosaic, a phenolic-dipped paper honeycomb is both overly costly and has certain properties that are unnecessary for the protection of the mosaic, such as thermal and

¹⁶⁷ Bassier 1978.

¹⁶⁸ For the Cowdin Memorial Mosaic Diptych at St. Mark's Episcopal Church in Mt. Kisco, N.Y., the Architectural Conservation Laboratory at the University of Pennsylvania chose to adhere ³/₄" phenolic honeycomb panels without skins to "function as a mechanical keying system between the original plaster support and the new aluminum honeycomb panel" (Matero, et al 1992, 10).

¹⁶⁹ These cost estimates come from Plascore[®], an industrial supplier of honeycomb products. The least expensive being the polypropylene and the most expensive being the phenolic-dipped paper.

dielectric insulation. The properties that are critical to the conservation of mosaics are available in the other two, less expensive materials. Although aluminum is the most commonly used honeycomb material for mosaic conservation, its properties are relatively comparable to the polypropylene and both can be considered as potential backing solutions (see Table 7.1).

Since the mosaic will not reside in a controlled environment, the temperature and humidity changes have the potential to cause issues with backing materials. Aluminum and polypropylene have very different coefficients of thermal expansion (CTE) although the CTE of aluminum (12.3x10⁻⁶ in/in °F at 77°F) is much closer to that of cement (5.6x10⁻⁶ in/in °F at 77°F) than polypropylene (80x10⁻⁶ in/in °F at 77°F).¹⁷⁰ Polypropylene is also known to be susceptible to degradation by exposure to ultraviolet rays. However, since the backing will be underground, this is not a concern for the conservation of the Megaron 2 mosaic. On the other hand, humidity could cause condensation on the surface of the aluminum honeycomb resulting in the development of white rust or the loss of adhesion. Another consideration between aluminum and polypropylene honeycombs is vast cost difference. Aluminum honeycomb is approximately four times as expensive per square foot as polypropylene, which, over 33 panels, would be extremely costly.

According to Plascore[®], a major distributor of honeycomb panels and supplier of samples for this thesis, their polypropylene honeycomb panels have sufficient compressive strength and flexural rigidity to support the weight of the mosaic panels.¹⁷¹

 $^{^{170}}$ The CTE of aluminum and cement were taken from the Engineering ToolBox

⁽http://www.engineeringtoolbox.com/linear-expansion-coefficients-d.95.html) and the CTE of polypropylene was provided by Plascore[®]; Thermal expansion will be further investigated before the selection of a backing material. ¹⁷¹ The glass-epoxy skin is thicker and stiffer than the polyester veil and thus, provides even more rigidity.



Figure 7.2. Honeycomb core terminology from Plascore[®] (http://www.plascore.com/pdf/Plascore_Terminology.pdf)

Discussion of adhesives. While the majority of the critical properties of each honeycomb material fall in line with those necessary for a new backing for the Megaron 2 mosaic, neither material can be considered alone and the honeycomb's interaction with the rest of the materials that would compose the backing is just as important. Therefore, the critical properties of the adhesives must also be examined.

Nearly all of the backing adhesives used in published mosaic conservation case studies, particularly those used with honeycomb panels, are thermoplastic polymers such as polyester, acrylic, and epoxy resins, although some projects have used lime mortars and plasters. Mortars and plasters in this application have similar issues to their use as backing materials, namely that they are too brittle and susceptible to moisture-related deterioration.

The epoxy resins, on the other hand, are highly ductile and provide the high bonding strength necessary to adhere to the relatively smooth surfaces of the honeycomb skins. This bonding connection should be the strongest in the entire backing system, and when used in conjunction with additional isolating layers, does not need to be particularly reversible. More importantly, this connection should resist de-adhesion due to changes in temperature. The majority of epoxy resins have a CTE between 25 and 36x10⁻⁶ in/in °F at 77°F meaning that it they are closer to the CTE of aluminum than polypropylene.¹⁷² However, since the temperature range at Gordion is not particularly extreme, especially considering the mosaic is nearly always under shade, this should not be such a concern for the backing system.¹⁷³ The adhesive that most closely fits these criteria is an epoxy resin. Two epoxy resins that have previously been used successfully in the re-backing of mosaics are the West System[®] 105 Epoxy Resin and the Huntsman Advanced Materials Araldite[®].¹⁷⁴ These were both used in conjunction with aluminum honeycomb panels. Both of these are less toxic than polyester and acrylic resins, particularly after curing. They generally have very high compressive and tensile strengths and high T_g.¹⁷⁵ They are generally only reversible through the application of high heat, but the inclusion of a more reversible isolating layer will prevent them from being a concern.

Discussion of isolating layers. In order to ensure that the backing is both strong and reversible, the majority of published mosaic conservation case studies suggest the use of a isolating or leveling layer between the original fabric of the mosaic and the backing assembly.¹⁷⁶ This practice is not limited to mosaic conservation but, according to Ellis and Heginbotham, "[is] widely used in conservation to add a measure of reversibility to an otherwise irreversible bond."¹⁷⁷ For this layer, numerous different materials have been used, including plaster, mortars, polyvinyl acetate emulsions, epoxy resins, and acrylic resins. Since the purpose of this layer is to

¹⁷² CTE for "Epoxy, cast resins & compounds, unfilled" (http://www.engineeringtoolbox.com/linear-expansion-coefficients-d.95.html).

¹⁷³ The effects of thermal expansion will be tested before any backing is applied to the Megaron 2 mosaic.

¹⁷⁴ West System[®] 105 Epoxy Resin: Matero, et al. 1992, 10-11; Araldite[®]: Tsu, et al. 2008, 112; The critical properties for these two adhesives are shown in more detail in Table 7.2.

¹⁷⁵ For the West System[®] 105/205 Epoxy Resin[®], these critical properties are: Compressive Strength = 11,418 psi; tensile strength: 7,846 psi, and $T_g = 129^{\circ}$ F (http://www.westsystem.com/ss/typical-physical-properties/).

¹⁷⁶ For example, Stout 1969, Blackshaw and Cheetham 1982, Munday 1986, Sturge 1987, Kosinka 1991, Matero, et al. 1992, and Uprichard, et al. 2010.

¹⁷⁷ Ellis and Heginbotham 2004, 23.

be the main reversible component in the backing system, it is important for the conservation of the Megaron 2 mosaic that its dissolution does not require large quantities of water nor toxic solvents. As with the other adhesive layer, it should be strong enough to maintain adhesion under moderate tensile stress but weak enough to fail before the cohesive failure of the mosaic. Again, the brittleness and low moisture-resistance of mortars and plasters indicate that they should not be used for this application and since the epoxy resins require heat for removal, it should not be considered for this application.¹⁷⁸ The polyvinyl acetate (PVAc) emulsions do not have a high enough T_g to be successful for the isolating layer.¹⁷⁹

An acrylic resin such as Acryloid B-67, on the other hand, is a synthetic polymer adhesive with a T_g around 122°F.¹⁸⁰ According to Ellis and Heginbotham, it is considered a Feller Class A material.¹⁸¹ Although this solution has moderate toxicity, it is relatively inexpensive. Acryloid B-67 has not been used in mosaic conservation, although its critical properties, particularly its moderate direct tensile strength (3,625 psi) and solubility in numerous nonaqueous solvents, suggest it would be an appropriate isolating layer.¹⁸² It is primarily soluble in volatile organic solvents such as acetone and other ketones, although it is also relatively soluble in various petroleum distillates. The Rohm and Haas Company Coatings Solvent Selection tables suggest that Acryloid B-67 ranges in viscosity depending on the solvent. In order to achieve a sprayable adhesive, it is important to have a relatively low viscosity solution. Although the adhesive is soluble in numerous hydrocarbons, it has low viscosities in xylene, toluene, heptane, and VM&P naphtha, as well as acetone, and a much higher viscosity in mineral spirits.

¹⁷⁸ According to West System's product literature, once the epoxy resins cure, they are unable to be dissolved in any solvents. The only way to reverse their hard set is to heat them beyond their ultimate T_g which is nearly 150°F (http://www.westsystem.com/ss/clean-up-removing).

¹⁷⁹ The T_g for polyvinyl acetate is approximately 100°F (Maynor and van der Reyden 1989, 47).

¹⁸⁰ Maynor and van der Reyden 1989, 62.

 ¹⁸¹ Feller Class A materials are those that are suitable for use in conservation and has at least a 100 year service life.
 ¹⁸² PVOH was used as an additive to PVAc to improve its reversibility in facing applications for the conservation of a tessellated Roman mosaic in Spain (Dominguez-Bella, et al. 2005, 356).

In order to confirm the solubility and viscosity of the adhesive in various solvents, 30% solutions were mixed in odorless mineral spirits, VM&P naphtha, Stoddard's Solvent, acetone, and toluene for comparison. The odorless mineral spirits, VM&P naphtha, and Stoddard's solvent were mixed with Acryloid B-67 and agitated periodically over two days. They did not dissolve completely so, at the recommendation of Lynn Grant, the head conservator of the University of Pennsylvania Museum of Anthropology and Archaeology, the solutions were gently heated in a warm water bath. After warming and some agitation with a glass stirring rod, the adhesives dissolved better in the hydrocarbon solvents, but not entirely. At this time, the solutions of Acryloid B-67 in acetone and toluene were prepared and immediately placed in the warm water bath. The adhesive dissolved almost immediately in the toluene and very quickly in the acetone (fig. 7.3). The toxicity of the toluene would be problematic, especially in the large quantities necessary for the larger panels on site. The acetone solution appears to be the best form of this adhesive for the isolating layer. Its low viscosty (94 cP at 40%) works well in the Preval[®] Spray Gun atomizer.¹⁸³ Also, since acetone evaporates rapidly in ambient temperatures, the adhesives will not be absorbed too deeply into the cement matrix and instead form an isolating surface film. One possible problem with the Acryloid B-67 in pure acetone is its very low viscosity which could lead to two potential issues. First, although acetone evaporates quickly, the adhesive could be absorbed, inhibiting reversibility. Also, the quick evaporative property of the acetone reduces the adhesive's working time. Because of this, a formulation of the adhesive with a 90:10 ratio of acetone to VM&P naphtha was made to determine how a solvent with a lower solubility in Acryloid B-67 affects the solubility, viscosity, and working properties. The adhesives were enclosed in a cheese cloth sock and suspended into the acetone. It was mixed overnight with a magnetic stir bar (fig. 7.4). Once the adhesive had been completely dissolved, the 10% fraction of

¹⁸³ Rohm and Haas, 2009, 2.

VM&P naphtha was added to second solution. The critical properties for the reviewed isolating layers are displayed in Table 7.3.



Figure 7.3. Acryloid B-67 solubility test in 30% w/v (from left to right) mineral spirits, VM&P naphtha, Stoddard's Solvent, acetone, and toluene. Results after 3 days.



Figure 7.4. The Acryloid B-67 adhesive dissolving in 100% acetone (left) and a 90:10 ratio of acetone and VM&P naphtha (right).

Selected Materials for Backing Tests

Based on the review of published mosaic conservation projects and the assessment of the specified materials according to the established criteria for this thesis, the backing materials selected for further examination are:

- Backing material: *Plascore[®] polypropylene honeycomb with non-woven polyester veil; Plascore[®] polypropylene honeycomb with glassy epoxy skin.* The polypropylene honeycomb conforms to nearly all of the required criteria and is significantly less expensive than the aluminum honeycomb. The non-woven polyester veil is compatible with epoxy resins and, according to Plascore[®], allows for better bonding than a honeycomb without a skin. The glass epoxy skin provides higher rigidity than the nonwoven polyester veil.
- Backing adhesive: *Araldite[®] 2013*. The Araldite[®] epoxy is cost effective and conforms to nearly all of the required criteria for adhesives.

• Isolating Layer: *Acryloid B-67 in acetone*. This isobutyl methacrylate polymer is a cost effective adhesive whose critical properties correspond to the required criteria and the acetone dissolves the resin in a manageable time and into a sprayable solution.

These materials were all evaluated as a completely assembled backing system for three of their critical properties: adhesive bond strength, weight reduction, and reversibility. These tests are detailed in Chapter 8.

		Weight	Moisture-		
Backing Material	Rigidity	Reduction	Resistance	Ductility	Shape/Cut-ability
Existing Cement Backing	High	N/A	Low	Low	Moderate
Foaming Epoxy Resin	Low^1	High	High	Low	Moderate
Epoxy Resin and vermiculite	Moderate ²	High	High	Low	Moderate
Lime mortar with granular expanded glass	High	Moderate	Low	Low	Moderate
Glass fiber reinforced concrete	High	High	Moderate	Low	Moderate
Aluminum Honeycomb	High	High	High	High	High
Polypropylene Honeycomb	$High^3$	High	High	High	High
Phenolic Honeycomb	High	High	High	High	High
Polyester foam with fiberglass skin	High	High	High	High	High

 1 Would need to be very thick or used with another rigid support 2 Galvanized mild steel weld mesh was necessary for added rigidity (Bradley 1983). 3 With rigid skin.

Table 7.1. Backing Material Criteria

Backing Material	Compressive Strength	Reversibility	Toxicity	Coefficient of Thermal Expansion	
Existing Cement Backing	High	Low (Mechanical)	Low	6.0×10^{-6} in/in °F at 77° F	
Foaming Epoxy Resin	High	Low^4	Low	25-36x10 ⁻⁶ in/in °F at 77°F	
Epoxy Resin and vermiculite	High	Low	Low	N/A ⁵	
Lime mortar with granular expanded glass	Low (50-300 psi) ⁶	Low	High	$14x10^{-6}~in/in~^\circ F$ at $77^\circ F^7$	0
Glass fiber reinforced concrete	High (7,000-12,000 psi) ⁸	Low	Low	$6-9 \times 10^{-6}$ in/in °F at $77^{\circ}F^9$	
Aluminum Honeycomb	Moderate (620 psi) ¹⁰	N/A^{11}	Low	$12.3 x 10^{-6} \ in/in \ ^\circ F$ at $77^\circ F^{12}$	
Polypropylene Honeycomb	Low (275 psi) ¹³	N/A	Low	$80 x 10^{-6} \ in/in \ ^\circ F$ at $77^\circ F^{14}$	
Phenolic Honeycomb	Moderate (470 psi) ¹⁵	N/A	Low	$19.4x10^{-6}~in/in~^\circ F$ at $77^\circ F^{16}$	
Polyester foam with fiberglass skin	Moderate (319 psi) ¹⁷	High	Low	N/A	

Heating the resin above its ultimate T_g is the only way to reverse its hard set (http://www.westsystem.com/ss/clean-up-removing).

⁵ Likely slightly lower than the CTE of unmodified epoxy resin.

⁶ For 0:1:3 Putty or Type N lime mortar (Boynton and Gutschick 1989, 6).

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⁷ Coefficient for thermal expansion of quicklime (Oates 1998, 118).

⁸ http://www.stonewear.com/psbs/images/20-Physical% 20properties.pdf, 9.

⁹ http://www.stonewear.com/psbs/images/20-Physical% 20properties.pdf, 9.

¹⁰ http://www.plascore.com/pdf/Plascore_3003.pdf

¹¹ Generally dependent on adhesive, although high cut-ability indicates possible mode of removal.

 $^{12}\ http://www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html$

¹³ http://www.plascore.com/pdf/Plascore_PP.pdf

¹⁴ Personal correspondence with Joe Mydosh of Plascore®

¹⁵ http://www.plascore.com/pdf/Plascore_PN1.pdf

¹⁶ http://www.hexcel.com/Resources/DataSheets/Brochure-Data-Sheets/Honeycomb_Attributes_and_Properties.pdf

¹⁷ http://www.corematerials.3acomposites.com/airex-t90-us.html

Table 7.1. Backing Material Criteria

Backing Material	Stability	Cost	Availability
Existing Cement Backing	Low^{18}	Low	High
Foaming Epoxy Resin	Moderate	Low	High
Epoxy Resin and vermiculite	Moderate ¹⁹	Moderate	High
Lime mortar with granular expanded glass	Moderate	Low	High
Glass fiber reinforced concrete	High	Moderate	Moderate
Aluminum Honeycomb	High	High (\$10/ft. ²) ²⁰	Low
Polypropylene Honeycomb	High	Low (\$1.50/ft. ²) ²¹	Low
Phenolic Honeycomb	High	High (\$20/ft. ²) ²²	Low
Polyester foam with fiberglass skin	High	High	Low

Table 7.1. Backing Material Criteria

Adhesive	Adhesive Bond Strength	Glass Transition Temperature (T_g)	Moisture Resistance	Ductility	Toxicity
West 105/205 Epoxy Resin	High	Approximately 130°F ¹	High	Low	Low
Araldite 2005 Epoxy Resin	High	Approximately 150°F	High	Low	Low
Polyester Resin	High	Approximately 150°F	High	High	High
Acrylic resin	Moderate	Approximately 220°F	High	High	High
Acryloid B-72	Moderate	Approximately 105°F ²	High	Low	High
Lime-based mortar	Moderate	N/A	Low	Low	Moderate
Keene's Cement	High	N/A	Low	High	Moderate
		Coefficient of Thermal			
Adhesive	Reversibility	Expansion	Stability	Cost	Availability
West 105/205 Epoxy Resin	Low ³	25-36x10 ⁻⁶ in/in °F at $77^{\circ}F^{4}$	High	Low	Moderate
Araldite 2005 Epoxy Resin	Low ⁵	$25-36 \times 10^{-6}$ in/in °F at 77° F	High	Low	Moderate
Polyester Resin	Low	$50x10^{-6}$ in/in °F at 77° F	High	Moderate	Moderate
Acrylic resin	Low	$45 \mathrm{x10^{-6}~in/in~^\circ F}$ at $77^\circ \mathrm{F}$	High	Moderate	Moderate
Acryloid B-72	Moderate	$35 \mathrm{x10^{-6}~in/in}~^{\circ}\mathrm{F}$ at $77^{\circ}\mathrm{F}$	High	Low	High
Lime-based mortar	Moderate	$14x10^{-6}$ in/in °F at 77° F	Moderate	Low	High
Keene's Cement	Moderate	$9 \mathrm{x} 10^{-6} \mathrm{in/in}$ °F at $77^{\circ} \mathrm{F}$	Moderate	Low	High

Table 7.2. Backing Adhesive Criteria

¹ http://www.westsystem.com/ss/typical-physical-properties/

² Too close to maximum air temperature in Gordion

³ http://www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html

⁴ Requires high heat (http://www.westsystem.com/ss/typical-physical-properties/; does not dissolve well in solvents.

⁵ Ibid.

Ductility Toxicity	ow Low	Jow Low	Jow Low	High Low	Jow Moderate	Jow Moderate	Jow High	High Low	ow Low		Cost Availability	Jow High	Jow High	Jow Moderate	Jow High	ow High	.ow High	Jow High	High Low	
Moisture Resistance	Low	High	High	High	High	High	Low	High	High		Stability	High	High	High	High	High	High	Low	High	
Glass Transition Temnerature (T_)	N/A	Approximately 130°F	Approximately 130°F	Approximately 100°F ¹	Approximately 105°F	Approximately 122°F	N/A	N/A	Approximately 175°F ²	Coefficient of Thermal	Expansion	9x10 ⁻⁶ in/in °F at 77°F	25-36x10 ⁻⁶ in/in °F at 77°F	$25-36x10^{-6}$ in/in °F at 77° F	$48 \text{x} 10^{-6} \text{ in/in } ^{\circ}\text{F} \text{ at } 77^{\circ}\text{F}$	35x10 ⁻⁶ in/in °F at 77°F	N/A	14x10 ⁻⁶ in/in °F at 77°F	19.4x10 ⁻⁶ in/in °F at 77°F	
Adhesiye Bond Strength	High	High	High	High	Moderate	Moderate	Moderate	N/A	High		Reversibility	Moderate	Low ³	Low ⁴	High	Moderate	High	Low	High	
Isolating Laver	Gypsum plaster	Epoxy Resin Primer	Foaming Epoxy	Polyvinyl acetate	Acryloid B-72	Acryloid B-67	Lime-based mortar	Phenolic honeycomb	Polyvinyl alcohol		Isolating Layer	Gypsum plaster	Epoxy Resin Primer	Foaming Epoxy	Polyvinyl acetate	Acryloid B-72	Acryloid B-67	Lime-based mortar	Phenolic honeycomb	

¹ Maynor and van der Reyden 1989, 47. ² Ibid., 62.

Table 7.3. Isolating Layer Criteria

Chapter 8: Evaluation of Backings

Replica Mosaic Panels

Due to their size, weight, and generally poor state of preservation, the actual Megaron 2 mosaic panels were not able to travel and therefore it was not possible to perform the requisite treatment tests on an original panel. It was therefore necessary to reproduce the mosaic conditions with scaled replica samples. These samples were made to be used as surrogates to test the facing of the pebble surface, the removal of the cement rudus, and to perform adhesive bond strength tests on the proposed new backing materials.

Essential Properties. In order to reproduce the necessary conditions to achieve accurate and comparable results from the testing program, it was important to replicate as near as possible the current conditions of the mosaic. The scaled replica panels, although smaller in surface area, reproduced the physical characteristics of the panels, particularly the irregular surface of the original pebbles, the hardness and thickness of the cement backing, and the inclusion of a narrow ferrous reinforcement bar between the bedding layer and the rudus. Certain mechanical properties were also replicated. This includes predominantly the adhesive bond between the pebbles and the cement bedding layer and the cohesive strength of the cementitious backing.

Materials

Pebbles. The primary concerns for the type of pebbles for the replica panels are their size and shape, not exact composition. The Gordion pebble samples were categorically sorted by type, photographed, cataloged, and described, in order to organize them and determine their size, shape, and sorting. This information was then used to more accurately create the replica panels. Table C.1 and Figures 8.1, 8.2, and 8.3 display the results of this analysis. The majority (25%) of the pebbles are rounded and equant although nearly as many (23%) are rounded/subrounded and elongate. During the creation of the replica panels, this information was consulted to select new pebbles. The new pebbles are predominately quartz river pebbles (EarthEssentials by Quikrete), purchased in bulk from Lowes Hardware Store. The large bags of pebbles contained a variety of sizes and shapes which had to be sorted and compared to samples of the originals in order to match more precisely (fig. D.1). The pebbles were also coated in yellow sand, which was washed prior to use. Once the pebbles were sorted and washed, they were allowed to dry overnight to ensure that there was no residual moisture when the cement was applied (fig. D.2).

> 5.4 12.5 46.4 • Rounded • Subrounded • Subangular • Angular

Pebble Roundness (% of total)

Figure 8.1. Graph showing percentage of pebble samples classified by roundness.



Figure 8.2. Graph showing percentage of pebble samples classified by shape.



Pebble Shape (% of total)



Cement. The composition of the cement backing applied in 1956 was not recorded; however, it can be assumed with reasonable certainty that the cement was a commercial Portland cement and sand mix since no specifics were recorded for the procedure. In order to retain a uniform consistency of the cement between all the testing samples, a standard Type I/II Portland cement with general mason's sand and no gravel was used. For the ferrous reinforcement, a steel rod, 1/8" in diameter was selected. In the original panels, the reinforcement appears to be less than ¹/4" from the base of the pebbles (fig. 8.4). Therefore, it will be important during the cement removal to use the reinforcement as an indicator of where the rudus transitions to the bedding layer and approximately where to stop the removal before damaging the pebbles.



Figure 8.4. Field sketch of the existing conditions of the mosaic panels (from the 2013 lifting report by Gordion site conservator, Elisa del Bono).

Procedure¹⁸⁴

The replica mosaics were made in 4"x4" panels to control the variables for testing. In order to achieve consistent dimensions for all of the panels, wooden forms were constructed for each one. The forms were all made of 3/4" plywood and standard 1-5/8" wood screws. In total, 27 forms were created; 13 were made with interior dimensions of 4"x4"x4" and 14 at 4"x4"x2". The larger forms were used for the scaled mosaic panels with pebbles and reinforced cement backings

¹⁸⁴ See Appendix D (D.3-D.20) for images of the construction process for creating the testing replicas.

for the empirical facing and cement removal tests. The smaller forms were used to make simple cement blocks for the new backing tests.

For both of the form sizes, all of the joints were sealed with strips of modeling clay to prevent the migration of cement out of the form. Next, all of the interior surfaces were coated with mineral oil using a small paintbrush. The mineral oil acts as a release agent for the disassembly of the form as well as a partial barrier to prevent the absorption of moisture out of the cement and into the wood.

The scaled replica panels were made by setting the sorted and washed pebbles into a 4"x4"x1/4" slab of modeling clay that had been laid into the oiled form. Next, a low viscosity slurry of the Portland Cement and sand at a 1:3 ratio for the bedding layer was prepared, following ASTM C192/192c-13a Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.¹⁸⁵ It was then poured to a height of approximately 1/8"-1/4" above the highest point of the pebbles. The forms were then covered and the slurry was allowed to cure slightly overnight. On top of the moderately solidified cement slurry was placed a 3-3/4" length of the steel reinforcement which was then covered, to the top of the form, with a higher viscosity layer of the same cement mix. According to the ASTM standard, the cement should be stored in an environment that prevents the loss of moisture from the unhardened specimens.¹⁸⁶ Therefore, the filled forms were put into sealed plastic bags to allow them to reach initial set in 100% humidity. The ASTM standard also recommends removing the specimens from their molds after approximately 24 hours and completing the curing process in a high moisture environment.¹⁸⁷ In order to allow the low viscosity slurry to reach initial set, the forms were instead removed after 7 days. They were then kept in the sealed bags until final set after a total of 28 days. The cement

 ¹⁸⁵ ASTM 2013.
 ¹⁸⁶ ASTM 2013, 7.
 ¹⁸⁷ Ibid.

blocks were set back on top of clay strips to allow all 6 sides of the cement blocks to cure as evenly as possible. After 28 days curing in the high humidity environment of the sealed plastic bags, the replicas were removed from the sealed bags to dry out before adhering the test assemblies and commencing testing.

Test Assemblies¹⁸⁸

Once the replicas and cement samples had completely cured and dried, they were ready for testing. The attachment assemblies for the adhesive bond strength test had to be fabricated to conform to the size and shape of the test samples as well as the size and attachment limitations of the Instron Model 4206 Universal Testing Machine. These assemblies included aluminum plates for the top and bottom of the test sample, stainless steel threaded rods for attaching the top plate to the grips of the Instron machine, and a very high strength epoxy for adhering the plates to the samples.

For the top plates, 3'x4"x3/8" aluminum plates were cut down to 4"x4"x3/8" squares on a bandsaw, then finished on a Bridgeport[®] milling machine with a 1/2" end mill bit. These plates were then milled to cut parallel grooves 1/8" wide and approximately 1/16" deep. The grooves were cut in order to provide additional surface area and some keying between the metal and the epoxy. A similar test previously performed by The Architectural Conservation Laboratory at the University of Pennsylvania showed that an epoxy bond to a flat, unmodified aluminum surface was not very strong and necessitated additional keying.¹⁸⁹ In addition to the grooves, sixteen 1/8" wide holes were drilled through the plates at regular intervals with a CNC milling machine to allow the epoxy to flow through the plate and provide additional keying of the epoxy. The centers of the top plates were then tapped with a 3/8" threaded hole to receive a stainless steel threaded rod that will be gripped by the Instron machine. The threaded rod was lathed to create a 1/4" tip

 ¹⁸⁸ See Appendix B (B.21-B.25) for images of the construction process for creating the mechanical testing assemblies.
 ¹⁸⁹ V. Pingarron-Alvarez, personal communication, January 29, 2014.

to fit into the grips. Finally, a hexagonal nut was threaded onto the rod above the plate to tighten the rod.

For the bottom plates, a similar procedure was followed, although they were cut to slightly different dimensions (6''x4''x3/8'') to allow them to be clamped to the base of the Instron machine. In addition, only the grooves and 1/8'' diameter holes were cut into these plates. No tapped holes were necessary.

The testing assemblies were completed with the selected backing materials and adhesives as described in the previous chapter. Since the tests involve two different backing materials and two different adhesive conditions, twelve test samples were constructed in order to obtain three samples of each of the following backing configurations (shown in schematic drawings in Appendix D, figures D.26-D.29):

- Backing system A: 1" polypropylene honeycomb with polyester veil; Araldite[®] 2013 epoxy adehsive; 15% w/v Acryloid B-67 in acetone isolating layer.
- Backing system B: 1" polypropylene honeycomb with polyester veil; Araldite[®] 2013 epoxy adhesive; no isolating layer.
- Backing system C: 1/2" polypropylene honeycomb with glass-epoxy skin; Araldite[®] 2013 epoxy adhesive; 15% w/v Acryloid B-67 in acetone isolating layer.
- Backing system D: 1/2" polypropylene honeycomb with glass-epoxy skin; Araldite[®]
 2013 epoxy adhesive; no isolating layer.

These four configurations will test both the performance of the isolating layer in the system as well as the adherence of each of the honeycomb panels.¹⁹⁰

It was also important to adhere the aluminum plates to the test samples with a high strength adhesive that would likely not fail during the tensile strength test. For this adhesive, the

¹⁹⁰ An additional sample, with the same configuration as backing system A, was constructed in order to calibrate the Instron machine.

West System[®] 105/205 epoxy with a reported direct tensile strength of 7,900 psi was chosen, which is well above the tensile strengths of the Araldite[®] 2013 and Acryloid B-67 (5,000 and 3,625 psi, respectively).

The order in which the testing assemblies were constructed was also important. Each assembly was prepared in the following manner:¹⁹¹

- 1. Since the isolating layer will be directly adjacent to the backing adhesive, the first step was to apply the Acryloid B-67 to the bottom of half of the cement blocks and allow them to completely cure. This was performed by spraying it in three lifts, waiting approximately 20 minutes before applying the next. The initial curing time for a film of Acryloid B-67 in acetone is less than 15 minutes, but a test of the application process showed that a 10 minute interval between lifts did not allow sufficient time for the solvent to fully evaporate, causing bubbling on the surface (fig. 8.5).¹⁹²
- 2. Once the Acryloid B-67 layers cured completely, the honeycomb backings were adhered to the cement blocks with the Araldite[®] 2013 by injecting it onto the surface of the honeycomb using a special syringe designed for the purpose of controlled mixing. The epoxy was then spread evenly over the surface by hand with a metal dry wall taping knife to a uniform thickness of approximately 1/8".
- 3. When the Araldite[®] 2013 had reached final cure (approximately 24 hours), the cement/honeycomb assemblies were adhered to the aluminum plates with the West System[®] 105/205 epoxy, which was applied by spreading the mixed adhesive and hardener onto the aluminum plates with a plastic palette knife and setting the honeycomb

¹⁹¹ See Appendix E (E.30-E.40) for images of the methodology to assemble the test samples.

¹⁹² According to the Society for Historical Archaeology, a 20% w/v solution of Acryloid B-67 in naphtha dried after 15-20 minutes. With a faster evaporating solvent such as acetone, the drying time will be even faster (http://www.sha.org/index.php/view/page/process).

between the two.¹⁹³ A small piece of silicon release paper was placed over the tapped hole on the top plate to prevent access of the epoxy.

- 4. The aluminum bottom plate was placed on a piece of silicon release paper to ensure the epoxy that flowed through the holes in the aluminum or over the side of the assembly did not adhere to the preparation surface.
- The West System[®] 105/205 epoxy was allowed to cure for a week to ensure maximum strength before testing.



Figure 8.5. Bubbling of the Acryloid B-67 isolating layer on the surface of one of the cement samples due to insufficient evaporation of the solvent between applications.

Critical Properties

Rigidity. The rigidity of the polypropylene honeycomb as provided by Plascore[®] is

described as flexural rigidity and resistance to plate shear. The polypropylene honeycomb with

polyester veil has not been tested for flexural rigidity but has a typical shear strength of 60 psi and

¹⁹³ The reported cure time for Araldite[®] 2013 is 10 hours, but to ensure complete cure, the assemblies were left to cure for 24 hours.

typical shear modulus of elasticity of 2.0 ksi. The polypropylene honeycomb with glass-epoxy skin has a flexural rigidity of 6,250 lb-in²/in width, a typical shear strength of 85 psi and a modulus of elasticity of 2.2 ksi. While the glass-epoxy has a higher flexural rigidity and shear resistance, both have similar low moduli of elasticity meaning that they will both deform elastically in response to shear stress to nearly the same degree.

Reversibility. The reversibility of the adhesives used for both the facing and backing is generally dependent on their stability and solubility. All of the adhesives selected for the new backing of the Megaron 2 mosaic are chemically and thermally stable, meaning that they will not degrade or cross-link after application. The Acryloid B-67 is highly soluble and reversible in acetone as shown by an informal reversibility test (fig. 8.6).¹⁹⁴ The Araldite[®] 2013 is not soluble in any solvents but can be removed by swelling the cured adhesive with a range of polar solvents to allow removal.

¹⁹⁴ The informal reversibility test was performed on a small limestone prism that was sprayed with three lifts of the Acryloid B-67, then attached to a small piece of PV honeycomb with the Araldite[®] 2013 epoxy. The acetone allowed for the solubility and reversibility of the Acryloid B-67 without affecting the Araldite[®] 2013. It was removed cleanly.



Figure 8.6. The result of the isolating layer reversibility test with acetone, showing the clean removal of the Araldite[®] 2013 epoxy.

Adhesive Bond Strength. The bonding of the new backing material to the remainder of the existing cement bedding must be strong enough to keep the backing attached but reversible and weak enough to fail under sufficient tensile stresses. This test primarily determined the adhesive strength of the bond between the Acryloid B-67 isolating layer and the Araldite[®] 2013 epoxy, which is the ideal point for adhesive failure in the backing system to ensure no damage to the mosaic. The test was also performed on samples without the isolating layer to provide points of comparison for the adhesive bond.

Standard Adaptation. The adhesive bond strength test generally followed ASTM Standard F521-83 (Reapproved 2010): Standard Test Methods for Bond Integrity of Transparent Laminates. This testing standard includes four different tests for bond integrity, although Test Method A – Flatwise Bond Tensile Strength is the appropriate test for this application. According to the standard,

The bond is subjected to a mechanical load in a direction perpendicular to the

plane of the bond. The adhesive or cohesive strength between the interlayer and the outer layers (flatwise tensile strength) is determined, and expressed in terms of pounds-force per square inch.¹⁹⁵

The test assembly for the adhesive bond strength test of the new mosaic backings is similar to those described in the testing standard but adapted to fit the Instron Model 4206 Universal Testing Machine at the Laboratory for the Research on the Structure of Matter (LRSM) at the University of Pennsylvania.¹⁹⁶ The standard recommends that the surfaces of the aluminum test assembly pieces should be cleaned with acetone and gently abraded to increase bonding. Instead, the grooves and drilled key holes were cut into the pieces for this purpose.¹⁹⁷

Test Procedure. After the test assemblies were constructed using the procedure specified above, the samples were brought to the LRSM for the adhesive bond strength test.¹⁹⁸ The samples were set into the Instron Model 4206 Universal Testing Machine, attaching the aluminum bottom plate to the base of the machine with clamps and to the tensile stressing mechanism with grips. The grip had been fitted to a U-joint to allow it to be self-centering. For all of the test samples, the testing machine used a 10 kN (2,000 lbf) load cell to accommodate the reported direct tensile strengths of the adhesive bonds in the two testing samples configurations: the Acryloid B-67 isolating layer at approximately 900 lb, the Araldite[®] 2013 at approximately 1250 lb, and the West System 105/205 at approximately 1975 lb. The test was then run until each sample failed by breaking apart.

Potential Modes of Failure. As an assembly, there are multiple ways in which the system could fail, although the ideal failure mode would concentrate any failure and damage in the new backing or backing interface and not in the mosaic. The following are the possible failure mode

¹⁹⁵ ASTM F521-83 (Reapproved 2010), 1.

¹⁹⁶ This custom assembly was developed in consultation with Alex Radin of the LRSM.

¹⁹⁷ The degreasing of the aluminum with acetone was still performed.

¹⁹⁸ Assistance for this test was provided by Alex Radin, of the LRSM.

scenarios during the mechanical testing (shown in diagrammatic models in Appendix D, figures D.41-D.46).

- Failure mode 1: The adhesive bond of the Acryloid B-67 isolating layer.
- Failure mode 2: The adhesive bond of the Araldite[®] 2013 epoxy at the interface with the isolating layer.
- Failure mode 3: The adhesive bond of the unknown epoxy between the polypropylene honeycomb and the skin or veil.¹⁹⁹
- Failure mode 4: The cohesive bond of the honeycomb panel or panel skin.
- Failure mode 5: The cohesive bond of the cement backing.
- Failure mode 6: The adhesive bond of the West System[®] 105/205 epoxy at the interface with one of the aluminum plates.

Results. The adhesive bond strength test was performed on 13 samples, 3 of each backing system and one extra to calibrate the load cell, crosshead speed, displacement limits, and assembly set up procedures. The results of the adhesive bond strength provide both quantitative data as stress-strain curves (Table 8.4) and visual display of the mode of failure behavior under maximum tensile stresses.²⁰⁰

Analysis of the results shows clear differences in the bond strength between those samples with and without the Acryloid B-67 isolating layer. Nearly all of the six samples with the isolating layer failed below 800 psi with a mean stress of 613.13 psi and a standard deviation of \pm 189.53 psi. (fig. 8.7). They also all failed in the same manner, with the Araldite[®] epoxy separating from the Acryloid B-67, without any cohesive failure of the epoxy. The majority of the samples displayed some limited decohesion of the cement which can be explained by differential penetration of the Acryloid B-67 into the surface of the cement.

 ¹⁹⁹ This epoxy is a proprietary formula to Plascore[®]. Plascore[®] did not provide any physical properties of the epoxy.
 ²⁰⁰ Individual stress/strain graphs and images of the samples after testing are in Appendix F.

The samples without the isolating layer performed very differently. Without the isolating layer, the Araldite[®] 2013 epoxy formed a stronger bond with the porous cement adherend. Nearly all six of the samples without the isolating layer failed above 800 psi with a mean stress of 1073.85 psi and a standard deviation of ±120.52 (fig 8.8). The mean failure stresses of the samples without the isolating layer were 43% higher than those with it and resulted in two different modes of failure. Two of the samples (9 and 11) failed at the interface between the honeycomb skin and the epoxy. Both of these samples had backing system B and the failure caused the fibers of the polyester veil to pull apart. The other three samples (8, 10, and 12) failed at the interface between the aluminum plate and the honeycomb (fig. 8.9).²⁰¹ This demonstrates that although the reported tensile strength of the Araldite[®] 2013 epoxy was lower than the West System[®] 105/205, the fact that the Araldite[®] epoxy was bonded to a porous, cementitious substrate and the West System[®] epoxy was bonded to a non-porous metal substrate meant that the relative strengths were reversed.

Statistical analysis of the data resulted in the identification of two outliers that could be considered insignificant results and discarded. Both of these had failure stresses well below the standard deviation for their respective data groups. Sample number 7, with backing system A, deviated from the mean of the samples with the isolating layer by approximately 540%; and sample number 13, with backing system D, deviated from the mean of the samples without the isolating layer by approximately 200%.²⁰²

The test showed that the differences between the honeycomb skins only yielded different results in those samples without the isolating layer (figs. 8.10 and 8.11). This is because the Acryloid B-67 had the lowest bond strength in the system and failed first. Without the isolating

²⁰¹ Two of these (samples 8 and 12) had backing system D and one (sample 10) had backing system B.

 $^{^{202}}$ The failures of samples #7 and #13 may have been due to residual Acryloid B-67 which had been applied to all of the samples and needed to be removed to from half of them.

layer, the tensile stresses caused failures in the next weakest bond in the system. In the case of backing system B, the weakest adhesion was the cohesive bond of the honeycomb skin's polyester fibers and the adhesive bond of the epoxy adhering the polyester veil to the honeycomb (fig. 8.12). In samples 9 and 11, both of these appeared to fail with an average failure stress of 1163.15 psi, approximately 20% above the mean polyester veil results. The glass epoxy skin had a stronger bond to the honeycomb and therefore, the tensile stresses caused adhesive failure between the West System[®] 105/205 testing assembly epoxy and the sample. This is shown in samples 8 and 12, with an average failure stress of 1007.81 psi, approximately 30% above the mean glass epoxy results. The one atypical was sample 10, which had backing system B and failed at the base of the test assembly. This result was likely due to the fact that tensile stress was loaded to one side because of the slightly uneven assembly. This caused the failure of the already weakened bond between the epoxy and the aluminum baseplate.

The differences in the evenness of the testing assembly were the likely cause of many of the differential failure stresses within data groups. For example, sample number 6, with the isolating layer, had the highest failure stress of that data group, at 894.56 psi. It was the most level and therefore the tensile stresses were spread through the sample more evenly and the sample broke cleanly at the interface between the isolating layer and the Araldite[®] backing adhesive (figs. 8.13 and 8.14). The rest of the samples were slightly pitched causing tensile loading to one side of the sample. This resulted in premature failure to one degree or another. The evenness of the assembly was also the likely cause of the different failure stresses between samples of other configurations. For example, the three samples with backing system C had failure stress levels approximately 125 psi apart. A review of the pre-testing assemblies shows that the pitch of the top plate varied between the three and sample number 1, which had the strongest bond, was the most level and sample number 3, which had the weakest bond, was the most pitched (fig. 8.15).

The adhesive bond strength test also served to determine the modulus of elasticity of proposed backing systems. The modulus of tensile elasticity, or Young's modulus, is the mathematical calculation of the propensity for a material to deform elastically, rather than fracture, under stress. In this experiment, the modulus of elasticity of the backing system is a combination of the moduli of each component under tensile stress and the mode of failure for each sample represents that component which has the lowest modulus. The samples with the isolating layer had a 34.60% higher mean modulus of elasticity than those without, meaning that the Acryloid B-67 is the most brittle component in the proposed backing systems.²⁰³ When statistically analyzed without the samples with the isolating layer, the results show that there is very little difference between the mean moduli of elasticity for all of these backing systems, however, suggest that they are fairly ductile and will tend to deform elastically under tensile stress.

²⁰³ With Acryloid B-67: 45200.31 psi; without Acryloid B-67: 29561.98 psi.

²⁰⁴ GE samples: 31129.97 psi; PV samples: 28516.65 psi.



Figure 8.7. Stress/strain curve comparing the bond strength results of all of the successful testing samples with the Acryloid B-67 isolating layer.



Figure 8.8. Stress/strain curve comparing the bond strength results of all of the successful testing samples without the B-67 isolating layer.



Figure 8.9. Sample KAW.0.08 after testing, showing the failure of the West System[®] testing assembly epoxy.



Adhesive Bond Strength Samples with 1/2" PP Honeycomb with Glass Epoxy Skin

Figure 8.10. Stress/strain curve comparing the bond strength test results of all of the samples with the 1/2" polyropylene honeycomb with glass epoxy skin.



Adhesive Bond Strength Samples with 1" PP Honeycomb with Polyester Veil

Figure 8.11. Stress/strain curve comparing the bond strength test results of all of the samples with the 1" polyropylene honeycomb with polyester veil.



Figure 8.12. Sample KAW.0.09 after testing, showing the failures of the polyester veil and honeycomb to veil adhesion.


Figure 8.13. Sample KAW.0.06 before testing, with a relatively level testing assembly.



Figure 8.14. Sample KAW.0.06 after testing, showing the nearly completely clean separation of the Araldite[®] epoxy from the Acryloid B-67 isolating layer.



Figure 8.15. Sample KAW.0.03 before testing, with a pitched testing assembly.

Weight Reduction. One of the justifications for removing the reinforced concrete rudus is to significantly reduce the weight of each panel to make them more manageable so that they can more easily be reconfigured in a new display and some of them can travel for international exhibitions. The proposed new backing systems utilize extremely lightweight but rigid and compressively strong materials in order to achieve this. The weight reduction is equal to the change in weight after the concrete rudus has been removed and the new backing has been applied.

Since the concrete removal procedure will not be performed on the test samples until the completion of this thesis, weight calculations of the cement blocks can be used to predict the change in weight of the original panels.

Materials. The following equipment was necessary to determine the weight reduction of the new backing system.

- A can of compressed air to remove all dust and particulates from the surface of the cement before testing.
- Electronic calipers to determine the volume of the cement blocks.
- An electronic balance to determine the masses of the cement blocks before and after the application of the new backing systems.

Test Procedure.

- 1. The cement blocks were sprayed with compressed air to remove dust and particulates from the surface.
- 2. The cement blocks were measured with the electronic calipers, weighed on the electronic scale, and the dimensions and masses were recorded.
- 3. After the backing systems were applied and the adhesives cured according to the procedure detailed above, the test samples were reweighed and the mass recorded.
- 4. The difference in the masses between the cement blocks before and after the backing systems were applied represents the masses of the backing system.

Results. The masses of the cement blocks were used to estimate the weight loss generated by cement removal, which was then compared to the masses of the new backing systems to determine the difference in weight between the cement and the backings. On average, the cement blocks weighed 2.15 lb. The average weight of the new backing systems with the 1/2" polypropylene honeycomb with glass epoxy skin (GE) was 0.09 lb. and with the 1" polypropylene honeycomb with polyester veil (PV) was 0.07 lb.²⁰⁵ The weight difference between the cement blocks and the GE backings was -95.83% and -96.86% for the PV backings (Table A.5). This is an enormous weight difference between material systems and when applied to the weight of one of the 15 ft.² panels that weighs approximately 560 lbs., this would represent

²⁰⁵ The weight of the Acryloid-B67 isolating layer was marginal, and therefore, the samples with and without it were grouped together.

a 80.15% weight reduction or a panel weight of 111.13 lbs. with the GE backing system and a 81.35% weight reduction or a panel weight of 104.45 lbs. with the PV backing system (Table A.6).²⁰⁶ In terms of gross weight reduction, this test showed that although these PV panels were thicker, they still weighed less because of the type of skin. However, with either of the new backings, the panels will be much more easily managed and manipulated.

²⁰⁶ The original mass of 560 lbs. for the panel was approximated from the reported weight of 1 cubic foot of concrete at 150 lbs. (http://www.concreteconstruction.net/concrete-articles/nominal-weight-of-standard-concrete.aspx). The 3'x5'x3" panel is 3.75 ft.³.

Discussion

Evaluation of the various backing systems was based on their performance according to standardized tests and identified criteria. The weight reduction calculations show that both honeycomb panel types will significantly reduce the weight of the Megaron 2 mosaic panels and while the polypropylene honeycomb with polyester veil is the lighter of the two, it is only marginally lighter. Also, although the bond strength test showed that the glass epoxy skin performed better at higher tensile stresses than the polyester veil, the fact that neither of the two honeycomb types failed before the isolating layer means that both would be effective backing materials, and since the glass epoxy skin did not fail in any of the tests, this is the best option for the Megaron 2 mosaic. The Araldite[®] epoxy performed very well in all of the tests, displaying high tensile strengths (over 1,000 psi). It was not negatively affected by the isolating layer and remained intact when the isolating layer failed in all samples.

The Acryloid B-67 isolating layer performed as expected. It had the weakest tensile strength of all of the adhesives and failed before any of the other elements in the samples by nearly half the tensile stress. The unequal failures of the samples with the isolating layers can be explained by either stress loading from the uneven test assemblies, slight variations in the quantity and uniformity of the isolating layer, or both. While the difference in mean tensile failure stresses between the samples with and without the isolating layer may be substantial, those with the layer all failed in a predictable manner, at the interface between the isolating layer and the Araldite[®] epoxy, without causing significant damage to the cement or loss of adhesion of the epoxy. This, along with the fact that the Acryloid B-67 is reversible with the application of acetone, demonstrates that it is an effective reversible layer.

Additional Considerations and Future Tests

Although the results of these limited test programs have shown that the Acryloid B-67, Araldite[®] 2013, and Plascore[®] 1/2" polypropylene honeycomb with glass epoxy skin appear to be appropriate materials for the re-backing of the mosaic panels, further investigations should be performed before these materials are applied to the Megaron 2 mosaic. Since aluminum honeycomb has become the industry standard for lightweight, rigid backings, it is important to compare the results of these tests on the polypropylene honeycomb panels with their aluminum counterparts.²⁰⁷ This should include the same adhesive bond strength tests and weight reduction calculations as well as additional tests such as shear strength and thermal expansion. Shear strength tests are important because differential shear strengths between the cement matrix of the mosaic and the backing could result in their separation. Thermal expansion tests are important and changes in temperature could also result in separation. These tests are planned for the period between the completion of this thesis and the application of re-backing treatments.

²⁰⁷ Plascore[®] produces aluminum honeycomb panels with aluminum skins and the same glass epoxy skins tested with the polypropylene.



Figure 8.16. Diagram of proposed re-backing treatment.

Chapter 9: Discussion and Conclusions

Since the realization in the 1970s that the backing of lifted mosaics with reinforced cement mortars and concrete could lead to new and irreparable modes of deterioration, especially in uncontrolled or unregulated environments, a variety of other backing systems have been proposed and used. In particular, conservators have rejected the use of iron or steel reinforcement because of its susceptibility to corrosion, as well as the use of cement because of its weight, high modulus of elasticity (brittleness), and possible source of soluble salts. Also, while it has not been previously investigated, the cementitious re-backing has the potential to lead to additional deteriorative conditions such as alkali-silica reaction if all of the necessary and sufficient conditions are met.

With the advent of strong and lightweight metallic, synthetic, and composite assemblies and high strength adhesives, conservators have applied these materials to create new systems of support. These properties include rigidity to increase mechanical stability and prevent bending, warping, cracking, and resulting loss of the lifted mosaic; low weight in order to make lifted mosaics more easily moveable; durability to avoid deterioration through weathering; and chemical stability to avoid deterioration through chemical processes such as oxidation and hydrolysis. While few of the published case studies for the conservation of mosaics detail these criteria or test materials, it is clear by their choice of backing systems that these are the primary concerns. The diversity of backing materials for mosaics speaks to the lack of standardization of this process and the fact that each mosaic conservation case presents different conditions and challenges that cannot necessarily be solved through the same backing treatment. However, it appears that conservation procedures are often based on previous work that is either not considered for the particularities of the new project, or at least the decision-making processes are not included in the publications. While the quantity of published treatment accounts is considerable, the fact that most do not include criteria for treatment selection is a significant lacuna and the extent to which the conservation materials are being tested prior to implementation is unclear from the published corpus. Published criteria and decision justifications would allow mosaic conservators to consult these publications for the advantages and disadvantages of particular treatments and to learn in what situations particular treatments have been used. This system would require the submission of details and critiques of the methods by mosaic conservators and would allow conservators who are facing similar challenges to learn from previous practice.

This is important because of the diversity of conditions that must be addressed in each case. For example, the materials and adhesives needed to face a relatively flat and uniform tessellated surface will be very different than those for an undulating and irregular pebble surface. Also, the materials available to a major, well-funded project in a place with developed technology will be different than those available to smaller operations in less industrially developed areas of the world.

Although pebble mosaics such as the Megaron 2 mosaic represent a small fraction of known archaeological mosaics, they are often some of the earliest examples and their materiality and the nature of their construction necessitate conservation treatments particular to their own conditions. The conservation of pebble mosaics has no track record in the published literature and they are sufficiently different from tessellated mosaics to require their own considerations. This thesis has shown the need for the modification of facing materials and cement removal techniques. Furthermore, the potential for deteriorative reactions from the cementitious backings, such as ASR, demands the careful examination of how all archaeological mosaics are examined and treated to ensure that every case is considered by its own particular conditions.

Discussion of Results

Alkali-silica reaction. The potential for ASR was considered as a possible deterioration mechanism because of the 1963 backing of the pebbles with reinforced cementitious mortar. The presence of cement in tandem with the pebbles and the presence of moisture meant that the condition warranted further investigation to determine if ASR had ever occurred or if it currently has the potential to occur. This investigation took the form of research to determine the reactive silica potential of each pebble type, microscopic analyses to possibly visualize the effects of ASR, as well as moisture content analysis, pH analysis, and salt content and semi-quantitative ion analyses of cement samples. The results determined that although each of the three pebble rock types did contain the necessary reactive silica for ASR to occur, the neutral pH certainly suggests that carbonation of the cement has occurred to sufficiently drop the pH below the threshold for ASR. The lack of soluble salts confirmed the cement pore solution's inability to increase alkalinity.

The polarized light and ultraviolet microscopy allowed for the visualization of microcracking on nearly all of the mosaic pebble samples. While the cause of this cracking is inconclusive, the location and pattern of the cracks on the top surface of the pebbles (the originally un-bedded section) suggest that they were caused by above-ground factors, such as thermal shock from the ancient fire, or ancient or more recent mechanical damage. Damage from ASR would likely manifest in micro-cracks emanating from the interior of the pebble towards the edge that narrow as they extend outwards. They would also likely originate in the area of the pebble that had been bedded within the cement. Additional examination after the removal of cement residues from additional pebbles may lead to the discovery of possible ASR-induced cracks. **Re-backing.** The replacement of the reinforced cementitious backings on each of the Megaron 2 mosaic panels is necessary because the cement is responsible for numerous deteriorative conditions and difficulties with interpretation. In order to better preserve the mosaic, reconfigure the panels for more accurate interpretation of the original design, reduce their weight, and make the panels more available for research and public viewing, two major conservation procedures must be performed. The cement rudus on each of the panels and the cementitious over-grout covering large areas of pebbles must be removed; and a new, stable, rigid, and lightweight backing must be applied. To perform both the cement removal and the application of the new backing, the surface of the pebbles must be faced to prevent their loss or damage during the subsequent operations.

This thesis has provided recommendations for all of the facing and backing materials and procedures for facing, cement removal, and re-backing. These recommendations have been developed through the establishment of performance criteria and definitions of critical properties necessary for every material in the facing and backing systems, as well as the assessment of materials, equipment, and techniques used in previous mosaic conservation cases.

Facing. The facing materials are all relatively inexpensive, can be easily procured, and when used together, create a multi-layered facing system that conforms to the uneven surface of the pebbles and protects them from damage or loss during the cement removal and re-backing procedures. Two options for each material have been suggested and will be tested after completion of the thesis and prior to implementation during the 2014 Gordion field season. These facing materials are:

- Primary facing material: *Cotton cheesecloth or crepeline*.
- Secondary facing material: *Muslin or burlap*.
- Cushioned bed: Slow-Recovery Super-Cushioning Polyurethane Foam.

• Facing adhesive: *Methylcellulose or Aquazol 200*.

Cement Removal. The recommended tools and procedures for removing the concrete rudus and cementitious over-grout were adapted from previous mosaic conservation case studies, although techniques from the concrete industry were also examined. These procedures attempt to reduce damage to the pebbles or their bedding by limiting the amount of vibration and impact stresses imposed on the mosaic. These tools and procedures are:

- Bulk cement rudus removal: *Cross-cut with a circular saw to a depth of approximately 1" above the reinforcing bars and emove with an angle grinder.* Alternatively, a more controlled removal system may be warranted to avoid dislodging of the pebbles or cracking from percussive stresses. This may require the use of a variable speed CNC machine or router to mechanically remove controllable lifts of the cement backing. This is currently being investigated.
- Fine cement rudus removal: *Carefully removed with a low vibration grinding or cutting tools such as a Dremel or microabrasive apparatus.*
- Over-grout removal: Carefully removed mechanically by hand or with a low vibration microabrasive apparatus or grinding or cutting tools such as a Dremel.

New backing system. The recommended backing system has been developed to be strong and rigid enough to support the weight of the reduced panels while also being reversible, chemically and environmentally stable, and light enough to permit moving of the panels for reconfiguration or travel. This backing system has been tested for reversibility and adhesive bond strength to ensure that the bond between the reversible isolating layer and the backing adhesive is strong enough to keep the backing together but weak enough to fail without damaging either the mosaic or any of the other backing materials.

• Backing material: 1/2" Plascore[®] polypropylene honeycomb with glass-epoxy skin.

- Backing adhesive: Araldite[®] 2013 epoxy resin.
- Isolating Layer: 15% w/v Acryloid B-67 in acetone.

These recommendations form a pilot conservation program for the Megaron 2 mosaic, to be performed on a limited number of panels during the 2014 Gordion field season. Based on the developed criteria and performance research and testing, they represent the materials and techniques best suited to treat this historically significant, yet poorly preserved and presented mosaic. The removal of the deleterious cementitious backing and over-grout, and replacement with a new, superior backing system is the first phase of a longer conservation program for the Megaron 2 mosaic. Additional conservation phases, which would not be possible without a new backing, aim to stabilize the panels and pebbles, prevent further damage and deterioration, and reintegrate the original design and configuration. In this way, the oldest known mosaic pavement will finally be preserved to contribute more effectively to the study of ancient mosaics, the history of Gordion, and Phrygian art and architecture.

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Appendix A: Testing Data Sheets

		Holder +							
Sample ID	Holder (g)	sample (g)	Sample (g)	H ₂ O Temp (°F)	Temp. (°F)	RH (%)	Oakton	Hanna	Strip
	$\mathbf{W}_{\mathbf{h}}$	$\mathbf{W}_{\mathbf{h}+\mathbf{s}}$	$\mathbf{W}_{\mathbf{s}}$						
KAW.C.1	39.29	46.55	7.26	71.40	69.10	3	8.95	8.22	~8
KAW.C.1B	38.49	44.05	5.56	71.40	69.10	3	8.80	8.44	~8
KAW.C.2	44.04	50.17	6.13	71.40	69.10	3	9.01	8.78	~8
KAW.C.2B	38.97	44.86	5.89	71.40	69.10	3	9.04	9.14	~8
KAW.C.3	46.87	53.95	7.08	71.40	69.10	3	8.92	9.10	~8
KAW.C.3B	40.38	46.37	5.99	71.40	69.10	3	9.12	9.21	~8
Distilled H ₂ O				71.40	69.10	3	6.42	6.80	~6
Sample ID									
KAW.C.1	Tile 10 cemei	nt fragment							
KAW.C.1B	Tile 10 cemei	nt fragment							
KAW.C.2	"Surface cond	crete around pan	el #7"						
KAW.C.2B	"Surface cond	crete around pan	el #7"						
KAW.C.3	"Surface conc	crete between ad	jacent panels (h	nard concrete)"					
KAW.C.3B	"Surface conc	crete between ad	jacent panels (h	nard concrete)"					

Table A.1. pH Analysis of Cement Data Sheet

RH (%)	23	23	23	23	23	23	Wt. Difference (%)	0.04	0.02	0.00	0.04	0.02	0.00	Holder + paper + sample 1 (g)	W _{h+p+ds}	111.02	114.68	110.75	113.29	119.68	113.29							
Temp. ($^{\circ}F$)	68.9	68.9	68.9	68.9	68.9	68.9	RH (%)	21	21	21	21	21	21	Holder + paper + sample (g)	When	125.59	129.23	125.93	127.84	136.76	129.47	% sol. salt content	4.33	4.53	4.59	4.65	4.15	4.88
Sample (g) W _g	15.25	15.25	15.91	15.28	17.83	17.01	Temp. (°F)	72.1	72.1	72.1	72.1	72.1	72.1	Filter paper (g)	W _p	4.44	4.34	4.37	4.37	4.37	4.39	Sol. salt content (g) W _{ss}	0.66	0.69	0.73	0.71	0.74	0.83
Holder + ground sample (g) W _{h+2}	55.54	55.14	59.95	54.25	64.70	57.39	Holder + ground sample 1 (g) W _{h+dg}	55.52	55.13	59.95	54.23	64.69	57.39	Rel. moisture content (%)		0.13	0.07	0.00	0.13	0.06	0.00	Dry sample (g) W _{ds}	14.57	14.55	15.18	14.55	17.08	16.18
Holder (g) W _h	40.29	39.89	44.04	38.97	46.87	40.38	Oven Temp. 1 (°F)	134.6	134.6	134.6	134.6	134.6	134.6	Dry sample (g)	W _{ds}	15.23	15.24	15.91	15.26	17.82	17.01	Holder + paper + sample 2 (g) $W_{h ext{-} h ext{-} h$	111.02	114.68	110.75	113.29	119.68	113.29
Sample ID	KAW.C.1	KAW.C.1B	KAW.C.2	KAW.C.2B	KAW.C.3	KAW.C.3B	Sample ID	KAW.C.1	KAW.C.1B	KAW.C.2	KAW.C.2B	KAW.C.3	KAW.C.3B	Sample ID		KAW.C.1	KAW.C.1B	KAW.C.2	KAW.C.2B	KAW.C.3	KAW.C.3B	Sample ID	KAW.C.1	KAW.C.1B	KAW.C.2	KAW.C.2B	KAW.C.3	KAW.C.3B

Table A.2. Soluble Salt Content Data Sheet

Sample ID	NO ²⁻	NO ³⁻	Cl	SO ₄ ²⁻
		mg/l	mg/l	mg/l
KAW.C.1	Negative	10	0	<200
KAW.C.1B	Negative	10	0	200 <x<400< td=""></x<400<>
KAW.C.2	Negative	10	0	200 <x<400< td=""></x<400<>
KAW.C.2B	Negative	10	0	<200
KAW.C.3	Negative	0	0	<200
KAW.C.3B	Negative	10	0	<200

Table A.3. Semi-Quantitative Analysis of Salt Anions Data Sheet

Strain (in/in) £	0.017	0.008	0.005	0.026	0.012	0.036	0.007	0.029	0.033	0.038	0.048	0.036	0.011		Degrees of Freedom	dF						2.00	2.00	1.00	2.00
Stress (psi) σ	616.94	499.50	366.26	759.6	541.89	894.56	113.25	935.24	1061.342	1027.32	1264.96	1080.37	510.87	Standard	Deviation	SD	± 333.75	± 189.53	± 120.52	±152.58	± 170.05	± 192.18	±229.93	±386.92	±139.37
Failure Mode	1	1	1	1	1	1	5	9	3,4	9	3,4	9	1, 6		Variance	Var	111388.36	35920.51	14524.94	23280.45	28916.10	36933.76	52867.51	149709.24	19422.74
Isolating Layer	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Mean Modulus of	Elasticity (psi)	E	37048.70	45200.31	29561.98	46848.00	30795.29	57326.70	33073.92	31129.97	28516.65
Honeycomb Skin	Glass epoxy	Glass epoxy	Glass epoxy	Polyester veil	Polyester veil	Polyester veil	Polyester veil	Glass epoxy	Polyester veil	Polyester veil	Polyester veil	Glass epoxy	Glass epoxy		Mean Strain (in/in)	εµ	0.02	0.02	0.04	0.02	0.03	0.01	0.02	0.03	0.04
Honeycomb Type	1/2" polypropylene	1/2" polypropylene	1/2" polypropylene	1" polypropylene	1" polypropylene	1" polypropylene	1" polypropylene	1/2" polypropylene	1" polypropylene	1" polypropylene	1" polypropylene	1/2" polypropylene	1/2" polypropylene		Mean Stress (psi)	σ_{μ}	744.01	613.13	1073.85	699.66	924.95	494.23	732.02	1007.81	1117.87
Sample	KAW.0.01	KAW.0.02	KAW.0.03	KAW.0.04	KAW.0.05	KAW.0.06	KAW.0.07	KAW.0.08	KAW.0.09	KAW.0.10	KAW.0.11	KAW.0.12	KAW.0.13		Data Group		All Data	B-67	No B-67	Glass Epoxy	Polyester Veil	B-67/Glass Epoxy	B-67/Polyester Veil	No B-67/Glass Epoxy	No B-67/Polyester Veil

Table A.4. Adhesive Bond Strength Data Sheet

Deviation Squared Without	Outliers	${ m D}_2^2$	14.55	12910.64	60942.33	21454.93	5074.43	79205.66	249875.02	19211.73	156.36	2164.71	36524.41	42.56	316942.43		T-Test	T_{tab}						30.00	00.60	38 50	2000
	Deviation Squared	\mathbf{D}^2	16146.24	59784.09	142693.44	243.12	40851.62	22665.95	397855.46	36569.74	100700.97	80265.78	271391.15	113139.50	54353.26		T-Test	T_{calc}						16 27	/ [] 01	6.03	
Deviation Without	Outliers	\mathbf{D}_2	3.82	113.63	246.87	146.48	71.24	281.44	499.88	138.61	12.50	46.53	11.191	6.52	562.98	Pooled Standard	Deviation	SD_p						14.53	CC:+I	11 00	0/:F1
	Deviation	D	127.07	244.51	377.75	15.59	202.12	150.55	630.76	191.23	317.33	283.31	520.95	336.36	233.14		F-Test	Ftab						d	~	8 53	- <u>-</u> 0
	Modulus of Elasticity (psi)	E	36290.59	62437.50	73252.00	29215.38	45157.50	24848.89	16178.57	32249.66	32161.88	27034.74	26353.33	30010.28	46442.73		F-Test	Fcalc						00 1	1:20	8L C	-1.2
	Sample		KAW.0.01	KAW.0.02	KAW.0.03	KAW.0.04	KAW.0.05	KAW.0.06	KAW.0.07	KAW.0.08	KAW.0.09	KAW.0.10	KAW.0.11	KAW.0.12	KAW.0.13		Data Group		All Data	B-67	No B-67	Glass Epoxy	Polyester Veil	B-67/Glass Epoxy	B-67/Polyester Veil	No B-67/Glass Epoxy	No D 67/Dolynostor Voil

Table A.4. Adhesive Bond Strength Data Sheet

_	_	_	_	_	_	-	_	_	_	_	_	_	_	-	 _	_	_	_	_	_	_	_	_	_	_	_	_	_	_
Mass after backing (lb)	M_2	2.27	2.31	2.13	2.28	2.20	2.34	2.21	2.16	2.18	2.16	2.21	2.28	2.23	Weight difference (%)		95.72	95.69	95.52	96.76	96.78	96.75	96.75	95.99	97.12	96.99	96.97	95.96	95.95
Original Mass (lb)	$\mathbf{M_{I}}$	2.17	2.21	2.04	2.21	2.13	2.27	2.14	2.07	2.12	2.10	2.15	2.20	2.14	Mass of backing (lb)	M_{2} - M_{1}	0.09	0.10	0.09	0.07	0.07	0.07	0.07	0.08	0.06	0.06	0.07	0.09	0.09
Cement Volume (in ³)	V_1	33.85	31.59	29.81	31.41	30.33	33.58	31.03	31.75	30.75	31.96	31.34	32.37	30.81	Volume of backing (in ³)		8.05	8.77	8.63	16.71	16.61	17.32	16.37	6.65	16.18	15.05	16.48	8.15	8.75
Cement Dimensions		4.022"x4.084"x2.061"	4.016"x4.022"x1.956"	3.986"x4.003"x1.868"	4.029"x4.022"x1.938"	4.002"x4.014"x1.888"	4.040"x4.025"x2.065"	4.011"x4.004"x1.932"	4.010"x4.044"x1.958"	4.010"x4.015"x1.910"	3.998"x4.009"x1.994"	4.032"x4.027"x1.930"	3.999"x4.005"x2.021"	4.008"x4.018"x1.913"	Volume after backing (in^3)		41.90	40.37	38.44	48.11	46.94	50.90	47.39	38.40	46.93	47.01	47.82	40.52	39.55
Isolating Layer		B-67	None	None	None	None	None	None	Dimensions after backing		4.022"x4.084"x2.551"	4.016"x4.022"x2.499"	3.986"x4.003"x2.409"	4.029"x4.022"x2.969"	4.002"x4.014"x2.922"	4.040"x4.025"x3.130"	4.011"x4.004"x2.951"	4.010"x4.044"x2.368"	4.010"x4.015"x2.915"	3.998"x4.009"x2.933"	4.032"x4.027"x2.945"	3.999"x4.005"x2.530"	4.008"x4.018"x2.456"						
Backing		GE	GE	GE	PV	PV	PV	ΡV	GE	PV	PV	ΡV	GE	GE	Density (lb/in ³)	D	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Sample #		1	2	3	4	5	9	7	8	6	10	11	12	13	Sample #		1	2	3	4	5	9	7	8	6	10	11	12	13

Table A.5. Weight Difference Data Sheet

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(in ³) Avg. Weight Difference (%)	N/A	95.83	96.86	³) Volume Reduced (in ³)	Vred	5400.00	N/A	N/A	(lb.) Change in Mass (%)		N/A	80.15	01.35
Avg. Density (lb. D _{ave}	0.068	0.011	0.004	Density (Ib./in	$\mathbf{D}_{\mathrm{avg}}$	0.086	0.011	0.004	Change in Mass		N/A	448.87	755 55
Avg. Volume (in ³) V _{ave}	31.58	8.17	16.39	Original Mass (lb.)	${ m M}_{ m avg}$	560.00	17.80	11.12	Mass After Backing (lb.)	Mback	N/A	111.13	101 15
Avg. Original Mass (lb.) M _{ave}	2.15	0.09	0.07	Volume (in ³)	$\mathbf{V}_{\mathbf{avg}}$	6480.00	1620.00	2700.00	Mass Reduced (lb.)	MIred	466.67	N/A	NIA
Backing System	Cement	GE Backing System	PV Backing System	Backing System		3'x5'x3" Panel	GE Backing System	PV Backing System	Backing System		3'x5'x3" Panel	GE Backing System	PV Backing

 Table A.6. Weight Reduction Potential Data Sheet

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Appendix B: Alkali-Silica Reaction Testing Images



Figure B.1. One of the cement samples being ground in an agate mortar.



Figure B.2. Ground cement samples awaiting testing.



Figure B.3. The ground test samples mixed with distilled water to dissolve any soluble salts.



Figure B.4. The dissolved soluble salts being filtered out of the cement samples.



Figure B.5. The dried cement samples after being filtered of its soluble salts.



Figure B.6. Nitrate (NO³⁻) and nitrite (NO²⁻) test strips for sample KAW.C.01.



Figure B.7. Chloride (Cl⁻) test strips for sample KAW.C.01.



Figure B.8. Sulfate (SO₄²⁻) test strips for sample KAW.C.01.



Figure B.9. Nitrate (NO³⁻) and nitrite (NO2-) test strips for sample KAW.C.01B.



Figure B.10. Chloride (Cl⁻) test strips for sample KAW.C.01B.



Figure B.11. Sulfate (SO₄²⁻) test strips for sample KAW.C.01B.



Figure B.12. Nitrate (NO³⁻) and nitrite (NO²⁻) test strips for sample KAW.C.02.



Figure B.13. Chloride (Cl⁻) test strips for sample KAW.C.02.



Figure B.14. Sulfate $(SO_4^{2^-})$ test strips for sample KAW.C.02.


Figure B.15. Nitrate (NO³⁻) and nitrite (NO2-) test strips for sample KAW.C.02B.



Figure B.16. Chloride (Cl⁻) test strips for sample KAW.C.02B.



Figure B.17. Sulfate (SO₄²⁻) test strips for sample KAW.C.02B.



Figure B.18. Nitrate (NO³⁻) and nitrite (NO²⁻) test strips for sample KAW.C.03.



Figure B.19. Chloride (Cl⁻) test strips for sample KAW.C.03.



Figure B.20. Sulfate $(SO_4^{2^{-}})$ test strips for sample KAW.C.03.



Figure B.21. Nitrate (NO³⁻) and nitrite (NO²⁻) test strips for sample KAW.C.03B.



Figure B.22. Chloride (Cl⁻) test strips for sample KAW.C.03B.



Figure B.23. Sulfate (SO₄²⁻) test strips for sample KAW.C.03B.

Appendix C: Pebble Characterization

				Approx.			Cement		
Tile #	Pebble #	Type	Color	Dimensions	Roundness	Shape	Residue	Intact?	Notes
2	1	Meta-quartzite	White	0.75" x 0.60"	Rounded	Equant	No	Yes	
2	2	Volcanic	Dark Blue	0.60" x 0.60"	Subangular	Subequant	No	No	2 Fragments
3	1	Chert	Dark Red	1.00" x 0.60"	Subrounded	Elongate	No	Yes	
3	2	Volcanic	Dark Blue	0.60" x 0.60"	Rounded	Equant	No	No	4 Fragments
7	1	Meta-quartzite	Pink	0.75" x 0.75"	Subrounded	Subequant	No	Yes	
7	2	Volcanic	Dark Blue	0.85" x 0.75"	Rounded	Equant	Minimal	Yes	
8	1	Chert	Dark Red	0.75" x 0.75"	Subrounded	Subequant	Minimal	No	Chipped
8	2	Meta-quartzite	Pink	1.00" x 0.60"	Subrounded	Elongate	Minimal	Yes	
8	3	Volcanic	Dark Blue	0.75" x 0.75"	Subrounded	Subequant	Minimal	Yes	
6	1	Volcanic	Dark Blue	1.00" x 0.40"	Angular	Elongate	Minimal	No	Chipped
10	-	Chert	Dark Red	1.00" x 0.60"	Angular	Elongate	Yes	Yes	Thin-Sectioned
10	2	Meta-quartzite	White	0.60" x 0.45"	Subrounded	Equant	Yes	Yes	Thin-Sectioned
10	3	Meta-quartzite	White	1.00" x 0.60"	Rounded	Subelongate	No	Yes	
10	4	Meta-quartzite	White	1.20" x 0.75"	Subangular	Elongate	Minimal	Yes	
11	1	Meta-quartzite	Pink	0.75" x 0.75"	Rounded	Equant	No	Yes	
11	2	Volcanic	Dark Blue	0.75" x 0.70"	Rounded	Subequant	No	Yes	
11	3	Unknown	Gray	1.00" x 0.75"	Angular	Elongate	No	Yes	
12	1	Volcanic	Dark Blue	1.20" x 0.75"	Subrounded	Subelongate	Yes	Yes	
12	2	Meta-quartzite	White	0.75" x 0.70"	Subrounded	Equant	No	Yes	
12	3	Chert	Dark Red	1.00" x 0.75"	Angular	Subelongate	Minimal	Yes	
13	1	Meta-quartzite	White	0.75" x 0.75"	Subrounded	Equant	No	Yes	
14	1	Meta-quartzite	White	0.70" x 0.45"	Rounded	Equant	No	Yes	

Table C.1. Megaron 2	Pebble Sample	Characteristics
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									Chipped	Chipped	Chipped	Chipped	Chipped	Chipped	Chipped	Chipped	Chipped	Chipped	Chipped	Chipped	Chipped Chipped Chipped Chipped
Minimal Yes		Minimal Yes	Minimal Yes No Yes	Minimal Yes No Yes No Yes	Minimal Yes No Yes No Yes Yes Yes	Minimal Yes No Yes Yes Yes Minimal Yes	Minimal Yes No Yes Yes Yes Minimal Yes Minimal Yes	Minimal Yes No Yes Yes Yes Minimal Yes No Yes	Minimal Yes No Yes No Yes Yes Yes Minimal Yes No Yes No No	Minimal Yes No Yes No Yes Yes Yes Minimal Yes No Yes No Yes Minimal Yes	MinimalYesNoYesNoYesYesYesMinimalYesNoYesNoYesNoNoMinimalYesNoNoNoNoNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYes	Minimal Yes No Yes No Yes Yes Yes Minimal Yes No Yes No Yes No Yes No Yes Minimal Yes	MinimalYesNoYesNoYesYesYesMinimalYesNoYesNoYesNoYesMinimalYesNoYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYes	MinimalYesNoYesNoYesYesYesMinimalYesMinimalYesNoYesNoYesNoYesMinimalYesMinimalYesNoYesMinimalYesNoYesNoYesMinimalYesMinimalYesMinimalYesNoYesNoYesNoYesNoYesNoYesNoYes	MinimalYesNoYesNoYesYesYesMinimalYesMinimalYesNoYesNoYesNoYesNoYesMinimalYesNoYesNoYesNoYesNoYesNoYesMinimalYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYes	MinimalYesNoYesNoYesYesYesMinimalYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesMinimalYesMinimalYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYes	MinimalYesNoYesNoYesYesYesMinimalYesNoYesNoYesNoYesNoYesMinimalYesNoYesNoYesNoYesNoYesNoYesMinimalYesNoYesMinimalYesNoYesNoYesNoYesNoYesNoYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYes	MinimalYesNoYesNoYesYesYesMinimalYesMinimalYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYes	MinimalYesNoYesNoYesYesYesMinimalYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesMinimalYesNoYesNoYesNoYesMinimalYesMinimalYesNoYesMinimalYesMinimalYesNoYesMinimalYesNoYesMinimalYesNoYesMinimalYesNoYesMinimalYesMinimalYesNoYesNoYes	MinimalYesNoYesNoYesYesYesMinimalYesMinimalYesNoYesNoYesNoYesMinimalYesNoYesNoYesNoYesNoYesNoYesMinimalYesNoYesNoYesNoYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesMinimalYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYes	MinimalYesNoYesNoYesYesYesMinimalYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesMinimalYesNoYesMinimalYesMinimalYesMinimalYesNoYesMinimalYesMinimalYesMinimalYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesNoYesYesYesYesYes
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 Table C.1. Megaron 2 Pebble Sample Characteristics

Notes					Chipped							Thin-Sectioned	Thin-Sectioned	Thin-Sectioned	
Intact?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
Cement Residue	No	No	Minimal	No	Minimal	Minimal	No	Minimal	No	No	No	No	No	No	Yes
Shape	Equant	Equant	Elongate	Equant	Subelongate	Elongate	Equant	Equant	Subelongate	Equant	Elongate	l in 2011	l in 2011	1 in 2011	Equant
Roundness	Subrounded	Rounded	Subrounded	Subangular	Rounded	Subrounded	Rounded	Rounded	Rounded	Rounded	Subangular	ned and cleaned	ned and cleaned	ned and cleaned	Rounded
Approx. Dimensions	1.20" x 1.00"	0.60" x 0.60"	0.75" x 0.60"	0.75" x 0.75"	0.60" x 0.40"	0.75" x 0.60"	0.75" x 0.60"	0.75" x 0.60"	0.75" x 0.45"	0.75" x 0.60"	1.20" x 0.60"	Thin-section	Thin-sectio	Thin-section	0.40" x 0.40"
Color	White	Pink	Dark Red	Gray	Dark Blue	Dark Red	White	Dark Blue	White	Pink	Dark Red	Dark Blue	Dark Red	White	White
Type	Meta-quartzite	Meta-quartzite	Chert	Unknown	Volcanic	Chert	Meta-quartzite	Volcanic	Meta-quartzite	Meta-quartzite	Chert	Volcanic	Chert	Meta-quartzite	Meta-quartzite
Pebble #	1	1	2	ю	4	1	2	1	2	3	1	1	2	3	1
Tile #	22	23	23	23	23	24	24	26	26	26	27	28	28	28	31

 Table C.1. Megaron 2 Pebble Sample Characteristics

Appendix D: Testing Replicas



Figure D.1. New pebbles being compared to original samples from the Megaron 2 mosaic.



Figure D.2. The new, sorted pebbles drying in preparation of making the replicas.



Figure D.3. Building the forms in the PennDesign Fabrication Lab.



Figure D.4. A 4"x4"x4" form for the scaled mosaic replica panels.



Figure D.5. A 4"x4"x2" form for the scaled mosaic replica panels.



Figure D.6. Coating the forms with mineral oil.



Figure D.7. Laying the modeling clay base inside the forms.



Figure D.8. The forms with modeling clay prior to setting the pebbles.



Figure D.9. A 4"x4"x4" form prior to pouring the cement.



Figure D.10. Cross-section of one of the replica panels prior to pouring the cement.



Figure D.11. Some of the 4"x4"x4" forms after pouring the cement slurry.



Figure D.12. Some of the 4"x4"x4" forms after laying the reinforcement.



Figure D.13. Applying the cement rudus into the forms.



Figure D.14. The filled forms curing in 100% humidity in sealed bags.



Figure D.15. A 4"x4"x4" mosaic replica after de-molding.



Figure D.16. A 4"x4"x2" cement block after de-molding.



Figure D.17. The de-molded samples curing in 100% humidity in sealed bags.



Figure D.18. Removing the clay facing from the replica panels.



Figure D.19. The samples drying outside of the bags.



Figure D.20. The replica panels after the clay facing removal.



Figure D.21. Cutting and shaping the aluminum plates on a Bridgeport[®] milling machine.





Figure D.23. Tapping the threaded hole in a top plate.



Figure D.24. Reducing the diameter of the stainless steel threaded rod on a lathe.



Figure D.25. Completed aluminum pieces awaiting assembly.



Figure D.26. 3D model of the test assembly with backing system A.



Figure D.27. 3D model of the test assembly with backing system B.



Figure D.28. 3D model of test assembly with backing system C.



Figure D.29. 3D model of test assembly with backing system D.



Figure D.30. Spraying the Acryloid B-67 isolating layer.



Figure D.31. Degreasing the honeycomb surface with acetone.



Figure D.32. Applying the Araldite[®] 2013 epoxy to the cement block.



Figure D.33. Spreading the Araldite[®] 2013 epoxy with a taping knife.



Figure D.34. Applying the Araldite[®] 2013 epoxy to the honeycomb.



Figure D.35. Attaching the honeycomb to the cement block.



Figure D.36. Applying the West System[®] 105/205 epoxy to the aluminum base.



Figure D.37. Spreading the West System[®] 105/205 epoxy on the cement block.



Figure D.38. Attaching the aluminum plates to a test sample.



Figure D.39. Allowing the epoxied testing assemblies to cure.



Figure D.40. One of the completed adhesive bond strength testing assemblies.



Figure D.41. Failure mode 1: Adhesive failure of the Acryloid B-67 isolating layer.



Figure D.42. Failure mode 2: Adhesive or cohesive failure of the Araldite[®] 2013 epoxy.



Figure D.43. Failure mode 3: Adhesive failure of the Plascore[®] proprietary epoxy used to adhere the polypropylene honeycomb and the polyester veil or glass-epoxy skin.



Figure D.44. Failure mode 4: Cohesive failure of the honeycomb backing.



Figure D.45. Failure mode 5: Cohesive failure of the cement.



Figure D.46. Failure mode 6: Adhesive failure of the interface between West System[®] 105/205 epoxy and an aluminum plate.

Appendix E: Adhesive Bond Strength Data


Figure E.1. Stress/strain curve for sample KAW.0.01.



Figure E.2. Stress/strain curve for sample KAW.0.02.





Figure E.4. Stress/strain curve for sample KAW.0.04.



Figure E.5. Stress/strain curve for sample KAW.0.05.





Figure E.6. Stress/strain curve for sample KAW.0.06.



Figure E.8. Stress/strain curve for sample KAW.0.08.



Figure E.10. Stress/strain curve for sample KAW.0.10.



Figure E.12. Stress/strain curve for sample KAW.0.12.



Figure E.13. Stress/strain curve for sample KAW.0.13.



Figure E.14. Sample KAW.0.01 after testing.



Figure E.15. Sample KAW.0.02 after testing.



Figure E.16. Sample KAW.0.03 after testing.



Figure E.17. Sample KAW.0.04 after testing.



Figure E.18. Sample KAW.0.05 after testing.



Figure E.19. Sample KAW.0.06 after testing.



Figure E.20. Sample KAW.0.07 after testing.



Figure E.21. Sample KAW.0.08 after testing.



Figure E.22. Sample KAW.0.09 after testing.



Figure E.23. Sample KAW.0.10 after testing.



Figure E.24. Sample KAW.0.11 after testing.



Figure E.25. Sample KAW.0.12 after testing.



Figure E.26. Sample KAW.0.13 after testing.

Appendix F: Recommended Conservation Materials List and Material Safety Data Sheets

Acryloid B-67 Talas 330 Morgan Ave. Brooklyn, NY 1121 www.talasonline.com

Aquazol[®] 200 Talas 330 Morgan Ave. Brooklyn, NY 1121 <u>www.talasonline.com</u>

Araldite[®] 2013 Huntsman Advanced Materials 10003 Woodloch Forest Drive The Woodlands, Texas 77380 www.huntsman.com

Burlap McMaster-Carr 200 New Canton Way Robbinsville, NJ 08691 <u>www.mcmaster.com</u> Cotton cheesecloth Talas 330 Morgan Ave. Brooklyn, NY 1121 www.talasonline.com

Crepeline Talas 330 Morgan Ave. Brooklyn, NY 1121 www.talasonline.com

Methylcellulose Talas 330 Morgan Ave. Brooklyn, NY 1121 www.talasonline.com

Muslin Talas 330 Morgan Ave. Brooklyn, NY 1121 <u>www.talasonline.com</u>

www.plascore.com

Polypropylene honeycomb Plascore[®] Northeast U.S. Pittsburgh, PA Plascore[®] Europe Feldborn 6 55444 Waldlaubersheim Germany Polyurethane memory foam

McMaster-Carr

200 New Canton Way

Robbinsville, NJ 08691

www.mcmaster.com

PARALOID™ B-67 Hydrophobic acrylic resin

ROHM 🔼	Ma	terial Safety	Data Sheet
UNITED STATES O	FAMERICA		
Fornon-emergency Infor Emergency telephone nu Spill Emer Health Emer Che	mation contact: 215-59 imber gency 215-592-300 gency 215-592-300 mtrec 800-424-930	2-3000 0 0 0	
3. HAZARDS IDENTI	FICATION		
Emergency Overview Appearance Form Colour	Granularsolid Hazy white		
Odour	Acrylicodor		<u> </u>
Hazard Summary	INHALATION OF DUS IRRITATION OF NOS HEADACHE NAUSEA MAY CAUSE EYE AN	ST CAN CAUSE THE F IE, THROAT, AND LUN ID SKIN IRRITATION.	OLLOWING: GS
PotentialHealth Effects PrimaryRoutes of Entry	: Eye contact Sitin contact		
Eyes: Monomer vapors fro slightimitation skin:Prolonged or repeate slightimitation inhalation:Inhalation of du mitationof mose, throat, an nhalationof monomer vap Maycause nose, throat, ar seadache	m heatedproduct can cau ad skincontact can cause list can causethe following d lungs or from heated product ca d lung irritation.	ise the following: the following: J: an cause the following:	
nausea Toluene		ACGIH	Notclassifiable as a human
Toluene Toluene		USCA65CRT IARC	carcinogen. Developmentaitoxin. Notclassifiable as to
Toluene Toluene Toluene		IRIS USCA65CRT IRIS	Varianogenciary to numans. Notclassified. Femalereproductive toxin. Inadequateinformation to assess carcinogenic potential (2005 Guidelines)
CONSULT A PHYSIC UNCONSCIOUS PER	IAN IFNECESSARY SON.	. NEVER GIVE AN	IYTHING BY MOUTHTO AN
USE THE FOLLOWIN MATERIAL:	IGEXTINGUISHING	MEDIA WHEN FIG	HTING FIRES INVOLVING THIS
Carbondioxide (CO2) Drychemical Waterspray Specifichazards during 1 Specialprotective equipn Furtherinformation:Use v Remainupwind.	Ire fighting: Material as s nent for fire-fighters: We vater spray to cool unope	old is combustible; bun ar self-contained breath ned containers.	ns vigorously with intense heat. Ing apparatus andprotective suit.
wordbreauning smoke.			

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Handling

nanoung Storein a cool, dry, well ventilated place. Avoid contact with eyes, skin andclothing. Washthoroughly after handling. Keep container tightly closed. Do notbreathe vapoursidust. Static charges can accumulate: usebonding and grounding between transfer equipment and receiving containers and for anyother operationscapable of generating static electricity.

Storage

Storageconditions:Material can burn; limit indoor storage toapproved areas equipped with automatic sprinklers. Ground all metal containers duringstorage and handling. Storagetemperature:-18.00 - 49.00 °C (-0.40 - 120.20 °F) FurtherInformation:

Monomervapors can be evolved when material is heated during processingoperations. See SECTION 8, for types ofventilation required

Exposure limits are listed below, if they exist.

Component	Regulation	Type of listing	Value
Toluene	Rohm and Haas	TWA	10 ppm
	Rohm and Haas	STEL	20 ppm
	Rohm and Haas	Absorbed via skin	
	ACGIH	TWA	20 ppm
	NIOSH/GUIDE	REL	375 mg/m3 100 ppm
	NIOSH/GUIDE	STEL	560 mg/m3 150 ppm
	OSHA/Z2	TWA	200 ppm
	OSHA/Z2	Celling	300 ppm
	OSHA/Z2	MAX. CONC	500 ppm
	Z1A	TWA	375 mg/m3 100 ppm
	Z1A	STEL	560 mg/m3 150 ppm

Eyeprotection: Use safety glasses with side shields (ANSI 287. for approved equivalent). Eye protection worn must be compatible withrespiratory protection system employed.

Handprotection:Cottonor canvas gloves. Respiratoryprotection:A respiratory protection program meeting OSHA 1910.134 and ANSI Z88.2requirements or equivalent must be followed whenever workplace conditionswarrant a respirator's use. None required under equivalent must be billowed where we wantable contained watant a respirator sole. Note required under normaloperating conditions. When dusty conditions are encountered, were a property fitted NIOSH approved (or equivalent) half-mask,air-purtying respirator. Air-purtying respiratorsshould be equipped with NIOSH approved (or equivalent) organic vapor cartridgesand NS5 filters. If oil mist is present, use RS5 or PS5 filters. Protectivemeasures: Facilitiessforing or utilizing this material should be equipped with an eyewash facility. Engineering measures: Use localexhaust ventilation with a minimum capture velocity of 150 f/min. (0.75m/sec.) at the point of dust or mist evolution. Refer to the current edition of "Industrial Ventilation: A Manualof Recommended Practice" published by the American Conference of Governmental Industrial Hygienists for Information on the design, Installation, use, and maintenance of exhaust systems.

) APPROXIMATELY

Lowerexplosion limit	notapplicable
Upperexplosion limit	notapplicable
Vapourpressure	Not Applicable
Relativevapour density	notapplicable
Watersolubility	practicallyinsoluble
Density	0.66g/cm3Bulk density
Viscosity,dynamic	notapplicable
Evaporationrate	notapplicable
Percentvolatility	2% maximum
NOTE: The physical data presented above are typicalvalues and should not be construed as a specification.	

polymerisation

Productwill not undergo polymerization.

> 5,000 MG/KG

Toxicitydata for a compositionally similar material.

Acutedermai toxicity LD50 rabbit > 3,000 mg/kg Toxicitydata for a compositionally similar material. Skinirritation

rabbit slight irritation

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PARALOID™ B-67 Hydrophobic acrylic resin

Toxicitydata for a compositionally similar material.

Eveirritation rabbit slight initiation Toxicitydata for a compositionally similar material.

Component:Toluene Acuteinhalation toxicity LC50rat 4 h15.07mg/ Component: Toluene Subchronictoxicity

IARCassessment: this product is not classifiable as to its carcinogenicity tohumans (Group 3).

Component:Toluene

Reproductivefoxicity in laboratory studies, birth defects, increased fetallethality and delayed fetal development have been observed in offspring of femaleanimals exposed during pregnancy.

Component:Toluene

Toratogenicity Toluenehas been demonstrated to be embryofetoloxic and teratogenic in laboratoryanimais.

13. DISPOSAL CONSIDERATIONS

Environmental precautions: CAUTION: Keep spills and cleaning runoff out of municipal sewers and open bodies ofwater. Disposal

WasteClassification: When a decision is made to discard this material as supplied, it doesnot meet RCRA's characteristic definition of ignitability, corrosivity, orreactivity, and is not listed in 40 CFR 261.33. The toxicity characteristic(TC), however, has not been evaluated by the Toxicity Characteristic LeachingProcedure (TCLP). Fordisposal, incinerate this material at a facility that complies with local,state, and federal regulations.

15. REGULATORY INFORMATION

Workplace Classification

OSHA:

Thisproduct is considered non-hazardous under the OSHA Hazard CommunicationStandard (29CFR1910.1200).

WHMIS:

Thisproduct is a'controlled product' under the Canadian Workplace Hazardous

Materialsinformation System (WHMIS). SARA TITLE III:Section311/312 Categorizations (40CFR370):This product is not a hazardous chemical under 29CFR1910.1200, and therefore is not covered by Title III of SARA.

CERCLAInformation(40CFR302.4)

CERCLAInformation(40CFR302.4) Releases of this material to air, land, or water are not reportable to the NationalResponse Center under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or to state and local emergency planning committeesunder the Superfund Amendments and Reauthorization Act (SARA) Title III Section304. US. Toxic Substances Control Act (TSCA) call components of thisproduct are in compliance with the inventory listing requirements of the U.S. Toxic Substances Control Act (TSCA) Chemical Substance Inventory. Pageney/series

Pennsylvania Anymaterial listed as "Not Hazardous" in the CAS REG NO. column of SECTION 2, Composition/information On Ingredients, of this MSDS is a tradesecret under the provisions of the Pennsylvania Worker and CommunityRight-to-Know Act. California (Proposition 65)

Thisproduct contains a component or components known to the state of California tocause birth defects or other reproductive harm: Components: Toluene 108-88-3

California (Proposition 65)

Thisproduct contains trace levels of a component or components known to the stateof California to cause cancer and birthdefects or other reproductive harm: Benzene 71-43-2 Components

HAZARD RATING

Healt	h	Fire	Reactivity	PhysicalHazard	PPE
1		1	0		
Legend					
ACGIH	Ame	rican Conference of Gove	emmental Industrial Hygi	enists	
BAc	Butyl	Butyl acetate			
OSHA	Occu	Occupational Safety and Health Administration			
PEL	Perm	Permissible Exposure Limit			
STEL	Short	Short Term Exposure Limit (STEL):			
TLV	Three	Threshold Limit Value			
TWA	Time	Time Weighted Average (TWA):			
1	Bard	Bar denotes a revision from prior MSD3.			

Theinformation provided in this Safety Data Sheet is correct to the best of ourknowledge, information and belief at the date of its publication. Theinformation given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and is

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PARALOID™ B-67 Hydrophobic acrylic resin

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not to beconsidered a warranty or quality specification. The information relates only tothe specific material designated and may not be valid for such material used incombination with any other materials or in any process, unless specified in thetext.

Version: 1 . 2 Print Date: 09/17/2010

http://www.dow.com/products/product_print.page?display-mode=print&product=1121220... 09/20/10

Polymer Chemistry Innovations, Inc Print Date: 04/15/02

Material Safety Data Sheet AQUAZOL 5/50/200/500

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**** MATERIAL SAFETY DATA SHEET ****

AQUAZOL® 5/50/200/500

Section 1 - Chemical Product and Company Identification

Product Name: AQUAZOL® 5/50/200/500 Chemical Family: Polyoxazoline

Chemical Name: Poly (2-ethyl-2-oxazoline)

Manufacturer's Name: Polymer Chemistry Innovations, Inc. (aka "PCI)

Manufacturer's Telephone Number: (520) 746-8446 Formula: -(C₅H₉NO)-

Manufacturer's Address: 4231 S. Fremont Ave. Tucson, AZ 85714

CHEMTREC Telephone Number: (800) 424-9300

Section 2 - Composition, Information on Ingredients

CAS# Chemical Name %

25805-17-8 *Poly (2-ethyl-2-oxazoline) 99.9 % 10431-98-8 2-ethyl-2-oxazoline <0.1 %

Reviewed in accordance with section 311 & 312 of SARA Title III and found not to be in any hazard class.

Section 3 - Hazards Identification EMERGENCY OVERVIEW

Chemical, Not otherwise specified. Protect from moisture. Keep container tightly closed. POTENTIAL HEALTH EFFECTS Eye No adverse health effects known or expected. Skin No adverse health effects known or expected. Ingestion No adverse health effects known or expected. Inhalation No adverse health effects known or expected Chronic Not available.

Polymer Chemistry		
Innovations, Inc	Material Safety Data Sheet	
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Section 4 - First aid Measures

Eyes	Flush e	Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.	
Skin	Wash	exposed area with soap and water.	
Inhalation	Remov respira	Remove from exposure to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.	
Notes to Physician	Treat symptomatically and supportively.		
		Section 5 - Fire Fighting Measures	
General Information		As in any fire, wear a self-contained breathing apparatus in pressure- demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Flammable Liquid.	
Extinguishir	ng Media	Use water spray, dry chemical, carbon dioxide, or chemical foam.	
Unusual Fire Explosion H	e & lazards	Material decomposes above 300 deg. C; toxic fumes may be generated	
		Section 6 - Accidental Release Measures	
General Information	Use	proper personal protective equipment as indicated in Section 8.	
Spills/Leaks	ipills/Leaks Persons not wearing protective equipment should be excluded from the area of the spill until clean up has been completed. Shovel spilled material into containers. Thoroughly sweep up residual material. Wash spill site after material pick-up is complete.		
		Section 7 - Handling and Storage	
Handling/ Storage Keep in closed or covered containers when not in use. Store in coordinate storage place with adequate ventilation. Protect from moisture. Do not sm areas where polymer dust is present.) in closed or covered containers when not in use. Store in cool dry with adequate ventilation. Protect from moisture. Do not smoke in swhere polymer dust is present.	
	Section	on 8 - Exposure Controls, Personal Protection	
Engineering	Controls	Use adequate ventilation to keep airborne concentrations low.	
		PERSONAL PROTECTIVE EQUIPMENT	
Eyes	Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.		
Skin	Wear app	ropriate protective gloves to prevent skin exposure.	
Clothing	Wear app	ropriate protective clothing to prevent skin exposure.	
Respirators	NIOSH/M	SHA approved dust respirator recommended if any dust is generated.	

Section 9 - Physical and Chemical Properties

novations, Inc	Material Safety Data Sheet	D
nni Dale. 04/10/02	AQUALUE 5/50/200/500	Fage. (
Physical State	Solid	
Appearance	Light yellow granules	
Odor	Not characterized	
pН	Neutral in aqueous solution	
Vapor Pressure	NA	
Boiling Point	NA	
Autoignition Temperatur	e > 400 deg C	
Flash Point	NA	
Explosion Limits, lower	NA	
Explosion Limits, upper	NA.	
Solubility in Water	Miscible	
Specific Gravity/Density	1.14 (H2O = 1)	
	Section 10 - Stability and Reactivity	
Chemical Stability	Product is stable under normal conditions of storage and handling.	

Chemical Stability	Product is stable under normal conditions of storage and handling.	
Conditions to Avoid	Material decomposes above 300 deg C; toxic fumes may be generated	
Incompatibilities with Other Materials	Strong oxidizing agents	
Hazardous Decomposition Products	Nitrogen oxides, carbon monoxide, carbon dioxide. Decomposition begins at 300 deg C	
Hazardous Polymerization	Does not occur.	
Section 11 - Toxicological Information		
Oral LD50 (rat)	3980 mg/Kg	
Section 12 - Ecological Information		
No Specific Data Available		
Sectio	on 13 - Disposal Considerations	
Dispose of in a manner consister	nt with federal, state, and local regulations.	
Sect	ion 14 - Transport Information	

Not regulated by current DOT, IMO or IAAO regulations. Chemical, Not Otherwise Specified

Polymer Chemistry
Innovations, Inc
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Material Safety Data Sheet AQUAZOL 5/50/200/500

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Section 15 - Regulatory Information

No specific information is available

Section 16 - Additional Information

MSDS Creation Date 04/09/96

Revision #5 Date 04/15/02

This data sheet and recommendations presented in this data sheet concerning the use of our product and the materials contained therein are believed to be accurate and are based on information that is considered reliable as of the date hereof. However, the customer should determine the suitability of such materials for his or her purpose before adopting them on a commercial scale. Since the use of our products by others is beyond our control, no guarantee, expressed or implied, is made and no responsibility assumed for the use of this material or the results to be obtained therefrom. Information on the form is furnished for the purpose of compliance with Government Health and Safety Regulations and shall not be used for any other purpose. Moreover, the recommendations contained in this data sheet are not to be construed as a license to operate under, or a recommendation to infringe, any existing patents, nor should they be confused with state, municipal, or insurance requirements, or with national safety codes.

Material Safety Data Sheet



ARALDITE® 2013 A

1. Product and company identification		
Material uses	ARALDITE® 2013 A : Resin for adhesive systems	
MSDS #	: 00072856	
Validation date	: 6/6/2012.	
Print date	: 6/6/2012.	
Supplier/Manufacturer	: Huntsman Advanced Materials Americas LLC P.O. Box 4980 The Woodlands, TX 77387	
	Non-Emergency phone: (800) 257-5547	
	E-Mail: MSDS@huntsman.com	
In case of emergency	: Chemtrec: (800) 424-9300 or (703) 527-3887	

2. Hazards identification

Physical state	: Liquid. [Paste.]
Odor	: Slight
Color	: Gray.
OSHA/HCS status	: This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).
Emergency overview	: WARNING!
	CAUSES RESPIRATORY TRACT, EYE AND SKIN IRRITATION. MAY CAUSE ALLERGIC SKIN REACTION. MAY BE HARMFUL IF SWALLOWED.
	Do not breathe vapor or mist. Do not ingest. Do not get on skin or clothing. Avoid contact with eyes. Use only with adequate ventilation. Keep container tightly closed and sealed until ready for use. Wash thoroughly after handling.
See toxicological informat	tion (Section 11)

GENERAL INFORMATION : Read the entire MSDS for a more thorough evaluation of the hazards.

3. Composition/information on ingredients CAS number Name <mark>%</mark> 30 - 60 9003-36-5 bisphenol F-epoxy resin 12001-26-2 13 - 30 mica Bisphenol A epoxy resin glycidylether of C12-C14 alcohols 25068-38-6 13 - 30 68609-97-2 3-7 titanium dioxide 13463-67-7 3-7 Carbon black 1333-86-4 0.1 - 1

6/6/2012.

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ARALDITE® 2013 A			
4. First aid m	4 . First aid measures		
Eye contact	: Check for and remove any contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.		
Skin contact	In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.		
Inhalation	Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.		
Ingestion	: Wash out mouth with water. Do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention immediately.		
Notes to physician	No specific treatment. Treat symptomatically. Call medical doctor or poison control center immediately if large quantities have been ingested.		

5. Fire-fighting measures

Flash point Hazardous thermal decomposition products	 Closed cup: >200°C (>392°F) [DIN 51758 EN 22719 (Pensky-Martens Closed Cup)] Decomposition products may include the following materials: carbon dioxide carbon monoxide sulfur oxides halogenated compounds metal oxide/oxides
Extinguishing media	
Suitable	: Use an extinguishing agent suitable for the surrounding fire.
Not suitable	: None known.
Special exposure hazards	Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Fire water contaminated with this material must be contained and prevented from being discharged to any waterway, sewer or drain.
Special protective equipment for fire-fighters	 Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

6. Accidental release measures

Personal precautions	:	No action shall be taken involving any personal risk or Evacuate surrounding areas. Keep unnecessary and entering. Do not touch or walk through spilled materi. Provide adequate ventilation. Wear appropriate respi inadequate. Put on appropriate personal protective e	r without suitable training. unprotected personnel from al. Avoid breathing vapor or mist. irator when ventilation is quipment (see Section 8).
Environmental precautions	:	Avoid dispersal of spilled material and runoff and con and sewers. Inform the relevant authorities if the pro- pollution (sewers, waterways, soil or air). Water pollu- the environment if released in large quantities.	tact with soil, waterways, drains duct has caused environmental ting material. May be harmful to
Methods for cleaning up	:	Stop leak if without risk. Move containers from spill a upwind. Prevent entry into sewers, water courses, ba spillages into an effluent treatment plant or proceed a spillage with non-combustible, absorbent material e.g diatomaceous earth and place in container for dispos (see section 13). Dispose of via a licensed waste dis absorbent material may pose the same hazard as the	rea. Approach release from isements or confined areas. Wash is follows. Contain and collect). sand, earth, vermiculite or al according to local regulations posal contractor. Contaminated is pilled product. Note: see section
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Accidental release measures

1 for emergency contact information and section 13 for waste disposal.

7. Handling and storage

Handling

Put on appropriate personal protective equipment (see Section 8). Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. Persons with a history of skin sensitization problems should not be employed in any process in which this product is used. Do not get in eyes or on skin or clothing. Do not ingest. Avoid breathing vapor or mist. Avoid release to the environment. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Keep in the original container or an approved alternative made from a compatible material, kept tightly closed when not in use. Empty containers retain product residue and can be hazardous. Do not reuse container.

Storage : Store between the following temperatures: 2 to 40°C (35.6 to 104°F). Store in accordance with local regulations. Store in original container protected from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see section 10) and food and drink. Keep container tightly closed and sealed until ready for use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage. Do not store in unlabeled containers. Use appropriate containment to avoid environmental contamination.

8. Exposure controls/personal protection

Ingredient	Exposure limits
mica	ACGIH TLV (United States, 2/2010). TWA: 3 mg/m ³ 8 hour(s). Form: Respirable fraction OSHA PEL Z3 (United States, 9/2005). TWA: 20 mppcf 8 hour(s).
titanium dioxide	ACGIH TLV (United States, 2/2010). TWA: 10 mg/m ³ 8 hour(s). OSHA PEL (United States, 6/2010). TWA: 15 mg/m ³ 8 hour(s).
Carbon black	ACGIH TLV (United States, 2/2010). TWA: 3 mg/m ³ 8 hour(s). Form: Inhalable fraction OSHA PEL (United States, 6/2010). TWA: 3.5 mg/m ³ 8 hour(s).
Recommended monitoring procedures	If this product contains ingredients with exposure limits, personal, workplace atmosphere or biological monitoring may be required to determine the effectiveness of the ventilation or other control measures and/or the necessity to use respiratory protective equipment.
Engineering measures	 Use only with adequate ventilation. If user operations generate dust, fumes, gas, vapor or mist, use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits.
Hygiene measures	Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Contaminated work clothing should not be allowed out of the workplace. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.
Personal protection	
Respiratory	: In case of inadequate ventilation wear respiratory protection. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.
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ARALDITE® 2013 A							
8. Exposure controls/personal protection							
Hands	 Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. >8 hours (breakthrough time): butyl rubber, Ethyl Vinyl Alcohol Laminate (EVAL) 						
Eyes	Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.						
Skin	Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.						
Environmental exposure controls	Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.						

9. Physical and chemical properties

General Information	
Appearance	
Physical state	: Liquid. [Paste.]
Color	: Gray.
Odor	: Slight
Important health, safety and	environmental information
pH	: 6 [Conc. (% w/w): 50%]
Boiling/condensation point	: >200°C (>392°F)
Melting/freezing point	: Not available.
Flash point	: Closed cup: >200°C (>392°F) [DIN 51758 EN 22719 (Pensky-Martens Closed Cup)]
Flammable limits	: Not available.
Auto-ignition temperature	: Not available.
Decomposition	: >200°C (>392°F)
temperature	
Vapor pressure	: <0.0001 kPa (<0.00075 mm Hg) [20°C]
Specific gravity	: Not available.
Water solubility	: practically insoluble
Partition coefficient: n-	: Not available.
octanol/water (log Kow)	
Viscosity	: Dynamic: 380000 to 720000 mPa·s (380000 to 720000 cP)
Density	: 1.4 g/cm ³ [25°C (77°F)]
Vapor density	: Not available.
Evaporation rate (butyl acetate = 1)	: Not available.
VOC	: Not available.

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ARALDITE® 2013 A 10 . Stability and reactivity

Chemical stability	: The product is stable.
	Under normal conditions of storage and use, hazardous reactions will not occur.
Hazardous polymerization	: Under normal conditions of storage and use, hazardous polymerization will not occur.
Conditions to avoid	: No specific data.
Hazardous decomposition products	: Under normal conditions of storage and use, hazardous decomposition products shou not be produced.
44	

11. Toxicological information

Potential acute health effects										
Inhalation	: Irri	itating to	respiratory system	L						
Ingestion	; Ha	armful if :	swallowed.							
Skin	: Irri	itating to skin. May cause sensitization by skin contact.								
Eyes	: Irri	itating to eyes.								
Acute toxicity										
Product/ingredient name			Result	Species	Dos	e	Exposure			
titanium dioxide			LD50 Oral	Rat	>100	00 mg/kg	-			
			Dusts and mists	Rat - Male	>0.8	2 mg/L	4 nours			
glycidylether of C12-C14 alcol	nols		LD50 Oral	Rat - Male	30.1	ml/kg	-			
.,			LC0 Inhalation	Rat	>0.1	5 mg/L	7 hours			
			Vapor							
Bisphenol A epoxy resin			LD50 Dermal	Rat - Male, Female	>200	0 mg/kg	-			
			LD50 Oral	Rat - Female	>200	0 mg/kg	-			
			LC0 Inhalation Vapor	Rat - Male	0.00	001 ppm	5 hours			
bisphenol F-epoxy resin			LD50 Dermal	Rat - Male, Female	>200	0 mg/kg	-			
			LD50 Oral	Rat - Male, Female	>500	0 mg/kg	-			
Chronic toxicity										
Product/ingredient name			Result	Species	Dos	e	Exposure			
titanium dioxide			Chronic NOAEL Oral	Rat	3500) mg/kg/d	- '			
			Chronic NOEC Inhalation Dusts and mists	Rat - Male, Female	10 m	ıg/m3	2 years; 5 days per week			
glycidylether of C12-C14 alcol	nols		Sub-chronic NOEL : Dermal	Rat - Male, Female	1 mg	/kg/d	13 weeks; 5 days per week			
Bisphenol A epoxy resin			Sub-chronic NOAEL Oral	Rat - Male, Female	50 m	ig/kg	14 weeks; 7 days per week			
			Sub-chronic NOEL : Dermal	Rat - Male, Female	10 m	ig/kg	13 weeks; 5 days per week			
			Sub-chronic NOAEL Dermal	Mouse - Male	100 (mg/kg	13 weeks; 3 days per week			
bisphenol F-epoxy resin			Sub-chronic NOAEL Oral	Rat - Male, Female	250 (mg/kg	13 weeks; 7 days per week			
Irritation/Corrosion										
Product/ingredient name			Result	Species	Score	Exposure	Observation			
6/6/2012.			000728	356		Fitterr an Manufi www.fitterransa.opt	Bala Laliec By atoring & Gilspip Co. Scott 2014214511 FREEMAM			

ARALDITE® 2013 A Toxicological information 11. titanium dioxide Eyes - Non-irritant. Rabbit Skin - Non-irritant. Rabbit Bisphenol A epoxy resin Skin - Mild irritant Rabbit Eyes - Mild irritant Rabbit bisphenol F-epoxy resin Eyes - Non-irritant. Rabbit Skin - Mild irritant Rabbit Skin : bisphenol F-epoxy resin: Slightly irritating to the skin. Reaction product: bisphenol A-(epichlorhydrin); epoxy resin (number average molecular weight < 700): Slightly irritating to the skin. titanium dioxide: Non-irritating to the skin. barium sulphate, natural: Non-irritating to the skin. Eyes bisphenol F-epoxy resin: Non-irritating to the eyes. Reaction product: bisphenol A-(epichlorhydrin); epoxy resin (number average molecular weight < 700): Slightly irritating to the eyes. titanium dioxide: Non-irritating to the eyes barium sulphate, natural: Non-irritating to the eyes. Respiratory : barium sulphate, natural: Irritating to respiratory system. Sensitizer Product/ingredient name Route of Species Result exposure titanium dioxide skin Guinea pig Not sensitizing glycidylether of C12-C14 alcohols skin Guinea pig Sensitizing Bisphenol A epoxy resin skin Mouse Sensitizing bisphenol F-epoxy resin Sensitizing skin Mouse Carcinogenicity Species Rat - Male, Dose Product/ingredient name Result Exposure Negative - Oral -15 mg/kg 2 years; 7 days Bisphenol A epoxy resin NOAFL Female per week Negative Rat - Female 1 mg/kg 2 years; 5 days Dermal - NOEL : per week Negative -Mouse - Male 0.1 mg/kg 2 years; 3 days Dermal - NOEL : per week Carcinogenic class Product/ingredient name ACGIH IARC EPA NIOSH NTP OSHA titanium dioxide A4 A3 2B None. Carbon black 2B + Mutagenicity Product/ingredient name Test Experiment Result Unknown guidelines titanium dioxide Experiment: In vivo Negative Subject: Mammalian-Animal glycidylether of C12-C14 alcohols OECD 476 In vitro Experiment In vitro Negative Mammalian Cell Gene Subject: Mammalian-Mutation Test Animal Metabolic activation: +/-Negative OECD 474 Mammalian Experiment: In vivo Erythrocyte Micronucleus Subject: Mammalian-Test Animal Cell: Somatic Metabolic activation: +/-Bisphenol A epoxy resin OECD 471 Bacterial Experiment: In vitro Positive Reverse Mutation Test Subject: Bacteria Metabolic activation: +/-OECD 476 In vitro Experiment: In vitro Positive Mammalian Cell Gene Subject: Mammalian-00072856 6/6/2012. Freeman Manufacturing & Supply Co. www.freemunauoply.com 500-821-8511

ARALDITE® 2013 A								
11. Toxicological infor	mation							
	Mutati	on Test		Animal Cell: Som Metabolic	atic activation: +/-			
	OECD Toxico Domin	OECD 478 Genetic Toxicology: Rodent Dominant Lethal Test			Experiment: In vivo Subject: Mammalian- Animal Cell: Germ		Negative	
	EPA C	PPTS		Experimer Subject: N Animal Cell: Som	nt In vivo Iammalian- atic	Negativ	ne -	
bisphenol F-epoxy resin	OECD Reven	471 Bacter se Mutation	ial Test	Experimer Subject: B Metabolic	nt: In vitro acteria activation: +/-	Positive	•	
	OECD Mamm Mutatio	476 <i>In vitro</i> nalian Cell G on Test) Jene	Experiment: In vitro Subject: Mammalian- Animal Cell: Somatic		Positive		
	OECD Mamm Chrom Test	OECD 473 <i>In vitro</i> Mammalian Chromosomal Aberration Test OECD 474 Mammalian Erythrocyte Micronucleus Test			Experiment: In vitro Subject: Mammalian- Human Cell: Somatic Metabolic activation: +/- Experiment: In vivo Subject: Mammalian- Animal Cell: Somatic		Positive Negative	
	OECD Erythro Test							
	OECD DNA S Test w Liver (486 Unsch Synthesis (U ith Mammal	eduled DS) lian	Experimer Subject: N Animal Cell: Som	nt In vivo Iammalian- atic	Negativ	e	
Conclusion/Summary : titaniu	um dioxide: No	ot mutageni	c in a st	andard bat	tery of genetic	toxicolog	gical tests.	
Teratogenicity					_	_		
Product/ingredient name	Result		Speci	es	Dose		xposure	
glycidylether of C12-C14 alcohols	Negati Derma	ve -	Rat - F	emale	200 mg/kg N :	IOEL 1	0 days	
Bisphenol A epoxy resin	Negati	ve - Oral	Rat - F	emale	>540 mg/kg NOEL :	1	0 days	
	Negati Derma	ve - I	Rabbit	- Female	>300 mg/kg NOEL :	1 P	3 days; 6 hours er day	
Kasharad F arananaia	Negati	ve - Oral	Rabbit	- Female	180 mg/kg NOAEL	1	3 days	
bisphenol F-epoxy resin	Derma	ve - I	Rabbi	- Female	>300 mg/kg NOEL :	P	3 days; 6 hours er day	
Conclusion/Summary : titaniu	um dioxide: No	o known sig	nificant	effects or c	ritical hazards.			
Reproductive toxicity								
Product/ingredient name	Maternal toxicity	Fertility	Deve toxir	elopment 1	Species	Dose	Exposure	
Bisphenol A epoxy resin	Negative	Negative	Neg	ative	Rat - Male, Female	Oral: 54 mg/kg NOEL :	40 238 days; 7 days per week	
bisphenol F-epoxy resin	Negative	Negative	Neg	ative	Rat - Male, Female	Oral: 54 mg/kg NOEL :	40 238 days; 7 days per week	
6/6/2012.		000728	56		Freeman www.doc.com	1 Manufactur Instructiy con	Unit Catles: By ng & Sitephy Co. 903-821-8511 FREEMAY	

11. Toxicological information

Conclusion/Summary		: titanium dioxide: No known significant effects or critical hazards.					
Potential chronic health effects							
Chronic effects	-	Once sensitized, a severe allergic reaction may occur when subsequently exposed to very low levels.					
Target organs	÷	No known significant effects or critical hazards.					
Carcinogenicity	2	No known significant effects or critical hazards.					
Mutagenicity	2	No known significant effects or critical hazards.					
Teratogenicity	2	No known significant effects or critical hazards.					
Fertility effects	2	No known significant effects or critical hazards.					
Developmental effects	1	No known significant effects or critical hazards.					
Medical conditions aggravated by over-							
Pre-existing skin disorders may be aggravated by over-exposure to this product.							

12. Ecological information

Environmental effects	: Toxic to environr released	aquatic organisms, nent. Water pollutin d in large quantities.	may cause long-ter ng material. May be	m adverse effects harmful to the env	in the aquatic ironment if
Aquatic ecotoxicity					
Product/ingredient name bisphenol F-epoxy resin		Test OECD 201 Alga, Growth Inhibition Test	Result Acute EC50 1.8 mg/L Fresh water	Species Algae	Exposure 72 hours Static
		OECD OECD 202: Part I (Daphnia sp., Acute Immobilisation test)	Acute EC50 1.6 mg/L Fresh water	Daphnia	48 hours Static
		-	Acute IC50 >100 mg/L Fresh water	Bacteria	3 hours Static
		OECD 203 Fish, Acute Toxicity Test	Acute LC50 0.55 mg/L Fresh water	Fish	96 hours Semi- static
		OECD 211 Daphnia Magna Reproduction Test	Chronic NOEC 0.3 mg/L Fresh water	Daphnia	21 days Semi- static
Bisphenol A epoxy resin		-	Acute EC50 9.4 mg/L Fresh water	Algae	72 hours Static
		OECD 202 Daphnia sp. Acute Immobilisation Test	Acute EC50 1.7 mg/L Fresh water	Daphnia	48 hours Static
		-	Acute IC50 >100 mg/L Fresh water	Bacteria	3 hours Static
		OECD 203 Fish, Acute Toxicity Test	Acute LC50 1.5 mg/L Fresh water	Fish	96 hours Static
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ARALDITE® 2013 A				
12. Ecological informa	tion			
	OECD 211 Daphnia Magna Reproduction Test	Chronic NOEC 0.3 mg/L Fresh water	Daphnia	21 days Semi- static
glycidylether of C12-C14 alcohols	OECD 202 <i>Daphnia</i> sp. Acute Immobilisation Test	Acute EL50 7.2 mg/L Fresh water	Daphnia	48 hours Static
	OECD 201 Alga, Growth Inhibition Test	Acute IC50 843.75 mg/L Fresh water	Algae - Selenastrum capricornutum (Pseudokirchneriella subcapitata)	72 hours Static
	OECD 209 Activated Sludge, Respiration Inhibition Test	Acute IC50 >100 mg/L	Bacteria	3 hours
	OECD 203 Fish, Acute Toxicity Test	Acute LC50 5000 mg/L Fresh water	Fish - Rainbow trout (Oncorhynchus mykiss, Salmo gairdneri)	96 hours Static
Biodegradability				
Product/ingredient name	Test	Result	Dose	Inoculum
bisphenol F-epoxy resin	EU	0 % - Not readily - 28 days	3 mg/L Oxygen consumption	Activated sludge
Bisphenol A epoxy resin	OECD Derived from OECD 301F (Biodegradation Test)	5 % - Not readily - 28 days	20 mg/L Oxygen consumption	-
glycidylether of C12-C14 alcohols	OECD 301F Ready Biodegradability - Manometric Respirometry Test	87 % - Readily - 28 days	100 mg/L	-
Other ecological information				
Biological Oxygen Demand : No (BOD 5 DAY)	t Determined			
Chemical Oxygen Demand : No (COD)	t Determined			
Product/ingredient name bisphenol F-epoxy resin	Aquatic half-life	Photolysis -	Biode Not re	<u>gradability</u> adily
Bisphenol A epoxy resin	Fresh water 4.83 days Fresh water 3.58 days Fresh water 7.1 days	-	Not re	adily
glycidylether of C12-C14 alcohols Bioaccumulative potential	-	-	Readil	У
Product/ingredient name	LogPew	BCF	Pote	ential
bisphenol F-epoxy resin	2.7 to 3.6	-	high	
alvoidvlether of C12-C14 alcohols	3.242	-	iow	
Other adverse effects : No I	nown significant effects o	or critical hazards.		
PBT : Not	applicable.			
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12. Ecological information

Other information

13. Disposal considerations

Waste disposal

The generation of waste should be avoided or minimized wherever possible. Significant quantities of waste product residues should not be disposed of via the foul sewer but processed in a suitable effluent treatment plant. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Care should be taken when handling emptied containers that have not been cleaned or rinsed out. Empty containers or liners may retain some product residues. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

Disposal should be in accordance with applicable regional, national and local laws and regulations.

14. Transport information

Proper shipping name

- DOT : Priving the standard sta
- RESIN). Marine pollutant
 IMDG : Privironmentally hazardous substance, liquid, n.o.s. (BISPHENOL F EPOXY RESIN, BISPHENOL A EPOXY
- RESIN), Marine pollutant
- IATA : Environmentally hazardous substance, liquid, n.o.s. (BISPHENOL F EPOXY RESIN, BISPHENOL A EPOXY RESIN)



ARALD	NTE® 2013 A						
14.	Transport info	ormation					
	MDG Class	UN3082	9		 ₩	Emergency schedules (EmS) F-A, S-F	
	ATA-DGR Class	UN3082	9			Passenger and Cargo Aircraft Quantity limitation: 450 L Packaging instructions: 964 Cargo Aircraft Only Quantity limitation: 450 L Packaging instructions: 964	
	PG* : Packing group	1		•	1		
15.	Regulatory in	formatio	n				
U.S. Fe	deral regulations						
HCS (Classification	: Irritating m	aterial				
U.S. F	ederal regulations	: United Sta	material Ites inventory (1	SCA	b): All compor	nents are listed or exempt	ed.
TSCA new u	5(a)2 final significant ise rule (SNUR)	: None.			,		
TSCA	5(e) substance	: None.					
TSCA	12(b) one-time t notification:	: None.					
TSCA notific	12(b) annual export ation	: None.					
SARA extrem subst	302/304/311/312 nely hazardous ances	: SARA 302	/304/311/312 ext	remely	/ hazardous s	ubstances: No Ingredien	t Listed
SARA identi	311/312 hazard fication	SARA 311/ Immediate	/312 MSDS distr (acute) health ha	ibutio azard;	n - chemical i	nventory - hazard identi	fication:
Clean - Vola Comp	Air Act Section 111 tile Organic ounds (VOC)	Not availabl	e.				
Clean 112(b) Pollut	Air Act Section) Hazardous Air ants (HAPs)	: Product na No Ingredie	ents Listed.		CAS number	Concentration	
Clean Deple (ODS)	Air Act - Ozone ting Substances	: This produc	t does not contai	in nor i	s it manufactur	red with ozone depleting s	ubstances.
SARA	313	No ingredie	nts listed.				
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15. Regulatory information

CERCLA: Hazardous substances: No ingredients listed.

STATE REGULATIONS:		
PENNSYLVANIA - RTK:	The following components are listed: TITANIUM OXIDE (TIO2); CARBON BLACK; BARIUM SULFATE	
California Prop 65 :		
	This product contains no listed substances known to the State of California to cause cancer, birth defects or other reproductive harm, at levels which would require a warning under the statute.	
Canada		
WHMIS (Canada)	 Class D-2A: Material causing other toxic effects (Very toxic). Class D-2B: Material causing other toxic effects (Toxic). 	
CEPA DSL	: All components are listed or exempted.	
This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations.		

International lists	: Australia inventory (AICS): All components are listed or exempted.
	China inventory (IECSC): At least one component is not listed.
	Japan inventory: All components are listed or exempted.
	Korea inventory: At least one component is not listed.
	New Zealand Inventory of Chemicals (NZIoC): All components are listed or exempted.
	Philippines inventory (PICCS): At least one component is not listed.

16. Other information		
Label requirements	: CAUSES RESPIRATORY TRACT, EYE AND SKIN IRRITATION. MAY CAUSE ALLERGIC SKIN REACTION. MAY BE HARMFUL IF SWALLOWED.	
Hazardous Material Information System (U.S.A.)	: Health 2 Flammability 1 Physical hazards 0 Personal protection	
The customer is responsible for determining the PPE code for this material.		
National Fire Protection Association (U.S.A.)	: Health 2 0 Instability Special	

6/6/2012.

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ARALDITE® 2013 A

16. Other information

 Date of printing
 : 6/6/2012.

 Date of issue
 : 6/6/2012.

 Date of previous issue
 : 6/6/2012.

 Version
 : 2

Indicates information that has changed from previously issued version.

Notice to reader

While the information and recommendations in this publication are to the best of our knowledge, information and belief accurate at the date of publication, NOTHING HEREIN IS TO BE CONSTRUED AS A WARRANTY, EXPRESS OR OTHERWISE.

IN ALL CASES, IT IS THE RESPONSIBILITY OF THE USER TO DETERMINE THE APPLICABILITY OF SUCH INFORMATION AND RECOMMENDATIONS AND THE SUITABILITY OF ANY PRODUCT FOR ITS OWN PARTICULAR PURPOSE.

THE PRODUCT MAY PRESENT HAZARDS AND SHOULD BE USED WITH CAUTION. WHILE CERTAIN HAZARDS ARE DESCRIBED IN THIS PUBLICATION, NO GUARANTEE IS MADE THAT THESE ARE THE ONLY HAZARDS THAT EXIST.

Hazards, toxicity and behaviour of the products may differ when used with other materials and are dependent upon the manufacturing circumstances or other processes. Such hazards, toxicity and behaviour should be determined by the user and made known to handlers, processors and end users.

NO PERSON OR ORGANIZATION EXCEPT A DULY AUTHORIZED HUNTSMAN EMPLOYEE IS AUTHORIZED TO PROVIDE OR MAKE AVAILABLE DATA SHEETS FOR HUNTSMAN PRODUCTS. DATA SHEETS FROM UNAUTHORIZED SOURCES MAY CONTAIN INFORMATION THAT IS NO LONGER CURRENT OR ACCURATE. NO PART OF THIS DATA SHEET MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM, OR BY ANY MEANS, WITHOUT PERMISSION IN WRITING FROM HUNTSMAN. ALL REQUESTS FOR PERMISSION TO REPRODUCE MATERIAL FROM THIS DATA SHEET SHOULD BE DIRECTED TO HUNTSMAN, MANAGER, PRODUCT SAFETY AT THE ABOVE ADDRESS.

6/6/2012.



Material Safety Data Sheet



ARALDITE® 2013 B US

1. Product and company identification						
Material uses	ARALDITE® 2013 B US : Hardener for adhesive systems					
MSDS #	: 00071589					
Validation date	: 1/20/2012.					
Print date	: 1/20/2012.					
Supplier/Manufacturer	: Huntsman Advanced Materials Americas LLC P.O. Box 4980 The Woodlands, TX 77387					
	Non-Emergency phone: (800) 257-5547					
	E-Mail: MSDS@huntsman.com					

In case of emergency

: Chemtrec: (800) 424-9300 or (703) 527-3887

2. Hazards identification

Physical state	: Liquid. [Paste.]
Odor	: Amine-like.
Color	: Beige.
OSHA/HCS status	: This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).
Emergency overview	: DANGER!
	MAY BE FATAL IF INHALED. CAUSES EYE AND SKIN IRRITATION. MAY CAUSE ALLERGIC SKIN REACTION. MAY BE HARMFUL IF ABSORBED THROUGH SKIN. CONTAINS MATERIAL THAT MAY CAUSE TARGET ORGAN DAMAGE, BASED ON ANIMAL DATA.
	Do not breathe vapor or mist. Do not get in eyes or on skin or clothing. Use only with adequate ventilation. Keep container tightly closed and sealed until ready for use. Wash thoroughly after handling.
See toxicological information	(Section 11)

GENERAL INFORMATION : Read the entire MSDS for a more thorough evaluation of the hazards.

3. Composition/information on ingredients CAS number 111-40-0 <mark>%</mark> 3-7 Name diethylenetriamine 80-05-7 4,4'-isopropylidenediphenol 3-7 triethylenetetramine 112-24-3 3-7 Silica. 7631-86-9 1-3 Silicon Dioxide, Amphorous, Furned 112945-52-5 1-3

1/20/2012.



ARALDITE® 2013 B US						
4 . First aid measures						
Eye contact	: Check for and remove any contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.					
Skin contact	In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.					
Inhalation	Call medical doctor or poison control center immediately. Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.					
Ingestion	: Wash out mouth with water. Do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention immediately.					
Notes to physician	 No specific treatment. Treat symptomatically. Call medical doctor or poison control center immediately if large guantities have been ingested. 					

5. Fire-fighting measures

Flash point Hazardous thermal decomposition products	Open cup: 124°C (255.2°F) [DIN 51584 (Marcusson open cup)] Decomposition products may include the following materials: carbon dioxide carbon monoxide nitrogen oxides metal oxide/oxides
Extinguishing media	
Suitable	: Use an extinguishing agent suitable for the surrounding fire.
Not suitable	: None known.
Special exposure hazards	: Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training.
Special protective equipment for fire-fighters	: Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

6. Accidental release measures

Personal precautions	:	No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Do not touch or walk through spilled material. Do not breathe vapor or mist. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment (see Section 8).
Environmental precautions	:	Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).
Methods for cleaning up	:	Stop leak if without risk. Move containers from spill area. Approach release from upwind. Prevent entry into sewers, water courses, basements or confined areas. Wash spillages into an effluent treatment plant or proceed as follows. Contain and collect spillage with non-combustible, absorbent material e.g. sand, earth, vermiculite or diatomaceous earth and place in container for disposal according to local regulations (see section 13). Dispose of via a licensed waste disposal contractor. Contaminated absorbent material may pose the same hazard as the spilled product. Note: see section 1 for emergency contact information and section 13 for waste disposal.

1/20/2012.



Handling and storage

Handling : Put on appropriate personal protective equipment (see Section 8). Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. Persons with a history of skin sensitization problems should not be employed in any process in which this product is used. Do not get in eyes or on skin or clothing. Do not breathe vapor or mist. Do not ingest. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Keep in the original container or an approved alternative made from a compatible material, kept tightly closed when not in use. Keep away from acids. Empty containers retain product residue and can be hazardous. Do not reuse container. Store between the following temperatures: 2 to 40°C (35.6 to 104°F). Store in Storage ÷ accordance with local regulations. Store in original container protected from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see section 10) and food and drink. Separate from acids. Keep container tightly closed and

appropriate containment to avoid environmental contamination.

sealed until ready for use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage. Do not store in unlabeled containers. Use

8. Exposure controls/personal protection							
Ingredient		Exposure limits					
diethylenetriamine		ACGIH TLV (United States, 2/2010). Absorbed through skin. TWA: 1 ppm 8 hour(s). TWA: 4.2 mg/m ³ 8 hour(s).					
Recommended monitoring procedures	: If this product of or biological mo or other control	If this product contains ingredients with exposure limits, personal, workplace atmosphere or biological monitoring may be required to determine the effectiveness of the ventilation or other control measures and/or the necessity to use respiratory protective equipment.					
Engineering measures	: Use only with a other engineeri recommended	adequate ventilation. Use process enclosures, local exhaust ventilation or ing controls to keep worker exposure to airborne contaminants below any or statutory limits.					
Hygiene measures	 Wash hands, for eating, smoking techniques sho work clothing si before reusing, workstation loc 	Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Contaminated work clothing should not be allowed out of the workplace. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.					
Personal protection							
Respiratory	: In case of inade be based on kn safe working lin	equate ventilation wear respiratory protection. Respirator selection must nown or anticipated exposure levels, the hazards of the product and the mits of the selected respirator.					
Hands	: Chemical-resis worn at all time necessary. >8 (EVAL)	stant, impervious gloves complying with an approved standard should be es when handling chemical products if a risk assessment indicates this is hours (breakthrough time): butyl rubber, Ethyl Vinyl Alcohol Laminate					
Eyes	 Safety eyewear assessment ind dusts. 	r complying with an approved standard should be used when a risk dicates this is necessary to avoid exposure to liquid splashes, mists or					
Skin	 Personal protect performed and this product. 	ctive equipment for the body should be selected based on the task being the risks involved and should be approved by a specialist before handling					
Environmental exposure controls	: Emissions from comply with the fume scrubbers necessary to re	n ventilation or work process equipment should be checked to ensure they e requirements of environmental protection legislation. In some cases, s, filters or engineering modifications to the process equipment will be educe emissions to acceptable levels.					
1/20/2012.		00071589 Etterran Man./acouring & Guephy Co. www.ficemunauryshy.com 100-321-3511 FREEM					

9. Physical and	chemical properties
General information	
Appearance	
Physical state	: Liquid. [Paste.]
Color	: Beige.
Odor	: Amine-like.
Important health, safety and	environmental information
pH	: 12
Boiling/condensation point	: Not available.
Melting/freezing point	: Not available.
Flash point	: Open cup: 124°C (255.2°F) [DIN 51584 (Marcusson open cup)]
Flammable limits	: Not available.
Auto-ignition temperature	: Not available.
Decomposition	: >200°C (>392°F)
temperature	
Vapor pressure	: 0.004 kPa (0.03 mm Hg) [20°C]
Specific gravity	: Not available.
Water solubility	: practically insoluble
Partition coefficient: n-	: Not available.
octanol/water (log Kow)	
Density	: 0.9 g/cm ³ [25°C (77°F)]
Vapor density	: Not available.
Evaporation rate (butyl	: Not available.
acetate = 1)	
VOC	: Not available.

10 . Stability and reactivity

Chemical stability	: The product is stable. Under normal conditions of storage and use, hazardous reactions will not occur.
Hazardous polymerization	: Under normal conditions of storage and use, hazardous polymerization will not occur.
Conditions to avoid	: No specific data.
Hazardous decomposition	 Under normal conditions of storage and use, hazardous decomposition products should
products	not be produced.

11. Toxicological information

Potential acute health effects						
Inhalation	ery toxic by inhalation.					
Ingestion	: No known significant effects or critical hazards.					
Skin	: Harmful in contact with skin. Irritating to skin. May cause sensitization by skin contact.					
Eyes	everely irritating to eyes. Risk of serious damage to eyes.					
Acute toxicity						
Product/ingredient name	Result Species Dose Exposure					
-						

1/20/2012.



ARALDITE® 2013 B US						
11. Toxicological inform	nation					
diethvlenetriamine	LD50 Derm	nal	Rabbit	1090	ma/ka	-
,	LD50 Oral		Rat	1500	to 2000	-
				mg/k	9	
	LC50 Inhal	ation	Rat - Male,	0.07	to 0.3 mg/L	4 hours
	Dusts and	mists	Female			
4,4'-isopropylidenediphenol	LD50 Derm	nal	Rabbit	>200	0 mg/kg	-
	LD50 Oral		Rat	>200	0 mg/kg	-
triethylenetetramine	LD50 Dem	nal	Rabbit - Male,	1465	mg/kg	-
	LD50 Oral		Female Rat Male	1718	malka	
	LUGU Oral		Female	1710	mgrkg	-
Chronic toxicity						
Des des dés adaptes des set a serve	Denut		e			E
Product/ingredient name	Result		species	Dose	•	Exposure
diethylenetriamine	Sub-chroni	c	Rat - Male,	70 to	80 mg/kg/d	13 weeks; 7 days
	NOEL : Ora	al	Female			per week
	Chronic NC	DAEL	Rat - Male,	114 n	ng/kg/d	400 days
	Dermal	NOFO	Female	FEO -		4E days
	Sub-acute	/anor	Rat - Male, Female	000 1	ng/m3	10 days
4 4'-isopropylidenediphenol	Sub-chroni	c	Dog - Male	75 m	a/ka	aveb 7 sveb 00
4,4 isopropylidenedipiterior	NOAEL Or	al	Female	75 11	8,48	per week
	Sub-chroni	c	Rat - Male.	10 m	a/m3	13 weeks: 6
	NOEC Inha	alation	Female		-	hours per day
	Dusts and	mists				
triethylenetetramine	Sub-chronic		Rat - Male, 50		g/kg/d	26 weeks
	NOAEL Or	al	Female			
Irritation/Corrosion						
Product/ingredient name	Result		Species	Score	Exposure	Observation
4,4'-isopropylidenediphenol	Eyes - Sev irritant	ere	Rabbit	-	-	-
	Skin - Mild	irritant	Rabbit	-	-	-
triethylenetetramine	Skin - Com	osive	Rabbit	-	-	-
Skin : 4,4'-iso	propylidenedip	henol:	Slightly irritating	to the ski	in.	
triethyle	enetetramine: (Corrosiv	ve to the skin.			
Eyes : 4,4'-iso	propylidenedip	henol:	Severely irritatin	g to eyes		
sensitizer	_					
Product/ingredient name	Route of		Species	Resu	lt	
diethylenetriamine	skin		Guinea nig	Sens	itizina	
triethylenetetramine	skin		Guinea pig	Sens	itizing	
Carcinogenicity						
Product/ingredient name	Result		Species	Dose		Exposure
diethylenetriamine	Negative -		Mouse - Male	56.3	mg/kg	3 days per week
	Dermal - N	OEL :			3.0	
4,4'-isopropylidenediphenol	Negative -	Oral -	Rat - Male, Female	-		103 weeks; 7 days per week
Careinogenio elars	HOALL		. critare			aays per week
Cardinogenic class						
Product/ingredient name	ACGIH	IARC	EPA	NIOS	1 NTP	OSHA
Silicon Diovide Amphorous Europed	-	3	-	-	-	-
Mutagenicity	-	-	-	-	-	-
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1/20/2012.	,	100710	08		Ector an Manufi Sow fra concerning upply	Unin Laite: By DATT scoring & Susply Co. scori - 500-821-8511 FREEMA

ARALDITE® 2013 B US									
11 Toxicologica	al	information							
		Test			-		Denut		
diethylenetriamine		-			Experiment: In vitro Subject: Mammalian- Animal Metabolic activation: +/-		Result Negative		
		-			Experimen Subject: ba Metabolic a	t: In vitro acteria/yeast activation: +/-	Negative		
		-			Experimen Subject: In Cell: Germ	t In vivo sect	Negative		
		-			Experimen Subject: M Animal Cell: Soma	t: In vivo ammalian- itic	Negative		
4,4'-isopropylidenediphenol	I	-			Experimen Subject: ba Metabolic a	Experiment: In vitro Subject: bacteria/yeast Metabolic activation: +/-		Negative	
		OECD Erythro Test	474 Mamr ocyte Micro	nalian nucleus	Experimen Subject: M Animal	t In vivo ammalian-	Negative		
triethylenetetramine		-			Experiment: In vitro Subject: Bacteria Metabolic activation: +/-		Positive		
		-			Experimen Subject: M Animal Cell: Soma	t In vivo ammalian- tic	Negative		
Teratogenicity									
Product/ingredient name		Result		Speci	es	Dose	Exp	posure	
4,4'-isopropylidenediphenol	I	Negati	ve - Oral	Rat - F	Female	640 mg/kg NOAEL	-		
Reproductive toxicity									
Product/ingredient name		Maternal toxicity	Fertility	Deve toxir	elopment n	Species	Dose	Exposure	
4,4'-isopropylidenediphenol	I	-	-	-		Rat - Male, Female	Oral: 5 mg/kg NOAEL	7 days per week	
Potential chronic health e	ffe	ats.							
Chronic effects	:	Contains material the Once sensitized, a s to very low levels.	at may cau evere aller;	se targe gic react	t organ dam ion may occ	age, based o our when subs	n animal da equently e	ata. xposed	
Target organs	:	Contains material wh lungs, liver.	nich may ca	ause dar	nage to the	following orga	ins: kidney	5,	
Carcinogenicity	5	No known significant	effects or	critical h	azards.				
Mutagenicity	2	No known significant	effects or	critical h	azards.				
Teratogenicity	2	No known significant	effects or	critical h	lazards.				
Pertility effects	÷	No known significani	effects or	critical h	azards.				
Medical conditions areas		no known significani	enects of	critical fi	azarus.				
exposure		ed by over-							

1/20/2012.



11. Toxicological information

Pre-existing skin disorders and disorders involving any other target organs mentioned in this MSDS as being at risk may be aggravated by over-exposure to this product.

12. Ecological information

Environmental effects : No known significant effects or critical hazards.

Aquatic ecotoxicity				
Product/ingredient name diethylenetriamine	Test -	Result Acute EC50 17	<mark>Species</mark> Daphnia	Exposure 48 hours
	-	Acute LC50 332	Fish	96 hours
	-	Chronic NOEC 5.6 mg/L Fresh water	Daphnia	21 days Semi- static
4,4'-isopropylidenediphenol	-	Acute EC50 3.9 to 10.2 mg/L	Daphnia	48 hours
	-	Acute EC50 2.5	Algae - Green	96 hours
	-	Acute LC50 7.5 mg/L	Fish - Rainbow trout (Oncorhynchus mykiss, Salmo gairdneri)	96 hours
riethylenetetramine	-	Acute EC50 800 mg/L Fresh water	Bacteria	30 minutes Static
	-	Acute EC50 31.1 mg/L Fresh water	Daphnia	48 hours Static
	OECD 201 Alga, Growth Inhibition Test	Acute ErC50 (growth rate) 20 mg/L Fresh water	Algae	72 hours Semi- static
	-	Acute LC50 330 mg/L Fresh water	Fish	96 hours Static
	OECD OECD 202: Part II (Daphnia sp., Reproduction Test	Chronic EC50 10 mg/L Fresh water	Daphnia	21 days Semi- static
Biodegradability				
Product/ingredient name	Test	Result	Dose	Inoculum
liethylenetriamine	-	<80 % - Not readily - 28 days	-	-
4'-isopropylidenediphenol	-	1 to 2 % - Not readily - 28 days	-	-
riethylenetetramine	OECD 302A Inherent Biodegradability: Modified SCAS Test	20 % - 84 days	DOC	Activated sludge
	OECD 301D Ready Biodegradability - Closed Bottle Test	0 % - Not readily - 28 days	Oxygen consumption	Activated sludge
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Freeman Manufacturing & Snephy Co.

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12. Ecological information

_			
Other ecological information Biological Oxygen Deman (BOD 5 DAY)	d : Not Determined		
Chemical Oxygen Demand (COD)	: Not Determined		
Product/ingredient name diethylenetriamine 4,4'-isopropylidenediphenol triethylenetetramine Bioaccumulative potential	Aquatic half-life - - -	Photolysis - - -	Biodegradability Not readily Not readily Not readily
Product/ingredient name diethylenetriamine triethylenetetramine	LogPex -1.3 -1.4 to 2.9	BCF - 99	Potential low low
Other adverse effects PBT	: No known significant effect: : Not applicable.	s or critical hazards.	
Uther information			

13. Disposal considerations

Waste disposal

: The generation of waste should be avoided or minimized wherever possible. Significant quantities of waste product residues should not be disposed of via the foul sewer but processed in a suitable effluent treatment plant. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Care should be taken when handling emptied containers that have not been cleaned or rinsed out. Empty containers or liners may retain some product residues. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

Disposal should be in accordance with applicable regional, national and local laws and regulations.

14. Transport information

Proper shipping name

- DOT : Not regulated.
- : Not regulated. TDG
- IMDG : Not regulated.
- IATA : Not regulated.

Regulatory information	UN number	Classes	PG*	Label	Additional information	1
DOT Classification	Not regulated.	-	-		-	
TDG Classification	Not regulated.	-	-		-	
MDG Class	Not regulated.	-	-		-	
ATA-DGR Class	Not regulated.	-	-		-	
		0007	1589			-

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14. Transport information

PG* : Packing group

15. Regulatory i	nfo	ormation			
U.S. Federal regulations					
HCS Classification	:	Highly toxic material Irritating material Sensitizing material Target organ effects			
U.S. Federal regulations		United States inventory (TSC/	A 8b): All compone	ents are listed or	exempted.
TSCA 5(a)2 final significat new use rule (SNUR)	nt :	None.			
TSCA 5(e) substance consent order	-	None.			
TSCA 12(b) one-time export notification:	-	None.			
TSCA 12(b) annual export notification	: :	None.			
SARA 302/304/311/312 extremely hazardous substances	:	SARA 302/304/311/312 extrem	ely hazardous su	ıbstances: No Ir	ngredient Listed
SARA 311/312 hazard identification	-	SARA 311/312 MSDS distribut Immediate (acute) health hazard	ion - chemical in 1, Delayed (chroni	ventory - hazaro c) health hazard	d identification:
Clean Air Act Section 111 - Volatile Organic Compounds (VOC)	ſ				
Clean Air Act Section 112(b) Hazardous Air Pollutants (HAPs)	:	Product name No Ingredients Listed.	<u>CAS number</u>	<u>Concentra</u>	<u>ition</u>
Clean Air Act - Ozone Depleting Substances (ODS)	:	This product does not contain no	r is it manufacture	ed with azone de	pleting substances.
SARA 313		Product name		CAS number	Concentration
Form R - Reporting requirements	÷	4,4'-isopropylidenediphenol		80-05-7	3-7
CERCLA: Hazardous subs STATE REGULATIONS:	stan	No ingredients listed.			
PENNSYLVANIA - RTK:	The ISO SILI	following components are listed: PROPYLIDENEDIPHENOL; 1,2-E CA	1,2-ETHANEDIAN	nne, n-(2-amin , n,n'-bis(2-ami	OETHYL)-: 4,4'- NOETHYL)-:
California Prop 65 :					
Canada					
WHMIS (Canada)	:	Class D-1A: Material causing im Class D-2A: Material causing oth Class D-2B: Material causing oth	mediate and serio ner toxic effects (V ner toxic effects (T	us toxic effects (/ery toxic). [°] oxic).	Very toxic).
CEPA DSL	-	All components are listed or exe	mpted.		
1/20/2012.		0007158	Ð	Erterran Mai www.ficemanau	Binin Anties: By n. fatouring & Siliphy Co. galy.com 900-821-8511 PREEMAN

15. Regulatory information

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations.

International lists	: Australia inventory (AICS): All components are listed or exempted.
	China inventory (IECSC): All components are listed or exempted.
	Japan inventory: All components are listed or exempted.
	Korea inventory: All components are listed or exempted.
	New Zealand Inventory of Chemicals (NZIoC): At least one component is not listed.
	Philippines inventory (PICCS): At least one component is not listed.

16. Other information

abel requirements	: MAY BE FATAL IF INHALED. CAUSES EYE AND SKIN IRRITATION. MAY CAUSE ALLERGIC SKIN REACTION. MAY BE HARMFUL IF ABSORBED THROUGH SKIN. CONTAINS MATERIAL THAT MAY CAUSE TARGET ORGAN DAMAGE, BASED ON ANIMAL DATA.
Hazardous Material nformation System (U.S.A.)	: Health 3



The customer is responsible for determining the PPE code for this material.



✓ Indicates information that has changed from previously issued version.

Notice to reader

While the information and recommendations in this publication are to the best of our knowledge, information and belief accurate at the date of publication, NOTHING HEREIN IS TO BE CONSTRUED AS A WARRANTY, EXPRESS OR OTHERWISE.

IN ALL CASES, IT IS THE RESPONSIBILITY OF THE USER TO DETERMINE THE APPLICABILITY OF SUCH INFORMATION AND RECOMMENDATIONS AND THE SUITABILITY OF ANY PRODUCT FOR ITS OWN PARTICULAR PURPOSE.

THE PRODUCT MAY PRESENT HAZARDS AND SHOULD BE USED WITH CAUTION. WHILE CERTAIN HAZARDS ARE DESCRIBED IN THIS PUBLICATION, NO GUARANTEE IS MADE THAT THESE ARE THE ONLY HAZARDS THAT

1/20/2012.

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16. Other information

EXIST.

Hazards, toxicity and behaviour of the products may differ when used with other materials and are dependent upon the manufacturing circumstances or other processes. Such hazards, toxicity and behaviour should be determined by the user and made known to handlers, processors and end users.

NO PERSON OR ORGANIZATION EXCEPT A DULY AUTHORIZED HUNTSMAN EMPLOYEE IS AUTHORIZED TO PROVIDE OR MAKE AVAILABLE DATA SHEETS FOR HUNTSMAN PRODUCTS. DATA SHEETS FROM UNAUTHORIZED SOURCES MAY CONTAIN INFORMATION THAT IS NO LONGER CURRENT OR ACCURATE. NO PART OF THIS DATA SHEET MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM, OR BY ANY MEANS, WITHOUT PERMISSION IN WRITING FROM HUNTSMAN. ALL REQUESTS FOR PERMISSION TO REPRODUCE MATERIAL FROM THIS DATA SHEET SHOULD BE DIRECTED TO HUNTSMAN, MANAGER, PRODUCT SAFETY AT THE ABOVE ADDRESS.

1/20/2012.





PP Polypropylene Honeycomb



Description:

PP polypropylene honeycomb exhibits a unique cell structure. The core has 3 orientations vs. the 2 orientations common with other honeycomb, making its properties more uniform. Each cell has a tubular form and is inherently stable.

PP polypropylene honeycomb is supplied with or without a non-woven polyester veil for better bonding. It is also supplied with or without a film barrier under the polyester veil to limit the amount of resin consumption.

Applications:

PP polypropylene honeycomb uses include sandwich panel cores, energy absorption and filtration media.

Features:

Availability:

PP polypropylene standard dimensi	e honeycomb is avai ions.	lable in the following
Densities:	3.5 to 20.0 pcf	
Thickness:	14" to 6" Laminat	ed; up to 24" open cell
Sheet Length:	Up to 50°	
Sheet Width:	72° max.	
Tolerances:	Length:	±.125*
	Width:	±.125
	Thickness:	±.02"
	Open Cell:	±.03"
	w/minforced PP facings	±.03"
	Density:	± 10%

- Sound and vibration dampening
 Energy absorbing
- Thermoformable
- Temperature use to 180°F

 High strength to weight ratio
 Corrosion, fungi, rot, chemical and moisture resistant

Recyclable

PP polypropylene honeycomb is specified as follows:

Material - Cell Size - Color - Thickness



PP Honeycomb Core Mechanical Properties																								
0511 8175		DENSITY		FLATWISE		BARE COMPRESSION ²								PLATE SHEAR ^a										
CORE		ULL	L				11.1	DILL	-	STRE	NGTH			MOD	ULUS			STAL	NGTH		-	MOD	OLUS	
	(in)	(mm)	DOT N	kala ²	INT ²	kala ²	a ini	MPa	111	MPa	-	MPa	kai l	MPa	kai kai	MPa		MPa	-	MPa	kai l	MPa	in the state	MPa
PP1-5.0-N1-8	0.315	8	5	80.0	4.75	75.0	130	0.89	275	1.89	255	1.55	11.5	79.2	9.5	65.4	85	0.58	75	0.52	2.2	15.2	1.7	11.7
PP1-4.0-N1-10	0.395	10	4	64.0	3.8	60.0	120	0.83	180	1.24	140	0.96	10.5	72.3	8.5	58.5	60	0.41	55	0.38	2.0	13.8	1.5	10.3
The data provided in based on the testing of -07 (real and of vertices of each care type).																								



Plascore, Inc., employs a quality management system that is AS/EN/JISO 9100, ISO 9001:2008 and ISO 14001:2004 certified.

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MATERIAL SAFETY DATA SHEET West System Inc.

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME:
PRODUCT CODE:
CHEMICAL FAMILY:
CHEMICAL NAME:
FORMULA:

..WEST SYSTEM[®] 105 Epoxy Resin ...105 ...Epoxy Resin. ...Bisphenol A based epoxy resin.

Not applicable.

MANUFACTURER: West System Inc. 102 Patiesson Ave. Bay City, MI 48706, U.S.A. Phone: 866-937-8797 or 969-684-7286 www.westystem.com 800-424-9300 (U.S.) 703-527-3887 (International)

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

WARNING May cause skin initation. May cause eye initation. May cause allergic reaction. Clear, viscous liquid with mild odor.

PRIMARY ROUTE(S) OF ENTRY:..... Skin contact.

POTENTIAL HEALTH EFFECTS:

EYE CONTACT:	. May cause initati	on.
INGESTION:	. Low acute oral to	xicity.

3. COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

INGREDIENT NAME	CAS #	CONCENTRATION (%)
Propane, 2,2-bis[p-(2,3-epoxypropoxy)phenyl]-, polymens	25085-99-8	60-100
Benzyl alcohol	100-51-6	10-30
Phenol-formaldehyde polymer glycidyl ether	28064-14-4	1-10

4. FIRST AID MEASURES

FIRST AID FOR EYES......Flush Immediately with water for at least 15 minutes. Consult a physician.

FIRST AID FOR INHALATION...... Remove to fresh air if effects occur.

MSDS #105-13a

<i>a</i> .	TINE FIGHTING MEASURES	
	FLASH POINT:	>200*F (Tag Closed Cup)
	EXTINGUISHING MEDIA:	Foam, carbon dioxide (CO ₂), dry chemical.
	SPECIAL FIRE FIGHTING PROCEDURES: prolective equipment. Closed containers may rupture (due to buildu	Wear a self-contained breathing apparatus and complete full-body perso p of pressure) when exposed to extreme heat.
	FIRE AND EXPLOSION HAZARDS: combustion products of varying composition which may be toxic and phenolics, carbon monoxide, carbon dioxide.	During a fire, smoke may contain the original materials in addition to lor initiating. Combustion products may include, but are not limited to:
6.	ACCIDENTAL RELEASE MEASURES	
	SPILL OR LEAK PROCEDURES: sand) and collect in a suitable, closed container. Warm, soapy wate	Stop leak without additional risk. Dike and absorb with inert material (e.g r or non-flammable, safe solvent may be used to clean residual.
7.	HANDLING AND STORAGE	
	STORAGE TEMPERATURE (minJmax.):	40°F (4°C) / 120°F (49°C)
	STORAGE: moisture absorption and loss of volatiles. Excessive heat over long	Store in cool, dry place. Store in tightly sealed containers to prevent periods of time will degrade the resin.
	HANDLING PRECAUTIONS: Launder confaminated clothing before reuse. Avoid inhaiation of va product in large quantities. When mixed with epoxy curing agents thi heat to damage or ignite surrounding materials and emit furnes and	Avoid proionged or repeated skin contact. Wash thoroughly after handli pors from heated product. Precautionary steps should be taken when curin is product causes an exothermic, which in large masses, can produce enou vapors that vary widely in composition and toxicity.
8.	EXPOSURE CONTROLS/PERSONAL PROTECTION	
	EYE PROTECTION GUIDELINES:	Safety glasses with side shields or chemical splash goggles. Wear liquid-proof, chemical resistant gloves (nitrile-butyl rubber, neoprer
	butyl rubber or natural rubber) and full body-covering clothing.	
	RESPIRATORY/VENTILATION GUIDELINES: NIOSHIMSHA approved respirator with an organic vapor cartridge w	Good room ventilation is usually adequate for most operations. Wear a menever exposure to vapor in concentrations above applicable limits is like
	Note: West System, inc. has conducted an air sampling study using components sampled for (epichiorohydrin, benzyl alcohol) were ethor OSHA's permissible exposure levels.	this product or similarly formulated products. The results indicate that the er so low that they were not detected at all or they were significantly below
	ADDITIONAL PROTECTIVE MEASURES: contact. Avoid skin contact when removing gioves and other protect clearly and following basic precautionary measures will greatly minil conditions.	Practice good caution and personal cleanliness to avoid skin and eye we equipment. Wash thoroughly after handling. Generally speaking, workin mize the potential for harmful exposure to this product under normal use
	OCCUPATIONAL EXPOSURE LIMITS: Exposure Level (PEL) or the ACGIH Guidelines for information on sp	Not established for product as whole. Refer to OSHA's Permissible pecific ingredients.
Э.	PHYSICAL AND CHEMICAL PROPERTIES	
	PHYSICAL FORM:	Liquid.
	COLOR:	Cléar.
	BOILING POINT:	> 400°F
	MELTING POINT/FREEZE POINT:	No data.
	VISCOSITY:	1000 (CP)
	SOLUBILITY IN WATER:	
	SPECIFIC GRAVITY:	
	BULK DENSITY:	9.6 (poundsigation)
	VAPOR PRESSURE:	< 1 mmHg @ 20°C.
	VAPOR DENSITY:	Heavier than air. ASTM D 2350.07 whe wood to determine the Visibilia Comfact of mixed
	WOLANLE OT WEIGHT.	No Twice 2009-07 Was used to determine the volatile Content of mixed
	eboxy resin and nardener. Refer to the nardener's MSUS for Inform	auon accul me icla, volaue content of me resilvina dener system.

Page 2 of 4

STABILITY:

West System Inc.

.....Stable.

MSDS #105-13a

Last Revised: 26APR13

WEST SYSTEM® 105 Resin

			-
Wast	 -	0.000	l no
WV CSI	× 5 I	em	
		_	_

INCOMPATIBILITIES: Strong acids, bases, amines and mercaptans can cause polymerization.

DECOMPOSITION PRODUCTS:.. ... Carbon monoxide, carbon dioxide and phenolics may be produced during uncontrolled exothermic reactions or when otherwise heated to decomposition.

11. TOXICOLOGICAL INFORMATION

No specific oral, inhalation or dermal toxicology data is known for this product. Specific toxicology information for a bisphenol-A based epoxy resin present in this product is indicated below:

...LD₅₀ >5000 mg/kg (rats) ...No Data. ...LD₅₀ = 20,000 mg/kg (skin absorption in rabbits) Oral: Inhalation:... Dermal:....

cts or other adverse exposed orally.

REPRODUCTIVE EFFECTS:....DGEBPA, in animal studies, has been shown not to interfere with reproduction.

MUTAGENICITY:DGEBPA in animal mutagenicity studies were negative. In vitro mutagenicity tests were negative in some cases and positive in others.

CARCINOGENICITY:

NTP	Product	not	listed.
IARC	Product	not	listed.
OSHA	Product	not	listed

No ingredient of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA, NTP or IARC

Many studies have been conducted to assess the potential carcinogenicity of diglycidyl ether of bisphenol-A. Although some weak evidence of carcinogenicity has been reported in animals, when all of the data are considered, the weight of evidence does not show that DGEBPA is carcinogenic. Indeed, the most recent review of the available data by the International Agency for Research on Cancer (IARC) has concluded that DGEBPA is not disastiled as a carcinogen.

Epichiorohydrin, an impurity in this product (<5 ppm) has been reported to produce cancer in laboratory animals and to produce mutagenic changes in bacteria and cultured human cells. It has been established by the International Agency for Research on Cancer (IARC) as a probable human carcinogen (Group 2A) based on the following conclusions: human evidence – inadequate; animal evidence – sufficient. It has been classified as an anticipated human carcinogen by the National Toxicology Program (NTP). Note: It is unlikely that normal use of this product would result in measurable exposure concentrations to this substance.

12. ECOLOGICAL INFORMATION

In the non-cured liquid form this product may cause long-term harm if released to the environment. Prevent entry into severs and natural waters

Movement and Partitioning: Bioconcentration potential is moderate (BCF between 100 and 3000 or Log Kow between 3 and 5).

Degradation and Transformation:

Theoretical oxygen demand is calculated to be 2.35 p/p. 20-day blochemical oxygen demand is <2.5%.

Ecotoxicology:

Material is moderately toxic to aquatic organisms on an acute basis. LCS0/ECS0 between 1 and 10 mg/L in most sensitive speci

13. DISPOSAL CONSIDERATIONS

methods.

incinerale, recycle (fuel blending) or reclaim may be preferred methods when conducted in accordance with federal, state and local regulations.

14. TRANSPORTATION INFORMATION

DOT Non-Bulk SHIPPING NAME:

Not regulated. Not applicable. TECHNICAL SHIPPING NAME: ...

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st System Inc.	Page 4 of 4	WEST SYSTEM® 105 Resi
	Not pollophi	
UNINA NUMPER	Not applicable	E.
PACKING CROUP	Not applicable	e. a
Phone and a court	Not approace	Ε.
IMDG		
SHIPPING NAME:	Environmenta	ally hazardous substance, liquid, n.o.s.
TECHNICAL SHIPPING NAME:	Epoxy Resin.	
HAZARD CLASS:		
U.N. NUMBER:		
PACKING GROUP:	PG III.	
Ems Number:	F-A, S-F	
MARINE POLLUTANT		
ICAOIATA		
SHIPPING NAME	Environmenta	ally hazardous substance, liquid, n.o.s.
TECHNICAL SHIPPING NAME:	Epoxy Resin.	
HAZARD CLASS:	Class 9.	
U.N. NUMBER:	UN3082	
PACKING GROUP:	PG III.	
MARINE POLLUTANT:	Yes	
REGULATORY INFORMATION		
OSHA STATUS:	Intant.	
TSCA STATUS:	All componer	ts are listed on TSCA inventory or otherwise comply with
TSCA requirements.		
Canada WHMIS Classification:	D2B - Toyle r	naterial equicing other tryle offerts
CEPA Chemical Inventory Status:	All componer	ts are listed or are otherwise compliant with CEPA
requirements		to are noted of the other mode outpital to the other to
requiremente.		
SARA TITLE III:		
SECTION 313 TOXIC CHEMIC	ALS None (demini	imus).
STATE RECULATORY INFORMATI	ON:	
The following chemicals are enorther	iv listed or otherwise regulated by individual st	ates. For details on your regulatory requirements you sho
contact the appropriate agency in yo	in state.	and, i or detaile on your requirementerite you and
COMPONENT NAME		
CAS NUMBER	CONCENTRATION	STATE CODE
Epichiorohydrin	_	1
106-89-8	< 5ppm	'CA
Benzyl alcohol		

16. OTHER INFORMATION

This information is furnished without warranty, expressed or implied, except that it is accurate to the best knowledge of West System inc. The data on this sheet is related only to the specific material designated herein. West System inc. assumes no legal responsibility for use or reliance upon these data.

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MATERIAL SAFETY DATA SHEET West System Inc.

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: PRODUCT CODE: CHEMICAL FAMILY: CHEMICAL NAME: FORMULA: .WEST SYSTEM[®] 205 Fast Hardener .205 .Amine. .Modified aliphatic polyamine. .Not apolicable.

MANUFACTURER: West System Inc. 102 Patienson Ave. Bay City, MI 48706, U.S.A. Phone: 866-937-8797 or 989-684-7286 www.westystem.com . e dalphatic polyamine. plicable. EMERGENCY TELEPHONE NUMBER5:

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

DANGER Causes burns to eyes and skin. Harmful if swallowed. Harmful if absorbed through the skin. May be harmful if inhaied. May cause allergic reaction. Amber colored liquid with ammonia odor.

PRIMARY ROUTE(S) OF ENTRY: Skin contact, eye contact, inhaiation.

POTENTIAL HEALTH EFFECTS:

ACUTE INHALATION:...... May cause respiratory tract irritation. Coughing and chest pain may result.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: Chronic respiratory disease, asthma. Eye disease. Skin disorders and allergies.

3. COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

INGREDIENT NAME	<u>CAS #</u>	CONCENTRATION (%)	
Reaction products of triethyinetetramine with phenol/formaldehyde	32610-77-8	40-70	
Polyethylenepolyamines	68131-73-7	10-30	
Triethylenetetramine	112-24-3	5-20	
Hydroxyberzene	108-95-2	1-10	
Reaction products of triethylenetetramine and propylene oxide	26950-63-0	1-10	
Tetraethylenepentamine	112-57-2	1-10	

4. FIRST AID MEASURES

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FIRST AID FOR INHALATION: Move to fresh air and consult pi FIRST AID FOR INHALATION: Give considues person at least vomiting. If vomiting should occur spontaneously, keep airway clear. Get medical attention. FIRE FIGHTING MEASURES FLASH POINT: >270°F (PMCC) EXTINGUISHING MEDIA: Dry chemical, alcohol foam, car powder. FIRE AND EXPLOSION HAZARDS: During a fire, smoke may conta contustion products of varying composition which may be toxic andrior initiating. Combustion produc oxides of nitrogen, carbon monoxide, carbon doxide, volatile amines, ammonia, nitric add, nitrosamir chips, or other cellulosic malerial, spontaneous combustion can occur under certain conditions. Heal if the heat is not dissipated quickly enough, it can ignite the sawdust. SPECIAL FIRE FIGHTING PROCEDURES: Use full-body protective gear ar Use of water may generate toxic aqueous solutions. Do not allow water nun-off from fighting fire to en user of water may generate toxic aqueous solutions. Do not allow water nun-off from fighting fire to en the on-combustion applit. Vertilate area. Large spill - dike and pump into appropriate conta use hert, non-combustion applit, as the possibility for spontaneous combustion exists. Wash sp necessary.	hysician if effects occur. 2 glasses of water. Do not induce ton dioxide (CO ₂), dry sand, limestone in the original materials in addition to ts may include, but are not limited to: ts. When mixed with sawdust, wood is generated as the air oxidizes the amind a self-contained breathing apparatus. ther drains or other water courses. . Wear proper personal protective iner for recovery. Small spill - recover or to not use sawdust, wood chips or other
FIRST AID FOR INHALATION: Move to fresh air and consult pi FIRST AID FOR INGESTION: Give conscious person at least vonting. If vonting should occur spontaneously, keep airway clear. Get medical attention. FIRE FIGHTING MEASURES FLASH POINT: >270°F (PMCC) EXTINGUISHING MEDIA: Dry chemical, alcohol foam, car powder. FIRE AND EXPLOSION HAZARDS: During a fire, smoke may conta combustion products of varying composition which may be toxic and/or inflating. Combustion product oddes or inflorgen, carbon doude, voiatile amines, annonia, nitre axid, nitrosami chips, or other cellulosic material, spontaneous combustion can occur under certain conditions. Heat if the heat is not dissipated quickly enough, it can ignite the sawdust. SPECIAL FIRE FIGHTING PROCEDURES: Use full-body protective gear ar Use of water may generate toxic aqueous solutions. Do not allow water run-off from fighting fire to encluse and contain split. Ventilate area. Large split – dike and purp into appropriate container. D cellulosic material is to absorb the split, as the possibility for spontaneous combustion exists. Wash sp necessary.	hysician if effects occur. 2 glasses of water. Do not induce toon dioxide (CO ₂), dry sand, limestone in the original materials in addition to is may include, but are not limited to: thes. When mixed with sawdust, wood is generated as the air oxidizes the ami and a self-contained breathing apparatus. ther drains or other water courses. . Wear proper personal protective inner for recovery. Small spill - recover or o not use sawdust, wood chips or other
FIRST AID FOR INGESTION:	2 glasses of water. Do not induce toon dioxide (CO ₂), dry sand, limestone in the original materials in addition to is may include, but are not limited to may include, but are not limited to is generated as the air oxidizes the ami of a self-contained breathing apparatus. ther drains or other water courses. . Wear proper personal protective iner for recovery. Small spill - recover or to not use sandust, wood chips or other
FIRE FIGHTING MEASURES FLASH POINT:	ton dioxide (CO ₂), dry sand, limestone in the original materials in addition to ts may include, but are not limited to: nes. When mixed with sawdust, wood is generated as the air oxidizes the ami nd a self-contained breathing apparatus. ter drains or other water courses.
FLASH POINT: ->270°F (PMCC) EXTINGUISHING MEDIA: Dry chemical, alcohol foam. car powder. FIRE AND EXPLOSION HAZARDS: During a fire, smoke may conta combustion products of varying composition which may be toxic and/or inflating. Combustion products of varying composition which may be toxic and/or inflating. Combustion products of varying composition which may be toxic and/or inflating. Combustion products of varying composition which may be toxic and/or inflating. Combustion products of varying composition which may be toxic and/or inflating. Combustion products of other cellulosic material, spontaneous combustion an occur under certain conditions. Heat if the heat is not dissipated quickly enough, it can ignite the sawdust. SPECIAL FIRE FIGHTING PROCEDURES: Use of water may generale toxic aqueous solutions. Do not allow waler run-off from fighting fire to enditional discontext of the and purpolition appropriate contaus use left, non-combustion applit. Vertilate area. Large spill - dike and purpolitio appropriate contaus use left, non-combustion absorb the spill, as the possibility for spontaneous combustion exists. Wash spinecessary.	ton dioxide (CO ₂), dry sand, limestone in the original materials in addition to is may include, but are not limited to nes. When mixed with sawdust, wood is generated as the air oxidizes the ami of a self-contained breathing apparatus. ther drains or other water courses.
EXTINGUISHING MEDIA:	toon dioxide (CO ₂), dry sand, limestone in the original materials in addition to is may include, but are not limited to: nes. When mixed with sawdust, wood is generated as the air oxidizes the ami nd a self-contained breathing apparatus. iter drains or other water courses.
FIRE AND EXPLOSION HAZARDS:	in the original materials in addition to ts may include, but are not limited to: tes. When mixed with sawdust, wood is generated as the air oxidizes the amind a self-contained breathing apparatus. ther drains or other water courses.
SPECIAL FIRE FIGHTING PROCEDURES:	nd a self-contained breathing apparatus. ter drains or other water courses. . Wear proper personal protective iner for recovery. Small spill - recover of o not use savdust, wood chips or other
ACCIDENTAL RELEASE MEASURES SPILL OR LEAK PROCEDURES:	. Wear proper personal protective iner for recovery. Small spill - recover o o not use sawdust, wood chips or other
SPILL OR LEAK PROCEDURES:Stop leak without additional risk equipment. Dike and contain spill. Ventilate area. Large spill - dike and pump into appropriate conta use inert, non-combustible absorbent material (e.g., sand, clay) and shovel into suitable container. D cellulosic materials to absorb the spill, as the possibility for spontaneous combustion exists. Wash sp necessary.	. Wear proper personal protective iner for recovery. Small spill - recover o o not use sawdust, wood chips or other
	oll residue with warm, soapy water if
. HANDLING AND STORAGE	
STORAGE TEMPERATURE (min./max.):	
STORAGE:	om high temperatures and moisture. Ke
HANDLING PRECAUTIONS:	Do not breath vapors or mists from heat ng. When mixed with epoxy resin this or ignite surrounding materiais and emit
EXPOSURE CONTROLS/PERSONAL PROTECTION	
EYE PROTECTION GUIDELINES: Chemical splash-proof goggles	or face shield.
SKIN PROTECTION GUIDELINES:	istant gioves (nitrile-butyi rubber, neopre
RESPIRATORY/VENTILATION GUIDELINES:	local exhaust ventilation to meet exposi ridge.
Note: West System, Inc. has conducted an air sampling study using this product or similarly formulal components sampled for (phenol, formaldehyde and amines) were either so low that they were not de OSHA's permissible exposure levels.	ed products. The results indicate that the decided at all or they were well below
ADDITIONAL PROTECTIVE MEASURES:	ccess to safety shower and emergency Generally speaking, working cleanly and product under normal use conditions.
OCCUPATIONAL EXPOSURE LIMITS:	whole. Refer to OSHA's Permissible
. PHYSICAL AND CHEMICAL PROPERTIES	
PHYSICAL FORM	
COLOR	
BOILING POINT	
MELTING POINT/FREEZE POINT ADDroximately 23*F	
pHAlkaline.	

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	_			

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WEST 5	ystem mc.	1 450 5 01 4	WEST STOLEN	200 Hardener
801		Antonna		
RDF	CIEIC CRAVITY	1.05		
BUI	K DENSITY	8.85 nounds/nation		
VAD	OR DRESSIRE	< 1 mmHa @ 2010		
VAP	OR DENSITY	Heavier than air		
VIE	CONTRACTOR	1 000 cDc		
96.10	OLATILE BY WEICHT	ASTM 2360-07 was us	A altrainty ant animately of has	latter Content of
mba	ed epoxy resin and hardener. 105 Resin a blned VOC content for 105/205 is 7.91 g/l	and 205 Hardener, mixed together at 5:1 by we L (0.07 lbs/gal).	ight, has a density of 1137 g/L	. (9.49 lbs/gal). The
10. STA	BILITY AND REACTIVITY			
STA	BILITY:	Stable.		
HAZ	ARDOUS POLYMERIZATION:	Will not occur.		
INC	OMPATIBILITIES:	Avoid excessive heat	Avoid acids, oxidizing materi	ais halogenated
orga	nic compounds (e.g., methylene chloride) na reaction were to take place in a waste	External heating or self-heating could result drum, the drum could expand and rupture viole	in rapid temperature increase antly.	and serious hazard. 1
DEC deca nitro	COMPOSITION PRODUCTS: Imposition. Decomposition products may samines.		gases when burned or otherwi , volatlie amines, ammonia, ni	se heated to tric acid, aldehydes,
11 TOX				
11. 104	COLOGICAL INFORMATION			
NO S	specific oral, inhalation or dermal toxicolog	y data is known for this product.		
Oral	•	Expected to be moderately toxic.		
Inha	lation:	Expected to be moderately toxic.		
Dem	nal:	Expected to be moderately toxic.		
Ads	orption of phenolic solutions through the s , pancreas and spieer; and cause edema	kin may be very rapid and can cause death. L of the lungs. Chronic exposures can cause d	esser exposures can cause d eath from liver and kidney dan	amage to the kidney, nage.
CAR	CINOGENICITY:			
	NTP	NO.		
	IARC	NO.		
	OSHA	No.		
	No ingredient of this product present at is NTP or IARC.	evels greater than or equal to 0.1% is identified	1 as a carcinogen or potential	carcinogen by OSHA,
12. ECC	LOGICAL INFORMATION			
In th of w	e non-cured, liquid form, this product may aler.	be harmful if released to the environment. Do	o not allow into sewers, on the	ground or in any body
13. DIS	POSAL CONSIDERATIONS			
WA: haza met	STE DISPOSAL METHOD: ardous waste, either by listing or character nods.	Evaluation of this prod tistics, in its purchased form. It is the responsi	uct using RCRA criteria show bility of the user to determine (s that it is not a proper disposal
Incir	nerate, recycle (fuel blending) or reclaim m	nay be preferred methods when conducted in a	ccordance with federal, state	and local regulations.
14. TRA	NSPORTATION INFORMATION			
DOT	Non-Bulk			
SHI	PPING NAME:	Polyamines, liquid, co	Tosive, n.o.s.	
TEC	HNICAL SHIPPING NAME	Triethvienetetramine		
HAZ	ARD CLASS:	Class 8		
U.N	/N.A. NUMBER:	UN 2735		
PAC	KING GROUP:	PG III		
MAF	INE POLLUTANT:	No		

ICAOIIATA	
SHIPPING NAME:	Polyamines, liquid, corrosive, n.o.s.
TECHNICAL SHIPPING NAME:	Triethylenetetramine
HAZARD CLASS:	Class 8
U.N. NUMBER:	UN 2735
PACKING GROUP:	PGIII

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we	est System Inc.	Page	4 of 4	WEST SYSTEM [®] 205 Hardener
	MARINE POLLUTANT:		No	
	IMDG		-	
	SHIPPING NAME:		Polyamines, Ilqu	d, corrosive, n.o.s.
	HAZARD OLASS-		Theurytenetetan	ine .
	IN NUMBER		LIN 2735	
	PACKING GROUP		DC III	
	EmS Number:		F-A.S-B	
	MARINE POLLUTANT		NO	
5.	REGULATORY INFORMATION			
	OSHA STATUS:		Corrosive; possil	bie sensitizer.
	TSCA STATUS:		All components I	isted on TSCA Inventory or otherwise comply with TSC
	requirements.			
	Canada WHMIS Classification		D2A Verv toxic	material causing other toxic effects: E – Corrosive
	CEPA Chemical Inventory Status:		All components a	are listed or are otherwise compliant with CEPA
	requirements.			•
	SECTION 313 TOXIC CHEMIC	ALS:	. This product con	tains hydroxybenzene (phenol) and is subject to the
	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE RESULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo	ALS: on 313 of Title III of the Superfu ION: ally listed or otherwise regulated ur state.	This product con nd Amendments a by Individual state	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. 6. For details on your regulatory requirements you sh
	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo COMPONENT NAME	:ALS: on 313 of Title III of the Superfu ION: ally listed or otherwise regulated ur state.	This product con nd Amendments a by Individual state	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. 66. For details on your regulatory requirements you sh
	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo COMPONENT NAME ICAS NUMBER	ALS: on 313 of Title III of the Superfu ION: ally listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. is. For details on your regulatory requirements you sh <u>STATE CODE</u>
	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specifica contact the appropriate agency in yo COMPONENT NAME /CAS NUMBER Tetraethylenepentamine 112-67-2	ALS: on 313 of Title III of the Superfu ION: ally listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. sc. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA
	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo COMPONENT NAME /CAS NUMBER Tetraethylenepertamine 112-57-2 Tetraethylenethamine	ALS: on 313 of Title III of the Superfu ION: ally listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. s. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA
	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo COMPONENT NAME (CAS NUMBER Tetraethylenepentamine 112-57-2 Tetraethylenepentamine 112-57-2 Tetraethylenethamine 112-24-3 Phenol	ALS: on 313 of Title III of the Superfu ION: ally listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. s. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA MA, NJ, PA
	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo COMPONENT NAME (CAS NUMBER Tetraethylenepertamine 112-57-2 Tetraethyleneptramine 112-57-2 Tetraethylenethamine 112-57-2	ALS: on 313 of Title III of the Superfu ION: ally listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. ss. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA MA, NJ, PA NJ, RI, PA, MA, IL
6	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo COMPONENT NAME (CAS NUMBER Tetraethytemetertamine 112-57-2 Tetraethytemetertamine 112-37-2 Tetraethytemetertamine 112-37-2 Tetraethytemetertamine 112-37-2 Phenol 108-95-2 OTHER INFORMATION	ALS: on 313 of Title III of the Superfu ION: ally listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1966 and 40 CFR Part 372. s. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA MA, NJ, PA NJ, RI, PA, MA, IL
6.	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo COMPONENT NAME (CAS NUMBER Tetraethytenepertamine 112-57-2 Tetraethytenepertamine 112-24-3 Phenol 108-95-2 OTHER INFORMATION	ALS: on 313 of Title III of the Superfu ION: ally listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. s. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA MA, NJ, PA NJ, RI, PA, MA, IL
16.	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo COMPONENT NAME /CAS NUMBER Tetraethylenepentamine 112-67-2 Tetraethylenetriamine 112-95-2 OTHER INFORMATION REASON FOR ISSUE:	ALS: on 313 of Title III of the Superfu IIV isted or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state Changes made 1	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. IS. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA MA, NJ, PA NJ, RI, PA, MA, IL n Sections 5, 10, 14 & 15.
16.	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The foliowing chemicals are specific contact the appropriate agency in yo COMPONENT NAME /CAS NUMBER Tetraethylenepertamine 112-67-2 Tetraethylenepertamine 112-67-2 Tetraethylenetramine 112-67	ALS: on 313 of Title III of the Superfu IIV listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state by Individual state changes made I G. M. House	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. ss. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA MA, NJ, PA NJ, RI, PA, MA, IL n Sections 5, 10, 14 & 15.
16.	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo COMPONENT NAME (CAS NUMBER Tetraethylenepertamine 112-57-2 Tetraethylenepertamine 112-37-3 Phenol 108-95-2 OTHER INFORMATION REASON FOR ISSUE: PREPARED BY: APPROVED BY:	:ALS: on 313 of Title III of the Superfu (<u>ON:</u> ally listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state Changes made I G. M. House G. M. House	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. s. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA MA, NJ, PA NJ, RI, PA, MA, IL n Sections 5, 10, 14 & 15.
16.	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The following chemicals are specific contact the appropriate agency in yo COMPONENT NAME /CAS NUMBER Tetraethylenetramine 112-57-2 Tetraethylenetramine 112-35-2 OTHER INFORMATION REASON FOR ISSUE: PREPARED BY: APPROVED BY:	ALS: on 313 of Title III of the Superfu ION: ally listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state 	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. IS. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA MA, NJ, PA NJ, RI, PA, MA, IL n Sections 5, 10, 14 & 15. Environmental Manager
16.	SECTION 313 TOXIC CHEMIC reporting requirements of Secti STATE REGULATORY INFORMATI The foliowing chemicals are specific contact the appropriate agency in yo COMPONENT NAME /CAS NUMBER Tetraethylenepertamine 112-67-2 Tetraethylenepertamine 112-67-2 Tetraethylenetramine 112-67	ALS: on 313 of Title III of the Superfu <u>ION:</u> ally listed or otherwise regulated ur state. <u>CONCENTRATION</u>	This product con nd Amendments a by Individual state by Individual state changes made I G. M. House Heath, Safety & Port 25, 2013	tains hydroxybenzene (phenoi) and is subject to the nd Reauthorization Act of 1986 and 40 CFR Part 372. ss. For details on your regulatory requirements you sh <u>STATE CODE</u> MA, NJ, PA MA, NJ, PA NJ, RI, PA, MA, IL n Sections 5, 10, 14 & 15. Environmental Manager
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