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COMPARISON OF THE OUTCOMES OF STUCCO REPAIR USING PRIMAL AND GLUE STICK. CASE STUDY OF STUCCO DECORATIONS OF TALAR-E ABYAZ AT GOLESTAN PALACE

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Abstract

In different historical periods, stucco decoration as an artistic symbol is seen in historical monuments and its application has longstanding antecedent. Materials used in stucco are not stable against damage caused by moisture and thus, it is necessary to apply glue for the purposes of conservation, consolidation and restoration of the stucco. The most common types of glue are glue stick and primal. The main purpose of this paper is to study the side effects of primal and glue stick on stucco. The principal research question is whether the stucco is ruined or remains stable after a while by using these kinds of glue. To answer this question and determine the concentration of these restoration materials, the laboratory methods such as electronic microscopy and elemental analysis along with aging of the samples by UV lamp have been used.

Keywords*: Conservation, Stucco, Electron microscope, Elemental analysis, Primal, Glue stick*

Introduction

Investigating human societies since the Neolithic era to the contemporary seemingly indicates that the use of gypsum goes back in history. Generally, humans recognized these two elements by making basic gypsum stone and limestone stoves. Some works discovered at Haft Tapeh in Khuzestan from the Middle Elamite era, such as elliptic bowls with spindle-like ends for cosmetics containing white pastes, which were a mixture of gypsum, lime, and kaolin, reveal the use of gypsum since many years ago [1].

As civilizations were formed, gypsum was commonly used as a building material to build shelters or plaster coating. Accordingly, after plinth, it was used in the Egyptian pyramids as the binder between stones for coiling purposes. Moreover, gypsum has been applied to arched coatings of channels as part of the buildings in Persepolis. Gypsum mortar had been frequently used for building structures' skeletons and designing facade in form of Rozas in the Sassanid era, and from ancient times to this day, has been considered among important building materials [2-4].

Gypsum is more flexible than brick and clay, enabling an artist to display his art by creating various designs on it. Variety of stucco decorations in different historical periods shows the importance of this building material which deserves to be profoundly investigated.

Golestan Palace Complex is a remaining monument from Tehran's Historical Citadel (Arg); Tehran's Historical Citadel Foundation dates back to the Safavid era during the reign of Shah Tahmasp I which was restored and renovated during Karim Khan Zand's era. The Royal

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Citadel was almost situated in the northern part of old Tehran at the time of Agha Mohammad Khan Qajar with its one end connected to the city wall and the rest three ends to the city itself. However, later, due to the development of the city and emergence of new districts and neighborhoods, the Citadel was located in the middle of the city [5, 6].

The Palace is limited to Imam Khomeini Sq. (Sepah St.) in the north, Panzdah-e-Khordad St. in the south, Naser Khosrow (Nasiriyah) St. in the east, and current Khayyam St. in the west. Panzdah-e-Khordad (former Arg) Sq. was considered as the first part of the Old Citadel. The government building and the king's place of residence, which was Golestan Palace Complex itself, was taken more than a third of the whole Citadel space. The building, which was a place for both the country’s court houses and the residence of the Qajar kings, underwent many changes during the reign of the Qajar until it turned into what it is today.

White Palace was built in an area in the southwest corner of Golestan Palace at the end of the reign of Naser al-Din Shah Qajar. The building came to be known as Abyaz (white) Palace due to its white stucco carvings on the facade executed in Europe’s XVIIIth century style as well as its stairways and plinths made of white veiny marble [7]. The palace was constructed where Kolah Farangi Mansion and Agha Mohammad Khani Tower were previously built for keeping the valuable gifts of Abdul Hamid II, the last sultan of the Ottoman Empire. Shortly after, the palace was used for administrative affairs of prime ministers and the premiers of next governments held their Cabinet meetings in its Great Hall, which was known as Abdul Hamid Hall due to the Ottoman Sultan Abdul Hamid’s gifts.

In 1954, the premier’s office was moved to a building on Pasteur Avenue and Abyaz Palace was used for fine arts, becoming a venue for holding temporary exhibitions and center for Museums and Mass Culture Directorate’s activities during the period. The first exhibition on women’s clothing was held in this museum in 1957.

Fig. 1. Images of the stucco: **a** and **b** - cracks in the Abyaz House’s column; **c** - erosion in the column; **d** and **e** - stucco falling and cracking at the base of a column.

After the establishment of the Culture and Arts Ministry which was soon moved to its new location, on the occasion of the coronation celebration of Mohammad Reza Pahlavi, repairs were conducted in 1965 and subsequently, a two-story building was annexed to the western wing of the museum and the Museum of Anthropology was transferred to this place in 1968 [5].

Museum of Anthropology is one of the oldest and richest anthropology museums nationwide. The two-story museum has different sections and the ground floor includes an administrative department and show halls. Stucco carvings are seen in columns in the exterior façade, which are included in figure 1.

The second floor hosts the attire of men and women of Qajar Era as well as the clothing of various parts of the country.

From the durability standpoint, plaster mouldings undergo erosion and are very unstable against moisture due to their intrinsic properties and therefore, are required to be maintained and restored. Selecting the type of restoration materials and the impact it can have on stucco decorations is regarded as the significance of the current research [8-11]. Therefore, in this study, it was attempted to investigate the nature of restoration methods and maintaining feasibility of primal and glue stick as the two target materials through conducting experiments and instrumental analysis.

Experimental

Materials

Plaster

Among the major properties of plaster is its affinity with water. Cooked gypsum powder is more or less soluble in water, such that an amount of gypsum powder ranging from 67 to 88 g can be solved in one liter of water. To make pure gypsum mortar, water is consumed to about 65 to 80% of gypsum weight, mostly depending on gypsum material and grains. It should be noted gypsum mortar setting time increases in greater amount of water. Theoretically, water needed for gypsum equals 20%, but in practice, 70mL per kg of water are required for common tasks.

In this action, rounded gypsum grains suck up water and once again come in the form of gypsum stone.

Of other properties of gypsum is increasing its volume, which is about 1 to 2 percent. Gypsum volume is hardened and loses its plasticity after becoming combined with water and prior to drying. This means that it forms after 16 minutes at normal temperature, and hardens after 36 minutes, and then its volume remains constant.

Mortar starts forming by the addition of gypsum powder to water. The setting time and hardening of mortar depend on a number of factors such as type of gypsum, type and degree of preparation, small size of gypsum grains, amount of consumed water, and ambient temperature. However, the use of additives such as sodium chloride (more than two percent by weight of gypsum) hydrated lime dust, clay, glue, and woodworking glue increases mortar setting time.

Kneading mortar while it is being formed delays its setting time. If this practice continues for 11 to 16 minutes, the setting time is postponed two days. The resulting material is called dead plaster which has low compressive strength and is used on the final plastered surfaces. This type of plaster can be quickly and easily formed as desired and is also very flexible even after hardening.

The hardening property of plasters can be increased in cases where it is necessary for structural purposes. For example, adding some alum or milk of lime to gypsum mortar increases its strength and therefore, reduces its hardening time [5, 10, 12].

Consumption of various amount of clay also increases setting time of gypsum mortar to various extents. The 1:1 clay to gypsum powder weight ratio increases the setting time of mortar to 10 minutes. With the use of soil, mortar setting time increases significantly. Thus, since ancient times, masons in Iran use cheap gypsum mortar with higher setting time to smooth surfaces beneath plaster layers.

The strength of hardened gypsum mortar depends on the type of gypsum, percentage of consumed water in preparing the mortar, and ambient temperature. Hardening of gypsum mortar in damp places takes to a few months. During this period, gypsum mortar strength gradually increases. It must be noted that greater amount of water used in mortar decreases its strength due to additional pores remained in hardened plaster or gypsum mortar as a result of additional water evaporation.

Gypsum mortar fills all surface pores due to its volume increase after being consumed and prior to hardening, and prevents germs and bacteria to develop in it. Moreover, plaster coating is a very good material in terms of acoustic, giving much less of an echo. Further, plaster coating has low heat transfer capability, is suitable for thermal insulation, and prevents the spread of fire. However, if becomes moisturized, whether in powder form or after hardening, produces sulfate after reacting with the combined metals. Therefore, metals must be well covered with color before plastering [13].

Other feature of gypsum is the property of staining. Pure building plaster is white. Hence, it can be stained. In addition, its outer surface can be stained and painted. Mixing paints and mortar, colored plaster mortar is obtained [14].

In general, the above factors have converted the gypsum into one of the most suitable raw materials for construction and internal decorations.

Primal

Primal is an emulsion of low concentration and an acrylic polymer, which is used for durability and stability of stucco, stony, and cement structures. Its pH varies from 9.1 to 9.9. Primal melting point, boiling point, specific gravity and maximum viscosity are, 100C°, 1-1/2, and 400cps, respectively. Primal is highly resistant against acids, alkalis, atmospheric conditions, water and salt is very resistant. Unlike herbal and animal adhesives which are the power supply of micro-organisms, primal cannot be dissolved by bacteria and fungi. Hence, it is used for conservation and restoration of monuments [11, 15].

In 1950s, acrylic dispersions gradually became common since their dried film was less yellow than that of the PVAc (polyvinyl acetate) dispersion. Acrylic dispersions are mainly being used as endothermic adhesives and liquid adhesives, including primal (AC-33, AC-634, AC-61, N-565) [16].

Primal is creamy in water; however, it is rotten over time and gets blue. After passing some time, it obtains tensile force [17].

Glue stick

The glue stick consisting of ethylene-vinyl acetate copolymer (EVA**)** and is mainly used in workshops and factories to stick arches and bolts in doors, windows and furniture. Another example is PVA-based emulsion paint, which is used for surface coating or as an adhesive.

One of the properties of polymers derived from vinyl acetate is that their glass transition temperature is at about room temperature. Therefore, despite having durability and adhesiveness, these polymers absorb dust after a while and can be solved in water, becoming creamy. When these derived polymers are dried getting transparent. Over time, these polymers sow high light resistance and don`t break down, that means don`t have cross connectivity when being exposed to air [18].

Methods

Due to the nature of the research subject, the study adopted the mixed-method research approach based on the analytical procedure.

Data collection methods included review and study of documentation records and historical documents, articles, and research carried out in the field. Field surveys also included video recording, stucco decorations sampling, laboratory analyzing using SEM-EDX, aging with UV lamps as well as natural conditions based on which conclusions are drawn [19, 20].

Preparation of the samples

Twelve samples of plaster moldings were prepared and soaked with different percentages of primal and glue stick, respectively. The samples were divided into six binary groups. Sampling location is shown in figure 1d and 1e. (Table 1)

Table 1. Six binary groups

Group1 Sample 1 and 2	**Group2** Sample 3 and 4	**Group3** Sample 5 and 6	**Group4** Sample 7 and 8	**Group5** Sample 9 and 10	**Group6** Sample 11 and 12
Pure primal was injected to the first binary group	Glue stick was injected to the second group	Pure primal and glue stick were injected to the third group	Primal 50% was injected to the fourth group	Primal 50% and glue stick were injected to the fifth group	Primal 25% was injected to the sixth group

All samples were prepared as shown in figure 2. One sample from each group was selected to be aged and places within a large wooden compartment containing the UV lamps. After a few days, they were taken out and aged naturally (a few days in direct exposure of sunlight and moisture). It should be noted that plaster molding is strength against sunlight; however, in this aging, the measurement is too assessing the changes of adhesives resistance under direct sunlight.

Aging process continued for 16 days and finally aged and non-aged samples were exposed to scanning electron microscopy. An UVA-340 lamp was used and he SEM involved was a TESCAN VEGA one coupled with EDX.

Fig. 2. Prepared samples.

Scanning ***electron microscopic examination and UV aging test lamps***

This laboratory method has been chosen because this equipment has zoom capabilities from 26 to 366,666 about 2nm resolution, inverse scattering detector, a capability to produce 2-dimensional images and to image different phases on non-etched surfaces, a secondary electron detector, reverse electron detector, and EDX detector. Figure 3 shows a view of aging in the UV lamp compartment [21-24]. A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with electrons in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum, low vacuum and in environmental SEM specimens can be observed in wet condition.

Ultraviolet light in the sunlight is harmful to materials including polymers and composites (fading, cracking, peeling, chalking, oxidation, etc.). For, accelerated aging testing is necessary to ensure the expected performance and lifetime. As such, Many UV testing services rely on UV lamps to determine the products' UV resistance. UV light accelerated weathering testing is mainly used to assess sunlight resistance retention through environmental exposure. There are many different spectral irradiances of UV lamp. UVA-340 lamps offer the best simulation of sunlight in the wavelength from 295nm to 365nm.

After preparation of the samples and using adhesives they were tested and the obtained images and spectra which are shown the adhesives resistance changes in each groups.

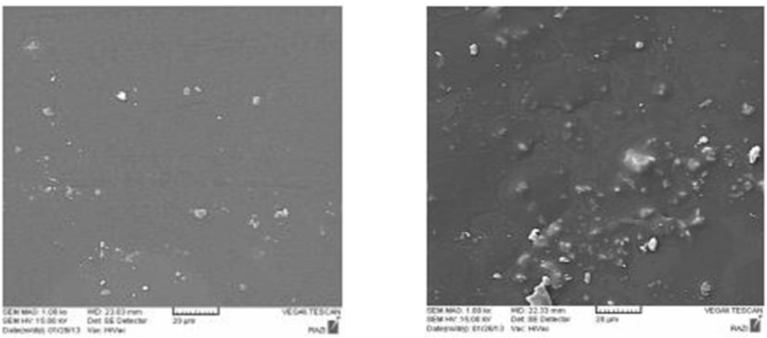
Fig. 3. Samples in the UV lamp compartment

Results and discussion

The microscopic image presented in figure 4 shows the first group in which the pure primal was added to strengthen and protect the surface of the gypsum. In this image, the entire surface is uniformly covered by primal and there is no sign of primal corrosion or shrinkage. In the second sample of the first group after aging and using pure primal, as it can be seen in Figure 4, primal is not uniform anymore and there are some cuts in some points. Absorbing the moisture makes cracks in the surface.

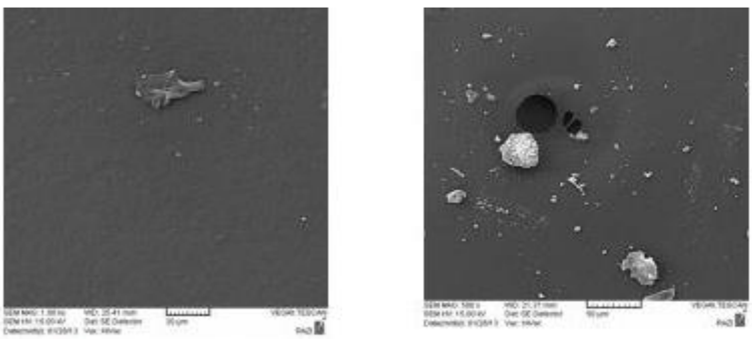
In Group 2, Sample 3 (Fig. 5), glue stick was used. As it can be observed, there is a perfectly smooth gypsum surface. In figure 5 on Sample 4, there are cavities caused by bubbles after aging

On Sample 5 in figure 6 (Group 3), pure primal and glue stick is used. In Figure 6a few scattered particles on the surface of the stick are marked and in figure 6 and on Sample 6, there are post-aging bubbles and this eventually leads to the surface distraction.



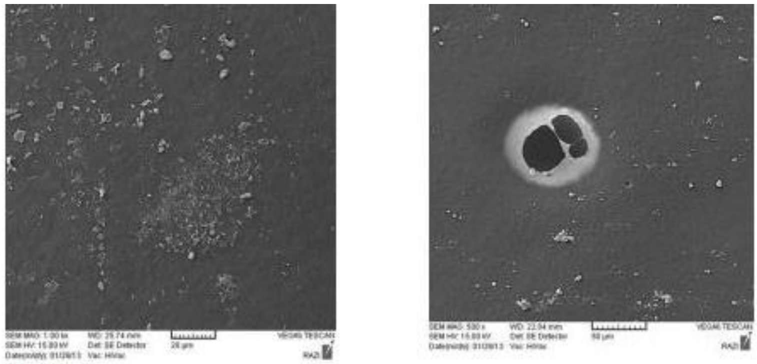
(a) Sample 1 (b) Sample 2

Fig. 4. Pre-aging (**a**) and respectively post-aging pure primal (**b**)



(a) Sample 3 (b) Sample 4

Fig. 5. Pre-aging (**a**) and respectively post-aging glue stick (**b**)

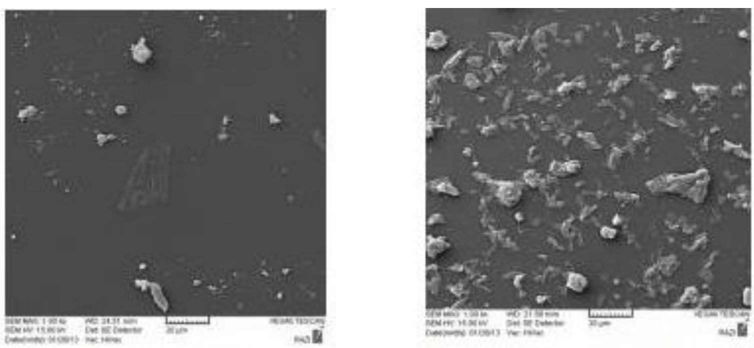


(a) Sample 5 (b) Sample 6

Fig. 6. Pre-aging (**a**) and respectively post-aging pure primal and glue stick(**b**)

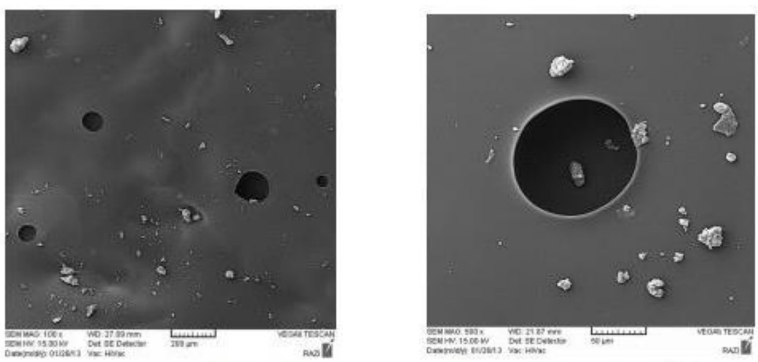
In Group 4, Sample 7, primal 50% percent was used after aging. In Figure 7, primal protective coating on the surface is quite uniform. In Figure 7, Sample 8 after aging, primal collection on the surface is observable.

In Group 5, Sample 9, primal 50% and glue stick are used. Figure 8 shows the cavities caused by the bubbles. In Figure 8, Sample 10, larger cavities and bubbles are also present after aging operations.



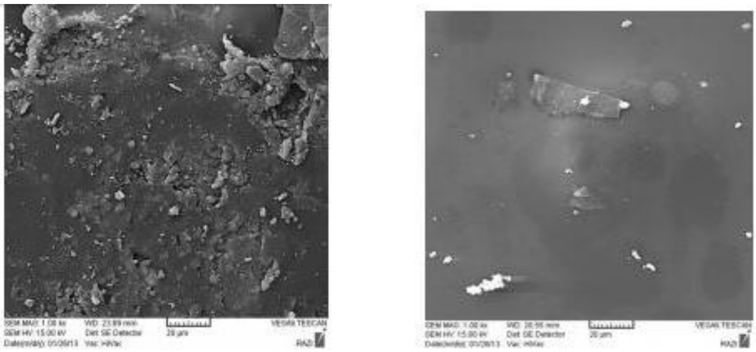
(a) Sample 7 (**b**) Sample 8

Fig. 7. Pre-aging (**a**) and respectively post-aging primal 50% (b)



(a) Sample 9 (b) Sample 10

Fig. 8. Pre-aging (**a**) and respectively post-aging primal 50% and glue stick (**b**)



(a) Sample 11 (b) Sample 12

Fig. 9. Pre-aging (**a**) and respectively post-aging primal 25% (**b**)

In Group 6, Sample 11, primal 25% was used. In figure 9, due to low concentration of primal (25%) and the presence of water 75%, the moisture is absorbed and the gypsum surface is not covered completely and its adhesive effect is not even. What is left is a small amount of primal on the surface. For post-aging operation of Sample 12, as shown in figure 9, due to the low concentration of primal, the effect of erosion is less-observed and the protective layer which acts as moisture insulation is almost destroyed and no primal is remained. In table 2 are presented the composition of the samples.

Table 2. Pre-aging (**a**) and respectively post-aging pure primal (**b**); pre-aging (**c**) and respectively post-aging glue stick (d); pre-aging (**e**) and respectively post-aging primal 50% and glue stick (**f**); pre-aging (**g**) and respectively post-aging primal 50% (**h)**

Sample	**a**		**b**		**c**		**d**		**e**		**f**		**g**		**h**	
Element	Wt%	At %	Wt%	At %	Wt%	At %	Wt%	At %	Wt%	At %	Wt%	At %	Wt%	At %	Wt%	At %
Carbon	45.71	62.53	49.01	65.59	42.62	64.96	43.39	59.38	49.52	63.15	47.52	65.29	49.62	63.65	47.62	65.29
Oxygen	33.96	34.88	32.54	32.69	44.93	43.49	37.96	39.00	37.03	35.45	31.86	32.80	35.84	34.51	31.86	32.80
Calcium	1.54	0.63	0.18	0.017	0.71	0.28	0.04	0.02	0.70	0.27	0.60	0.25	1.63	0.63	-	-
Iron	0.25	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copper	1.97	0.51	0.94	0.24	0.92	0.22	0.27	0.07	0.87	0.21			0.87	0.21	0.60	0.25
Gold	16.58	1.38	17.33	1.41	10.44	0.82	18.33	1.53	11.89	0.92	19.92	1.67	11.91	0.93	19.92	1.67
Chlorine	-				0.08	0.08	-	-	-	-	-	-	-	-	-	-
Iron	0.25	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silicon	-	-	-	-	-	-	-	-	-	-	-	-	0.13	0.07	-	-
Sodium	-	-	-	-	0.29	0.20	-	-	-	-	-	-	-	-	-	-

The spectra obtained from the SEM-EDX tests based on the $CaSO_4$ formula revealed that the existence of other elements such as gold is associated with the type experiment to be covered. Other elements are related to additives and impurities are presented in table 2.

Conclusions

The results of tests and microscopic images on twelve samples at pre- and post-aging stages suggest that primal which is used as a restoration adhesive and protection layer after aging loses its protective property and mounts on the surface and eventually cause cracking in the plaster. Therefore, the protective role of primal insulation is weakened and the possibility of plaster molding damage is high. As a result, in the case of using primal as a protective layer, renewed injection is recommended.

According to the results of experiments being conducted at various concentrations, due to its inherent property to absorb moisture, gypsum at the concentrations 25% and 50% absorbed the moisture available in the primal emulsion. Subsequently, it reduces its possible protective role and remains small amounts of primal on the surface of gypsum. Hence, primal with low concentrations cannot be used as a material consolidating the plaster moldings. However, primal at the concentration 100% is a more appropriate and more acceptable protective layer to be used on plaster molding surface and protects the plaster molding surface uniformly in short term.

The microscopic images showed that glue stick causes the formation of bubbles and cavities which lead to deterioration of plaster molding, due to producing pores.

The results of spectrums show no changes in the amounts of materials and only small declines in aging time can be observed. This suggests that the basic structure is remained unchanged and what is analyzed include physical damage consisting of cracks and holes.

To sum, using primal as a protective layer is not suitable in the long run and it should be renewed. Glue stick is also not appropriate in general.

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