

PRE-CASTING AS AN ALTERNATIVE TECHNIQUE FOR COMPENSATION OF MISSING PARTS: APPLIED TO THE LID OF THE GRANITIC SARCOPHAGUS OF TJAY, TOMB -TT23 AT LUXOR-QURNA

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Article history: Received: 11-11-2021 Accepted: 20-5-2022 Doi: 10.21608/ejars.2022.246576	Abstract: <i>This research deals with some defects resulting from the compensation of granite artifacts by direct casting including the leakage of a used liquid or plastic substance on the surface of the artifact causing its distortion. It also includes the subsequent treatment that is carried out to clean such leakage by using mechanical abrasive tools resulting in scratches, cracks, surface deformation, loss, etc. Additionally, the application of unsuitable materials such as white cement has its defects. This work aims to make a blank of the missing area and then mould and cast it away from the object as an alternative gap-filling technique. That was applied on a granitic sarcophagus of Tjay tomb 23. An original sample was taken from the broken fractures of the sarcophagus and examined in terms of color, texture, and strength, then the same type of granite was brought from Aswan and crushed, then mixed with two types of Araldites, and white cement as binders. After evaluation of different mixtures, Araldite 1092 PY was chosen to be applied with coarse granite grains to be pre-casted and reinstalled. Compared to the traditional method of compensation, the authors' opinion described technique will provide a useful example of an alternative casting technique reducing the potential for any damage.</i>
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1. Introduction

Many of the exhibits and archaeological finds made of various stones are subjected to deterioration factors whether at the time of discovery, and/or during transport, storage, and display. Some of these factors may lead to crushing, breaking, and losing some parts. Among these objects and finds are the archaeological stone carvings in general, and in granitic ones in particular [1]. Many of which are exposed to several damage factors that lead to different aspects of deterioration [2-7] including the loss of

some parts. Accordingly, in certain cases, it needs some interventions to ensure its survival and display in a decent and resistant manner. One of the most important of these interventions is to reconstruct missed areas or fill in the gaps [8]. This process is carried out in more than one way through a variety of materials depending on each case with limitations. ICOMOS stated that it should not be completed unless it is feared that the antiquity will collapse or disappear. It should be completed with the same material

as the artifact [9], highlighting the places of restoration of different colors and attribution [10]. Usually, the process of reassembling and gluing the archaeological fragments is sufficient if the shape of the antiquity is reached, and if there are missing parts that do not need to be completed. Therefore, conservators do not resort to the (controversial) completion process [11] except in necessary cases [12,13] including:

- a)** Missing part should be less than the existing trace, but if the missing part is more than the existing, there is no need to carry out the completion process to achieve a minimal scale of intervention.
- b)** The need to preserve archaeological, architectural, artistic, or technical information about the monument, which is revealed through the completion [14].
- c)** Providing support and strengthening of the object and its parts, which were assembled and glued, which represent weaknesses and may affect the integrity of the object, fearing that it will collapse or destroy.

Regarding the reconstruction procedures, it should be considered that the filling material is compatible and homogeneous with the material of the trace and that the reconstructed part is distinct from the original, and differs at least in the degree of its color or surface level from the original parts [15], as well as the texture does not differ much from the object falsifying the artistic or historic evidence. Many studies have been conducted on the compensation and treatment of stone monuments using various materials [16], including the evaluation of materials used such as plaster [17] or even acrylic resin-based with stone fillers [18,19] for marble, limestone, and sandstone [20,21] in terms of their compatibility, ease of application, their appearance. Such acrylic fills are favorable as they provide better properties (i.e., translucency, infinite modification) with none of the disadvantages including extreme hardness, toxicity, and difficulty in reversibility [22]. On the other hand, a few references dealt with the evaluation of the application methods used in the compensation processes

[23] for stone artifacts in general. Those methods often include molding with a similar part of the object body and then placing it over the missing area then direct casting. Some operations used direct applications to fill cracks and missing parts, such as what is carried out in pottery [24], wooden coffins, and other metallic objects [25-28]. Although patching up with a filling material is used as a preventive or remedial treatment [29], some of which had been applied directly with some subsequent negative effects increasing the potential for damaging the object and possibly creating stresses between the newly cast area and the object itself. As an example, previous restoration processes for similar sarcophagus and other granitic artifacts including statues were carried out applying the direct casting method with materials containing (WPC) white Portland cement as a binder, fig. (1) some associated dangers arise from that procedure can be summarized technically as follow: This direct casting technique lacks to ensure that mixture used in the process would not leak outside the boundaries of the required area to be compensated – especially when not using clay cups [30], which may affect the outer and inner surfaces of the sarcophagus. This leakage becomes more dangerous in cases containing inscriptions, writings, or colors of high value. As a result of such a leak, the restorers had to use other subsequent actions including mechanical and chemical cleaning operations to remove the resulted dirt on the surfaces by the grinding machines and the different sanding tapes, which may be used resulting in the deformation of the surface in the form of abrasions, scratches and perhaps loss of colors -if present. Some of the used materials vary between cement-based mortars composed of white or black cement containing soluble salts which is still an important cause of decay to historic materials and harm to the original material [31]. Moreover, the heterogeneity between repair mortar and original material, a setting process that may cause side effects resulting from heat and

inappropriate amount of water. Based on the foregoing reasons, the authors tried to use an alternative proposed application by preparing pre-casted replacements that could be installed. The precast application idea is a viable alternative that has been used for the replacement of missing parts of many small-sized museum objects made of different materials such as stone and glass [32,33]. In our case, it would be applied on rather a large item made of granite as a necessity for strengthening strategic areas to give stability to the object taking into consideration respect for the original material [34].



Figure (1) Shows **a.** examples of defaults resulting from direct completion represented in leakage aspects, crack formation, **b.** inappropriate materials (white cement) on granitic sarcophagus and statue respectively.

2. Historical Background

The Theban tomb TT23 is located at Sheikh Abd el-Qurna, part of the Theban necropolis, on the west bank of the Nile, opposite Luxor [35]. It is the burial place of the ancient Egyptian official, “Tjay” or “Thay”, who was a royal scribe of the dispatches

of the Lord of the Two Lands [36], during the 19th dynasty. This tomb contains a granitic sarcophagus belonging to Thay composed of a base and lid [37] with valuable drawings and colored inscriptions. Historically, this tomb was first described by C. R. Lepsius in the 1840_s, then it was visited by Ch. E. Wilbour in 1881 until it was excavated by Sir. Robert Mond at the beginning of the 20th century [38]. Among discovered objects, a granite sarcophagus was found in its original position in the burial chamber, then transported to room 5 of the tomb. Since the tomb is being open to many scholars. The tomb was neglected for some time until 1983 when the Egyptian Supreme Council of Antiquities (*ESCA*) took action. In 2006 the Center for Egyptological Studies of the RAS started a project on the study and conservation of the Theban tomb of Thay (TT 23). Since it has not received adequate care, restoration, or maintenance, it was noticeable that it has been suffering from a lot of problems including different deterioration aspects such as spots, dirt, and dust which require cleaning. In addition, some cracks, fractures, and missing parts were observed. Due to the importance of the granite sarcophagus, which contains drawings, and colored inscriptions, many interventions were primarily required to keep it in a stable condition, and to facilitate the task of Egyptologists to complete the required studies, on the other hand, this work focuses and reports the cons of completing by the direct casting of the lost areas and adopts the method of compensation using prefabricated pieces instead, to avoid the dangers arising from it.

3. Materials and Methods

Visual inspections in situ took a place to document the number, and locations of cracks and missing parts along with description and classification due to their widening and depth using a digital caliper, digital camera, and AutoCAD & Photoshop CS3

software. Small fallen fractures from the body of the sarcophagus were collected to be examined on a macro scale [39] by a digital USB Microscope with Picosmos software. Then, six mixtures as proposed patching materials were prepared, tab. (1). Three types of binders have been used in all mixtures (Araldite PY 1092, Araldite 106 IN, and white cement) while crushed granite fragments as the original type brought from Aswan of stone have been used [40] as a filler as shown in figs. (2 & 3), then examined in terms of compatibility issues. A pigment of red color composed of iron oxide has been added for testing providing special effects such as a change in the transparency, texture, color, and surface appearance of the fill [41]. All samples were mixed as shown in table 1. Three cubes (5 cm×5 cm×5 cm) of each mixture were poured and left to dry (For

samples containing white cement, they were left 28 days at least before testing). Polished sections of all six mixtures have been also prepared as well as the original granite of the sarcophagus to achieve acceptable minimum compatibility issues in terms of color, texture, and density. Compressive strength values of the prepared cubes have been determined to meet compatibility issues as much as possible by comparing the strength between repair materials and original archaeological ones [42] and to ensure that the materials used in the compensation operations are weaker than the original materials [43]. Examination and testing of new repair materials have been done to choose the best one of the available proposed mixtures for compensation in terms of compatibility and ease of application.

Table (1) Mixtures proposed as patching materials

Mix. No.	Binder	Filler type
1	Araldite PY 1092 (2:1 hardener) 100ml	3 parts Coarse granite grains
2	Araldite PY 1092 (2:1 hardener) 100ml	3 parts Coarse granite grains 1.5 g Iron oxide pigment
3	Araldite PY 1092 (2:1 hardener) 100ml	3 parts Fine granite grains 1.5 g Iron oxide pigment
4	White cement 1 part cement 100ml	3 parts Coarse granite grains 1g iron Oxide pigment
5	Araldite 106 IN (1:1 hardener HV 953 U) IN100ml	3 parts Coarse granite grains 1.5 g Iron oxide pigment
6	Araldite 106 IN (1:1 hardener HV 953 U) IN100ml	Coarse granite grains



Figure (2) Shows a. & b. crushing granite by mac-hine and manually to obtain the required gain size, c. crushed granite, d. & e. preparation of cubes via pouring in a wooden mold lined with polyethylene sheets (5 cm×5 cm×5 cm)



Figure (3) Shows examples of produced cubes of mixtures with dimensions of 5 cm×5 cm×5 cm

4. Results

Due to the inspection of the state of preservation of the sarcophagus, many aspects of damage that need rapid interventions have been observed. In addition to the aspects of damage represented by spots, dirt, and dust, there were some cracks, separated parts, and missing ones that needed to be reassembled and completed, eventually reaching a stable condition. Due to the inspection, cracks and gaps had been observed either at the base or at the lid of the sarcophagus. They can be characterized by horizontal cracks on the south side of the body of the sarcophagus, and vertical cracks at the head of the sarcophagus with widths ranging from 0.5 cm to 3.7 cm). The missing parts were counted and highlighted at the head and leg of the lid in two relatively large sizes, fig. (4-a & b). Physical properties in terms of density revealed similar values ranging between minimum 2.079 gm/cm³ of mixture no. 5 Araldite 106 IN (1:1 hardener HV 953 U IN) + Coarse granite grains to maximum 2.338 gm/cm³ of mixture no. 3 Araldite PY 1092 + fine granite grains + iron oxide. While the average compressive strength revealed diverse values between a minimum of 16.86 MPa of mixture no. 2 Araldite PY 1092 + coarse granite grains+ iron oxide, to a maximum of 64.10 MPa of the mixture no.1 composed of Araldite PY 1092 (2:1 hardener) + coarse granite grains. Table (2) shows the results of average bulk density and the compressive strength of the prepared mixtures. Macroscopic and microscopic investigations of the bulk and the polished sections of the mixtures using a USB microscope revealed slight differences in their colors and textures as shown in fig. (5). For color, mixtures no. 1, 5, 2, and 6 were close to the original pinkish granite. Mixtures no. 3 and no. 4 have rather dark and light-dense reddish colors respectively. As for texture, macroscopic and microscopic features have revealed matching between the original granite sample and mixtures no. 1 and no.5.

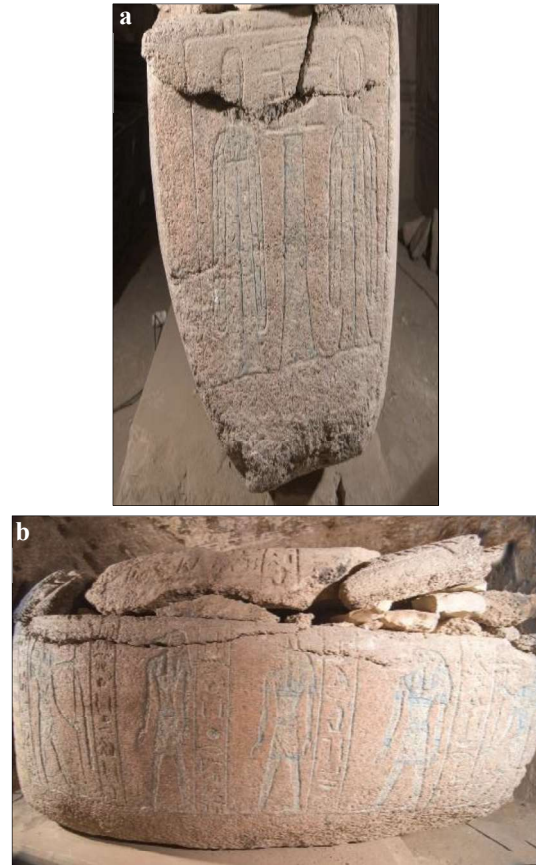


Figure (4) Shows **a.** vertical crack at the end of the base, **b.** extended horizontal cracks along the body of the sarcophagus and fragmentations.

Table (2) Average of results of density and compressive strength of prepared mixtures.

Mix. No.	Average bulk density (gm/cm ³)	Average compressive strength (MP _a)
1	2.173	64.1025
2	2.103	16.8691
3	2.338	42.5101
4	2.336	30.6122
5	2.079	19.7238
6	2.205	39.4477

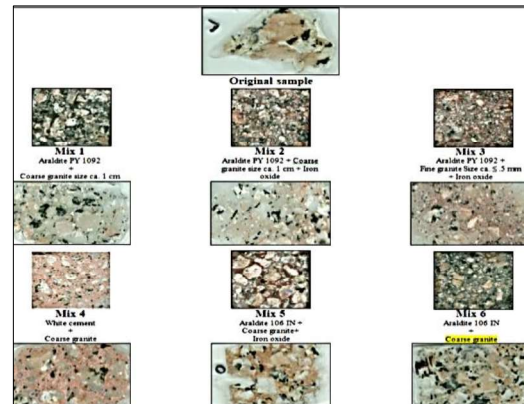


Figure (5) Shows reveals results of microscopic investigations of bulk and polished sections

5. Discussion

Investigation in situ enabled making a survey and classifications of deterioration symptoms. Accordingly, cracks, gaps, and many fragments were determined. This step would help in estimating the treatments in order up to the stage of identifying the missing parts as a final step to complete them according to accurate profile and the overall pattern of the object. As for color and texture, although, using such epoxies are exposed to color changes after a while, it was noticeable that mixture 1 and 6 have the closest features to the original granite because of the balance between Araldite and the used coarse grains of granite, and their distribution. Mixture no. 4 containing white cement was different in color, where white cement as a binder was predominant and granite particles are not visible properly resulting in irregular tone. Since the results of average density values were almost similar, it was notable that the highest values belong to mixtures 3, 4, and 6. This is owed to the added fine aggregates as well as the pigment (fine particles) in mix no. 3 and using cement in mix no. 4. On the contrary, mixtures 1, 2, and 5 have relatively low density because of adding coarser granite gains. Although relatively similar values of the density were obtained, the compressive strength values were diverse. The highest value of compressive strength related to mix no. 1 composed of Araldite 1092 with coarse grains of granite 64.10 Mpa. As an indication of strength comparable to original granite which ranges from 102.96 to 133.17 Mpa [44], it is still in the safe range to use since it has less than the value of original granite. The whole evaluation of filling materials took into consideration compatibility in color, texture, less strength of the original substrate, and avoiding further consequential damage. The strategy to achieve this aim was to use the most matched mixture with specific characteristics involving lesser strength close to the original via the addition of crushed natural stone [45] than using pigments, as the migration of unreacted pigments to the perimeters of patches is a

common problem [46]. Moreover, to exclude the application of mortars containing salts as white cement for unsuitable features [47] as well as its associated dangers related to the formation of salts that may provoke fissures in mortars and affect the surrounding surfaces [48].

6. Treatment

After mapping and documentation steps, mechanical cleaning with brushes and scalpels to remove dust and dirt, and chemical treatments to remove some old adhesives were took a place, figs. (6-a & b). Then, reassembling of the broken fragments in a sandbox had been carried out using epoxy (Araldite). Subsequently, it was possible to determine the missed areas that requires reconstruction, which varied from small ones (about 3-4 cm in width) to large ones which were confined to the sarcophagus lid at the head and foot end. Accordingly, reconstruction was decided upon to strengthen the object and to hide the places where the stainless-steel bars (thickness 6 mm and 8 mm) were used for better display. Although adopting cutting edge technologies represented in non-contact techniques such as photogrammetric techniques and 3D modeling for virtual reconstruction, replacement of missing parts [49-52], and assessment of gap filling process [53]; the availability of materials and tools, the local technological and operating conditionings, the economic resources, are also important constraints to be considered in the final selection of the measures to be implemented [54] Therefore, the following is a treatment description to recover the lost large areas from the lid of the granite sarcophagus of Tjay, tomb TT 23. It is hoped that the described technique will provide a useful example of an alternative casting technique in which major work is carried out away from the granite body, thus may help to reduce the possibility of any damage as much as possible. As a first step, taking down the lid from the base coffin for easier handling, where the light fragments were taken down manually, and the heavy ones by using a manual

lifting machine carefully, fig. (6-c). Then, the removal of the debris inside the base took a place. The small horizontal and vertical cracks have been injected via installing the tube point after mechanical and chemical cleaning of the internal surfaces. Filling gaps of granite lid (which located between permanent part and re-assembled parts) by molding process have been carried out in situ as follow:

- a) Cleaning all gaps using air vacuum and distilled water then drying them.
- b) Isolating all gaps and their rims with soap for easy removal achievement of the silicon blank without damaging the stone surfaces, fig. (6-d).
- c) Applying silicon paste inside the gaps for picking up very fine detail, release well from both the objects and the materials used to make positive casts, then left overnight until drying, then the mold has been divided into parts to avoid wrapping and isolating silicon mold by soap for ease removal.
- d) Filling the silicon mold paste with gypsum to be as a strong flexible mass

without shrinkage figs. (6-e, f & g) respectively. Then, the divided blanks have been removed and prepared for the final casting of granite mixture, figs. (6-h, i & j).

- e) Mixing the crushed granite thoroughly into liquid epoxy 1092 which has been used widely for bending and reassembling purposes [55]. As a final step, casting a positive part via mixture 1 composed of Araldite PY 1092 with coarse granite grains by pressing the filling material into the gypsum blank with a nickel spatula, fig. (6-k). Then, smoothing the final product after releasing it from the blank, figs. (6-l & m).
- f) Fixing the granite positive fragment on the original place via gluing with epoxy Araldite, figs. (6-n & o). A map of where to use the stainless bars covered by reconstructed areas near the head and foot end of the lid fig. (7-a). Finally, figs. (7-b & c) reveal the lid before and after conservation.



Figure (6) Shows **a.** & **b.** documentation of the damage and mechanical cleaning, **c.** taking down of the coffin lid, **d.** isolating gaps with soap, **e.** applying silicon paste, **f.** silicon molding before removal, **g.** dividing silicon mold, **h.** removal of mould, **i.** blank preparation for casting, **j.** isolating gypsum blank, **k.** filling of gypsum blank with granite mixture via pouring and scalpel, **l.** removal granite positive fragment, **m.** smoothing granite fragment, **n.** connecting cured granite fragment, **o.** after reassembling and installation.

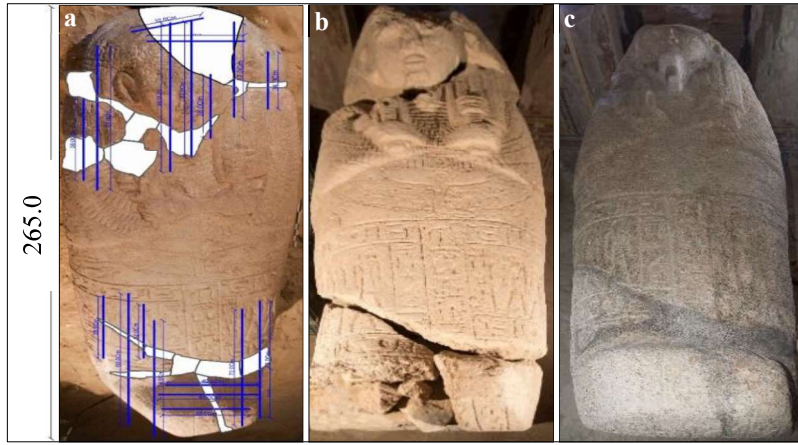


Figure (7) Shows **a.** map of where to use the stainless-steel bars covered by reconstructed areas **near** the head and foot end of the lid, **b.** missing parts, **c.** after reconstruction

7. Conclusion

Many of the archaeological stone carvings are exposed to various deterioration factors. The loss of the artifacts' parts is one of the serious challenges faced by these sculptures. The process of reconstruction of the lost areas of granite stone carvings needs further development. Using direct casting for compensation has occasionally some defects, which may cause more subsequent damage, in addition to the defects of using unsuitable materials such as white cement as a binder in the patching mortar. The compensation of missing parts employing the pre-casting may help to avoid the dangers arising from the application of the direct casting method. It can be concluded that the proposed method with available simple measurements in situ is useful in large areas and would be more effective if cutting edge techniques are used to scan the missing parts, however, it may have limited application in the case of very small voids and gaps, which can be filled with the traditional method if it is under control of the conservator. This paper does not discuss the materials used in the restoration process, as well as possible general reservations about the usage of epoxies and their reversibility. However, it should be taken into consideration that the use of white cement is still ineffective and incompatible, which should not be used even as an additive for patching mortar because of its high alkalinity, and soluble salt content which causes subsequent harmful effects and contribution of accelerating deterioration of the adjacent materials. Finally, it can be concluded the pre-casting technique enables the path to be changed from the stage of compensation via direct casting into the stage of assembly and reinstallation, reducing the risk of compensation by the direct casting of large missing spaces.

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