Investigating the corrosion and microstructure of five copper-based archaeological artefacts from *Tell el-Ajjul*

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Abstract

The corrosion of five copper-based archaeological artefacts originating from Tell el-Ajjul in Gaza was investigated to determine their state of preservation and conservation needs. Elemental composition and microstructure were studied to determine the type of alloy and manufacturing technique. Preliminary condition assessment was carried out by visual examination and polarised light microscopy (PLM). Scanning electron microscopy/energy dispersive spectrometry (SEM/EDS) was used to study the morphology of the surface and to identify the elemental composition of the corrosion products and original alloys. Metallographic microstructure of etched cross-sections was studied by PLM. The corrosion investigation results showed the presence of active chloride-based corrosion products; the elemental composition showed the presence of arsenic and/or tin as alloying elements; and the metallographic examination results showed that four of the artefacts were worked and annealed after casting, while the fifth artefact was cold-worked without annealing.

Key words: copper, artefact, corrosion, microstructure, SEM/EDS, PLM

Introduction

A central aim of the technical study of archaeological metal artefacts is to identify the corrosion processes and products present. This can be a first step in determining the conservation needs of the artefacts and can also provide information about their archaeological history. Metallographic studies of microstructure can indicate the manufacturing techniques used and can also show how the quality of the original materials and techniques used can influence the nature of subsequent corrosion mechanisms. By characterising the original alloy used to fabricate the artefact and matching this with the archaeological periods associated with the known use of certain alloy compositions, an estimated date of manufacture can be proposed.

A comprehensive examination of five copper-based artefacts (dagger, toggle pin, bent rod, tweezers, bronze pin) combining visual, technical, and metallographic investigations is presented in this study (refer images in Table 1). The objects, all from an archaeological site at Tell el-Ajjul, and now housed at the Australian Institute of Archaeology in Melbourne, were selected for investigation to confirm their preservation status. As there is no information available pertaining to the objects’ precise burial location at Tell el-Ajjul, or their date of manufacture, the extended study aimed to gather as much physical information about the objects as possible. This paper details information derived from the technical study, and describes the state of preservation, metallic structure, morphology and manufacturing techniques used in the five artefacts.

Context

*Tell el-Ajjul* (‘mound of the little calf’) lies about 10 km south-west of the centre of modern Gaza, Palestine.
and 1.8 km from the Mediterranean coast on the edge of Wadi Ghazzeh near the road that has connected Egypt with the Levant all through the historical ages (Figure 1) (Fischer and Sadeq 2000).

The site was excavated by Sir Flinders Petrie between 1930–34 (Petrie 1931–34), Mackay and Murray in 1938 (Mackay and Murray 1952), and Fischer and Sadeq in 1999 and 2000 (Fischer and Sadeq 2000, 2002). Petrie estimated the area of the Tell to be about 13 hectares. In 1999, Fischer and Sadeq found that some of the areas that had been excavated by Petrie were difficult to recognise and the Tell had become smaller due to erosion and bulldozing. They estimated the remaining area of the Tell to be about 10 hectares.

It is generally agreed that the site reached its zenith in the Middle Bronze Age (2000–1550 B.C.). However, the detailed chronology of the excavated areas of the site has been controversial and problematic (Albright 1938, Dessel 1997, and Fischer and Sadeq 2000). The site has other remains dating from the Iron Age, and the Hellenistic, the Roman and the Islamic periods (Fischer and Sadeq 2000).

Petrie (1931) mentioned that copper and bronze objects from Tell el Ajjul were in unusually uncorroded condition but were covered with a thin ‘black patina’ that he expected to be copper oxychloride, due to their proximity to sea air. Given that black copper (II) oxide tenorite (CuO) is normally associated with a higher temperature corrosion of archaeological objects, the ‘black patina’ is more likely to have been a copper sulfide or a mixed tin-copper sulfide. Subsequent post-excavation exposure to poor storage conditions can result in activation of the underlying chloride ions that leads to the production of secondary alteration products, such as blue-green hydroxy-chlorides, which without treatment will lead to continued deterioration.

The original number that the dagger was given upon excavation (F 889) is still visible on the bottom left end of the obverse, indicating it comes from one of the rooms at area (F) of the site that date to the Hyksos/15th Dynasty or Middle Bronze Age IIc (1650–1550 B.C.) (Petrie 1934). There is no number appearing on the other artefacts that could link them to a certain area at the tell.

Materials and methods

The surface condition of the five artefacts was assessed by visual examination and polarised light microscopy (PLM) using an Olympus BX51 microscope. PLM was also used to study the microstructure of the artefacts to determine the manufacturing technique and the mode of corrosion of the artefacts during burial. Photomicrographs were taken using an Olympus DP70 camera attachment.

Scanning electron microscopy (SEM) was used to study the surface morphology of the artefacts using an FEI Model XL30 ESEM. Wet mode was used at 0.5 Torr H₂O and the operating conditions for the electron
beam were 20kV and spot size 4-6. Elemental analysis of the corrosion products was carried out using scanning electron microscopy/energy dispersive spectrometry (SEM/EDS) and the SEM used an Oxford–INCA EDS system. The EDS results are indicative only; no standards were run to get quantitative results.

Cross-sections were taken from fractured parts of four objects using a scroll saw; the fifth object, the dagger, had an extreme hardness and required a fine jeweller’s saw to take the cross-section. The objects were photographically documented before and after taking the cross-sections. The cross-sections were embedded in an Araldite K 3600 epoxy resin. Following curing for 24 hours, the samples were ground on a series of silicon carbide papers from 150 to 1200 grit and then polished on diamond laps beginning at 8-4 µm down to 0.5 µm paste. The embedded cross-sections were examined by SEM/EDS to determine the elemental composition of the corrosion products and original material. Any oxygen content was excluded from the EDS quantitative results to concentrate on the ratio of copper to other alloying elements or inclusions in the original material. All the SEM images were based on the back-scattered secondary electron mode.

The embedded cross-sections were etched with alcoholic ferric chloride (120ml distilled water: 30ml hydrochloric acid HCl: 10g ferric chloride FeCl₃) and acidified potassium dichromate (80 ml distilled water: 1g potassium dichromate K₂Cr₂O₇: 4ml sulfuric acid H₂SO₄: 2 drops hydrochloric acid HCl).

Results

Condition assessment

General visual and microscopic examination of the artefacts shows that their surfaces are covered with soil deposits, substantial uniform corrosion layers and some active corrosion spots. Some parts of the outer surface have cracked and flaked off as a result of active corrosion. This is clearly evident on the dagger edges and the curves of the bent rod and is consistent with the artefacts having been worked without sufficient annealing. This process produces stressed grains that are significantly more prone to corrosion.

None of the artefacts are complete; they all exhibit fractures and missing parts; some (i.e. the dagger and the tweezers) have previous adhesive repairs which are now failing.

Examination of the artefacts’ corrosion products shows that there are three types of corrosion; an inner red-brown copper (I) oxide [Cu₂O], corrosion product; an outer green basic copper carbonate malachite [Cu₄CO₃(OH)₃], corrosion and blue-green corrosion spots that penetrate the two layers and reach the core alloy. Analysis described later in this paper confirmed that these spots contain active copper chloride nanotokite [CuCl] and the hydroxy-chlorides atacamite (orthorhombic) and paratacamite (rhombohedral) [Cu₂Cl(OH)₃] which result from the active corrosion cycle commonly called ‘bronze disease’.

Corrosion and microstructure

Dagger IA10.3560

The SEM investigation of the dagger shows that there are two distinctive corrosion products of different colour intensities (areas a and b in Figure 2). These areas were analysed by EDS which showed that the lighter colour is a tin-rich phase corrosion product, while the darker corrosion is copper rich.

The copper-rich corrosion zone is also higher in chloride, which suggests that it has the active copper chloride nanotokite (CuCl) and hydroxychlorides atacamite, paratacamite (Cu₂Cl(OH)₃) corrosion products that are indicative of ‘bronze disease’. Detailed examination of the surfaces of the dagger shows a macroscopic grain structure and different corrosion zones shown in Figure 2, which are reflective of intergranular corrosion and which explain the particular fracture patterns on the object.

The SEM image of the cross-section (Figure 3) shows severe intergranular corrosion. The EDS analysis confirmed that the elemental composition of the alloy in the middle of the grain is an 85/15 copper tin alloy, while the corroded area between the grains is rich in tin (approximately 22%) with approximately 17% chloride. This suggests decuprification of the internal alloy and
active 'bronze disease' corrosion. This is consistent with a high chloride burial environment as the site is only 1.8 km away from the Mediterranean Sea coast.

The corrosion profile was also investigated using SEM/EDS. The SEM image shows three consecutive corroded layers above the internal alloy (Figure 4). The EDS analysis showed that the outer layer is rich in copper in comparison with the internal alloy (84.0% Cu, 3.8% Sn). Chloride and iron are also present in this corrosion product. The EDS analysis of the second layer that appears less dark in the SEM image confirmed the presence of tin (20%) and chloride (17%), which supports the suggestion of a decuprification process in which copper is depleted from the alloy during the chloride-based corrosion cycle. In the presence of chloride ions the primary tin corrosion product is either SnCl₂ or a soluble SnCl₃⁻ complex that is subject to hydrolysis with or without concomitant oxidation to produce mixed Sn (II) and Sn (IV) corrosion products (MacLeod and Wozniak 1997). The third layer is composed of a corrosion layer that has a horizontal crack visible in the cross-section. It is likely that this crack occurred as a result of dehydration processes converting more voluminous and amorphous matrices into crystalline substances. The EDS analysis showed that the corrosion layer is rich in chloride (33%). This suggests that the high chloride concentration of the coastal microenvironment has promoted mobilisation of copper out of the alloy as the soluble CuCl₂⁻ complex which subsequently underwent oxidative hydrolysis to the blue-green copper (II) hydroxychlorides that dominate the external corroded surfaces (MacLeod 1981).

Figure 5 shows a cuprite layer just beneath the outer surface, and an intergranular crack with green corrosion products that EDS analysis identified as chloride based. Scott has shown that these cracks or slip bands suggest that the object was overworked and the annealing process was not sufficient to remove the stress within all the grains (Scott 1991, pp. 9, 88–89).

Figure 6 shows the variable size and structure of the grains and evidence of coring represented by differences in the shading of the alloy (Scott 1991, p. 25), while Figure 7 shows that the overworking did not affect the internal alloy, as no intergranular cracks are present; it also shows that the average grain size is 45µm.

Broken toggle pin IAIO.3545

The SEM image of the corrosion spot at the broken edge of the pin shows how it has cracked and detached from the surface of the pin (Figure 8). The EDS analysis identified the corrosion as mainly chloride based with the presence of sulfur, indicating the corrosive attack of chloride ions on the copper sulfide that is consistent with a period of anaerobic burial, as reported by Petrie (1931), or it could indicate the use of copper sulfide ore, such as chalcocite Cu₂S or chalcopyrite CuFeS₂ in the
smelting process common in the Middle Bronze Age.

The SEM image of the internal alloy of the cross-section shows the presence of air holes and white lead globules, which were confirmed by EDS (Figure 9). The SEM image clearly shows considerable gas porosity in the sample, with an average hole size of 5.5µm covering 4.3% of the surface; while the lead microdroplets have an average diameter of 2.5 µm and cover 0.35% of the surface area. The EDS analysis identified that the rod is made of a leaded low-tin bronze with about 2.3% tin added to toughen the alloy. Approximately 0.5% arsenic is also present.

SEM images of the edge of the cross-section (Figures 10 and 11) show that the principal corrosion mechanism is intergranular corrosion. The EDS analysis of the corrosion matrix between the crystals showed a tin-rich zone (8% Sn) with a sulfur percentage higher than that in the internal sound alloy (2.9% S). EDS analysis of the grains showed that their composition is similar to that of the internal uncorroded grains of the alloy. Given the dominance of chloride within the overall object and on the surface, its presence in the EDS analysis was not unexpected. The EDS analysis of the grain edge showed that it is relatively high in arsenic (1.3%) which has clearly inhibited the normal intergranular corrosion mechanism at the grain boundaries (Figure 11). One impact of the increased corrosion resistance is that the boundaries are preserved and the corrosion extends from the grain boundaries into the more anodic grains, which also have a lower arsenic concentration. It is likely that the chemical resistance of the boundaries is due to the formation of copper-arsenic intermetallic species such as Cu₆As.

PLM shows worked and recrystallised grains which suggest the object was cold-worked then annealed (Scott 1991, p. 7). On the edge, the grains are completely recrystallised, cored with the presence of strain lines and intergranular corrosion. The internal structure is less affected by intergranular corrosion, it shows recrystallised grains, annealing twins and lead globules that appear as white spots due to etching by the chromate solution used in the sample preparation. The porosity in the metal was not eliminated by working.

The depth of corrosion in the upper section of Figure 12 shows that the degradation front has extended to a depth of approximately 300 µm which is equivalent to a corrosion rate of 0.079 microns per year over the estimated 3,800 years since burial. The small amount of tin (2.2%) in the toggle pin means that the phase diagram is dominated by the presence of the copper-rich α-phase and most of the tin appears to have remained in solid solution. In terms of overall materials performance, the presence of the arsenic in this copper alloy
has had a very beneficial effect. The extensive working of the object can be seen in Figure 13 by the presence of numerous grains with length to width ratios of 3:1. This indicates extensive elongation which has not been fully relieved during the annealing process; some equi-axed grains are visible in the left hand side of the image.

Tweezers IA1.931

The SEM image of the corrosion spot on the tweezers' broken arm shows adhesive residue from a failed post-excavation repair probably intended to adhere the currently missing part of that arm. The adhesive covers most of the corrosion spot as indicated by the dark grey matte-finish matrix in Figure 14; however, a corrosion spot is visible at the end of the adhesive coated corrosion matrix. Most of the rest of the arm shown in Figure 14 is covered with soil deposit. The EDS analysis identified that the corrosion spot is mainly chloride based with the presence of some sulfur that, as with the toggle pin, could be associated with a either a period of anaerobic burial of the object or the use of a copper sulfide ore in manufacture.

The SEM image of the cross-section shows grains of the alloy with holes within them (Figure 15). The EDS analysis revealed that the tweezers are made of a tin bronze with arsenic as a minor constituent (approximately 93.4% Cu, 4.35% Sn, 0.9% As). The SEM image of the corroded edge shows that there is intergranular corrosion (Figure 16). The EDS analysis of the corrosion between the grains showed that it is rich in tin (12% Sn) with the presence of chloride and sulfide. This suggests a decuprification process as a result of the active chloride-based corrosion. The grains within the corrosion have a similar composition of the internal uncorroded grains.

The microstructure image (Figure 17) shows worked and recrystallised grains which suggest that the object was cold-worked then annealed or hot-worked (Scott 1991, p. 7). The grains are completely recrystallised; there are no grains representing the as-cast original structure. The corrosion has penetrated the alloy and caused intergranular cracks. This suggests that the final annealing and shaping of the tweezers was not sufficient to remove the stress within the grains (Scott 1991, p. 89). The porosity in the metal was not eliminated by working as the average size of the gas bubbles in the alloy is 2.2µm that covers 0.4% of the surface section. The extensive annealing of the tweezers seems to have resulted in a less-structured grain boundary region than in the other arsenical leaded tin bronze artefact, the toggle pin. Comparing Figure 16 with Figure 11 shows that the tweezers exhibit extensive intergranular corrosion while the toggle pin has a very stable grain boundary composition that has caused the more anodic grains to be preferentially corroded where they are in close proximity to the arsenic-inhibited grains.

Bent rod IA1O.3543

The SEM investigation of the rod shows a loss of thickness as a result of the continuous corrosion in the area of the corrosion spot on the curve (Figure 18). The EDS analysis confirmed that this corrosion is chloride induced. The dark grey band of intrusive materials visible in the SEM image in Figure 18 indicates the presence of entrained claylike minerals and sand grains. The mottled appearance of the surface shows extensive corrosion at the surface of the grains while the grain boundaries are relatively intact, resulting in the pitted surface profile. The SEM image of the rod's cross-section shows the microstructure of the internal uncorroded material and small amounts of original ore body being present.
as microscopic inclusions, many of which can be seen as dark spots on the right-hand side of the SEM image (Figure 19). Annealing twins are very clearly indicated in the SEM image. The EDS analysis indicated that the object is made of copper alloy that has traces of arsenic with the presence of sulfur that would have come from the ore as mentioned before.

The edge of the cross-section in the SEM image in Figure 20 shows the surface corrosion layer of the bent rod.

The EDS analysis showed that there is a mixture of copper sulfide and chloride in the corrosion product. As with the objects discussed previously, the sulfur is associated with anaerobic burial of the artefact and/or the use of copper sulfide ore, while the chloride is associated with the proximity of the burial environment to the Mediterranean Sea.

The microstructure of the object indicates it was hot-worked, as there are recrystallised grains and many annealing twins (Figure 21), and that there was a high degree of reduction of the metal thickness with many of the grains having marked linear elongation perpendicular to the direction of the applied force. This information matches with the fact that the object is bent, which means it needed to be hot-worked to form that shape. The porosity in the metal was not eliminated by working, and the gas porosity associated with the original manufacture is shown clearly in the SEM image in Figure 20 with circular cross-sections about 4µm in diameter.

Bronze pin IAIO.3556

EDS analysis of the main corrosion spot in the body of the pin showed a high concentration of chloride in the corrosion matrix and a considerable loss of the artefact’s original material (Figure 22). The EDS from this area also showed the presence of tin and arsenic which were likely used as alloying elements of copper, though it is possible that the arsenic is present as an impurity in the copper ore and that tin was added to improve the metallurgical or corrosion performance of the object (Tylecote 1992, pp. 19–20).

Figure 22 also shows a network-like structure underneath the powdery corrosion that indicates the residual α-phase of the cast dendritic structure with selective corrosion of the tin-rich α+δ eutectoid.

The SEM image of the core of the pin shows that there are air holes across the whole image, and there are no distinguished grains (Figure 23). The EDS analysis showed that the core metal is primarily copper with minor alloying by adventitious arsenic impurities; tin was

Figures 22–24 (clockwise from above): SEM image of an active corrosion reaching the internal alloy of the pin IAIO.3556; SEM image showing the microstructure of the pin IAIO.3556; SEM image showing the corrosion zones of the pin IAIO.3556.
not present in the point analysed, consistent with the selective corrosion of the tin-rich \( \alpha+\delta \) eutectoid mentioned above. Sulfur and iron were present in the EDS spectrum which is consistent with unrefined ore present as inclusions, and suggests that the parent ore body may have been derived from a deposit of chalcopyrite \( \text{CuFeS}_2 \) or bornite \( \text{Cu}_5\text{FeS}_4 \).

The SEM image of the edge of the cross-section shows that there are two corrosion layers with different colour intensity (Figure 24). The EDS analyses showed that they are both chloride based and the outer one is richer in chloride. This suggests that the chloride corrosion is active and extending into the body of the alloy.

The PLM image of the edge of the cross-section shows a distorted dendritic structure (Figure 25). The presence of these cored distorted dendrites suggests that the object was cold-worked without annealing (Scott 1991, pp. 7–8). It also shows that the porosity in the metal was not eliminated by cold working and the average size of the copper-iron-sulfide inclusions is of the order 3\( \mu \)m, covering about 6.5% of the surface area of the sectioned objects.

**Discussion**

To compare and summarise the results of the investigation of the microstructure of these five artefacts, Table 2 shows a summary of the elemental composition of their internal copper alloys that represent their original materials.

Analysis of the corrosion matrices and the parent alloys for the tin-bronzes (the dagger, broken toggle pin and tweezers) shows that for most microenvironments there is a direct correlation between the ratio of \( \text{Cu/Sn} \) in the corrosion matrix and the underlying alloy in the metal. This is illustrated in Figure 26, which shows the linear relationship between the ratios of the alloying constituents and their fraction reporting to the corrosion matrix. The ratio of the corrosion products to the parent alloy is given by the following equation:

\[
(Cu/Sn)_{\text{corrosion}} = 2.1414 + 0.2062 (Cu/Sn)_{\text{alloy}}
\]

Thus, low values of the \( (\text{Cu/Sn}) \) ratio are found for the higher tin alloys such as the bronze dagger and the lowest value was found in the toggle pin. The linear dependence of the ratios in the corrosion matrix and the underlying alloy is consistent with the degradation of the alloys being dominated by the difference in underlying reactivity of the \( \alpha \)-phase and the \( \alpha+\delta \) eutectoid. Where the microstructure shows small amounts of the eutectoid, this phase is selectively corroded over the \( \alpha \)-phase in what appears to be a thermodynamically controlled corrosion process, that is, where the more reactive phase is selectively oxidised. The phase which did not conform to this general relationship was in the sections of the dagger that were associated with very high levels of chloride in the corrosion matrix.

When the mean wt% of chloride was compared across the range of values found in all the samples, those associated with the high ratio of \( (\text{Cu/Sn}) \) in the corrosion matrix of the dagger were much higher at a mean of 22 \( \pm \) 15 wt% chloride than the average of 6 \( \pm \) 5 wt% Cl. The significance of this is that in areas where the chloride ions can form higher concentrations there is marked mobilisation of copper as \( \text{CuCl}_2^- \) species and the corrosion control moves from being dominated by thermodynamic processes to those of kinetic control of oxidation of the primary copper-rich \( \alpha \)-phase.

A comparison of the ratios of \( \text{Cu/As} \) in the alloys

<table>
<thead>
<tr>
<th>Artefact</th>
<th>Element</th>
<th>Cu</th>
<th>Sn</th>
<th>S</th>
<th>Cl</th>
<th>Pb</th>
<th>As</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dagger IAIO. 3560</td>
<td></td>
<td>84.2</td>
<td>14.80</td>
<td>0.80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken toggle pin IAIO.3545</td>
<td></td>
<td>95.3</td>
<td>2.30</td>
<td>1.00</td>
<td>0.37</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Tweezers IAIO.931</td>
<td></td>
<td>93.4</td>
<td>4.35</td>
<td>0.20</td>
<td></td>
<td></td>
<td>0.90</td>
</tr>
<tr>
<td>Bent rod IAIO.3543</td>
<td></td>
<td>97.7</td>
<td>1.10</td>
<td></td>
<td></td>
<td></td>
<td>0.70</td>
</tr>
<tr>
<td>“Bronze” pin IAIO.3556</td>
<td></td>
<td>97.0</td>
<td>1.90</td>
<td></td>
<td></td>
<td></td>
<td>0.55</td>
</tr>
</tbody>
</table>
and in the corrosion matrix shows that there is no selective reporting of arsenic which means that the distribution of arsenic in the corrosion products is in the same proportion as its presence in the original metal alloy. The four objects with measurable amounts of arsenic were the broken toggle pin IAIO.3545, the tweezers IAIO.931, the bent rod IAIO.3543 and the bronze pin IAIO.3556 with a mean ratio of Cu/As of 153±46 which is consistent with these objects having a common source of the copper ore. These alloys also have a mean sulfur content of 1.05 ±0.76 wt%, which indicates that the arsenic is likely to be associated with a mixed arsenic copper sulfide present in the parent ore body containing copper sulfides as well as mixed copper-iron sulfides such as chalcopyrite CuFeS₂ and bornite Cu₅FeS₄. While the amount of iron and sulfur in the dagger is not statistically significantly different from that of the other objects, the lack of arsenic is consistent with the object’s being from a later period than the other artefacts. This is in accord with information from the archaeological records of the site, where the area number (Area F) that is still visible on the object dates the dagger to the Middle Bronze Age IIc (1650-1550 B.C.). This agrees with the fact that tin bronze is known to have replaced copper arsenic alloys as the preferred metal for these kinds of worked implements in the Near East from around 1500 B.C. (Lechtman and Klein 1999). It also suggests that the arsenic containing artefacts are more likely to be from periods preceding that transformation (i.e. the Middle Bronze Age IIa (2000–1800 B.C.) or the Middle Bronze Age IIb (1800–1650 B.C.)).

**Conclusion**

The investigation of the five copper-based artefacts revealed that the corrosion processes are driven by the presence of oxygenated chloride-rich solutions in the burial environment. This microenvironment data can be reasonably deduced from the ubiquitous presence of chloride-based corrosion products containing both tin and copper matrices. Conservation options for this active corrosion can be either in the form of direct intervention, through washing treatments and the use of corrosion inhibitors, or through passive means such as controlling the relative humidity. The metallographic results show that the dagger, broken toggle pin, tweezers, and bent rod were worked and annealed after casting, while the bronze pin was cold-worked without annealing. The manufacturing technique has affected the nature of the internal corrosion of the alloy as evident by the intergranular corrosion and occasional transgranular cracks along the lines of unannealed stress from cold-working. The investigation of the internal corrosion was complementary to that of external corrosion and helped in providing complete information about the ongoing corrosion of these artefacts.

**Biography**

Ahmad N Abu-Baker graduated from Jordan University of Science and Technology with a Bachelor of Science in applied chemistry in 2003. He received a master’s degree in conservation and management of cultural resources from Yarmouk University in 2005. Ahmad is currently a PhD candidate at the Centre for Cultural Materials Conservation, the University of Melbourne, investigating the inhibition of the corrosion of archaeological copper alloys.

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Book reviews

William N FitzGerald
www.astragalpress.com
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Reviewed by Helen Privett
Senior Conservator, Collection Development and Access, Museum Victoria

Recently a team of conservators from Museum Victoria and experts in coach building, blacksmithing and upholstery from Sovereign Hill completed a restoration of an Australian-designed Cobb and Co coach dating from 1880. Deciding on an approach for the wooden structure was relatively easy, as was deciding on a treatment path for missing metal components and the paint surface. One of the most difficult areas proved to be deciding on an appropriate approach for the upholstery. What would it have looked like? What materials would have been used? And finally, how was it constructed? While there are publications regarding the structure of coaches and, in the case of our coach, a number of photographs of the object in use, there is little documentation to guide the conservator's path through re-upholstery and trimming.

This book is a reprint of an edition first published in 1881 and goes some way towards solving the upholstery and trimming dilemmas facing conservators and restorers of coaches. Written by an expert coach trimmer with more than 30 years experience in the trade, the book is divided into 18 chapters, each divided further into smaller sections, with titles like 'Little Things to be Looked After' and 'Characteristics of Good Work'. One of the delights of this book is the language; it is an historical document and transports the reader to the time of horse-drawn vehicles trimmed with plush velvets, fitted with hooks for parasols and featuring compartments for storing cigars. The book starts with a useful modern glossary of terms and ends with a brief dictionary contemporary to the book. An added quaint touch is that the original typeface has been reproduced, as have a series of adverts for trimmers' supply companies.

The book roughly divides into three parts; the first three chapters are concerned with choice and preparation of appropriate quality and quantities of materials for trimming. There are extensive descriptions of the characteristics of good quality leather, cloth and padding materials such as hair; this information is supplemented with lists of quantities required for specific types of vehicles, an illustration of which is provided with each list. Further inclusions are recipes for adhesives, expected prices and advice for the most economical way to cut materials such as hides.

Following this are chapters which provide directions for constructing specific parts of the coach. There are detailed diagrams and instructions for each component in a range of styles with tips regarding which vehicles they are best suited to. This section is highly technical and would be most useful to someone carrying out trimming of a standard type of vehicle rather than seeking information about materials.

The final section contains a diverse collection of information. There are chapters on tools, costs of repairs in the different geographical regions of the United States, recipes for materials used in production and maintenance of coach trimmings, and care instructions to prolong the lifespan of the vehicle. The latter two chapters are fascinating; the book gives a good sense of understanding the damage that can be wrought by exposing organic materials to insect activity, light, moisture and dust. The book strongly recommends coach owners and manufacturers keep their vehicles in well-ventilated, dust-free environments, advice we certainly wish had been followed with our coach!

Of particular interest to conservators may be the series of recipes for adhesives and polishes. While they give conservators and restorers information about original materials, should replication be required, they also allow us an insight into what we may be observing when we first examine a vehicle requiring treatment. A favourite was the recipe for 'a washing liquid for silk' comprised of, amongst other things, half a pint of gin and two ounces of strained honey. While some of the recipes are familiar, there are references to materials such as 'rotten stone', which aren't explained in the glossary or dictionary.

Ultimately this book confirms what we suspected as we restored our coach: that upholstery of coaches followed certain conventions in terms of materials and styles, but was a very personal design choice made by the owners and makers of coaches. The book has some application for conservators as it provides information about materials and construction of trim for standard American vehicles, but would have less application for coaches outside of this purview. Regardless of these limitations the book is a wonderful document from the time and would be useful to conservators working with vehicles from this period.
Light for Art’s Sake: Lighting for Artworks and Museum Displays
Christopher Cuttle.

Reviewed by Elizabeth Hinde
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Light for Art’s Sake looks at the interaction between light and the object it illuminates, in the context of the museum. An analysis of techniques that optimise or detract from the presentation of museum objects is provided. Particular attention is paid to the central conundrum of museum lighting, that is, the simultaneous ability of light to enable visibility and appreciation of an object, whilst also initiating photodegradative reactions in the materials used to make the object. As a direct consequence, Cuttle notes that the aims of lighting design and preservation come into conflict. In response, the lighting strategies presented in Light for Art’s Sake are a compromise with both departments in mind.

Cuttle begins the discussion on museum lighting by introducing the reader to the general philosophy behind the presentation of art. He addresses the goals that are strived for when implementing illumination in a museum, and with these in mind, the remaining text goes through the practicalities involved in achieving them. Several case studies and photos of various lighting strategies Cuttle has observed in galleries and museums around the world are presented.

In order to understand the practicalities of the lighting strategies presented, Cuttle dedicates Chapters 2 and 3 to familiarising the reader with the necessary terminology and background information on the subject of illumination. Explanation of the human response to light, and how we adapt to low light levels or discern colour, is provided. Definitions regarding quantification of light, and the various reactions it can initiate in objects, are described. Light for Art’s Sake is thus aimed at a reader who has a competent but not esoteric knowledge of the properties of light.

Lighting typologies based on the use of natural daylight are the first strategy to be presented. Architectural considerations such as diffusion of light via use of side-lit rooms and specially designed skylights are examined. Materials used for blocking the ultraviolet component of daylight from entering the museum environment are assessed. This is a nice illustration of how the interdisciplinary approach of Light for Art’s Sake can provide answers that might not be arrived at when departments work independently. For example, Cuttle introduces the reader to electrochromic glazing as an effective means of filtering out ultraviolet light. This technology is routinely used in architecture, however, its application to a preservation problem may not have been realised without the interdisciplinary approach advocated by a book like Light for Art’s Sake.

Lighting typologies based on the use of electric lighting are then presented. The various lamps commonly employed in museum electric lighting are discussed. Particular attention is paid to the different considerations in illuminating two- versus three-dimensional objects. Cuttle explains that lighting two-dimensional objects usually involves three-dimensional factors. For example, a painting which is considered two-dimensional may contain three-dimensional elements like impasto, and so should be illuminated accordingly to avoid shadow. What does become clear upon Cuttle’s discussion of electric lighting typologies, is that an awareness of the subjectivity involved in various lighting strategies is required. This is particularly relevant to issues regarding what is deemed to be aesthetically acceptable to viewers and to retaining and representing artists’ intent.

In conclusion, Light for Art’s Sake provides a holistic education to those involved in the interdisciplinary action of museum lighting. It would be useful reading to anybody involved, or becoming involved, in museum exhibition planning. It is by no means comprehensive in its coverage of illumination properties and technologies but serves as a useful reference in directing further enquiry.

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