Museum reproduction of metallic archaeological artefacts: from lost wax casting techniques to artificial metals

Miquel Angel Herrero-Cortell, Xavier Mas-Barberà, Carmen Marcos Martínez, Montserrat Lastras Pérez, Mario Culebras Rubio

Abstract: Reproductions of archaeological artefacts play a necessary role in our societies while allowing an induced multiplicity of the original, which supposes benefits for conservation, dissemination and promotion of our heritage. But the reproduction of metal objects has been a challenge for museums and institutions, due to the complexity of emulating metals, and thus, the implementation of traditional techniques such as lost wax casting or electrolytic processes have been set in many cases as the mainly solution. The aim of this paper is to propose an alternative procedure, based on the use of thermosetting resin composites with metallic fillers. A comparison between the solutions provided by artificial metal and artistic casting techniques is done for two cases of study, juxtaposing advantages and limitations of both procedures.

Keyword: cold-casting metal, preventive conservation, metals, lost wax casting, reproductions, archaeology

Reproducciones museísticas de piezas arqueológicas metálicas: de las técnicas de fundición a la utilización de metales artificiales

Resumen Las reproducciones de piezas arqueológicas cumplen una necesaria función en nuestras sociedades en tanto permiten una multiplicidad inducida del original, que redunda en beneficios para la conservación, divulgación y promoción de nuestro patrimonio. La reproducción de objetos metálicos ha supuesto un desafío para las instituciones museísticas, dada la complejidad de emular metales, y así se ha propuesto en muchos casos la implementación de técnicas tradicionales como la fundición a la cera perdida o los procesos electrolíticos, limitando la investigación en otros materiales El presente artículo propone una solución alternativa, fundamentada en el uso de *composites* de resinas termoestables con cargas metálicas. A través de dos casos de estudio se aborda una comparativa entre las soluciones aportadas por el metal artificial y por las técnicas de fundición artística ante un mismo modelo, yuxtaponiendo ventajas y limitaciones de ambos procesos.

Palabras clave: metales artificiales, conservación preventiva, metales, cera perdida, reproducciones, arqueología

Reproduções museológicas de peças arqueológicas metálicas: das técnicas de fundição à utilização de metais artificiais

Resumo: As reproduções de peças arqueológicas cumprem uma necessária função nas nossas sociedades, uma vez que permitem uma multiplicidade induzida do original, que resulta em benefícios para a conservação, divulgação e promoção do nosso património. A reprodução de objetos metálicos tem sido um desafio para as instituições museológicas, dada a complexidade de emular metais, e assim se propôs, em muitos casos, a implementação de técnicas tradicionais como a fundição a cera perdida ou os processos eletrolíticos, limitando a investigação a outros materiais. O presente artigo propõe uma solução alternativa, fundamentada no uso de composites de resinas termo estáveis com cargas metálicas. Através de dois casos de estudo aborda-se uma comparação entre as soluciones obtidas pelo metal artificial e pelas técnicas de fundição artística no mesmo modelo, justapondo vantagens e limitações de ambos os processos.

Palavras-chave: metais artificiais, conservação preventiva, metais, cera perdida, reproduções, arqueologia

Introduction

Since the 20th century, the benefits of the reproductions in heritage field have been exploited beyond conservation purposes: thus the creation of artistic duplicates has become a widespread institutionalized practice, due to its various functions such as conservation, protection, exhibition, dissemination, research, and heritage promotion. (Aguilar Galea 2004: 151; Marcos Pous 2003: 37-40). In the case of archaeological metallic materials, due to its unstable nature, the fragility that characterizes them as well as the need for complex infrastructures to ensure their conservation have frequently pushed reproductions to become the only possible mediation between preservation and dissemination of original artefacts. Hence, some museums, like the Museo Arqueológico Nacional, have been provided with good replicas of some treasures from their own collections, produced by goldsmiths in metallic materials, or metallized plastic, which may be able to replace the originals in the exhibitions. (Marcos 2003: 37). Indeed, today, traditional metallurgical production techniques, such as goldsmithing and casting, coexist with novel electrolytic systems (Pérez 2009: 20-33), even on plastics cores (Panchi 2009). Sometimes other materials, like thermoset resins are chosen with these purposes, usually coloured with paintings or dyes (Garcia et al., 2007: 432), glitters (Catalán 2008: 313), with metallic pigments in surface (Garcia Diez 2012: 38), graphite (Fernández 2015) or by gold foil (García *et al*. 2007: 488). At present the research focuses to two aspects: "*avoid the original to get damaged in the process and find effective reproduction methodologies*" (Negrete Plano 2003: 83; Caetano Henriquez 2012). Since the last decade, the arise of the 3D scanning (Pereira, 2008) as well as the 3D printing, even with metal coloured plastics (Lipson; Kurman 2014) has opened new ways to explore in the field of conservation of archaeological metals (Zhang *et al*. 2015). But the fact is that it's still an expensive technology if not small reproductions are required, and the texture and finishes of 3D printings are not suitable for mimetic reproductions.

For purposes of reproduction of small and medium archaeological metal objects, traditional casting techniques have been proposed as useful procedures, specially centrifugal micro-fusion and lost wax with ceramic shell (Aguilar Galea 2004: 151-163) due to "*the extraordinary quality of surface recording through this technique, coupled with special conditions, amongst minimal intervention with original work must be highlighted*"[1] (151). Furthermore, through the patination of bronze this alloy is able to emulate various metals, copper, iron, silver, etc., while maintaining the formal quality of the original. (151-152). This "chromatic looking" is favoured by the abundant literature on metals patination (Leddon 1931; Huges & Rowe 1982).

The technique of lost-wax casting with ceramic shell, developed by C. Marcos (2000) serves the purpose of casting artworks, where it has become one of the most important techniques. It is also a common procedure in the reproduction of heritage bronze objects by getting quite approximate results to the respective models and even recalling a process analogous to that used in creating originals: lost-wax (Tylecote 1976, Lambert 2002). This is, definitely, a successful procedure that appears to be the most accepted among institutions and museums, in part due to a lack of research on alternative solutions as effective as casting, but by using other materials. However, it is striking that, in the case of carved stone sculptures, alternative solutions considered highly effective do exist for some years, and there is abundant literature about them (Negrete 2003; Lowe 2003; Aguilar 2005; Mas-Barberà 2006; Crasborn 2007: 187- 199; Martínez *et al*. 2009: 261-266; Scott 2012-2013). The lack of such studies to achieve metal reproductions is paradoxical, attending to the quality and functionality of results that have been obtained in recent decades in imitation of stone materials, both in the field of conservation and the sculptural and ornamental production.

A brief state of affairs on the use of 'artificial metals' for these purposes was recently published (Herrero & Culebras 2014). In it, the little research on cold-casting metals was exposed, as well as the causes that led this lack. The name 'Artificial Metal' refers generically to the various metal composites consisting of thermoset resins blended with metal fillers, following the most common name of 'Artificial Stones'. Although their uses in sculpture have been documented since the early 1960s (Percy 1962: 37-61), artificial metals did not then become popular composite materials because of the limitations presented either by resins and metal particles, although there was some research about them (Adams 1968); (Spenik 1976). In the field of conservation-restoration they had little reception, though some attempts to normalize them as materials were also done (Gilroy 1976: 30-32; Engel 1988: 103-111; Poncelet; Texier, 2001: 138-145). Even now, there are still very few qualitative and formal studies of these novel compounds. More recently there has been a first approach to the use of these composites, for purposes of conservation and dissemination of metal heritage, and first research results in our country have been displayed (Herrero *et al*. 2016, and 2017).

The aim of this paper is to present artificial metals as alternative materials in reproductions of metallic archaeological objects, by making a comparison between the results obtained by casting techniques and cold-cast metals, to address the advantages and limitations of both procedures in obtaining museum artefact's duplicates.

Experimental

—*Case Studies*

As case studies, two archaeological objects are presented here, whose reproductions were committed by *Sección* *de Estudios de Arqueología y Prehistoria* of the *Real Academia de Cultura Valenciana* for an exhibition at the headquarters of the institution. The models are a copper chalcolithic axe and a roman figurine bust, made of bronze [Figure 1].

—Methodology and materials

In order to obtain museum quality reproductions, as tight as possible to original models, two distinct ways were explored: traditional casting and artificial metal cold casting. For the axe reproductions, a ceramic shell lost-wax casting was chosen (Aguilar 2004), while figurines were cast by lost-wax centrifugal micro-fusion, considering their tiny size. Meanwhile, artificial metal cold casting was also used to obtain reproductions of both models. The properly condition of both artefacts, the lack of holes and pores observed with a 200x magnifying digital microscope, as well as their formal integrity, facilitated the task of obtaining a mould for each one. The first step was to avoid any damage in the originals during the mould making, (Matteini *et al*. 1990; Gisbert *et al.* 2006; Mas-Barberà *et al*. 2013) so a layer of protection of an acrylic resin (Paraloid B-72® 7% solution in ketone) was applied over the original metal surfaces. This coating was chosen due to its ability to produce a very thin texture-less film over surfaces, but also capable to block the silicone and work as a release agent. The whole process started with the mould making, using RTV silicone (Tosini 1999).

Figura 1.- (From left to right) *Chalcolithic axe.* Ca. 3000 b.C. [Weight: 375g. Size: 111,2 x 37,45 x 16,1] mm. *Roman figurine bust, representing Juno.* Faustino Heritage. (I – IV Centuries) Weight: 37g. Size: 43,2 x 25,7 x 20 mm. Courtesy of Sección de Estudios Arqueológicos y Prehistóricos (SEAP) of the Real Academia de Cultura Valenciana (RACV).

Before performing artificial metal casting, 20 samples of 70 x 10 x 5 mm were prepared, (10 with bronze and 10 with copper, 5 for each resin) in order to adjust the colour and aesthetic appearance to original pieces. In a recent paper, (Herrero *et al*. 2017) dosing possibilities for artificial metallic fillers metals were explored. In it, it was determined a ratio of filler for resin depending on the type of sculptural procedure (casting or lamination), and several morphological types of metal particles and different sizes were studied. The study concluded that the most suitable particles were those atomized and not deoxidized, with an irregular shape, and a size between 200 and 50 µm. Since the artefacts were too small to suit a lamination process, it was preferred a casting process. It was also determined that an optimum ratio of metal filler for this type of process was about 82% metal by total weight (w/w) for bronze and 85% w/w for copper, allowing the composites to flow into the mould surfaces, but keeping at the same time some viscosity. The resins used were epoxy (Araldite LY554® with amine based curing solution LY956 20%) and polyester (Glaspol 9900® hardened with methylethylketone peroxide [MEKP] P-200® Promox, 2% by weight for the bronze and 3% for copper). All metallic powder fillers were supplied by Pometon®, and 106µm irregular morphology copper and bronze particles (CUPM 100®, and CuSn15 W 75®), were used.

Since both reproductions would be exposed in a showcase without controlled lighting conditions, and knowing the trend of colour changing of resins by ultraviolet action, it was decided to conduct a brief study of aging of these materials, by using spectrophotometry-colourimetry. For this purpose 18 CUSn15 W75® samples of 50 x 20 x 10mm were performed with a metal content of 70% w/tw, conglomerated in epoxy and polyester resins with the same proportions as mixtures used for casting. The objective was to detect changes in colour appearance in both kinds of resins. Colour was measured in 12 samples, using a Minolta CM-2600d colourimeter. The CIELab values of the samples before and after UV aging were measured with specular component excluded and included (SCE and SCI) using the CIE illuminator D65 (6500° K) and 10° standard observer. Then, samples were subjected to an aging test by ultraviolet light action, which was performed by using a QUV/Basic solar simulation cell, with 8 UVB 313EL lamps, setting radiation 0.77W/m/nm, with equivalence to 40watt fluorescent lamps. The spectral region of UVB lamps is between 280 and 315nm, with peak emission at 313nm one. The study was carried out following a program of 120 hours. After this aging new shots with the colourimeter were performed, always over the same points of each sample, and thus, colour variation was determined. A binocular microscope Leica S8APO, provided with a tube adapter to engage a Nikon D-5000 camera, was used to observe the structural morphology of the artificial metals. Scanning electron microscopy (SEM) was also used for the same purpose. The images were obtained from Hitachi S-4800 microscope at an accelerating voltage of 20 kV and a working distance of 14 mm. The surfaces were coated with a thin gold-palladium alloy layer by sputtering.

Figura 2.- (Left) Wax cast axes attached to a sprue system with cup, before making a ceramic shell mould. (Right) The three wax figurines attached to a central sprue ready for centrifugal casting.

Six wax reproductions (three for each model) were obtained by pouring molten wax into the silicon moulds. The mixture of waxes chosen was 45% virgin bee wax, 35% paraffin and 20% of rosin, to alleviate the high shrinkage of the wax. The wax axes copies were sprued with a treelike structure of wax that eventually provided paths for the molten casting material to flow and for air to escape.

The carefully planned spruing began at the top with a wax "cup," which was attached by a wax cylinder and with little cylinders from the central one to various points on the three wax axes [Figure 2]

After this process, a ceramic–shell multilayer mould was made. This is a long and time-consuming process that is not going to be described here since there is much literature about it (Marcos 2000). The figurines were also assembled to a jewellery micro-fusion wax sprue [Figure 2], for centrifugal casting, and set into an iron cylinder in which it was poured a refractory paste to get a fire-proof mould. After having both moulds burned out, wax had run out of moulds, so they were empty and ready for the metal casting processes, which will be neither described here. An 85/15 bronze alloy was used in both cases for the final castings [Figure 3].

In order to obtain a faithful chromatic finish for all pieces, both the casting ones and the artificial metal ones, a patina test was performed over 16 cold-casting samples, similar to those used for UV aging. Various treatments were applied (acid and base patinas commonly used for bronze patination purposes). The selected formula for both cases was achieved with a treatment by NH_3 (30% in distilled water) vapours action in a sealed hood, during 48 hours [Figure 4], prompting the development of a characteristic brown hue patina under a blueish pigmentation (due to copper ammonia salts) that was removed by washing with distilled water. The same formula was used for colouring the real bronze specimens.

Figura 3.- Liquid bronze at 1200 °C is poured into the dried and empty casting mould of copper axes. The shell mould is reheated in the kiln to harden the patches and remove all traces of moisture, then, placed cup-upwards into an iron grill. Metal is melted in a crucible in a furnace, and then poured carefully into the shell. After cooling, moulds are hammered and pieces are chased

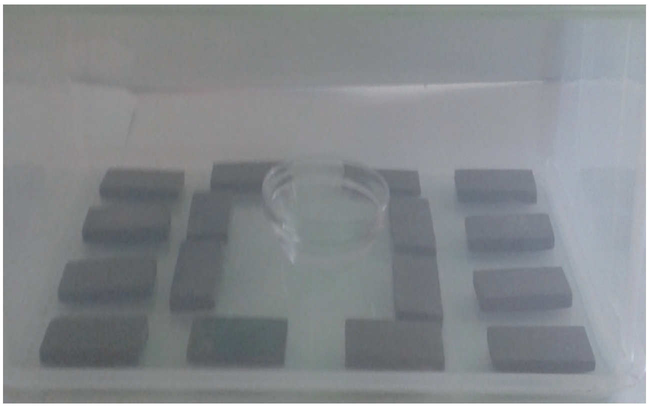


Figura 4.- Samples of artificial bronze developing a NH_3 fumes patina in a sealed hood. Photograph has been taken after 24 hours, thought samples stood during 48 hours.

The final results obtained by both methods were properly measured and organoleptically compared, according to their dimensional properties of size and weight, in order to check aspects such as fidelity to originals, maintenance of the scale, presence or lack of contractions or deformations, as well as the mimetically topographical record of the surfaces, texture and colour.

Finally, as lost-wax bronze casting has been described as an effective procedure for archaeological museum reproductions (Aguilar 2004), the effectiveness of cold-casting metals for the same purposes was intended to be measured. With this objective, and as something complementary, the public response to effectiveness of the artificial metal reproductions was tested. For this statistical evaluation a survey was performed, showing the originals and reproductions to 150 people, who had to visually discern between original artefacts and copies, without being able to touch them. People were also asked about the effectiveness of the material, and the data collected assessed the utility in its role as substitutes, their effectiveness in emulation of metal surfaces and finally, the popular perception of such kind of reproductions made of metal composites.

Results and Discussion

—Organoleptic Results

After performing bronze lost-wax casting processes, all items were demoulded. To get the real bronze reproductions all shells were hammered and sand-blasted away, releasing the rough casting. The sprues, which were also faithfully recreated in metal, were cut off, and the castings were worked until the telltale signs of the process were removed, so that the bronze casting now looked like the original model. Cold-cast metal reproductions were also demoulded without problems, although epoxy castings showed a trend to get more wedged to the mould. Artificial metals reproductions required an easy work: cutting off the only sprue, the one for pouring the composite, and they were ready to burnish with steel wool. Six reproductions of each artefact were released, (3 cast bronze and 3 cold-cast copper for the axe, and 3 cast bronze and 3 cold-cast bronze for the figurine). Additionally 6 more wax pieces (3 from the axe and 3 from the figurine) were obtained in order to be measured and compared. A table with all measures average was made [Table 1], and all pieces were photographed together [Figure 5].

A glance at the results in Table 1 is enough to evidence significant differences in weights and sizes for the respective pieces. Mainly, it shows that both reproductions in bronze from wax models suffer a notorious reduction in size and weight, resulting from a process of shrinkage caused by

Tabla 1.- Measurements of the original artefacts and reproductions with artificial metals, wax and bronze.

Copper Chalcolithic Axe	Weight (g)	Loss (%)	Size (mm)	Loss (%)
Original	375	-	111,2 x 37,45 x 16,1	-
Artificial Copper cold-cast	160	58%	111,2 x 37,41 x 16,1	0%
Wax cast	38	-	107 x 35,8 x 15	4%
Cast Bronze	336	11,4%	105,5 x 35,2 x 14,8	5,5%
Roman Bust figurine	**Weight (g)**	**Loss (%)**	**Size (mm)**	**Loss (%)**
Original	37	-	43,2 x 25,7 x 20	-
Artificial bronze Cold-cast	26	30%	43,2 x 25,7 x 20	0%
Wax cast	2,5	-	41,9 x 24,9 x 19, 2	3%
Cast Bronze	28	24,4%	41,1 x 24,4 x 18,8	5%

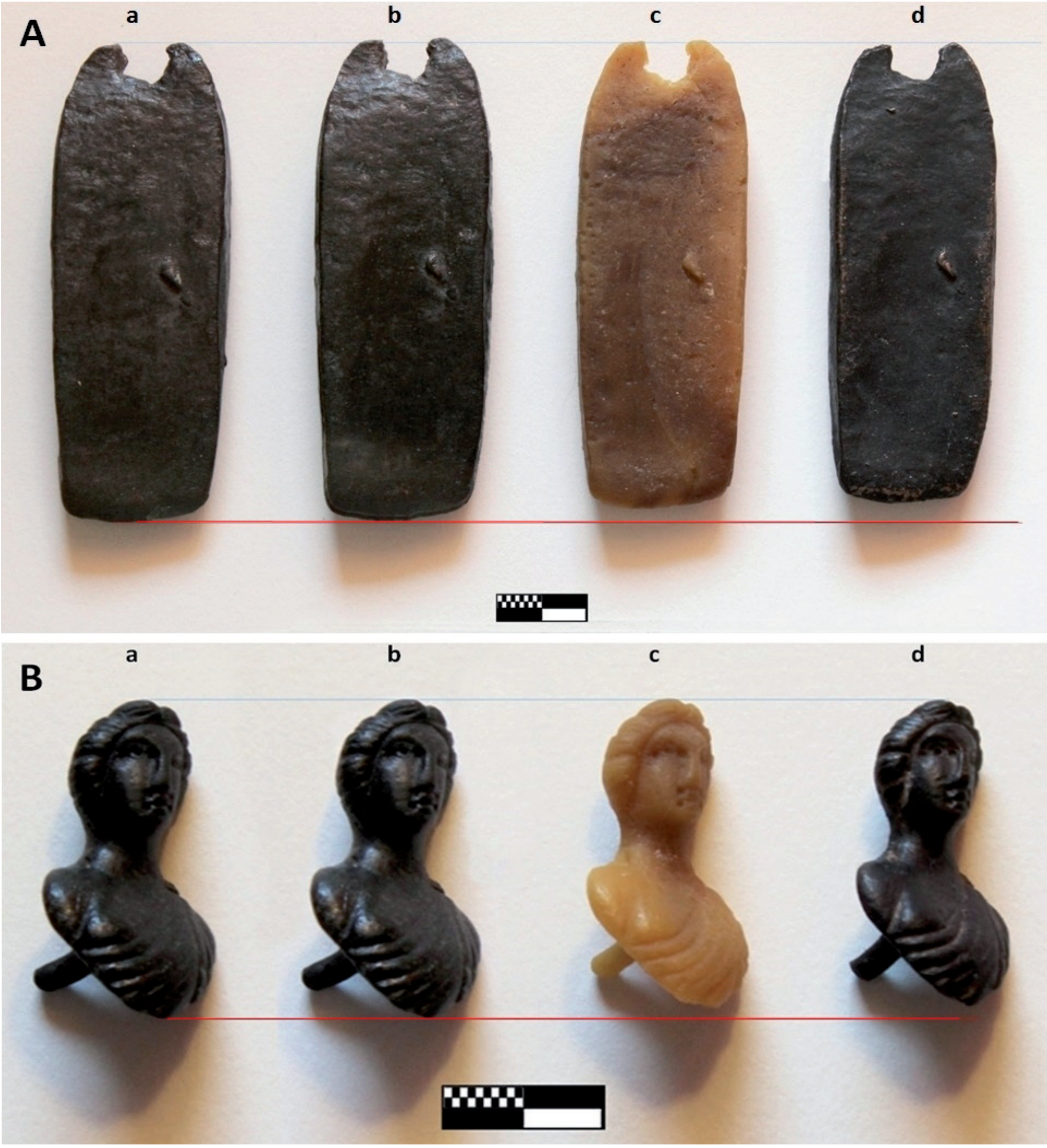


Figura 4.- [A] a) Original chalcolithic copper axe, b) artificial copper cold-casting reproduction, c) wax cast, and d) final bronze cast. Note the progressive size reduction in wax and bronze reproductions. The lower red line shows the proportion decrease. Shrinkage can also affect the texture and surface details of reproductions. Note how the only piece that keeps an accurate faithfulness to the original is the one made with artificial copper. [B] a) Original bronze figurine, b) artificial bronze cold-casting reproduction, c) wax cast, and d) final bronze cast. As in the previous example, the progressive size reduction becomes evident, attending to the lower red line. Once more the most accurate result has been obtained with artificial bronze, by cold-casting.

cooling. As it has been stated by some authors, contraction of cast bronze occurs in three steps: 1) liquid contraction during cooling prior to solidification; 2)Contraction during the phase of change from liquid to solid, called solidification shrinkage, and 3) thermal contraction of the casting solidified during cooling to the ambient temperature. The solidification shrinkage observed in step 1 has two effects. First, the contraction causes a further reduction in the height of the casting. Second, the amount of liquid metal available to power the upper portion of the casting centre is restricted. This is usually the last region to solidify; the absence of metal creates a vacuum in this area of the casting. This shrinkage cavity is called internal suck-in, or void. Once solidified, the casting undergoes subsequent contraction in height and diameter while cooling, as in step 3) .This contraction is determined by the thermal expansion coefficient of the solid metal, which in this case is applied in reverse to determine shrinkage. (Groover 1997: 252-253). But bronze is not the only material which suffers such process: wax also undergoes shrinkage when passing from liquid to solid (Moreno 1993: 28). Thus, the parts subjected to lost wax casting processes undergo a double process of contraction (by the wax and by the bronze), which definitely alter the actual dimensions of the work; an alteration that can reach rates of loss of up to 10% in larger items.

Moreover, some resins may also suffer contraction or deformation processes when used without fillers. A high percentage of metal filler (70 % p/p or more) is enough to cut this phenomenon. So, none of the reproductions obtained with artificial metals underwent any contraction, neither in polyester resin, nor in epoxy examples.

The surface quality is also different in all results [Figure 5] being mimetic only in the case of the resin casts. The aforementioned shrinkage of wax and bronze cannot be controlled, and these contractions always involve deformations, loss of texture or lack of quality of registration, all of them very negative factors when working with reproductions that must be identical to the originals. Manipulation of the wax for sprue installation, subsequent welding of wax cylinders, and the metal-chasing process (to remove sprues and other signs of the casting) also lead to a loss in texture and detail of the reproduction surfaces. Although centrifugal precision casting offers a good quality of surface reproduction, shrinkage cannot anyway be avoided. The quality and richness of textures and surfaces can only be guaranteed by using artificial metals, since their cold-casting process does not involve heat and no major chasing is required.

The light weighting in artificial metal plays a clear advantage: in larger pieces weight reduction means greater ease of handling, and usually a cheapening of the processes derived from manipulation (handling, shipping, etc.).

For the moment, it can be concluded that in terms of fidelity, centrifugal lost-wax casting means better results than ceramic shell lost-wax casting for archaeological reproduction purposes of little artefacts, but none of both are able to ensure scale maintenance, nor avoiding shrinkages or deformations. Both methods involve costly and difficult processes, sometimes also risky, which pose a high handling time and require a fairly specific infrastructure. By the other hand, cold-casting with artificial metals ensures faithful results keeping the original scales 1.1, while they much faster working processes and they can be cast without specific infrastructures. Furthermore, they are much lighter than whole metal casts, and they are cheaper to produce, using much less metal.

—Morphological results

The morphological behaviour of artificial metals is similar to other composites: the particles are bonded in a resin matrix forming a heterogeneous material, which, at first glance, looks like a metal. The metal filler exerts thus a dual function as structure and as aesthetic agent. (Herrero *et al.* 2016, p . 141-145) In an image obtained by SEM [Figure 6 (A)], particles of atomized bronze (106 µm), with irregular morphology can be seen conglomerated in a polyester matrix. The variety of forms of these particles helps to achieve a strong bond between the polymer and the filler. Buckling strengths to 80 Mpa have been reached with this kind of composites (Herrero *et al*. 2016, p. 143). The metallic appearance is obtained by saturation of metal filler, and, specially, due to a surface polishing treatment, that can be observed in the upper region of the SEM composite image [Figure 6 (B)].

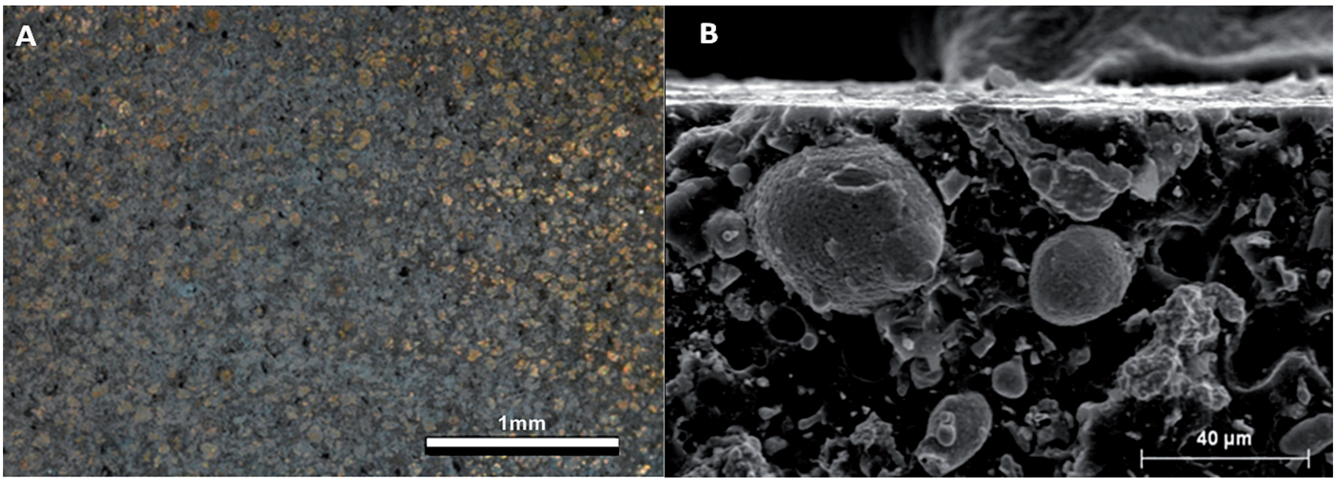


Figura 6.- [A] Image obtained with binocular microscope, at 30x, from a sample with NH_3 patina developed on surface after 12 hours of vapour action. Note the dark brown hue colour under the bluish salts. Some particles have been eroded to make them visible. [B]: SEM image of a bronze-polyester composite. Note the irregular morphology of particles, and the glittering of surface after polishing.

While such kinds of fillers are not noticeable with the naked eye, when artificial metals are observed in magnified images, particles become visible. Hence, they do not distort the metallic finish appreciation of surfaces but they can also be easily identified, which avoids confusion of any kind. They meet, therefore, the discernibility criterion, which has become a must in conservation and restoration; the one that cast bronze reproductions cannot meet in any way. In fact, artificial metals reproductions can only be visually confused with metals, but not by touch or weight, so they are not susceptible to misunderstandings while they prevent any attempt of forgery.

—*Colourimetry*

The results provided the colourimeter –based on measurements obtained both before and after artificial ultraviolet aging–, reported the degree of change and the fading of colour that had taken the seized specimens.

Two measurements were performed on specimens of the groups E, L, X, and P. The E and L groups were composed of epoxy and copper and epoxy and bronze, and P and X groups, made up of polyester and copper and polyester and bronze. Three measurements were taken from each group.

Before aging, 12 shots were performed, and repeated over the same samples after aging.. After all, mean and standard deviation of values was calculated, as well as the variation of the chromaticity coordinates L *, a *, b * with the formula $\Delta E= \sqrt{} [\Delta L]^2 + [\Delta a]^2 [\Delta b]^2$. Table 2 shows the mean and deviation of L *, a *, b *, for each of the groups of samples. The two yellow results (X and P) correspond to polyester resins. Note that polyester values are below 3 points, so alteration is not visible to the naked eye. However the E and L groups, (red and orange respectively), do experiment a higher change of colour after UV aging. While polyester matrix specimens do not seem to mutate in excess, those ones agglomerated with epoxy resin are closer to the values of +b corresponding to yellow, and also suffer a slight retraction toward +a, corresponding to the spectrum of the red. For this to be seen in a more representative way, a graph of colour deviations is presented [Figure 7]. However it should be noted that these colour changes in the resins are not perceptible to the naked eye, especially if surface is burnished after demoulding the composite, which generates the typical metallic finish, on which the colour of the resin is not significant, unlike in artificial stones, in which whiter mineral fillers are used. In addition, if composites are patinated, the colour change of the resin will be invisible under the oxidation layer. From all this it can be concluded that both resins are functional for releasing reproductions of archaeological artefacts with artificial metals, although if it is considered that copies may be exposed to the weather is better to select polyester composite.

—*Statistic approach*

The statistic study evaluated the effectiveness of artificial metals on artistic or archaeological reproduction purposes. Respondents had the original artefacts and their respective cold-cast copies shown. They had to determine which ones were the originals and which ones the reproductions. The 77% of respondents failed on determining in one (49%) or both of the cases (28%) which were the original artefacts. Only 23% were able to successfully distinguish both original items [Figure 8 (A)]. Up to 96% of respondents admitted that guessing which ones were the original items became a matter of chance. An 86% of public considered it a very effective solution, and they also expressed the difficulty in discerning between the two kinds of objects [Figure 8 (B)]. Only a 4% stated that artificial metal reproductions were not effective at all in such purpose. But the following data must be considered: all that 4% were people who had identify successfully both reproductions. Thus, they all considered that copies were not effective enough, stating that they had been able to identify both original items.

Conclusions

Lost wax casting procedures (both by ceramic shell castings and centrifugal ones), are used successfully in sculpture production, for artworks casting, but they don't have enough precision to reproduce mimetically archaeological artefacts, since such kinds of castings suffer shrinkage and eventual deformations, being unable to keep the scale and achieve a perfect register of surfaces. Furthermore, the use of bronze casts can suppose confusions and eventual attempts of forgery. Thus, such kind of reproductions should be avoided for these purposes.

Artificial metals become useful materials in archaeological metallic reproductions. Their use instead of bronze castings in the field of conservation and prevention has special benefits. The first one is the maintenance of the scale 1: 1. The use of these composites means a weight reduction if compared with metals, which furthermore implies ease of handling for larger pieces, reduction of safety risks, lower need for infrastructures, and of course, lower costs. By using artificial metals a methodological simplification of procedures is carried, which means a notorious save of time and an increase of the process speed, which therefore supposes higher profitability of production. Artificial metals have also capability of reproducing any metal with multiple available finishes, even glowing, or corroded. The last, but maybe the most important advantage in the use of these composites in the field of conservation is the material differentiation; there is no possibility of confusion with an original artefact, if touched or looked very close. A plain touching is enough to reveal the semi-metallic condition of material, due to its temperature and feeling.

Tabla 2.- Mean and standard deviation of the chromaticity coordinates a*, b* y L*, and total colour variation of epoxy (E & X) and polyester (L &P) bronze composites.

Ref.	a*	a* (After)	Δa*	σ	b*	b* (After)	Δb*	σ	L*	L* (After)	ΔL*	σ	ΔE
E	3,18	3,39	0,21	0,15	12,30	21,12	8,82	6,23	23,79	22,88	-0,91	0,64	8,87
X	2,13	2,25	0,12	0,08	15,54	15,82	0,29	0,20	29,60	30,88	1,29	0,91	1,33
L	1,10	3,02	1,91	1,35	19,60	26,40	6,80	4,81	28,08	29,23	1,15	0,81	7,16
P	3,57	3,31	-0,26	0,18	12,32	12,51	0,19	0,13	27,67	27,79	0,12	0,08	0,34

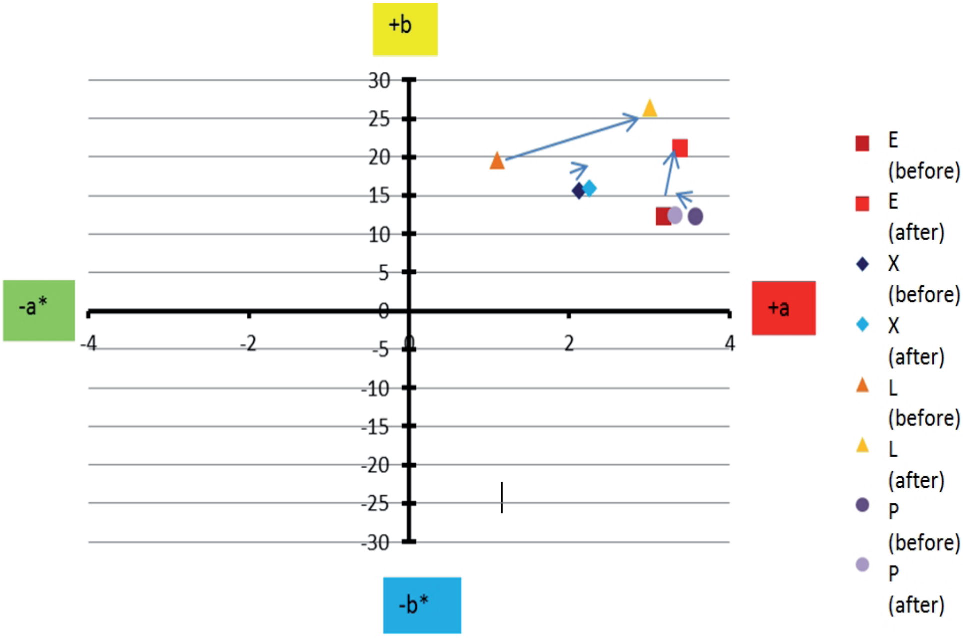


Figura 7.- The geometric symbols represent groups of aged specimens, where E and L are epoxy mixtures, and X and P polyester blends. Note the short variation undergone by the circle and the diamond with polyester matrixes, and the most remarkable variation suffered by triangle and square, both epoxy resin composites.

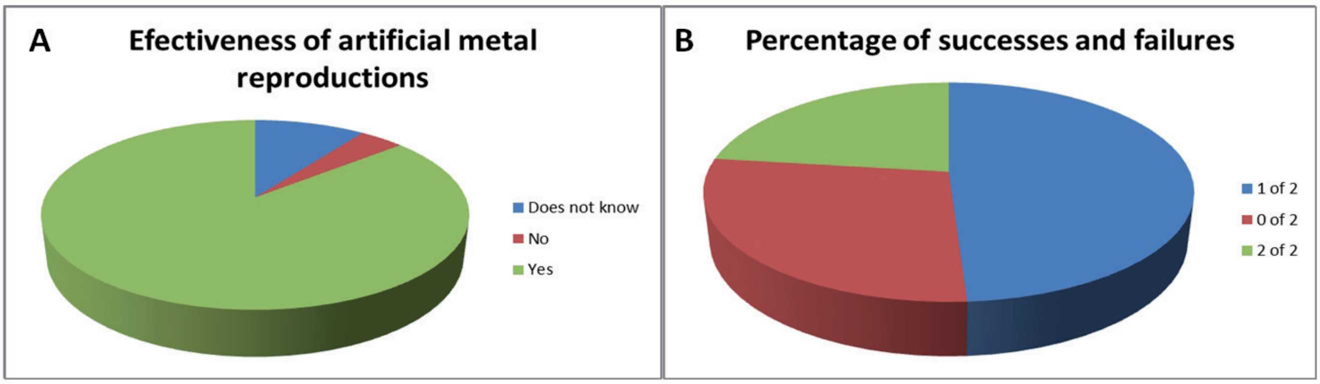


Figura 8.- A) The graphic shows the opinion of respondents about the effectiveness of artificial metals in archaeological reproduction purposes. Note that people who stated that artificial metals were not effective enough (4%), had been able to identify original artefacts in both cases. B) The graphic shows the percentage of successes and failures in the identification original artefacts with the naked eye. Note how almost the half of respondents failed at least in one case. The percentage of people who had two successes (28%) or two failures (23%) were very similar.

Therefore, artificial metals turn out to be helpful materials for casting archaeologic reproductions, even considering the modern 3D metal printings. Although these new 3D (both scanning and printing) technologies may appear to be very accurate they may have also several problems of access, cost and precision in the reproduction. Furthermore, very specific (and expensive) equipment and software are required, being in addition difficult to manage and work with. Such technologies may not always be available to many cultural institutions, especially because reproductions do not use to be a priority when designating the resources. Hence, artificial metals for such purposes become a more accessible choice, in terms of human resources, infrastructures, and economic bulk. But anyway, in perhaps the future, artificial metals will be a print media material, considering the increasing developments in three-dimensional printing.

Acknowledgements

The authors would like to thank and recognise their collaboration to PhD Clara Gomez Clari and Andres Cantarero, chairmans in the Instituto de Ciencia de los Materiales (ICMUV) de la Universitat de València. Thanks also to PhD Borja Franco, who directed the statistic work; and finally, to PhD Jose Aparicio, Director of Sección de Estudios de Arqueología y Prehistoria of the Real Academia de Cultura Valenciana, (RACV).

Notes

[1] "*la extraordinaria calidad de registro superficial de los resultados obtenidos por medio de esta técnica, unido a unas especiales condiciones entre las que destaca fundamentalmente la mínima intervención que sufre la obra original*". This premise is not entirely accurate, since it is recalled that obtaining a silicone mould might suppose a potential additional stress procedure for the original piece, and usually previous studies on separators are convenient to ensure the safety of the process. Furthermore, except for the techniques of microfusion, which allow a good record, lost wax casting presents medium results for this purpose. Subtle surface textures can disappear at different stages of the process due to handling and contraction, assuming small defects in reproductions.

[2] The survey was done for the final grade thesis on Art History Grade, in Universitat de Valencia, and was directed by PhD Borja Franco.

References

AGUILAR GALEA J. A. (2004). "La microfusión de cascarilla cerámica: una técnica adecuada para la reproducción en bronce de piezas arqueológicas", *Antiqvitas* 16: 151-163.

AGUILAR GALEA J. A. (2005). "Las técnicas de reproducción escultóricas como instrumento para la pervivencia del patrimonio arqueológico: los ídolos de Morón", *Antiquitas*, 17: 169-172.

CAETANO HENRÍQUEZ, E. (2012). "La producción escultórica en la era digital: una tríada entre la industria, la formación y la creación artística contemporánea", ASRI: *Arte y sociedad. Revista de investigación*, 1: 4-8.

CATALÁN, E.; MARCOS, A. (2008-2009). "Informe sobre la copia de una placa de bronce con inscripción, procedente de la ciudad romana de Andelos", T*rabajos de Arqueología Navarra*, 20: 311-322

CRASBORN, J.; ORREGO, M. (2007). "La elaboración de réplicas: un instrumento de conservación y protección al patrimonio cultural". En *XX Simposio de Investigaciones Arqueológicas en Guatemala,* Ciudad de Guatemala: Museo Nacional de Arqueología y Etnología, 187-199.

ENGEL, G. (1988). "Die Rekonstruktion eines silbernen Monumentalkreuzes aus der Karolingerzeit (Peterskirche zu Rom)" *Arbeitsblätter für Restauratoren*, 21: 103-111.

FERNÁNDEZ CAÑEDO, F. J. (2015). *Materiales y técnicas empleados durante el moldeado y copia de una escultura en bronce del escultor Paul Troubetzkoy*. (Tesis final de Máster) Valencia: Departamento de Conservación y Restauración, Universitat Politècnica de València.

GARCÍA DÍEZ, S. (2012). "Resinas de poliéster + colorantes = piezas escultóricas". *Revista Iberoamericana de Polímeros*, 13: 11-19.

GARCÍA DIEZ, S. (2013). "Resinas de poliéster+ cargas de relleno= piezas volumétricas". *Revista Iberoamericana de Polímeros*, 14: 101-107.

GARCÍA ROMERO, A. et al. (2007). "Resultados y función de procesos de investigación sobre intervención en esculturas del patrimonio" En *III SOPCOM, VI LUSOCOM E II IBÉRICO*, Volume I. Coimbra: Universidade de Coimbra, 487-494.

GILROY, D. (1976). "The use of metal powder impregnated resins for replica and restoration work". *ICCM Bulletin*, 2.1: 30-32.

GISBERT, S.; ORTÍ, V.; ROIG, J.L., (2006) "Application of new material release agent - interface support /silicone rubber - in the reproduction of porous pieces", in *16th International Meeting on Heritage Conservation*, 2-4 Noviembre, Valencia, Editorial UPV, Valencia Vol. I, 655-664.

GROOVER, M., (1997). *Fundamentos de manufactura moderna: materiales, procesos y sistemas*. Mexico: Prentice Hall Hispanoamericana.

HERRERO M.; CULEBRAS , M. (2014). "El 'metal artificial' en la obtención de reproducciones arqueológicas y escultóricas. Breve estado de la cuestión". En EMERGE, *Jornadas de Investigación Emergente en Conservación y Restauración de Patrimonio.* Valencia. Universitat Politècnica de València, 461-470.

HERRERO, M., *et al*. (2016). "El 'bronce artificial' en la reproducción de objetos arqueológicos, escultóricos y ornamentales. Una solución para la conservación preventiva y la divulgación del patrimonio metálico". In *MetalEspaña* 2015, 139-148.

HERRERO, M.; CULEBRAS, M.; MAS-BARBERÀ, X. (2017). "Metales artificiales en aplicaciones escultóricas: matrices termoestables y cargas metálicas". *Revista Iberomericana de Polímeros*, 18, Vol 18, nº 1, pp. 21-37..

HUGHES, R.; ROWE, M. (1982). *The colouring, bronzing and patination of metals, a manual for the fine metal worker and sculptor.* London: The Crafts Council.

LAMBERT, D. (2002). M*oulage et fonderie d´art: Du modèle au bronze fina*l. Torino: Vial.

LEDDON, G. (1947). L*os métodos más modernos y prácticos para la limpieza, coloreado y preservación de los metales.* Barcelona: Ossó.

LIPSON H.; KURMAN M. (2014). *La revolución de la impresión 3D.* Madrid. Anaya Multimedia.

LOWE, A. (2003). *La Dama de Elche: Digital Technology in Conservation*, Madrid: Factum Arte, 2003.

MARCOS, C. (2000). *Fundición a la cera pedida: Técnica de la Cascarilla Cerámica*. Tesis Doctoral. Valencia: Departamento de Escultura, Universidad Politécnica de Valencia.

MARCOS, A. (2003). "Copias y preproducciones arqueológicas. Resumen histórico y función en los museos". En *XIII Cursos Monográficos sobre el Patrimonio Histórico*. Santander: Universidad de Cantabria, 31-40

MARTÍNEZ, S.; MAS-BARBERÀ, X.; KRÖNER S. (2009). "La reposición como medio de reconocimiento histórico-estético y funcional. El caso de la portada del sol de la Basílica de Santa María, Elche (Alicante)". En *IV Congreso del GEIIC*. Cáceres: Universidad de Extremadura, 261-266.

MAS-BARBERÀ, X. (2006). *Estudio y caracterización de morteros compuestos para su aplicación en intervenciones de sellados, reposiciones y réplicas de elementos pétreos escultórico-ornamentales*. (Tesis doctoral). Departamento de Conservación y Restauración de Bienes Culturales. Valencia: Universitat Politècnica de València.

MAS-BARBERÀ, et al. (2010). "Análisis y aplicación de separadores en el moldeado de originales. El busto fenicio de Puig des Molins, Ibiza". *Arché*, 4.5: 45-52.

MAS-BARBERÀ, X.; KRONER, S., MARTÍNEZ, M; et al. (2013). "Application of the double layer system as preventive method in the moulding process of sculptures and ornament". In *Science and technology for the conservation of cultural heritage*. CRC Press Taylor and Francis, 329-332.

MATTEINI, M.; MOLES, A.; TOSINI, I. (1990). "Interazioni tra i materiali costitutivi dei manuffati e le sostanze utilizzate per il calco: controllo di alcune procedure", in *De Sculture da Conservare. culture da conservare. Studi per una tecnologia dei calchi*. Milano: Vallardi & Associati, 138-147.

MORENO PORTILLO, J. W (1993). Obtención de ceras para el proceso de fundición a la cera perdida. *Ingeniería e Investigación,* 29, 26-33.

NEGRETE, A. (2003) "Las reproducciones de esculturas: del mármol a los materiales imitadores". En *XIII Cursos Monográficos sobre el Patrimonio Histórico*. Santander: Universidad de Cantabria, 77-88.

PANCHI, V. F. (2009). *Proceso de electrodeposición de metales sobre una base polimérica*. (Tesis Doctoral). Facultad de Ingeniería Mecánica. Quito: Universidad Politécnica Nacional.

PERCY, H. M. (1962). *New matherials in sculpture*. London: Alec Tiranti.

PEREIRA, C., (2008). *Conservar la información. Clones y documentación*. Madrid: Universidad Complutense de Madrid. Facultad de Bellas Artes.

PÉREZ, L., et al. (2009) "Tradición e innovación en las artes industriales: el palio de plata de 1871 de F. Isaura". *Revista ph*, , 69: 20-33

PONCELET, E.; TEXIER, A. (2001). "La restauration de la fontaine des Mers, Place de la Concorde, Paris". *Monumental*, n/n: 138-145

SCOTT, S. (2012-2013) "The development of artificial Stone". *Institute of Concrete Technology Bulletin*, 1: 9

SPENIK, R. (1998). *Succesful cold-casting and mould making*. London: Stobart Davies.

TYLECOTE, R. F. (1976). *A history of metallurgy*. London: The Metals Society.

ZHANG, F., CAMPBELL, R. I., & GRAHAM, I. J. (2015). "Application of Additive Manufacturing to the Digital Restoration of Archaeological Artifacts". *Procedia Technology,* 20: 249-257.

Miquel Angel Herrero-Cortell
miquelangel.herrero@hahs.udl.cat
Centre d'Art d' Època Moderna CAEM, Universitat de Lleida. Colaborador del Instituto de Restauración del Patrimonio, IRP, Universidad Politécnica de Valencia

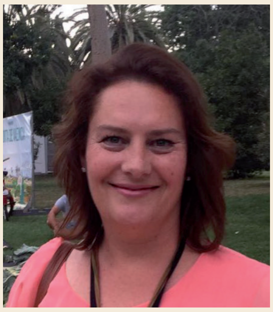
Miquel Herrero-Cortell es licenciado en Bellas Artes por la Universidad Politécnica de Valencia (UPV) y licenciado en Historia del Arte por la Universidad de Valencia (UV), Máster en Conservación y Restauración de Bienes Culturales y Máster en Producción Artística. Actualmente se encuentra cursando estudios de Doctorado en Historia del Arte en la Universitat de Lleida (UdL). Colaborador del Instituto de Restauración del Patrimonio (IRP) de la UPV, y del Instituto de Ciencia de los Materiales de la Universidad de Valencia (ICMUV). Ha desarrollado su labor como investigador centrándose en el ámbito de las reproducciones de bienes patrimoniales, en la conservación y restauración de objetos arqueológicos, así como en el estudio físico y óptico de diversos materiales artísticos. En la actualidad desempeña su labor investigadora en el Centre d'Art d'Època Moderna (CAEM) de la UdL.

Xavier Mas-Barberà
jamasbar@upvnet.upv.es
Instituto de Restauración del Patrimonio, IRP, Universidad Politécnica de Valencia

Xavier Mas-Barberà. Profesor Titular de Universidad en el Departamento de Conservación y Restauración de Bienes Culturales de la Facultad de Bellas Artes de la Universitat Politècnica de València (UPV). Investigador miembro del Instituto Universitario de Restauración del Patrimonio (IRP) de la UPV, en el Taller de Escultura y elementos Ornamentales. Participa en diversos contratos y proyectos de I+D+i y dirige diferentes proyectos de investigación desarrollando nuevas metodologías basadas en la aplicación de técnicas y materiales en los procesos de tratamiento y reproducción de obras de arte. La relevancia de estos trabajos queda patente en diversas publicaciones en revistas nacionales e internacionales, actas de congresos especializados y contribuciones a libros.

Carmen Marcos Martínez
cmarcos@esc.upv.es
Instituto de Reconocimiento Molecular y Desarrollo tecnológico, IDM Universidad Politécnica de Valencia

Carmen Marcos Martínez es profesora titular de Fundición Artística en el Departamento de Escultura de la Facultad de Bellas Artes de la Universitat Politècnica de València (UPV), e investigadora en Instituto Interuniversitario de Investigación de Reconocimiento Molecular y Desarrollo Tecnológico, (IDM) de la UPV. Especialista en escultura, ha desarrollado su carrera como artista y como investigadora en técnicas de fundición.



Montserrat Lastras Pérez
monlaspe@crbc.upv.es
Departamento de Conservación y Restauración de Bienes Culturales. Universidad Politécnica de Valencia

Doctora por la Universitat Politécnica de Valencia, en el programa de Conservación y Restauración de Bienes Culturales en 2007 y Licenciada en Bellas Artes con la especialidad de Restauración. Especialista en el campo de la conservación y restauración de materiales arqueológicos, desde 2004 docente e investigadora del Departamento de Conservación y Restauración de Bienes Culturales de la UPV en los títulos de Grado y Máster. Responsable de la asignatura en el Grado en Conservación y Restauración de Metales y asignaturas de máster en Conservación y Restauración de Metales Arqueológicos y Conservación y Restauración de Dorados, ha dirigido numerosas tesis de grado y máster en relación a estos temas. Ha dirigido y participado en numerosos proyectos de investigación, catalogación e intervención de materiales arqueológicos, nacionales e internacionales, destacando La conservación y restauración de la ciudad Maya de La Blanca, Petén, Guatemala y la conservación y restauración de los restos metálicos de Torre la Sal, Cabanes, Castellón.

Ha publicado numerosos artículos en revistas nacionales e internacionales como, por ejemplo, en Microchemical Journal, Solid State Electrochem y Forensic Science International. Es co-autora del libro La Conservación y restauración de la azulejería (2006).

Mario Culebras-Rubio
mario.culebras@uv.es
Instituto de Ciencia de los Materiales, ICMUV Universidad de Valencia

Mario Culebras es graduado en Química por la Universidad de Valencia, (2011), y Master en Ciencia y Tecnología de Coloides e Interfaces (2012). Actualmente se encuentra finalizando sus estudios doctorado en la Universidad de Valencia bajo la dirección de Andrés Cantarero. Sus investigaciones se centran en el ámbito de los materiales poliméricos de tipo termoestable, termoplástico y elastomérico, además del desarrollo de semiconductores orgánicos y nanocomposites para diversas aplicaciones.

Artículo enviado el 05/08/2016
Artículo aceptado el 08/02/2017