SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 7, No. 2, (2021), pp. 69-79
Open Access. Online & Print

DOI: 10.5281/zenodo.4465536

NON – DESTRUCTIVE XRF ANALYSIS OF METALLIC OBJECTS FROM BENAKI MUSEUM OF ISLAMIC ART

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Received: 10/11/2020
Accepted: 25/02/2021

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ABSTRACT

Islamic art is present around the world, Benaki Museum, Museum of Islamic Art (Athens, Greece) has a collection of various objects, a part of this collection was studied through portable XRF analysis. The objects that were studied are sixteen (16) metallic Islamic artifacts; three candlesticks, six basins, a cup, an ewer, two compasses, two pen boxes and an incense burner. These artifacts are dated in the 13th to 15th century, with origin from Iran, Syria, Turkey and Egypt, and are of great aesthetic value and the unique metalworking techniques revealed by their shapes, decorations and complex manufacturing alloys. Portable X-ray fluorescence analysis provided information about the artifacts' construction materials, which were mainly copper, zinc, iron, lead, tin and nickel.

KEYWORDS: Islamic Art, Metalwork, 13th – 15th century, X-ray Fluorescence Analysis

1. INTRODUCTION

This research studies results of the XRF analysis of a part of the Islamic collection from the Benaki Museum, Museum of Islamic Art. The objects of the collection are 16 Islamic metalwork artifacts and vary in their use, there are 3 candlesticks, 6 basins, a cup, an ewer, 2 compasses, 2 pen boxes and an incense burner. They are dated in the 13th to 15th century and derive from Iran, Syria, Turkey and Egypt (Fig.1).

Minerals and ores are the main source of metals in order to produce metallic artifacts. Metals and alloys vary, metalworkers created alloys that were not always manufactured on purpose, but minerals were not always that pure, having traces of other metals that the metalworkers did not even know their existence, is common (Forbes 1971).

Islamic metalwork is high ranked in Islamic art's hierarchy, due to the unique construction techniques and decoration, such as the various metals that were used. Islamic art consists of all the arts that bloomed in the region that Islam was the main religion (Fig.1).

The X-ray fluorescence analysis was conducted with a non-destructive method aiming to the identification of the artifacts' construction materials. The study's results are documented and the construction materials, enlist the artifacts as classic Islamic art metalwork, without an extend use of precious metals.

Figure 1 Map of the Islamic World around 1300 A.D. (Museum of Islamic Art, Benaki Museum, Athens, Greece).

2. ISLAMIC ART & METALWORKING

Islamic art is a term used in order to categorize all the artistic work that was made in the Islamic region, including all the cities that were under the Islamic influence, such as areas in North Africa, East Europe, Russia, India, China etc. (Fig.1). It is important to mention that the artifacts are not only connected to religion or are related in any way to their craftsmen's religion (Jenkins-Madina et al 2001, Blair et al 2003).

Metalworking in Islamic art has a tremendous tradition, each city and region has its own characteristics and techniques, all affected by Islam giving a common cultural identity. Each category had specific techniques, therefore the metalworkers usually mastered the art of one of them. The basic categories of metallic objects include tools and scientific instruments (compasses and astrolabes were used by sailors from the 3rd to 18th century A.D.), kitchen utensils (bowls, basins, sprinklers for perfumed water, incense burners, cups, plates, ewers, jugs, cauldrons, ladles), various lighting devices (lanterns, candlesticks, lampstands, lamps, candelabras are known to be found in Spain and Tunisia with exceptional decorations) and furniture for multiple usage (Ward 1993, Allan 1986, Bloom and Blair 2009).

A unique category is weapons, such as swords, blades, armors and many more. Swords and helmets made of iron with gold and silver decorations have been found. Steel armors were manufactured with arabesque and inscriptions made of gold and silver and

their spears were made of damask steel with gold inlays. Various sizes of blades existed with ivory and bone handles, while sword handles were made of carved steel with inscriptions from the Koran (17th century), decorated with semiprecious stones, with patterns of leafs and flowers or parts from poems usually in daggers. In the 14th century in India weapons, cannons, grenades and rockets were introduced by metalworkers. In Iran there were the famous double axes that were held with one hand (Ward 1993, Bloom and Blair 2009).

Islamic metalwork may be lacking of objects for worship purposes as they were not necessary in the Islamic religion, but luxurious furniture, ornaments, silver doors with gold doorknobs are common in temples, such as silver plaques with the names of their donators (Bloom and Blair 2009).

2.1 METALWORKING TECHNIQUES

In Islamic metalworking, craftsmen used mostly gold, silver and alloys of copper (brass and bronze), tin, lead and iron. Steel was used in weapons and doors. The so called "white copper" was used as a replacement of silver as at times there was a lack of the metal, this was an alloy of copper with high amount of nickel, hence the silver-colored appearance (Baer 1983).

The techniques that were used to create a metallic artifact vary as the craftsmen progressed in tools and materials. A technique's category may have numerous methods, for instance casting could be done in moulds (open, piece or false cored moulds), or via the lost wax method, where the object was modeled in wax, inside a clay mould, the metal was poured over and the wax melted leaving the metal take its form. In Islamic artifacts with a lattice form, a unique version of the lost wax method was used, as they created the clay mould out of green sand, the lack of moisture in it made it easier to use as there was no heating or drying required before they poured the molten metal. A large amount of objects were manufactured from multiple parts, for their attachment craftsmen usually used the soldering method, a soft metal was used as "glue" in order to join them, however, there were other techniques; metallic nails, running on, burning on, welding, that was a quite interesting method, as the two metal parts were heated and joined through hammering (Baer, 1983; Hodges, 1989).

Cold working copper alloys was common, annealing, hammering, sinking, striking (used in coins and medals) are some of them. During the cold-working process metals tend to be very brittle, at that point the craftsmen had to heat them up again and cool them in water, in order to restart the process. The designs were remarkable as cutting and shaping the metals after being cold-processed was not as challenging. The raising method is probably the most difficult, as they had to hammer the item on the outside to create its form, but the complexity and variety of objects that could be made placed it high in the craftsmen's preference. Objects were often manufactured from a single metal sheet (made from metal rods), the process was complex and required multiple tools (lathes, anvils, hammers, knives, chisels etc.). (Hodges 1989; Mattusch 1988).

Decoration techniques vary in forms and methods, objects were carved, pierced (creating lattice forms), incised, inlayed with gold, silver or copper. Carving soft metals as copper and its alloys, with knives and sharp tools, created perforated objects of great aesthetic value. Niello is a kind of inlay with a silver, copper, lead and sulfur alloy, creating black patterns on silver. Plating with a precious metal was common, gilding and silvering were the most known and used methods, such as the use of gold leafs. The repousse technique is quite known, in which a metallic sheet is hammered from the back, as it is placed in an auxiliary bedding of leather, sand and later on, bitumen, designs were embossed or intaglio. Damascene decoration (from Damascus, Syria) is a method used to inlay a metal to a substrate metal by hammering it into place into a pre - carved pattern. However, there were other forms of this method, one of them is the False Damascene, as the metal is not inlaid but placed upon an incised substrate and sometimes heated too. Wired patterns from soft metals like gold are preferred as they were easy to create, such as, small pellets of molten metal that were applied in cold water and then soldered of hammered onto an artifact. They usually smoothed the surfaces by applying or soaking the items in acid (Hodges 1989 & 1992; Mattusch 1988; Maryon 1971; Todd et al 1994; Untracht 1986; Baer 1983; Lasseter – Clare et al 2008; La Niece 2009; Shen 2017; Thompson 1998).

3. **STUDIED METALLIC ARTIFACTS**

The part of the collection of Islamic artifacts that is studied is originally in the permanent exhibition of the Museum of Islamic Art, Benaki Museum, Athens, Greece (Figs 2, 3, 4). There are objects of unique Islamic metalwork with inlaid decoration, derived from Iran, Syria, Turkey and Egypt, placed chronologically from the 13th to 15 century A.D. (Fig.5). Artifacts made of brass with gold, silver and copper inlays were massively produced around the 12th century A.D. in Iran. Mosul, Syria, Damask and later on Cairo became important metalworking centers from the 13th century. Metalworking decorations were affected from the previous years, there are a lot utensils decorated with everyday life illustrations, astrological symbols etc.,

but they were shortly replaced with inscriptions of the Mameluke era. The artifacts have an unknown inlaid black compound on their surface, assumed to be a decoration.[1]

Basins are manufactured by a single metal sheet through hammering, the ewer and the candlesticks are probably made piece by piece in moulds and then soldered together. The cup and the compasses seem to be crafted in single moulds, in item 13166 the lid is missing. Pen box, 1174, was made from thin metal sheets (with silver-colored pellets as decoration), the pen box, 13175, has a thick metallic core, probably made in moulds. The incense burner has a unique pierced body, with a repeating cross pattern. The inlays are characterized by color (gold –colored or silver colored) in order to differentiate them. All of them have an unknown black bituminous substance on their surface.

Figure 2 Basins inscribed with representation of horsemen or arabesque patterns (Museum of Islamic Art, Benaki Museum, Athens)

Figure 3 Candlesticks and pen boxes with inlays and black substance (Museum of Islamic Art, Benaki Museum, Athens)

[1] The information, descriptions and the photographs of the objects were provided by the Museum of Islamic Art of the Benaki Museum, Athens, Greece.

Figure 4 Compasses, cup, ewer (with inlays and black substance) and incense burner (Museum of Islamic Art, Benaki Museum, Athens)

Figure 5 Map of the Islamic World around 1300 A.D. (Museum of Islamic Art, Benaki Museum, Athens, Greece) - Main areas of the studied objects' origin

4. PORTABLE X-RAY FLUORESCENCE ANALYSIS

The objects have particular characteristics that could categorize them but a physicochemical analysis could provide with specific information about the construction materials and techniques.

It was necessary to have a quantitative and qualitative analysis, hence the use of the X-ray fluorescence spectroscopy (XRF), as it provides information about the elemental atomic structure or the microcrystalline structure of solid materials and identifies traces. It is widely used on metallic objects in order to determine the construction materials, which is the main objective of this study (Beckhoff, 2006; Kousouni and Panagopoulou, 2018; Laskaris et al, 2020).

The surface to be examined, should be flat and the same size as the fixed reference material calibrated by the device. The object and reference material are placed on the spectrometer in the same position and at the same angle with respect to the guide and the primary X-ray beam. In order to collect valid quantitative results, the elements should be homogeneously distributed in the analysis volume, and that is required for the whole sample. The homogeneity is usually impaired by conservation treatments, in this case the objects of the collection have gone through me-

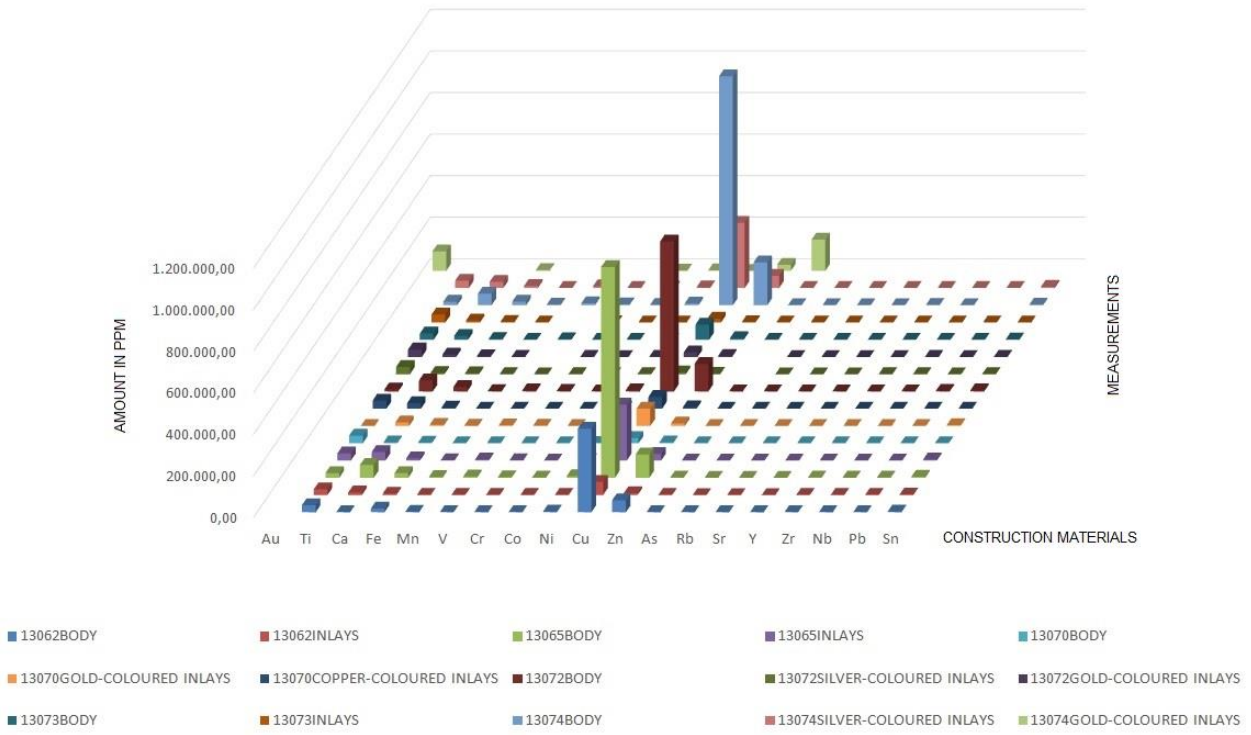
chanical cleaning, and thus the samples were not affected. The many layers of a surface can contribute to inconclusive results, to prevent this the analyzed areas were representative of each artifact and did not have any kind of deposits or corrosion. X-ray Fluoresence Analysis can be challenging when performed with a portable device on a stratified surface, but a properly calibrated PXRF could provide measurements that could be easily interpreted. The detected construction materials provide information that could help the classification of the objects and contribute to the apprehension of multiple manufacture technologies (Karydas, 2007; Trojek and Bartova, 2018).

X-ray Fluorescence Spectroscopy (XRF) was performed with a portable instrument, Skyray EDX Pocket III. The EDX-Pocket Series Handheld X-ray Fluorescence Spectrometer can detect at least 24 chemical elements (ppm precision), in solid, liquid or powder form, with detection limit 0,001% - 0,01%. The excitation source has 40KV / 50uA-Ag as an anode with integrated X-Ray tube (mini W-Target X-Ray Tube). Its high intensity and short measurement time (10 to 200 seconds depending on variables), can contribute to a precise handheld mode, with 0,05% - 1% deviation, as it has in-built modes for correction and calibration. The X-ray source uses a collimator (6mm) designed to automatically focus, in order to eliminate any improper sample alignment, such as the Laser-Light, that insures an accurate reading location. The detection of the elements was performed after the factory default operation for metal alloys was set. As the artifacts of the collection have inlays and various decorations, the specific areas of measurements were decided in each one of them, according to the information needed to be extracted, on a flat, homogenous surface, without corrosion products as shown in Figure 6 (Skyray Instrument, 2018; Skyray XRF, 2006 & 2008).

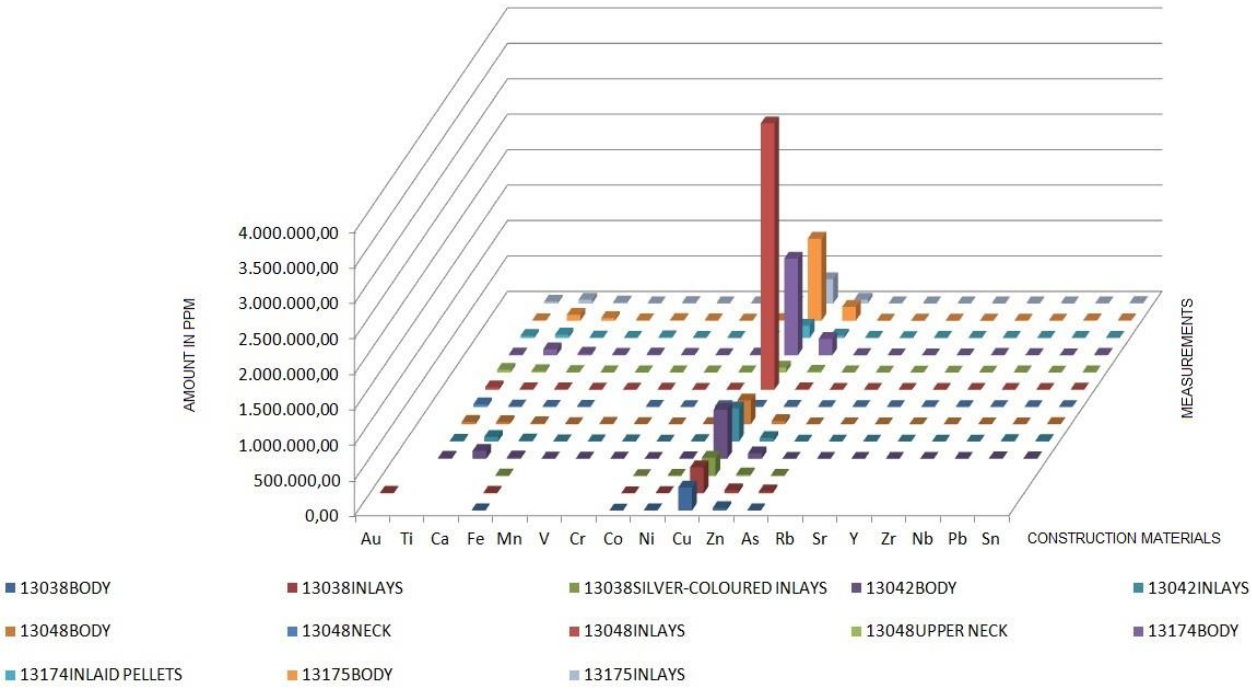
Figure 6 Candlestick (13038), Indicative examined surface (inlays) using X-ray Fluorescence Analysis

4.1 X-RAY FLUORESCENCE ANALYSIS - RESULTS

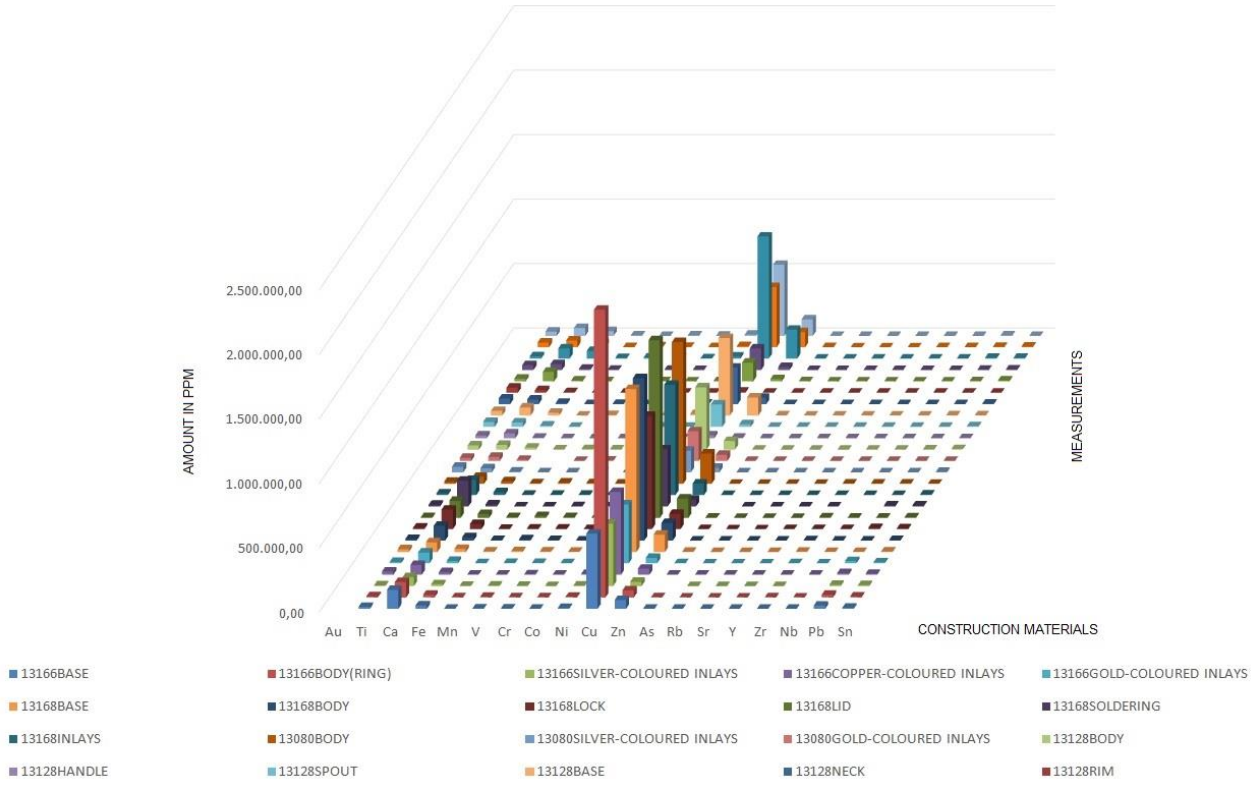
X- RAY Fluorescence Analysis was conducted with the portable Skyray EDX Pocket III (EDX- Pocket Series Handheld X-ray Fluorescence Spectrometer). The main construction materials were copper (Cu), zinc (Zn), iron (Fe), lead (Pb), tin (Sn) and nickel (Ni), although traces of multiple elements were found titanium (Ti), calcium (Ca), manganese (Mn), chromium (Cr), cobalt (Co), arsenic (As), strontium (Sr) and zirconium (Zr). The only precious metal found is gold (Au), only on the candlestick, 13038 and basin, 13074, on their inlays. The graphs below (Graph 1, 2 & 3) show the amounts (in ppm) of the found elements in each artifact.



Graph 1 X-Ray Fluorescence Analysis (Results in ppm) - Basins



Graph 2 X-Ray Fluorescence Analysis (Results in ppm) -Candlesticks, Pen Boxes

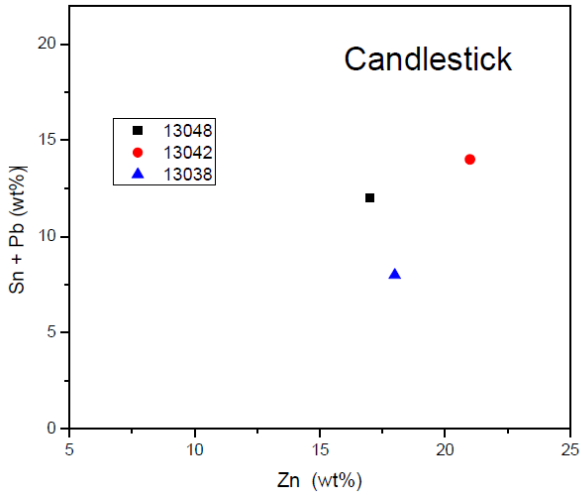


Graph 3 X-Ray Fluorescence Analysis (Results in ppm) - Compasses, Cup, Ewer, Incense Burner

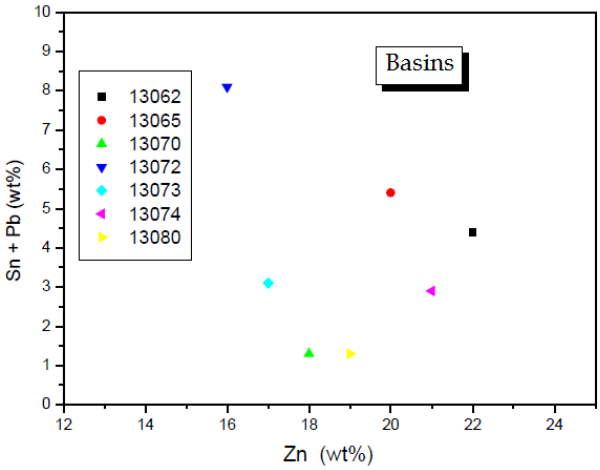
Based on previous researches (Orfanou et al, 2018) the alloys that were found were categorized according to the amount of particular metals detected in them. They are presented as it follows;

- Alloy I ; Copper (Cu) with high amount of lead (Pb)
- Alloy II; Copper (Cu) with high amount of tin (Sn)
- Brass (Copper, Cu, and zinc, Zn, alloy)
- Brass (Copper, Cu, and zinc, Zn, alloy) with high amount of lead (Pb)

A comparative study on groups of artifacts such as basins and candlesticks was conducted, in order to identify the sum of tin and lead (%) in comparison with the amount of zinc (%). The graphs (Graphs 4 & 5) have a fluctuated course as the objects of each group are different, being originated from multiple metalwork centers and metalworkers. The amounts of each metal, gave information about their availability and usage.



Graph 4 Comparative results Sn + Pb (wt %) to Zn (wt %), Candlesticks



Graph 5 Comparative results Sn + Pb (wt %) to Zn (wt %), Basins

The results were categorized due to the fact that their measurements were very different. In "Alloy I'' it was detected an alloy of copper and lead (Pb), with the latter in amount 2 to 8%, in "Alloy II'' an amount of tin (Sn) from 1 to 7% was found but without any Pb in the mix. Lead in the brass alloy was unexpectedly high in percentage (9 to 15%).

In Islamic metalwork, complicated decorations are a common characteristic, thus, the metals and alloys used in each decorative category are recorded, according the time and the place. For example, it was common for metallic inlays to be forged and leveled to the substrate metal sheet, in the studied collections' items, the metallic inlays were placed higher than the substrate metal creating an embossed surface.

The metalworking centers and laboratories are scattered in the Islamic world although some of them are more known. Based on the decorations and metals used, the objects could be products of the Khorasan workshop in east Iran and Afghanistan (Fig.7), which was a contemporary metalwork center of that time, as well as the Herat laboratory, the Fars laboratory in west Iran and the workshop of the well – known metalworker Mahmud Al Kurdi. Herat's laboratory was a tremendous source of items with unique inlays, manufactured in molds or forged, usually made of bronze or brass due to the lack of silver at the time, in the Museum of Islamic Art in Doha, Qatar, there are copper objects with silver inlays and the unknown black compound. Fars laboratory bloomed during the 14th century A. D. with craftsmen gathered from the region that created a metalwork center that caused mass production of metallic artifacts, with extraordinary decorations made of copper with gold and silver inlays, such items are in Lyon Museum of Fine Arts. Mahmud Al Kurdi was one of the most known and respected craftsmen during the 15th century A. D. in west Iran, his work with the unique shapes, decoration patterns and inlays, became really popular and crossed across the continent all the way to Venice, some of them are displayed in the Victoria and Albert Museum in London (Orfanou et al, 2018; Porter, 2012; Komaroff, 1994; Bloom and Blair, 2009).

An important aspect of the extended use of copper is that it may be a substitute for silver. During the 12th century A.D. the lack of silver was noticeable, even though it has yet to be confirmed. However, silver inlays were common during the bloom of Islamic metalwork (Allan, 1976).

Figure 7 Map of the region of Khorasan adapted from Google Earth 2019

5. CONCLUSIONS

The studies for Islamic Art and particularly for metallic artifacts are numerous. Metalworking techniques and decorations vary according to the place, time and craftsman. The complete manufacturing process, including the materials used, is an important characteristic in order to classify the artifacts. Decoration became an art of its own form, as the techniques bloomed through the centuries.

The choice of these particular artifacts is not random, their origin from the center of the Islamic World and their classic Islamic form was an important aspect to be studied, it requires a lot of effort to trace the trail of the materials' journey, from the mines, to the metalworkers and their final form as the unique artifacts that they are. The relations between areas are very important to be documented, as the characteristics of the metalworking techniques and decorations from different objects that come from various metalworking centers, have remarkable similarities.

The information given through the physicochemical analysis were a key factor into understanding the way craftsmen worked during 13th to 15th century A.D. X-Ray Fluorescence Analysis determined the construction materials to be copper, zinc, iron, lead, tin and nickel, such as Ti, Ca, Mn, V, Cr, Co, As, Rb, Sr, Y, Z, Nb in small amounts. The extended use of copper led to conclusions regarding the lack of silver at the time. The lack of precious metals is noticeable in the collection as only gold (Au) was found in the inlays of only two artifacts (Candlestick, 13038 and Basin, 13074). It is apparent that metalworkers used a variety of metals and had a good knowledge of how these metals would react in alloys and in processing.

This study is a step forward to understanding the value of the construction materials of metallic artifacts and the need of documentation in order to identify the similarities of numerous objects around the world.

ACKNOWLEDGEMENTS

This work was part of Master's thesis by CK, of the University of the Aegean, Laboratory of Archaeometry, Department of Mediterranean Studies, Post Graduate Program, "Applied Archaeological Sciences". We are grateful to the Benaki Museum – Museum of Islamic Art, Athens, Greece, especially to Mr. Paschalis Vassilis, Head of Department of Conservation for supporting this collaboration, Ms. Moraitou Mina, Curator of the Islamic Collection, for granting us permission to study the collection, Ms. Kotzamani Despoina for her valuable help during the study and physicochemical analysis, such as Ms. Foka Anthia and Zacharia Maria. Mr. Savvatis Dimitris and Ms. Vasileiou Greta were of great help during our time in the Museum. We would like to express our appreciation to Ms. Maria Perraki, Assoc. Professor, in the Department of Mining and Metallurgical Engineering of the National Technical University of Athens (NTUA) for her technical support and cooperation for the XRF analysis.

REFERENCES

Allan, J. W. (1976) *The Metalworking Industry in Iran in the Early Islamic Period, Vol. 1,* Oxford University Press, Oxford.

Allan, J. W. (1986) *Metalwork of the Islamic World, The Aron Collection*, Published for Sotheby's Publications by Philip Wilson Publishers Ltd, London.

Baer, E. (1983) *Metalwork in Medieval Islamic Art,* Published by State University of New York Press, Albany.

Beckhoff, B., Kanngießer, B., Langhoff, N., Wedell, R., and Wolff H. (2006) *Handbook of Practical X-Ray Fluorescence Analysis,* Published by Springer Verlag Berlin Heilderbeg, Germany.

Blair, S. S., Bloom, J. M., (2003) The Mirage of Islamic Art: Reflections on the Study of an Unwieldy Field, The Art Bulletin, Vol. 85, No. 1. (Mar., 2003), pp. 152-184

http://www.collegeart.org/pdf/artbulletin/Art%20Bulletin%20Vol%2085%20No%201%20Blair%20and%20Bloom.pdf (accessed in 17/3/2018).

Bloom, J., Blair, S. (2009) *The Groove Encyclopedia of Islamic Art and Architecture*, New York: Oxford University Press Inc.

Forbes, R. J. (1971) *Studies in Ancient Technology*, 2nd Revised Edition, Published by E.J. Brill, Leiden, The Netherlands.

Hodges, H. (1989) *Artifacts. An introduction to early materials and technology*, Published by Duckworth.

Hodges, H. (1992) *Technology in the Ancient World,* Published by Marboro Books Corp. a division of Barnes & Noble Inc., United States of America.

Jenkins-Madina, M., Ettinghausen, R. and Grabar, O. (2001) *Islamic Art and Architecture: 650–1250*, Published by Yale University Press, USA.

Karydas, A., G. (2007), *Application of a portable XRF Spectrometer for the Non-Invasive Analysis of Museum Metal Artefacts*, Annali di Chimica, 97, pp. 419-432.

Komanoff, L. (1994) Paintings in Silver and Gold: The Decoration of Persian Metalwork and Its Relationship to Manuscript Illustration, *Studies in the Decorative Arts* 2, no. 1 (FALL 1994), https://www.journals.uchicago.edu/doi/pdfplus/10.1086/studdecoarts.2.1.40662524

Kousouni, C-K. and Panagopoulou, A. (2018) Non -destructive Physicochemical Analysis and Conservation of Metallic Book Covers of Ecclesiastical Books from Saint Mavra and Timotheos Church in Zakynthos (Greece), *Scientific Culture*, Vol. 4, No 2, pp. 85-95. DOI: 10.5281/zenodo.1214571

La Niece, S. (2009*) Gold*, The British Museum Press

Laskaris, N., Varalis, I., Tsodoulos, C. and Dolmas, C. (2020) Evidence of Au –Hg Gilding Process in Post Byzantine Ecclesiastical Silverwares (Chalices) of Eastern Thessaly by PXRF, *Mediterranean Archaeology and Archaeometry* Vol. 20, No 1, pp. 189-203. DOI:10.5281/zenodo.3605677

Lasseter – Clare, T., Lins, A. (2008) *Finishing Techniques in Metalwork: An introduction to the History and Methods of Decorating Metal,* Published by Philadelphia Museum of Art, U.S.A.

Map of Iran and Afghanistan showing the region of Khorasan and Transoxiana© adapted from Google Earth 2012/ Rante - Collinet 2013

https://ars.els-cdn.com/content/image/1-s2.0-S0305440318301869-gr1.jpg (accessed in 4/6/2018)

Maryon, H. (1971) *Metalwork and Enamelling: A practical treatise on gold and silversmith's work and their allied crafts*, 5th Edition, Published by Dover Publications Inc., United States of America

Mattusch, C.C. (1988) *Greek Bronze Statuary: From the Beginnings Through the Fifth Century B. C.,* Published by Cornell University Press, United States of America

Orfanou, V., Collinet, A., El Morr, Z. and Bourgaritef, D. (2018) *Archaeometallurgical investigation of metal wares from the medieval Iranian world (10th-15th centuries): The ISLAMETAL project*, Journal of Archaeological Science, Volume 95, https://doi.org/10.1016/j.jas.2018.04.008 (accessed in 3/6/2018)

Porter, V., Rosser-Owen, M. (2012) *Metalwork and Material Culture in the Islamic World, Art, Craft, Text,* Published by IB Tauris & Co. Ltd, UK

Shen, L. (2017) *Silver: Nature and Culture*, Published by Reaction Books Ltd, London

Skyray Instrument (2018) *Hand-Held Pocket III Spectrometer*, http://www.skyrayinstrument.com/PDF/EDX-Pocket-III_Brochure.pdf, http://www.skyrayinstrument.com/PDF/PDF_Products/Pocket-III-Alloy-Brochure.pdf, http://www.skyrayinstrument.com/pocketIII.html

Skyray XRF (2006), *The Pocket-III: portable xrf technology*, http://www.skyrayxrf.com/portable-xrf.php

Skyray XRF (2008), *XRF Accuracy: using high-quality calibration standards*, http://www.skyrayxrf.com/calibration-standards-blog.php

Thompson, D.V. (1998) *The techniques and materials of medieval painting*, Published by Armos, Athens, Greece (in Greek).

Todd, R. H., Allen, D. K. and Alting, L. (1994) *Manufacturing Processes Reference Guide*, Published by Industrial Inc., New York

Trojek, T. and Bártová, H. (2018), *Calibration of Handheld X-ray Fluorescence Spectrometer for Identification and Semi-quantitative Analysis of Objects with Stratified Structure,* Radiation Physics and Chemistry 155, pp.310-314

Ward, R. (1993) *Islamic Metalwork*, Published by the British Museum Press, London

Untracht, O. (1985) *Metal Techniques for Craftsmen*, Published by Robert Hale, London