Review paper

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Interdisciplinary research of museum objects: practical experience with various analytical methods

Interdisciplinarne raziskave muzejskih predmetov: praktične izkušnje z različnimi analitskimi metodami

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Abstract

Analytical investigations of museum objects can provide entirely new insights into historical artifacts and ancient technologies. Museum curators and conservators have long since recognized the value of interdisciplinary research. Collaboration with experts versed in technical and material analyses often yields highly encouraging results, uncovering new layers of information that could not be derived otherwise with a traditional museum approach. However, interdisciplinary research of historical artifacts presents serious challenges that may not seem readily apparent at first. In order to obtain optimal results, common ground must be found between the museum curator and conservator on the one hand and the scientific analysts on the other hand. The following paper examines some examples of recent research collaboration carried out on behalf of the National Museum of Slovenia, with an emphasis on metal artifacts and particularly arms and armour. Various analytical methods are discussed based on practical examples, as well as their potentials and limitations. It is hoped that the overview will help promote further interdisciplinary cooperation and possibly contribute toward establishing common standards for future analytical work on museum objects.

Key words: museums, historical artifacts, material analyses, arms and armour, research methodology

Izvleček

Naravoslovne analize lahko odprejo povsem nov vpogled v muzejske predmete in stare tehnologije. Muzejski kustosi in konservatorji se že dolgo zavedajo pomena interdisciplinarnih raziskav. Sodelovanje s specialisti naravoslovnih in tehniških ved pogosto prispeva zelo pozitivne rezultate, saj lahko razkrije popolnoma nove ravni podatkov, do katerih se ne bi mogli dokopati zgolj s tradicionalnim muzejskim načinom. Interdisciplinarne raziskave pa pomenijo tudi svojevrsten izziv, čeprav se tega marsikdaj niti ne zavedamo. Do zares koristnih izsledkov lahko privedejo šele, če muzejskemu kustosu in konservatorju uspe najti skupni jezik s predstavniki naravoslovnih oz. tehniških ved. V prispevku povzemamo nekaj primerov raziskovalnega sodelovanja, ki smo ga v zadnjih letih izvedli pod okriljem Narodnega muzeja Slovenije – s poudarkom na kovinskih predmetih oz. še posebej orožju in bojni opremi. V diskusiji na podlagi praktičnih izkušenj predstavljamo različne analitske metode, ob tem pa opozarjamo na njihove možnosti in pomanjkljivosti. Upamo, da bo takšen pregled pripomogel k nadaljnji krepitvi interdisciplinarnega sodelovanja, morda pa lahko spodbudi tudi k vzpostavitvi splošnih standardov za analitske raziskave muzejskih predmetov v prihodnje.

Ključne besede: muzeji, zgodovinski predmeti, naravoslovne analize, orožje in bojna oprema, raziskovalna metodologija

Introduction

Since their inception, museums have become much more than mere keepers of historical heritage. Their responsibilities have grown increasingly diverse during the last century, but among the most important remains undoubtedly in-depth scholarly research of historical artifacts and material culture.
Museum curators and theorists have long been aware of the fact that every museum object, even one seemingly of little note, represents a unique source of information. Tapping the full information potential of a particular museum object and placing it within a telling historical context is therefore the curator's primary goal. How to achieve that goal in practice – and by what means – remains a matter of discussion, though.[1, 2]
The traditional museum approach is focused on establishing a datation and typology of the historical artifact, relying mostly on the curator's basic training in (art) history, archaeology, ethnology or some other related field of study. Nonetheless, the curator usually lacks the knowledge and equipment required for in-depth analyses of the more technological aspects of the object at hand, such as its workmanship and materials. To some degree, the curator may receive welcome assistance by the museum conservator. However, only systematic scientific and technical analyses of historical artifacts carried out by properly trained specialists can reveal the full scope of their composition, methods of manufacture and material properties.[3]
It is no surprise that such interdisciplinary collaboration has become standard during the past decades. Yet it should not be taken for granted. In most museums, few – if any – formal standards exist specifying how such work is to be carried out and on what methodological ground. For the most part, these considerations are left entirely to the judgement of the respective curator, as well as to the goodwill and experience of analytical experts employed for the examination of a particular historical material.
The purpose of this paper is to present a brief overview of some recent collaborative efforts conducted on behalf of the National Museum of Slovenia (Narodni muzej Slovenije), with an emphasis on the author's experience related mostly to his work as the curator of the arms and armour collection. The strengths and weaknesses of various research methods – used primarily on metal objects – are outlined, pointing out some of the crucial challenges encountered during practical work.
Hopefully, this experience will stimulate even greater interest in analytical research among museum curators employed in various institutions. Moreover, it may help to familiarize specialists in scientific and technical branches with some common demands and issues pertaining to the research of historical artifacts. At any rate, this contribution may be seen as an attempt toward establishing common research standards for future analytical work on museum objects – something that remains lacking to this day not only in Slovenia, but in many other countries across the globe.

Evaluation of a museum object

Determining the authenticity of an antique, its date and place of manufacture is often a demanding task that requires a good deal of knowledge and experience. It is not a process set in stone. In fact, it is not something normally taught at a formal level either. Rather, it is a complex skill refined by the individual over the course of time as an on-the-job learning process based on interaction with antiques and experienced colleagues who may be able to pass on valuable knowledge first-hand.[4]
A museum curator generally begins by visually inspecting the studied object as a whole and establishing a preliminary typology. A comparison to other similar, reliably dated objects with a solid provenance will usually allow the curator to establish at least a rough chronology and place of manufacture. Comparing the material already in the museum's collections and documentation database is likely going to be the first step. Also, specialist literature, museum catalogues and other scholarly publications will be consulted to narrow down the search pattern as far as possible.
If the object conforms well to the comparative material it should be relatively easy to place it within a widely accepted typology. However, a

detailed examination will be necessary to determine whether the object is actually genuine or fake, whether it has been restored to any considerable degree or modified during the course of its working life.[5]

In order to answer the above questions, it is necessary to pay particular attention to the materials and workmanship. Again, a detailed visual examination will be used to check whether the object is made of historically appropriate or "period" materials. Intact surface patina may already point out quite reliably whether the artifact is authentic or a modern fake, perhaps artificially aged to give the impression of an original object. Closer inspection of the surface, possibly under magnification with a loupe or microscope, may also reveal the tell-tale traces of workmanship methods and tools used in the process – forging, stamping, welding, soldering, grinding etc.

Depending on the individual's knowledge and expertise, this traditional approach may yield excellent results. However, its success relies entirely on the curator's knowledge of historical materials and craftsmanship. In a typical history museum the curator is usually an historian, art historian, archaeologist or ethnologist by profession. Although a university degree in one of these fields may prepare the future curator well for most aspects of his trade it does not by itself provide an effective foundation for the advanced study of museum objects in terms of their workmanship.

It is no surprise that the museum curator often works in close tandem with the conservator, a specialist trained in cleaning and preserving antique objects. Through their work, conservators invariably become intimately acquainted with museum objects on their technological level. The conservator's formal background – which may include training in woodworking, metalworking, painting, chemistry, goldsmithing, engineering etc. – can assist the curator greatly in the interpretation of museum objects. Nonetheless, even a seasoned conservator might lack the skills and tools required to make a sound evaluation of the workmanship and materials present in a museum object. Fortunately, this deficiency may be addressed by consulting outside specialists, whose assistance can prove to be an invaluable asset.

Advanced methods and analytical techniques

During the past decades, interdisciplinary work has become increasingly popular in museums. Usually, this involves combining the skills of museum curators and conservators with chemists, engineers, metallurgists and other specialists versed in scientific analytical methods.[6]

An interdisciplinary approach toward studying museum objects can reveal a surprising amount of information otherwise inaccessible to the curator. Properly planned and conducted analyses may answer how a particular object was made, what sort of technology was available in a given historical period, how well the craftsmen mastered their techniques and how their products may have performed in practice. Fakes can be exposed, old restorations and additions identified. Additionally, the analyses may suggest whether a particular method of conservation works well in the long run or whether it should be replaced by a more appropriate technique.

However, such research is also fraught with pitfalls. Since museum objects are by definition precious and irreplaceable, proper analytical methods must be selected in the first place. Nondestructive and noninvasive techniques are generally preferred. Physical removal of samples is often impossible, especially in the case of well preserved antiques, as it would cause irrepairable harm to a sensitive object of great historical value.

Even though interdisciplinary research has become downright fashionable in recent years, it does impose new burdens on both the museum personnel and outside specialists in technical and applied sciences. Quite often, the two sides are initially somewhat incompatible in their methodology and expectations. Hence a considerable mutual effort is required to bridge the gap between their areas of expertise.

Museum curators are often hampered by a general lack of familiarity with scientific analytical methods and technology. An average (art) historian, ethnologist or archaeologist has little to no formal background in material sciences – and possibly little inclination to study the more technical aspects of material culture as represented by museum objects. Under such circumstances there may be little desire to carry out any ambitious analytical research in the first place. Sometimes, this is further compounded by an apprehensive attitude toward any sort of technical analyses due to fear – realistically founded or merely perceived – of damaging an historical artifact.

A typical chemist, engineer or metallurgist on the other hand may be well versed in their trade, but this usually involves working with modern materials and technologies. Museum objects are generally products of ancient – and today obsolete – craftsmanship. Many techniques developed and perfected by old craftsmen are poorly understood. A modern expert familiar only with industrial manufacturing methods may struggle with the interpretation of analyses carried out on museum objects, which were the product of a very different age. Also, many analytical techniques taken for granted in the industry may be completely inapplicable to sensitive museum objects. For instance, an intact medieval sword blade cannot be simply sawed in half to examine its cross-section under a microscope.

Great care must be taken to realistically assess whether a particular museum object is suitable for analytical research and what method would yield the best results considering all the constraints and restrictions inherent in dealing with historical artifacts. Perhaps even more importantly, the interdisciplinary research team must first define clear goals of their work – what is the purpose of the attempted analyses, what answers the museum curator is looking for, what methods are available to provide optimal results with a minimum of irreversible effects to the examined objects and how the interpretation of the analyses is going to be of actual benefit to the study of historical heritage – perhaps through publishing the findings in a scholarly paper, developing a new method of conservation, determining the authenticity of a spurious object etc. Unless these issues are addressed beforehand, there is a real danger of carrying out analytical research merely for its own sake – with little positive impact in the long run.

Material analyses at the National museum of Slovenia

The National Museum of Slovenia, founded in 1821, is the oldest public museum and indeed one of the very oldest scientific institutions in Slovenia. Based in the capital city of Ljubljana, it houses some 300 000 objects ranging from prehistory to the contemporary period. As the leading state institution of its kind, the National Museum of Slovenia has a comparatively long history of interdisciplinary scientific research.[7, 8] During the last decades, some basic analytical methods have been carried out in-house, mostly by specialists employed at the Department of Conservation and Restoration. These methods rely mainly on microscopic examinations and XRF analyses. Further analytical work has been carried out in cooperation with other scientific institutions, such as the Jožef Stefan Institute and various faculties of the University of Ljubljana.[9, 10]

The stimulus for analytical research at the Museum is generally two-fold. Most of the basic analyses are carried out on demand of the musem conservators to investigate the material composition of museum objects. In this respect, basic material analyses have become an indispensable tool at the Department of Conservation and Restoration, allowing the conservators to select the most appropriate method of treatment for the particular object. The results of the analyses are also of direct use to the curators, providing a solid identification of historical artifacts and sometimes detecting fakes or later restorations.

More ambitious research is generally planned and supervised by individual curators who specialize in a particular field of study and rely on analytical data to establish a more reliable identification of selected objects, determine their exact age and origin through comparative material and databases, reveal details of their workmanship etc. Since such goals usually require the assistance of an outside specialist or institution, obtaining proper financial support is not easy – especially with the great economic recession in recent years. The Museum's funds have been consistently inadequate for large-scale scientific undertakings, making the struggle for additional resources – research grants, projects and programs – all the more vital. However, it has also been possible to carry out a sizeable amount of interdisciplinary work through the generous support of other Slovenian public institutions and even private enterprises that have made their resources available to the Musem in joint cooperation on a few particularly interesting or unique challenges.

Some recent examples sorted by methodology

Light microscopy

Detailed visual examination is the first obvious step toward studying any museum object. A hand-held or head-mounted magnifying glass, usually between 5 × to 10 × magnification, is a highly practical tool. It can already reveal a number of details that cannot be distinguished clearly with the naked eye. The examination is generally focused on crucial details, such as stamps, inscriptions, etching or surface decoration. However, a specialist familiar with historical manufacturing techniques can also detect traces of tools, machining processes and other evidence of workmanship on the surface of the object.

As an inexpensive, easily available and entirely nondestructive method even better results can be obtained with a full-sized microscope. A portable or bench-mounted stereo zoom binocular microscope is ideal for the task. Lower ranges of magnification (10–100-times) are sufficient to observe such details on metal objects. Obviously, greater magnifications are needed for examining properly prepared metallographic samples and identifying textile fibres or organic materials such as bone, antler and ivory.[11, 12]

In museum work, the success of basic light microscopy as a means of identifying workmanship methods and identifying materials is dependent on the operator's skill level and experience. It allows an experienced museum curator or conservator to spot tool marks, traces of machining, welded, brazed or soldered joints, riveting, etching, gilding and other decoration techniques. A systematic visual examination of such details can determine whether the workmanship is consistent with the supposed age of the artifact, whether it was made by hand or machine and if any parts were subjected to a later repair or modification (Figure 1).

Figure 1: *Macro photograph of an old repair – details of riveting and brazing on a 16th century sword blade. (Photo: T. Lazar)*

At the National Museum of Slovenia light microscopy is carried out in-house regularly during conservation treatment. It has been used with effect to identify textile fibers and organic materials. In recent years, light microscopy has been used to investigate an interesting armoured glove – a mail mitten of a type found in several museum collections in the Balkans and identified as late-medieval Ottoman hand defence. However, a close-up identification of the glove has revealed that the metal links were machine-made, as demonstrated by identical wear marks repeated on all the links analysed (Figure 2).[13]

Figure 2: *A detailed examination of a 19th century butcher's mail glove shows discernible tool and wear marks. (Photo: T. Lazar)*

Scanning electron microscopy (SEM)

A complementary method, SEM requires considerably more advanced equipment often inaccessible to the museum curator. In practice, its uses are similar to light microscopy – most notably, microstructure analyses. Also, semi-quantitative composition analyses may be performed with energy dispersive X-ray spectroscopy (EDS) or wavelength-dispersive spectroscopy (WDS). Typically, such analyses cover a surface area of approximately 10 mm in diameter and are restricted to a depth of a few ten µm. The method is particularly useful when dealing with microscopic samples. Still, generally this requires at least a minimally invasive approach, which negatively affects the integrity of the object.[14]

Ultraviolet fluorescence (UVF)

A technique often used in forensic research, UVF has had a long history in art conservation. UV lighting, most commonly in the spectre between 300 nm and 400 nm, creates a highly visible contrast between the original and recent layers of materials applied to the surface. This makes it an ideal research tool for analysing paintings and artwork, where UVF can be used to identify later restorations or additions to the original surface.

Figure 3: *UV photography of a miniature suit of armour easily identifies various layers of varnish. (Photo: Andrej Hirci)*

The method itself is relatively straight-forward and does not require particularly complex equipment. Its use seems to be primarily restricted to art galleries, but it is really much more versatile and can be applied with good effect on historical collections as well. Recently, UVF has been used to analyse two miniature suits of armour from the late 19th century kept at the National Museum of Slovenia. UV photographs have shown very distinctly the difference between the original surface and all the later conservation treatments as well as attempts at more extensive restoration (Figure 3).

Energy dispersive X-ray fluorescence (EDXRF)

In-house EDXRF analyses have been performed at the Museum regularly since 1999, when a custom-made EDXRF apparatus was acquired from the Jožef Stefan Institute. It has become indispensable to the Museum's curators and conservators.

Initially, EDXRF analyses have been used primarily as a quick, noninvasive means of roughly identifying the object's composition. However, the increasingly more sophisticated equipment and software developed by the Jožef Stefan Institute have opened up new possibilities – at this point, much more accurate quantitative analyses of material composition have become possible. For instance, the current PDZ-01 device developed at the Institute can provide a quantitative analysis of elements from Al to U with an inherent uncertainty of some 5–10 %, depending on the homogeneity of the sample. The beam diameter covers an area of roughly 0.9 cm in diameter, reaching to a depth of some 10–100 µm depending on the composition of the object. Furthermore, specialized methods can be used, such as measuring the thickness of film applied to the surface of the object (e.g. gilding, tinning, electroplating).

Particularly good results have been obtained on objects made of nonferrous metals, such as bronze or brass, gold, silver and tin alloys.

Advanced EDXRF analyses can provide relatively accurate information on their composition and help identify the alloying elements, even if present in minute quantities. The method is somewhat less useful for iron or steel, as it cannot determine their carbon content. Nonetheless, most other common alloying elements can be detected and quantified.[15–17]

At any rate, it is generally necessary to take a number of readings on each examined object in order to arrive at statistically reliable average values – obviously depending on the size of the beam as well. This is particularly important when dealing with heterogeneous materials whose composition may vary a good deal throughout the object.

The method is entirely nondestructive per se. Due to limited penetration of the beam, the readings are representative only of the microscopic surface layer. If a portable device is used, analyses may be carried out in-situ, even on relatively inaccessible parts. This is an important advantage, as the transport of large or particularly sensitive and valuable museum objects to a research laboratory may be highly impractical and expensive.

Although the analyses require no special surface preparation it is nevertheless important to note that secondary contamination may distort the results. In almost all cases, Ca has been detected on metal objects, most likely due to contamination with dust. The unexplained presence of Cu and Zn on steel or iron artifacts has also caused considerable confusion. During the recent in-depth analyses of a 15th century sword blade it has been proved with additional testing that the readings of Cu and Zn must be attributed to later contamination during conservation treatment – in the past, brass brushes were frequently used at the Museum for mechanical cleaning but their application invariably left microscopic residue of brass on the surface (Figure 4).[14]

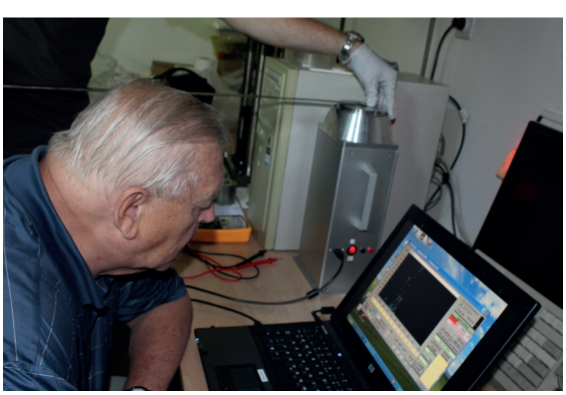

Figure 4: *EDXRF examination of a sword blade. (Photo: N. Nemeček)*

In another instance, As was found on the surface of Indonesian kris daggers – clear evidence of the ritual cleaning process using warangan, a compound containing liquid As. Hence, one must factor in such occurences when dealing with historical artifacts.[18]

Particle-induced X-ray emission

Another nondestructive analytical method with a proven track record, PIXE has been applied quite extensively to the study of paintings and museum artifacts. Largely comparable to EDXRF analyses, it shares many advantages and limitations. PIXE may be used to detect only the presence of elements lighter than Si. Above all, the measurement is limited to the very surface of the object (≈ 10 μm).[19–22]

The application of in-air proton beam of the Tandetron accelerator of the Jožef Stefan Institute has been used to investigate some particularly heterogeneous objects. The tightly focused beam with a surface area in the range of 1 mm^2 is very useful for measuring the composition of isolated inclusions or impurities on the surface of the object. During an investigation of Indonesian kris daggers, the PIXE method has been able to confirm the high Ni content in highly visible silvery patches on the surface. As high quality kris daggers were reportedly made of meteorite steel, the analyses have given new evidence for such practice – albeit only in older blades of particularly good workmanship.[18]

X-ray radiography

Investigations with X-ray radiography have long ago become commonplace in museum work. Especially in the period after World War II the easy availability of X-ray technology has led the Department of Conservation and Restoration of the National Museum of Slovenia to establish regular links with laboratories specialized in technical radiography (Figure 5).

X-ray investigations have been found very useful as a preliminary step prior to conservation treatment, especially when dealing with an archaeological find or a heavily corroded object with an encrusted surface. Radiography may reveal quite clearly how much of the object's metal core is preserved and whether any additional parts or components remain hidden underneath the layer of corrosion products.

For instance, historical metalwork is frequently ornamented with inlays, engravings or some other means of decoration that might be removed during mechanical cleaning unknowingly. One may be dealing with a composite object, including organic materials. Through X-ray radiography such factors may be discovered noninvasively – as well as the location of rivets, joints, brazing or soldering etc.[23]

Radiographic images can also reveal the complex interior of objects such as sword blades deposited in a sheath or the arrangement of a lock mechanism in an antique crossbow or firearm without the need to dismantle the object

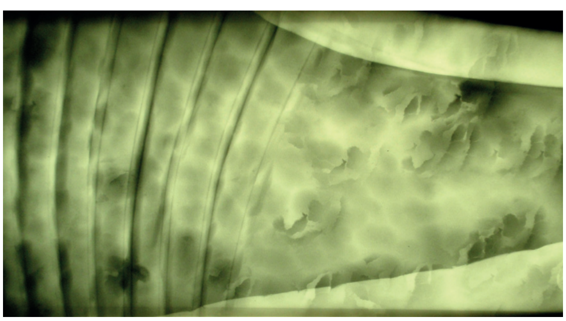

Figure 5: *X-ray radiography of a 16th century breastplate. (Photo: M. Žgavec, B. Zorc)*

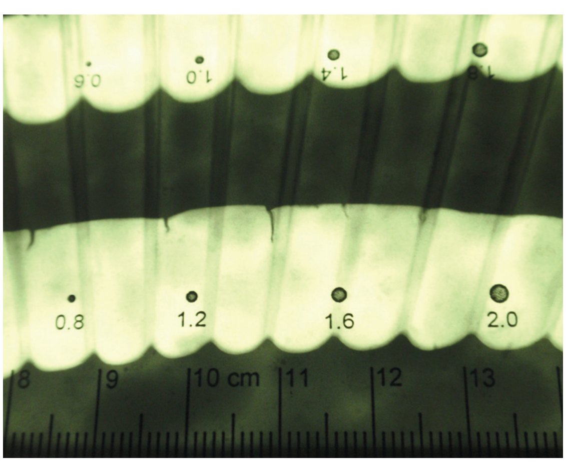

Figure 6: *Apart from detecting invisible details, inclusions and various internal flaws, a radiographic image may also be used to gauge the thickness of metal such as in the case of a skirt belonging to a 16th century suit of armour. (Photo: M. Žgavec, B. Zorc)*

completely. Again, such data is invaluable for scholarly study as much as it is of great assistance to museum conservators.[24]

Overall, X-ray radiography is a highly practical method for investigating a broad range of historical artifacts. However, its usefulness is necessarily limited by the thickness of metal. When dealing with particularly large, solid objects or those of composite structure alternative methods may offer better results (Figure 6).

Neutron radiography

As a complementary nondestructive method, neutron radiography offers useful information otherwise impossible to obtain by X-ray imaging. Many of the most commonly used metals, such as Fe, Cu, Sb, Zn or Pb, as well as earthenware or glass, are penetrated easily by neutrons – in contrast to light organic materials.

Therefore, neutron radiography can be used to detect the presence of organic materials hidden underneath a metallic surface. It is particularly useful when dealing with composite objects containing wood, leather, textile or plant fibres.[25, 26]

Ir- and Co-radiography

Objects made of thicker, solid metal that cannot be penetrated efficiently by X-ray may be examined successfully by using a radioactive isotope such as Ir-192 or Co-60. Such specialized radiographic equipment is not easily obtainable, being limited to large-scale industrial production and testing. However, Ir- or Co-radiography can be used as a particularly valuable means for analysing the composition and manufacturing techniques of large museum objects such as cannon barrels (Figure 7).[27]

Recently, the two oldest surviving medieval artillery pieces in Slovenia have been subjected to extensive research. Of greatest importance were the radiographic analyses carried out with an Ir-192 isotope placed inside the barrels and a more powerful Co-60 source positioned vertically above the guns. Due to the considerable thickness of metal (over 10 cm in the thickest sections) a very long exposure time was necessary – up to 12 h. The images recorded on photographic film show clearly the complex construction of late-medieval gun barrels made of wrought iron (Figure 8).[28]

Figure 7: *Preparation for Ir-radiography of a late medieval cannon. (Photo: T. Lazar)*

Figure 8: *Co-60 radiography of a 15th century gun or bombard. (Photo: A. Hudej)*

Metallography

Metallographic analyses represent a technically simple and inexpensive, but altogether exceptionally useful method for determining the microstructure and material properties of a metal object. They are particularly valuable for analysing steel tools or weapons. In simplest terms, they require the removal of a sample – which may be quite small or nearly microscopic – that is then ground, polished, etched and examined under a microscope.[29]

Due to its destructive method, metallography is sometimes considered impractical in museum work. In some cases, especially when dealing with fragmentary objects or considerably damaged archaeological finds, it may be relatively easy to detach small flakes without affecting the overall integrity of the object to any major degree. On historical armour, bits of metal can be cut relatively unobtrusively from the inside of rolled or turned edges etc. Otherwise, reasonably inconspicuos removal of samples may be impossible. At best, one might decide to polish and etch very small sections of the surface and examine them in-situ on an inverted microscope. However, such an approach enables the researcher to determine merely the micostructure of the very surface – that may not be representative of the microstructures deeper within the core of the object (Figure 9).[30]

It is important to note that most functional steel objects of the preindustrial era, such as tools, weapons or armour, exhibit a highly complex internal structure. In the first place, the metal may be of highly heterogeneous composition, containing large quanities of slag and impurities. Quite often, the outer surface, especially cutting edges, is carburized or made of a relatively harder steel with a higher carbon content. However, the core may be much softer, possibly forged of wrought iron welded to an outer jacket of higher quality steel. Therefore, it is highly desirable to remove samples from various sections of the object in order to obtain a clear picture of its workmanship and arrive at statistically acceptable values.[31–38]

Within its limitations, metallography offers potentials so far unrivalled by any standard noninvasive analytical method. It may be used to determine the quality of materials used as well as the heat treatment or cold working techniques used during its manufacture. The latter may be used to asses the maker's degree of technological skill and capabilities. In case of historical arms and armour, various techniques of heat treatment can provide a unique

Figure 9: *Careful removal of a small sample from a late medieval brestplate. (Photo: T. Lazar)*

fingerprint, helping identify unknown specimen and ascribing them to various workshops known for a trademark manufacturing procedure (Figure 10).[14, 39, 40]

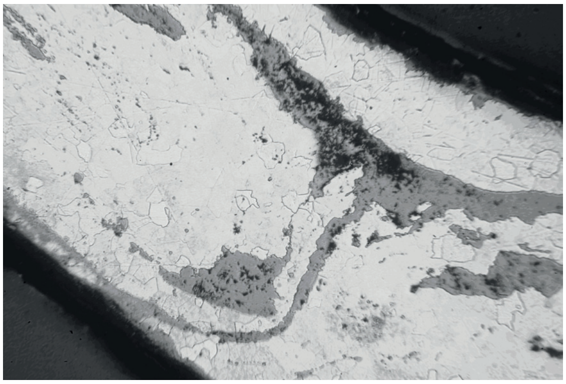

Figure 10: *Metallographic examination of a welded iron link from a medieval mail armour. (Photo: E. Wood)*

Hardness testing

Several methods of hardness measurements exist. Perhaps the one most commonly used on historical artifacts made of iron and steel is the Vickers pyramid method. Vickers microhardness testing is a minimally invasive technique, leaving only a microscopic indentation on the surface of the object. For that rason, it is highly versatile and can be employed on any metal object as long as the appropriate equipment is used and the surface on the measuring location is sufficiently smooth, even and free of corrosion products (Figure 11).

A portable hardness tester, generally operating on the UCI principle, is a highly versatile and accurate analytical tool. As a stand-alone method, hardness testing is of limited value as the results provide only a general indication of the object's material composition and heat treatment. However, in combination with metallographic analyses, systematic hardness testing can be used to assess the uniformity of the object's microstructure and the quality of heat treatment (Figure 12).[14, 18, 30–34]

On the other hand, hardness measurements as well as metallographic analyses can reveal the true microstructure and workmanship of a historical artifact only insofar as it has not been altered during its later life. During the preliminary hardness testing of a number of medieval swords from the National Museum of Slovenia it has been found that many of their blades were surprisingly soft, ranging around 100 HV 0.2. The readings seemed altogether incompatible with the fine workmanship of the specimen, which were clearly well made weapons that one would expect to have been heat treated according to the best capabilities of the contemporary bladesmiths.

However, the surprisingly low values might be explained by an unexpected twist. During the late 19th and early 20th century, conservators would frequently treat historical steel objects by heating them to red heat (around 900 °C), then cleaning them in an acid bath. Such a treatment would invariably anneal the object and destroy its original microstructure. Although very little conservation documentation from the period exists at the National Museum of Slovenia, there is nevertheless clear evidence that in 1906 such an approach was used at least on two early medieval swords from Kranj, and possibly more specimen in later years.[41]

Figure 11: *Investigating a 15th century sword blade with a portable hardness tester. (Photo: T. Lazar)*

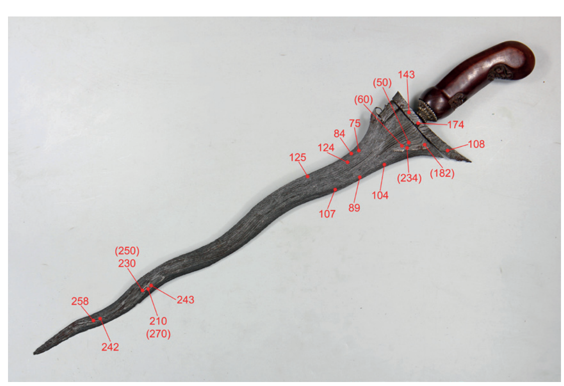

Figure 12: *Hardness measurements on an Indonesian kris dagger. (Photo: T. Lazar)*

Differential scanning calorimetry (DSC)

Thermal analysis of metal samples is destructive insofar as small samples need to be removed from the object, then heated to a very high temperature. During the process, phase transitions can be observed, thus providing an exact identification of the metal's material properties.[42]

During our research at the National Museum of Slovenia, DSC has been tested for the first time during the analyses of a broken late-15th century sword or Messer. The results have shown the method to be of considerable value, showing great potential for further work whenever samples can be removed with a minimum risk of affecting the object's integrity.[14]

Conclusions

Close collaboration between museums and specialists in technical and applied sciences has proved its benefits time and again. Thanks to such interdisciplinary research, our knowledge of ancient technologies and craftsmanship techniques has increased exponentially. Nonetheless, it is crucial to understand that historical artifacts present particular challenges, which the research team must be aware of beforehand.

Objects of cultural heritage are bound by highly specific standards of preservation. In practice, this may rule out a number of analytical methods that might yield the best results in theory but are simply inapplicable due to their destructiveness. Especially when dealing with well preserved artifacts of great value, nondestructive methods may be the only realistic option despite their possible shortcomings. Highly invasive procedures, such as removing large sections of material or polishing extensive surfaces on an object, may cause irrepairable harm to an otherwise unique artifact. For that reason alone, they should be avoided unless absolutely necessary.

A conscious decision may be made to sacrifice a particular object for extensive destructive analyses – such as sawing an object in sections or removing large samples. But such a decision should never be taken lightly. It may be permissible only when dealing with an artifact of no unique value – for example, when a large group of more or less identical specimen is available and the results are expected to justify such drastic measures.

Scientific analyses can provide seemingly extremely exact information. However, the actual value of such information in itself may be quite limited or even misleading unless interpreted in the correct context. For example, metallographic analyses of a medieval sword blade may reliably reveal the microstructure and material properties at the analysed locations. However, these locations may not be representative of the entire blade unless a large number of samples were removed or an alternative method used to check the uniformity of the examined object. Unlike most modern industrial products made of homogeneous materials, historical artifacts tend to vary far more in their material composition and properties.

The interpretation of results may prove to be a highly problematic issue. An analyst whose working experience is limited solely to modern materials and manufacturing techniques may not be able to understand the pitfalls of the great technological gap between the 21st century and the earlier historical periods. A particular historical artifact, such as a pattern-welded blade or armour forged of wrought iron, may have been a technological marvel in its time. Yet purely by today's standards, it could be seen anachronistically as a markedly inferior product. Again, one should not lose track of the technological level of the historical era in question.

It should never be assumed that a particular artifact has not been altered or tampered with during more recent periods. Unless its full history is known and documented, it is quite possible that the object may have been subject to a later repair, modification or aggressive conservation treatment that might have affected its microstructure and material properties.

As much as scientific analytical methods may help with the identification of an historical artifact, the museum curator should be wary of drawing quick conclusions based on limited analytical data. If at all possible, published analyses of similar historical objects should be studied and cross-checked to see if the obtained results are believable or seem out of place.

In case of doubt, it is always advisable to check again for any errors in the analytical process. The limitations of analytical research must be cleared up beforehand. The curator may be under the false impression that a given scientific method will automatically determine the object's age and provenance. In reality, it only provides data that must be compared to other known samples and analyses before any such conclusion can be made. Hence, it is not only worthwile but highly necessary to publish all the analytical results as comprehensively as possible or at least structure them within an internal database to ensure that the work will be of benefit to future research and possibly other research teams as well.

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