Article: Dry ice blasting in the conservation of metals: A technical assessment as a conservation technique and practical application in the removal of surface coatings
Author(s): Cassy Cutulle and Seoyoung Kim
Source: *Objects Specialty Group Postprints, Volume Twenty-Two, 2015*
Pages: 77-100
Editors: Emily Hamilton and Kari Dodson, with Sarah Barack and Kate Moomaw, Program Chairs
ISSN (print version) 2169-379X
ISSN (online version) 2169-1290

1156 15th Street NW, Suite 320, Washington, DC 20005 (202) 452-9545
www.conservation-us.org

Objects Specialty Group Postprints is published annually by the Objects Specialty Group (OSG) of the American Institute for Conservation of Historic & Artistic Works (AIC). It is a conference proceedings volume consisting of papers presented in the OSG sessions at AIC Annual Meetings.

This article is published in the *Objects Specialty Group Postprints, Volume Twenty-Two, 2015*. It has been edited for clarity and content. The article was peer-reviewed by content area specialists and was revised based on this anonymous review. Responsibility for the methods and materials described herein, however, rests solely with the author(s), whose article should not be considered an official statement of the OSG or the AIC.

DRY ICE BLASTING IN THE CONSERVATION OF METALS: A TECHNICAL ASSESSMENT AS A CONSERVATION TECHNIQUE AND PRACTICAL APPLICATION IN THE REMOVAL OF SURFACE COATINGS

CASSY CUTULLE AND SEOYOUNG KIM

There is a growing necessity within the field of conservation to seek out new methods of cleaning that are safe, effective, and sustainable. The use of dry ice blasting to clean museum objects has been investigated as a potential option in recent years. To continue such research, an experimental methodology was devised to evaluate the risk of abrasion using this method and its efficiency in removing traditional and modern conservation surface coatings from metallic artifacts. Additionally, an assessment of dry ice blasting as a conservation cleaning technique was conducted. Two types of experiments were carried out to measure the performance and efficiency of dry ice cleaning. The first experiment utilized brass, cupronickel, and mild steel metal coupons that were coated, blasted, and assessed under a Hitachi S-3400N scanning electron microscope to evaluate the risk of surface abrasion as a result of dry ice cleaning. The second experiment evaluated the practical efficacy of dry ice blasting in the removal of coatings from historic and modern objects, such as gilded brass furniture mounts and steel musket lock replicas. All experiments were undertaken using the Cold Jet i3 MicroClean dry ice shaving unit. Various coating materials, such as natural and synthetic waxes, petroleum jelly, Paraloid B-72, Paraloid B-48N, Incralac, nitrocellulose lacquer (Ercalene), and shellac were tested in the experiments. The results revealed that the risk of surface abrasion on the metal surfaces using dry ice blasting is minimal at the tested durations and settings used. Effectiveness in coating removal was seen to be variable. Wax-based and petroleum jelly coatings were more effectively removed compared to polymer-based coatings. This project was completed as dissertation research for University College London's Masters of Science in Conservation for Archaeology and Museums degree program.

This article also presents a case study that focuses on the practical application of dry ice blasting for the cleaning of mail (often known as chain mail) on the Oriental helmets at the Wallace Collection in Central London. The mail on the helmets had previously been coated with petroleum jelly, which interacted with the metal over time, resulting in discolored, tacky, and greasy mail. Dry ice blasting was employed to remove the aged surface coatings on the mail as an alternative technique to conventional chemical cleaning methods. The detailed process of the project, with an evaluation of its effectiveness and the practical limitations, is outlined.

KEYWORDS: Cold Jet i3 MicroClean, Dry ice blasting, Mail, the Wallace Collection

1. INTRODUCTION TO DRY ICE BLASTING

In the conservation care of historic metals, cleaning is one of the more challenging jobs undertaken. The careful removal of dirt, dust, tarnish, corrosion products, and previously applied coatings is vital to the future stability and condition of the object (Grossbard 1992; Garcia et al. 1998; Caple 2000; Harris 2006b). In the case of social history objects, cleaning is often focused on the removal of a previously applied coating. Such coatings were applied in the past to protect the metal from moisture, pollutants in the environment, and handling, all of which can cause tarnishing and corrosion (Grossbard 1992; Garcia et al. 1998; Harris 2006a, 2006b). Often these coatings have degraded, affecting the condition and appearance of the object. In these situations, removal should be considered (Grossbard 1992; Harris 2006b). Ideally, the methods employed to remove the coating should be safe, efficient, and environmentally responsible. It is therefore vital that appropriate techniques are available to conservators charged with the cleaning of historic metals.

In recent years, dry ice blasting has been explored as such an option. Hailed as a dry, non-toxic, sustainable, and gentle technique, conservators have tested, researched, and used this method on a range of objects (Spur et al. 1999; Silverman 2008; Brush 2010; van der Molen et al. 2010; Higginson and Prytulak 2012; Lizarraga 2012; Posner 2012; Sullivan 2013; CleanLink 2014). The process of dry ice blasting is carried out with the use of dry ice—solid carbon dioxide or CO_2.

Typically, the process of dry ice blasting includes a mechanized dry ice shaving or pellet unit, which is used in conjunction with compressed air to transport and emit the dry ice particles (Spur et al. 1999). Depending on the machinery, the dry ice can be shavings less than 1 mm in size or pellets that are approximately 3 mm in length (Brush 2010). On the mechanized unit, pressure (in bar or pounds per square inch) and mass flow (in kilograms per minute) control the speed and volume of the dry ice transported through the hose and a specially constructed nozzle (Spur et al. 1999; Cold Jet LLC 2004; Otto et al. 2011). In addition to this type of dry ice cleaning, there is also the single-stage unit, whereby compressed liquid CO_2 is converted to a fine, solid CO_2 "snow" within the nozzle, without the use of compressed air (Lizarraga 2012).

Research on the mechanisms of dry ice blasting examines several effects that are responsible for the removal of surface accretions. First, there is the impact force of the dry ice particles, which prompts the cracking and weakening of the accretion through the forced contact of the jetted dry ice (Spur et al. 1999; Liu et al. 2011; Otto et al. 2011; Zhou et al. 2012). Second is the kinetic effect that is the mechanical action of the high-velocity dry ice working against a surface accretion (Spur et al. 1999). The freeze-fracture effect is another mechanism aiding in the removal of contaminants. The extremely low temperature of the dry ice creates contraction of an accretion or coating on a surface, rendering it brittle (Spur et al. 1999; Cold Jet LLC 2004; Otto et al. 2011; Zhou et al. 2012). This also generates a contraction differential between the coating and the substrate, weakening the adhesion between the two as one shrinks at a different rate than the other (Otto et al. 2011).

The sublimation effect also plays an important role in removal. As solid dry ice hits a surface at room temperature, it sublimates. During this process, it expands to approximately 800 times its size, exploding at the surface as it does. The energy transfer as a result of this expansion and explosion consequently aids in the removal of surface accretions (Cold Jet LLC 2004; Hailstorm Industrial Cleaning Solutions 2009; van der Molen et al. 2010; Otto et al. 2011; Cryogenesis Ltd. UK 2014b; Yara CO_2 and Dry Ice 2014). Together with the drag force, or the effect of the jetted air lifting/pushing a coating from the substrate, these mechanisms combine to make dry ice blasting a successful means of surface cleaning (Otto et al. 2011; Zhou et al. 2012).

2. DRY ICE CLEANING AT THE WALLACE COLLECTION: A TECHNICAL ASSESSMENT AND PRACTICAL APPLICATION

In preparation for the creation of a new Oriental Arms and Armor catalog at the Wallace Collection, it was decided that dry ice blasting should be employed to aid in the cleaning of the Oriental Helmets collection. In December 2013, the Cold Jet i3 MicroClean dry ice shaving unit was rented for a week to conduct this work. This project allowed for a practical assessment of the method and revealed its benefits and limitations. During this time, conservation intern Cassy Cutulle was permitted to conduct experiments for her Masters of Science dissertation at University College London (UCL).

2.1 UNIVERSITY COLLEGE LONDON DISSERTATION PROJECT

2.1.1 Introduction to the Experiments

Two experiments and qualitative observations were conducted to answer three primary research questions:

1. Is there any risk of abrasion associated with this method of cleaning?
2. Is this method a successful means of removing coatings from metal museum objects?
3. Is this method a practical one for museum conservation use?

The dry ice shaving unit utilized was the Cold Jet i3 MicroClean. Table 1 lists the technical properties for this machine. The settings for all experiments discussed in this article remained constant at a mass flow of 0.45 kg/min. and 1.4 bar. These settings were chosen because the increased amount of dry ice at 0.45 kg/min. was thought to make the cleaning process more efficient, whereas the lower pressure setting mitigated the risk of abrasion. During blasting, heat supplied by a hot air dryer on low settings was used to prevent the freezing of the coupon or object and to increase the temperature difference between the object/coupon and the dry ice. This methodology was suggested to the authors by the Senior Furniture Conservator at the Wallace Collection, Jürgen Huber, who has had experience in utilizing this method for object cleaning. Additionally, research has shown that the use of heat can intensify the freeze-fracture effect by producing a larger energy transfer during the sublimation of the dry ice particles—a result of the increased temperature difference between the dry ice and the contaminant (van der Molen et al. 2010; Cold Jet LLC 2004). The use of heat is therefore regarded as a means of increasing the likelihood of contaminant removal. This, of course, is also dependent on the type and chemical properties of the coating to be removed, such as glass transition temperature (Tg), freezing point, and melting point.

2.1.2 Experimental Methodology: Risk of Abrasion Assessment

For the first of the dissertation experiments, 12 metal coupons were used to assess the risk of abrasion as a result of dry ice blasting. Four mild steel, brass, and cupronickel coupons[1] were each sectioned into four quadrants, whereas the center area was maintained as the control (table 2). For the cupronickel coupons, the quadrants were square in shape and measured 2.5 × 2.5 cm. For the brass and

Table 1. Technical Properties of the Cold Jet i3 MicroClean Unit (Cold Jet LLC 2014c)

Pressure	1.4–9.7 bar or 20–140 psi.
Mass Flow (Feed Rate)	0–0.50 kg/min.
Size of Unit	55.9 × 40.6 × 53.3 cm
Weight of Unit	59.1 kg
Hopper Size	9.1 kg
Single- or Two Hose	Single-hose system
Nozzle Type	"Advanced 'MERN'" nozzle (blasting span 6.6 mm and 7.4 mm)
Pellets or Shavings	Shavings emitted from dry ice block (size of block is 5 × 5 × 10 in.)

Table 2. Coatings Applied to Metal Coupons

Metal Coupons	Coatings
Mild Steel Coupons	• One coat of Paraloid B-72 (ethyl methacrylate copolymer) 10% w/v in 1:1 IMS: acetone applied by brush • One coat of Paraloid B-48N (methyl methacrylate copolymer) 10% w/v in 1:1 IMS: acetone applied by brush • Two coats of Renaissance Wax (80% White Spirit and 20% Blended Micro-crystalline waxes) applied by brush and buffed in with a cotton cloth • One coat of petroleum jelly applied by brush
Brass and Cupronickel Coupons	• Two coats of Ercalene (cellulose nitrate chloride-free lacquer) applied by brush • Five coats of blonde shellac approx. 15%–20% w/v in IMS applied by brush • One coat of Incralac (74% Paraloid B-44, 20% toluene, 5% ethanol or butyl acetate, 0.5% benzotriazole, 0.5% epoxidized soya oil) applied by brush • Two coats of Renaissance Wax applied by brush and buffed in with a cotton cloth • Five coats of Briwax (xylene, mixed isomers: 90%–99%, 1-butanol: 10%–30%) applied by brush

mild steel coupons, quadrants were in the approximate shape of an isosceles triangle with a rounded base measuring 2.5 × 2.5 × 3.8 cm. Prior to imaging and experimentation, each coupon was cleaned using 1:1 acetone: Stoddard solvent (aliphatic solvent with an aromatic content of 16%).

A small triangle was engraved into each quadrant (fig. 1a) and two images per quadrant were taken before dry ice blasting in a Hitachi S-3400N scanning electron microscope (SEM) on secondary electron imaging at 20 kV. The first image was an overall photograph of the triangle at 20x (fig. 1b), whereas the second was a photomicrograph of a specific reference point on each triangle at 650x (fig. 1c). This reference point varied between the top, bottom left, and bottom right corners of the carved triangle. The use of the location-specific point made before and after comparison images of the surface at high magnification possible. A coating was then applied to each quadrant and the control area was covered with 3M Performance masking tape to prevent it from being affected by the blasting. Two quadrants were used per coating type for replication of the results (see table 2).

Blasting took place for approximately 15–20 seconds per quadrant. This time limit was chosen due to the small surface area of the quadrant. The nozzle angle varied within the range of approximately 35–50°. Two images of the same areas on each quadrant were again taken in the SEM after blasting to determine whether abrasion had occurred on either a macroscopic or microscopic scale. The settings in the SEM were kept as consistent as possible for the "before" and "after" blasting images.

2.1.3 Experimental Methodology: Coating Removal Tests

For the coating removal tests, the aim was to get an idea of the machine's efficiency in removing coatings from actual objects with differences in surface morphology and structure (fig. 2). Prior to coating and blasting, all objects were cleaned. The furniture mounts were previously coated with shellac and had to be placed in an industrial methylated spirits (IMS; 95% ethanol, 5% methanol) vapor

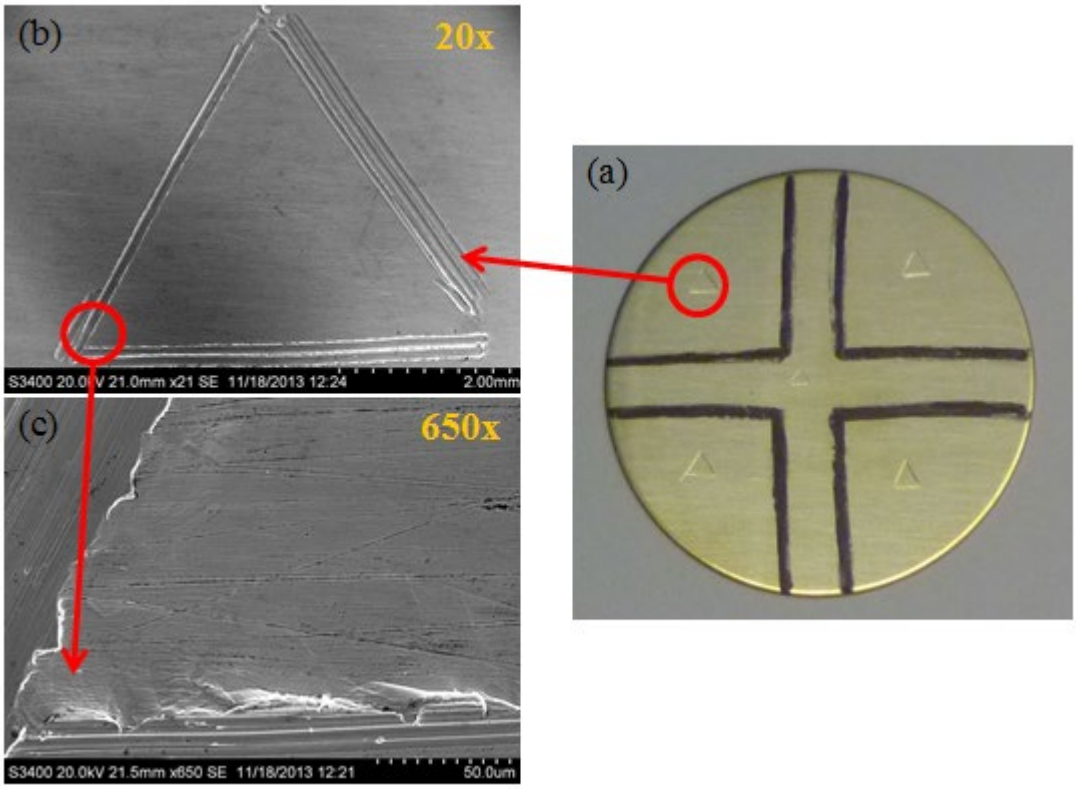

Fig. 1a–c. Photograph of the coupon preparation for SEM photography. A small triangle etched into the metal (a) coupon was photographed at 20x (b) and a location-specific point was photographed at 650x (c) to assess for micro-abrasion. On this quadrant of the brass coupon, a picture of the lower left corner of the quadrant triangle was used. (Courtesy of Cassy Cutulle, University College London)

Fig. 2. All objects and coupons used in the experiments for this dissertation project prior to dry ice cleaning (Courtesy of Cassy Cutulle, Trustees of The Wallace Collection, ©The Wallace Collection, London)

chamber to enable the shellac's removal. The musket locks were de-greased using a 1:1 acetone: Stoddard solvent solution. After cleaning, the objects were coated; one half of each furniture mount was used for coating and blasting. Three sections on that half of the mount were taped off, and each section was coated. Each musket lock was coated with one type of coating applied to the front (fig. 3, table 3).

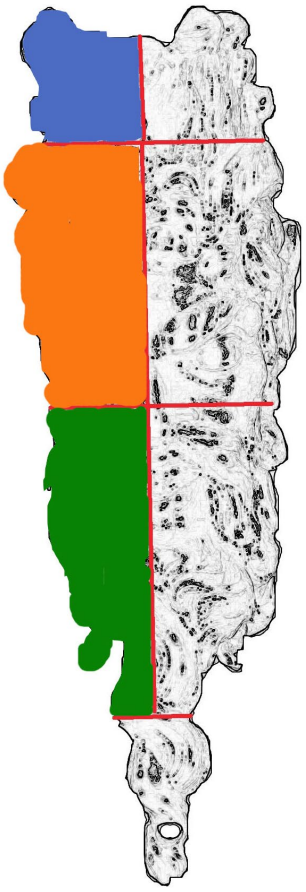

Fig. 3. Diagram of Mount #1 displaying the setup for the coating application. Paraloid B-72 was applied in the blue area, shellac in the orange area, and Briwax in the green area. (Courtesy of Cassy Cutulle, Trustees of The Wallace Collection, ©The Wallace Collection, London)

Table 3. Coatings Applied to Furniture Mounts and Musket Locks

Objects	Coatings
Three Furniture Mounts (each coating applied to each mount)	• One coat of Paraloid B-72 10% w/v in 1:1 IMS: acetone applied by brush • Four coats of Briwax buffed into the surface using furniture brushes • Eight coats of shellac approx. 15%–20% w/v in IMS applied by brush
Three Musket Lock Replicas (one coating per musket lock)	• One coat of Paraloid B-72 10% w/v in 1:1 IMS: acetone applied by brush • One coat of Paraloid B48N 10% w/v in 1:1 IMS: acetone applied by brush • One coat of petroleum jelly applied by brush

Table 4. Risk Rankings and Corresponding Percentages

1: 0%–25%: Low Risk
2: 25%–50%: Low–Medium Risk
3: 50%–75%: Medium–High Risk
4: 75%–100%: High Risk

Each section on the objects was blasted for approximately one minute. Nozzle distance, angle, and object position varied throughout. Particular aspects like surface changes, the removal process on the objects, and general ease of use were observed.

2.1.4 Results: Risk of Abrasion Assessment

To estimate the risk of abrasion, each metal and type of surface alteration observed (polishing, micro-abrasion, movement of metal, etc) was listed alongside the occurrence for that type of alteration. A total percent occurrence was then approximated for all cleaned quadrants. A risk-potential ranking system was used to correlate the percent values to a number that corresponded to a risk level (table 4). The various categories for surface alterations include:

- *New abrasion*: New scratch marks apparent on the surface in the "after" images
- *Impact marks*: Small, circular areas present marking the impact point of the dry ice shavings
- *Polishing effect*: The disappearance or reduction of previously established surface features indicating a polishing effect on the surface
- *Movement of metal*: The movement or loss of established metal material between the "before" and "after" SEM images.

Based on the results, the potential for surface alterations is low when dry ice blasting at the durations and settings employed in this project. Comparing across metal types, the brass and cupronickel coupons ranked the lowest in risk for potential surface alterations with an average between 8% and 10%. However, the smaller amount of cleaned quadrants for both metal types has also skewed this data. The mild steel coupons displayed the highest average percent occurrence of surface change at 12.5%. The larger amount of cleaned quadrants on the mild steel coupons can also account for this higher average. At any rate, the risk of surface alterations as a result of blasting is still considered low. Additionally, with the surface changes exhibited, many of them were miniscule in nature and could not be viewed by the naked eye (fig. 4).

2.1.5 Results: Coating Removal Tests

Coating removal was assessed visually and the percent removed estimated. The total space of a coated section represented 100%. If half of the coating was removed from that section, it was estimated as having been 50% removed. For the coupons, each quadrant represented one section.

Although the coating removal tests focused on the removal of coatings from objects, it was interesting and useful to look at the results of coating removal from the metal coupons as well, and thus those results are included in appendix 1. On average, 90% of the Briwax coating was observed as removed from the furniture mounts, whereas the removal averages for Paraloid B-72 and shellac were considerably less at 2.5% and 0%, respectively. For the musket locks, the Paraloid B-72 and petroleum jelly coatings were each assessed as 25% removed, whereas approximately 7.5% of the Paraloid B-48N coating was estimated as removed.

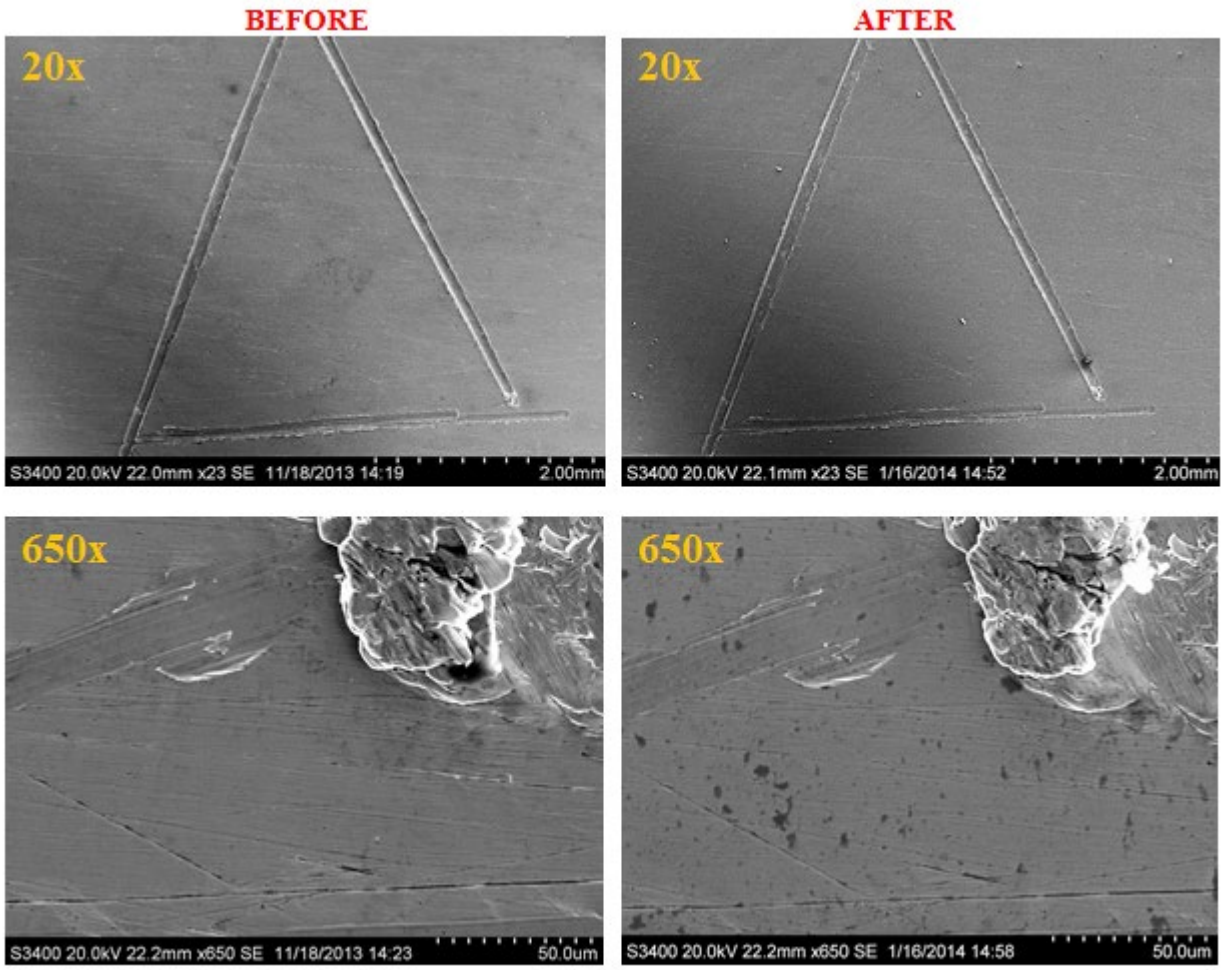

Fig. 4. SEM images of a brass coupon quadrant coated with Briwax at 20x and 650x before and after dry ice blasting (Courtesy of Cassy Cutulle, University College London)

The results have revealed that the settings utilized were sufficient for removal of Briwax and Renaissance Wax coatings (fig. 5a, b). The partial removal of petroleum jelly and Paraloid B-72 indicated that the mass flow and pressure settings were adequate, but a longer blasting time was needed to completely remove those coatings. Since Paraloid B-48N, shellac, Incralac, and Ercalene were not totally removed, a change in settings or blasting method would be needed for removal in a timely manner.

2.2 CLEANING THE ORIENTAL HELMETS AT THE WALLACE COLLECTION: A PRACTICAL CASE STUDY

2.2.1 Background

The Wallace Collection is a national museum within a historic house situated in central London, housing superb collections of decorative art, paintings, and furniture, as well as world class collections of European and Oriental arms and armor. The previous catalog of the Oriental Arms and Armor collection was published in 1914 without any illustrations, and the need for a new illustrated catalog has since been sought. The entire Oriental Arms and Armor collection, comprising around 1,000 objects, is currently being assessed, conserved, and photographed for the upcoming catalog.

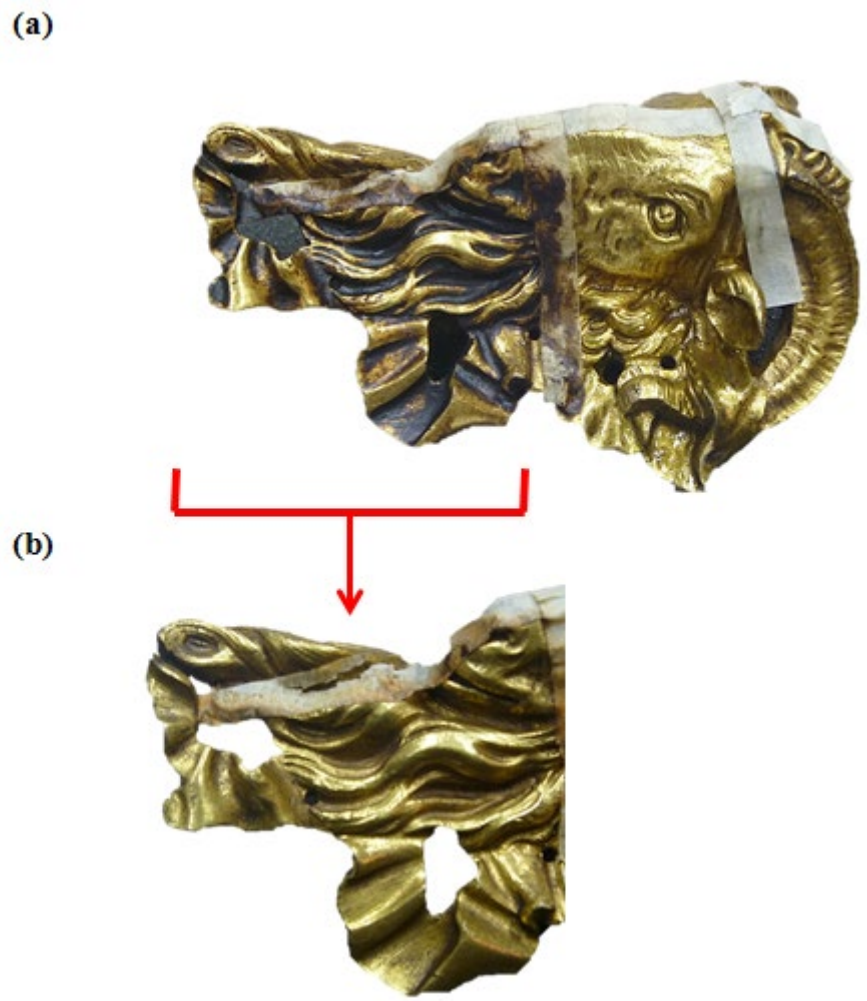

Fig. 5a, b. Furniture mount #2 before (top) and after (bottom) dry ice cleaning of Briwax (Courtesy of Cassy Cutulle, Trustees of The Wallace Collection, ©The Wallace Collection, London)

There are 74 helmets among the collection. A helmet usually consists of bowl and mail. The surfaces of most helmets, like many other objects in the collection, had previously been coated with petroleum jelly and other oils in the 1980s. These are now badly aged, discolored, and tacky. Interlinked mail rings were often clogged with these previous coatings along with accumulated dust and dirt, resulting in the loss of intended mobility and flexibility (fig. 6). Mail is conventionally cleaned with chemicals (e.g., Stoddard solvent, acetone, ethanol), often immersed in chemical baths in combination with mechanical cleaning. However, the cleaning of such intricate objects is often difficult to execute and demands a great deal of resources. Although it is considered a fast and effective method, chemical cleaning can have undesirable implications in terms of environmental sustainability, costs, and health and safety.

The application of dry ice blasting was first initiated at the Wallace Collection several years ago for the cleaning of furniture mounts, which had been coated with shellac and various waxes. Following successful results of those trials, it was decided to employ dry ice blasting for cleaning the mail on helmets as an alternative to chemical cleaning methods (fig. 7).

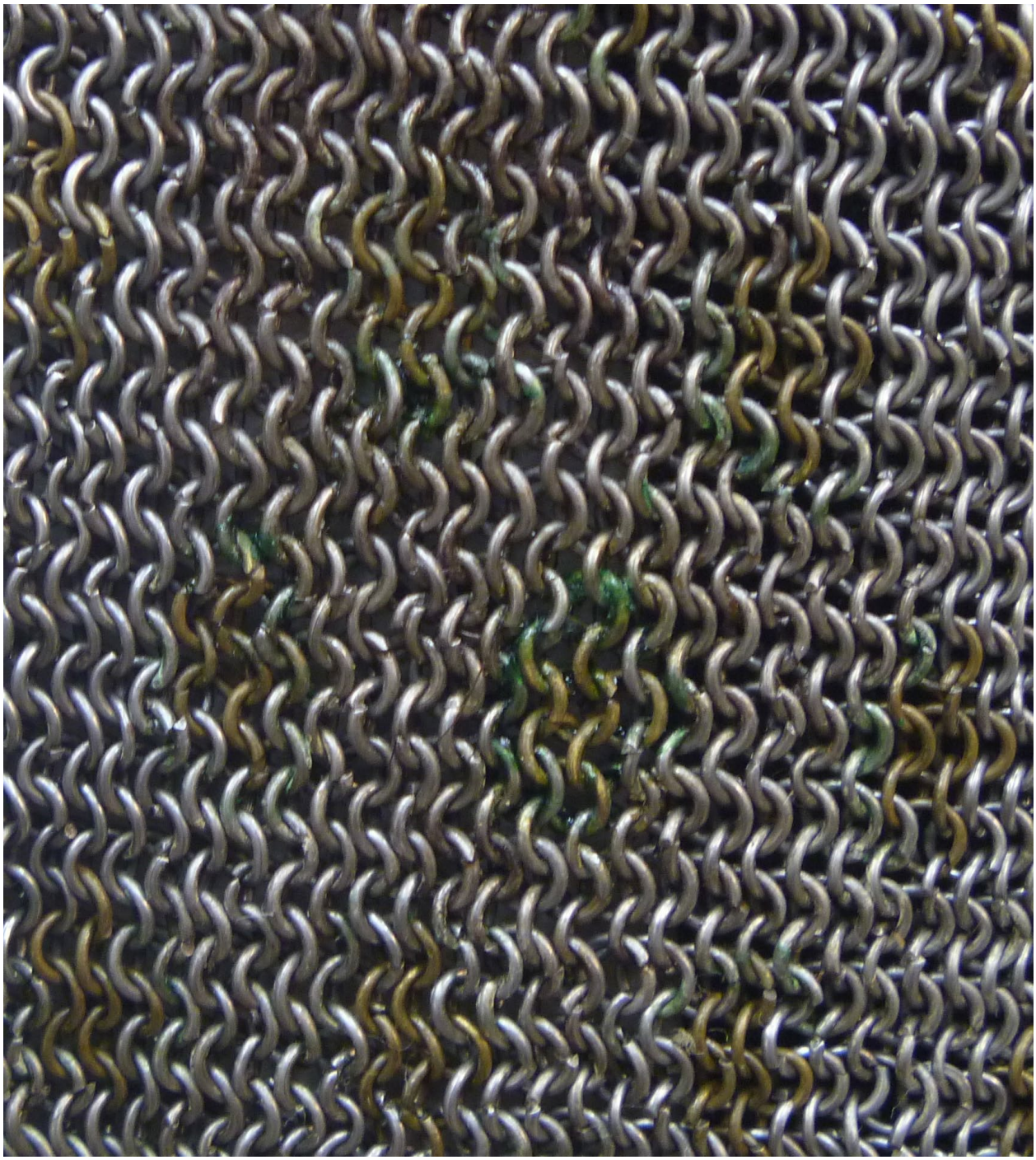

Fig. 6. Copper corrosion products within the links of the mail (Courtesy of Seoyoung Kim, Trustees of The Wallace Collection, ©The Wallace Collection, London)

Fig. 7. Several helmets on stands before dry ice blasting (Courtesy of Seoyoung Kim, Trustees of The Wallace Collection, ©The Wallace Collection, London)

2.2.2 Application Methods

The Cold Jet i3 MicroClean unit was rented for a week to clean the mail on the helmets (see table 1). Various settings of mass flows (0.09–0.45 kg/min.) and pressures (0.5–2.0 bar) were tried, and different nozzles were tested to find an efficient working method and to reduce any risks associated with this cleaning technique. A hot air gun was used to minimize the build-up of condensation on the blasted surfaces. The mail was initially cleaned with dry ice only. Dry ice blasting was effective in removing soft accretions from the surface; however, it was considered time-consuming and often required several rounds of blasting in one area to achieve satisfactory results. Due to limited resources within the restricted time scale, the working method had to be altered to complete the project within the given time (fig. 8).

The use of Stoddard solvent was consequently introduced to aid in the removal of accretions and old coatings. After preliminary dry ice blasting, Stoddard solvent was locally applied to areas where further cleaning was required with brushes, and then the helmet was dried with cotton cloths. This added step improved the overall appearance of the mail, resulting in an even surface cleaning. However, this method required thorough inspection, which expended more time. For heavily soiled mail, it was less time-consuming to briefly immerse the mail in a Stoddard solvent bath for one to two minutes with gentle agitation. The mail was then completely air-dried before dry ice blasting was undertaken as a second step.

The choice of cleaning methods was mainly determined by the condition of the mail. Out of 74 helmets, mail on 16 helmets required no treatment or minor localized cleaning due to previous cleaning treatment. Mail on 8 helmets was cleaned with dry ice blasting only, and mail on 12 helmets was cleaned

Fig. 8. Dry ice blasting the mail (Courtesy of Cassy Cutulle, Trustees of The Wallace Collection, ©The Wallace Collection, London)

with dry ice blasting first with further localized chemical cleaning. Mail on 38 helmets was cleaned with chemical immersion, followed by dry ice blasting. Twenty-two liters of Stoddard solvent was used for the chemical immersion of 38 helmets. Although the actual quantity of Stoddard solvent used was more than initially anticipated, it was still significantly less than using the conventional chemical cleaning method alone, which would have exhausted more than 100 liters of Stoddard Solvent to clean 38 helmets.

Cleaned mail was buffed with a brass bristle brush to improve surface sheen. Mail was then waxed on both interior and exterior surfaces with Renaissance microcrystalline wax, and the waxed surface was then heated with a hot air dryer on a low setting to melt any lumps of wax in crevices among the interlinked rings.

2.2.3 Results and Evaluation

Dry ice blasting was found to be effective as a complementary method for the cleaning of the interlinked mail rings of helmets (fig. 9) and a good alternative to traditional chemical cleaning, particularly for its environmentally friendly benefit. The success of dry ice blast cleaning does depend on the project aims and object types. Despite the practical limitations and issues, it was a worthwhile endeavor to apply dry ice blasting to the mail cleaning. Overall results were satisfactory. In particular, its environmental benefits can be immensely advantageous when it is used for the right project and suitable objects. Although chemical cleaning was reintroduced in this project to maximize limited resources and to alleviate time restrictions, it is possible that dry ice blasting can produce good results as a solitary technique. An evaluation of its practicality in the museum is discussed further in Section 4.

Fig. 9. Patterns on the mail after dry ice blasting and chemical immersion (Courtesy of Seoyoung Kim, Trustees of The Wallace Collection, ©The Wallace Collection, London)

3. VARIABLES AND LIMITATIONS

3.1 BLASTING PROCESS

A range of variables influenced the experimental approach and results achieved in the projects discussed earlier. First, the success with which objects were cleaned varied according to how the object was blasted and in what environment. In a test conducted by the authors, it was observed that dry ice blasting a brass coupon without the use of heat caused freezing of the metal, resulting in an accumulation of condensation as the metal warmed after blasting (fig. 10). The use of a hot air dryer on low settings during blasting facilitated the cleaning process by preventing the freezing of the object or coupon, inhibiting the accumulation of condensed water.

Although details such as the temperature of the surface of the objects and coupons before, during, and after blasting were not monitored in these projects, the effectiveness of the use of heat during blasting was observed qualitatively. By varying the point in time at which heat is applied (before, during, after) or not applying heat at all, different rates of success can be observed. More research is needed at this time, particularly to investigate the variable of heat application in dry ice cleaning.

The position, movement, angle, and distance of the object and nozzle during blasting can also influence the effectiveness with which the coating is removed from the surface (Veloz 1993; Scott 2002; van der Molen et al. 2010). In some instances, leaving the object stationary will allow the user to focus on an area for cleaning. However, moving both the object and the nozzle can also aid in a more complete removal from crevices and areas of relief. These aspects varied throughout the experiments discussed.

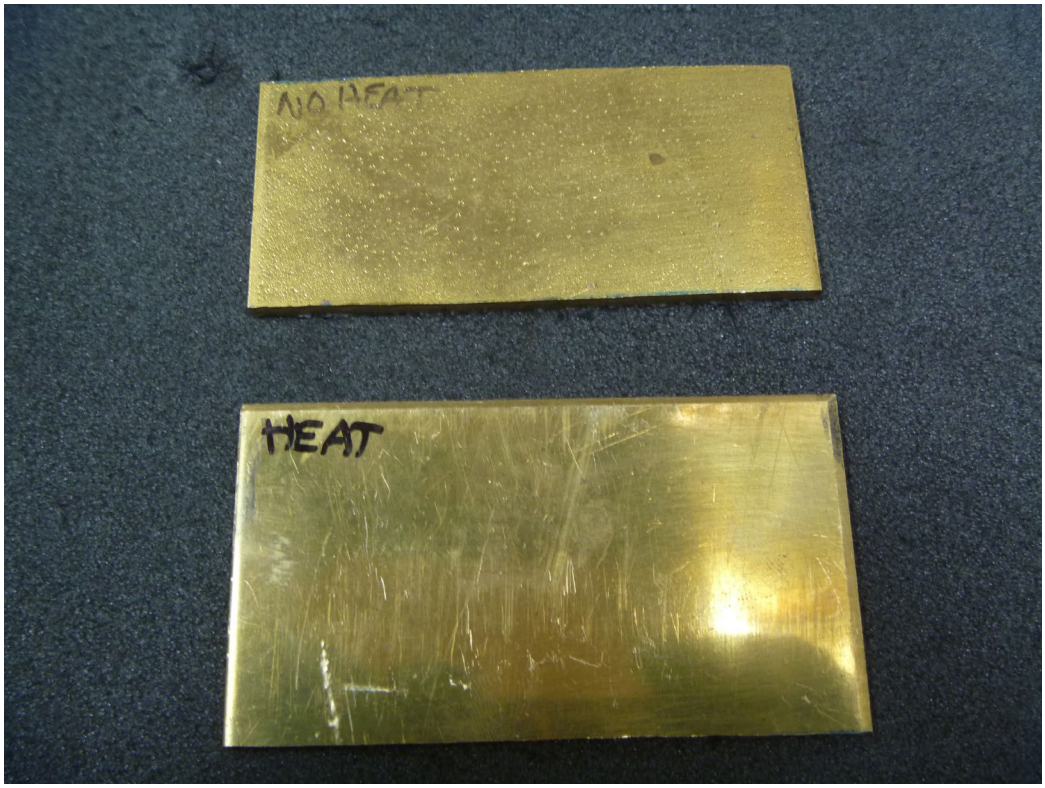

Fig. 10. Comparison between a metal coupon dry ice blasted with heat and one without heat. Note the presence of water on the surface of the metal coupon that was blasted without heat, which accumulated as the coupon warmed to room temperature after dry ice blasting. (Courtesy of Cassy Cutulle and Seoyoung Kim, Trustees of The Wallace Collection, ©The Wallace Collection, London)

Blasting duration utilizing the dry ice machinery is also an important variable to consider when undertaking dry ice blast cleaning. An effective blasting time will vary according to the coating to be removed and the structure of the object to be cleaned. Unfortunately, the time restrictions for these projects prevented the examination of the variable of time in dry ice cleaning.

3.2 OBJECT AND COATING

The type, composition, and structure of the object to be blasted are also important details to consider. The complexity of an object's structure can prevent the full removal of a coating, whereas differences in surface finishes will affect the adhesion between the coating and metal substrate.

Likewise, the nature of the coating to be removed is a substantial variable with a range of aspects, each of which will determine the success of the process. Details such as the composition of the coating, the age, and any interaction between the coating and object surface will heavily affect the ease of removal. For the dissertation experiments, artificial aging was not possible and therefore the coatings used were relatively new, having been applied approximately one week prior to blasting. In the case of the Oriental Helmets collection, the coating was approximately 30–35 years old. The overall results have thus been strongly influenced by this.

3.3 MACHINE, ACCESSORIES, AND SETTINGS

The machinery and accessories used are also factors that can dictate the outcome of the cleaning process. The machinery and settings control the pressure, the amount of dry ice being released, and *how* it is emitted. Ultimately this will determine the effectiveness of the dry ice blasting mechanisms (Otto et al. 2011). Likewise, accessories such as the nozzles, applicators, and air compressor units control the power and focus of the blasting. The use of pellets or shavings will also determine the efficiency of removal (van der Molen et al. 2010). Typically, pellets are considered more abrasive and are used with more tightly adhered coatings and accretions, whereas dry ice shavings are favored for their gentleness (Spur et al. 1999; Cold Jet LLC 2014e).

When analyzing the results from the abrasion experiment for the dissertation project, a range of variables also affected an understanding of the types of surface changes present and the extent of those changes. Differences in lighting, contrast, and charging of the metal surface in the SEM between the "before" and "after" images were common variables—a result of uncontrollable machine variations. These particular visual inconsistencies between images may have falsely indicated surface damage by obscuring previously established scratches—making it appear as though polishing had occurred—or altering the surface topography in the "after" image. Every effort was taken to consider these variations in the analyses of the "after" images.

3.4 LIMITATIONS

In addition to the variables inherent in these projects, some limitations also affected how the experiments were undertaken and the results gained. First, time constraints presented limits on how much preliminary research and testing could be done prior to conducting the experiments. This had a direct impact on the amount of time available for cleaning, ultimately restricting the blasting time. This was especially important in situations where a longer blasting time may have contributed to further removal of the coating.

There is also a learning curve associated with using this machinery. Although the unit is user-friendly and relatively easily operated, understanding which settings were appropriate for the cleaning job was more difficult. The availability of more time would have allowed for further testing and research; however, this was not possible given the circumstances of this project. As a result, this greatly influenced the experimental methodology and therefore the conclusions.

4. PRACTICALITIES OF DRY ICE CLEANING IN THE MUSEUM: QUALITATIVE OBSERVATIONS

The practical experience of using dry ice blasting at the Wallace Collection allowed for an assessment of the applicability of this cleaning method, both in terms of its use on actual objects and its viability in a conservation workshop setting. Observations were recorded on aspects that are considered particularly valuable to conservation work, such as ease of use, waste generated, costs, sustainability, health and safety, and accessibility, among other criteria. This information can be quite useful in providing an understanding of its utility and efficiency, thereby aiding in a decision about whether or not dry ice blasting is an appropriate means of cleaning metallic museum objects in any particular situation. It is important to note that these observations are subjective and refer to the use of the Cold Jet i3 MicroClean dry ice blasting machine for the projects discussed earlier.

4.1 USE IN THE MUSEUM

When considering the use of dry ice blasting as a cleaning method, the size of the unit and equipment must be taken into account. The dry ice shaving unit used in these projects measured 56 × 41 × 53 cm and weighed slightly less than 60 kg, allowing it to be easily situated on a laboratory bench (Cold Jet New Zealand LLC 2014). Additional equipment, however, was more difficult to position. Two large storage chests were needed: one in which to store surplus dry ice blocks in the long-term, and the other to store dry ice blocks for short-term use in the workshop. These storage chests kept the dry ice contained and decreased the evaporation rate, thereby increasing working time. When situating the machinery and accessories in the museum workshop, the large size and temperature requirements for the chests caused difficulties. In the case of this project, there was no large freezer available for the long-term storage of the dry ice, and thus one of the chests needed to be kept outdoors. This chest measured approximately .6 × .6 × 1 m. The second chest—the one that was placed in the workshop as temporary storage for the day's blasting—measured approximately 1 × .7 × .6 m. Additionally, the air compressor unit was needed in the blasting space, measuring approximately 1 m in length. Another consideration was the amount of power cords and hoses that occupied space and required close proximity to power outlets.

4.2 CONTROLLABILITY

In this project, *controllability* was defined as the ease of control of the machinery and ability to reach all areas of the object. For the cleaning of the furniture mounts and musket locks, it was difficult to reach tight spaces with the dry ice nozzle. This is concerning for the instrument's use in conservation, as it reveals that a complete cleaning of objects can be difficult to achieve. Additionally, concentrated blasting in tight spaces introduces the possibility of increased risk of surface damage, risk of condensation forming, or dry ice accumulation. However, since only one type of nozzle (MC29MH, with a length of 15.2 cm and blast range of 0.7 cm) was used in these projects, there is the possibility of more successful results with the use of different nozzle types.

Overall the machinery is user-friendly and easily operated by one person. A relatively simple setup, the dry ice shaving machine is connected to the air compressor unit and plugged into an electrical outlet. The hose that transports the dry ice and connects to the nozzle is also hooked up to the shaving machine. A block of dry ice can be easily inserted into the shaving machine by lifting the top lid and placing it in horizontally. The gun and nozzle work by way of a pressure-sensitive trigger. Due to the use of compressed air, there is a small kickback associated with blasting and objects must be held down to prevent movement during blasting.

4.3 ACCESSIBILITY

For use at the Wallace Collection, the machine and accessories were rented for a week from Cryogenesis Limited, UK. To avoid any delays, it was necessary to rent the machinery ahead of schedule and plan for the delivery and setup in the workshop. Since renting time was limited, this placed constraints on the work to be done. For these reasons, dry ice blasting was not seen as an incredibly accessible method of cleaning. This is in contrast to the use of solvent or air abrasive cleaning—both of which are usually located on-site. Additionally, in the case of the projects conducted at the Wallace Collection, dry ice blocks were supplied with the unit; however, this is not always the case, and oftentimes dry ice needs to be sourced separately from the machine.

The key to mitigating these challenges is to organize and plan the cleaning jobs to be done with the dry ice blasting machinery well in advance to avoid possible setbacks. These criteria are vital to understanding the worth of the machinery and in what situations it is best used. Knowing that it is not easily accessed may mean that it is only good to use dry ice blasting in situations where bulk or special cleaning is needed.

4.4 HEALTH AND SAFETY

Safety during operation is also an important factor to take into consideration. Heavy-duty gloves must be worn at all times when handling the extremely cold dry ice, which can burn if it comes in contact with skin. Additionally, the high noise levels of the air compressor can damage hearing at a range of 85−130 decibels (Cryogenesis Ltd. UK 2014a). It is therefore essential that protective gear such as goggles, ear defenders, and laboratory coats/long sleeves are worn at all times throughout the process.

Furthermore, although CO_2 is considered non-toxic, large gaseous amounts can be dangerous, especially in smaller workshops or laboratory spaces where it will replace the oxygen in the room (Cold Jet LLC 2014b; Health and Safety Executive 2014). The use of devices such as the Extech CO200 meter can allow for the monitoring of these levels (Air Concern Ltd. 2014). Adequate extraction and ventilation is therefore needed at all times when using this machinery indoors. Additionally, the air compressor generates fumes that can be considered noxious, and thus opened doors and extraction will aid in alleviating this.

Last, the user may also experience small-scale static electrical shocks when dry ice blasting metal, which can be remedied by connecting the object to grounding wires included with the blasting unit (Cold Jet LLC 2009d).

4.5 COSTS, RESOURCES, AND WORKING CAPABILITY

Conservators should be mindful of the costs involved and the usage of resources when undertaking dry ice blasting. Typically, the machinery is rented out through suppliers. Depending upon the supplier and location, prices will vary. Based on the work carried out at the Wallace Collection, the pricing range for one week of rental was approximately $1200.00, which included the dry ice, storage chests, two nozzles, gloves, air compressor, and hoses. Although this can be regarded as an expensive endeavor, it is important to note that the use of this machinery in cleaning negates the need for waste disposal (Cold Jet LLC 2004). In situations where this cleaning method is deemed appropriate and efficient and a bulk amount of objects are in need of cleaning, this method can be quite useful. Likewise, it may not be economical to rent the machinery for the cleaning of only a small number of objects.

In the case of dry ice shaving machines, working time is limited by the dry ice. The dry ice blocks will sublime and the size of the blocks will diminish over time. After a week of use for this project, remaining blocks had decreased by about 30%−45% of their original size in the surplus storage. This does depend on the thermal efficiency of the storage and whether or not freezers are available to store the dry ice, which would greatly enhance the working time.

The process of shaving down the blocks for blasting is another aspect to take into account. Depending on the mass flow setting, which controls the rate at which the blade shaving the ice operates, the ice block will be exhausted more slowly or quickly. At 0.45 kg/min., the maximum continuous working time was up to around 1.5 hours. Additionally, there is a drop in pressure when using a less powerful air compressor system. Less powerful systems will only yield a designated pressure before dropping off and needing a recovery time, as was evident in the work that was conducted at the Wallace Collection.

It is important to note that there are surface and material types for which dry ice blasting may not be an appropriate means of cleaning. Heavily decorated areas such as gilded, inlaid surfaces, or friable, softer, and delicate surfaces should be avoided because of the mechanical stresses caused by the blasting, which may lead to loss of material. Organic materials such as paper, wood, hard tissue, and leather require adequate testing before use to understand the potential hazards and benefits of dry ice cleaning on these materials.

4.6 SUSTAINABILITY

Since dry ice blasting utilizes non-toxic, recycled solid CO_2, which safely sublimates into the atmosphere, it is considered sustainable (Cold Jet LLC 2004; Continental Carbonic Products Inc. 2013; Cold Jet LLC 2014f). However, exhaust fumes from the air compressor can be considered harmful to the environment, so this should be taken into consideration. The ability to recycle the CO_2 would make this process even more sustainable, and more research needs to be conducted to determine if this is a viable possibility (US Department of Energy 2014).

4.7 WASTE GENERATED

During the cleaning of the furniture mounts, musket locks, and coupons, little to no waste was generated and virtually no cleanup was needed. Of course, this will differ according to the cleaning job undertaken—more objects with more coating increases the residual waste from blasting. The sublimation of the dry ice also prevents the need for disposal of the cleaning media. Although the dry ice blasting process does not produce new waste, the contaminant that is to be removed through blasting will relocate. Proper protection of surfaces in the working space is therefore needed.

5. CONCLUSIONS AND DISCUSSION

An important goal of these projects was to ascertain whether or not surface abrasion was occurring to the metal after dry ice blasting. Visually and at low magnification (20x), slight polishing and a low incidence of impact marks were observed. At the microscopic level (650x), minute surface alterations were evident, mostly in the form of the movement of loose metal around the area where the triangle had been incised in the coupon. This signifies that the risk of abrasion is low with the machinery, settings, and times used.

The use of the 0.45 kg/min. mass flow and 1.4 bar pressure settings allowed for the removal of 90%–100% of the Briwax and Renaissance Wax coatings within the allotted time on the coupons and objects, constituting the process and settings efficient for these coatings. This is a useful note for conservators interested in using this technique on metal objects.

For coating removal, the results also revealed that the object structure, coating type, and coating age are the main factors that will determine the time it takes to remove a coating.

Although some coatings remained untouched at the end of blasting, research does indicate the potential to remove such coatings (Veloz 1993; van der Molen et al. 2010; Liu et al. 2011; Zhou et al. 2012). For each coating, these suggested changes are detailed in table 5. These adjustments in settings or

Table 5. Coatings Used and Potential Adjustments Needed for Total Removal

Coating	Longer Blasting Time at Same Settings	Variation of Nozzle Angle or Distance, Nozzle Type, Object Movement	Change of Settings (Mass Flow, Pressure, or Both)	No Adjustment Needed
Renaissance Wax				X
Briwax				X
Petroleum Jelly	X			
Paraloid B-72	X	X		
Incralac		X	X	
Paraloid B-48N			X	
Shellac			X	
Ercalene			X	

blasting approach reveal the versatility of this cleaning method and the potential for greater efficiency in coating removal.

For coatings that were not removed, three main adjustments may aid in removal:

1. A longer blasting time at the same settings
2. Variation in nozzle type or angle, blasting distance, or object movement
3. Changing of settings (mass flow, pressure, or both).

The cleaning of the Oriental helmets at the Wallace Collection revealed that dry ice cleaning can sometimes be a lengthy endeavor, but benefits such as sustainability and reduction in exposure to toxic solvents can make it worthwhile to pursue.

Ultimately, to determine whether or not this method is a useful one, it is important to take into consideration the aspects discussed previously, to conduct thorough testing on sample materials, and to take time to find the most efficient settings and blasting approach for the object and coating type. Aspects of the job such as the amount of objects to be cleaned, the structure of the objects, the coating to be removed, and the amount of resources available—including staff time and money—need to be thoroughly considered prior to rental to understand whether or not this method of cleaning is an appropriate one in any situation. Further testing in the future will determine which changes in variables can remove specific coatings from metals. The projects discussed here are therefore just the start to a much wider investigation.

ACKNOWLEDGMENTS

The authors would like to acknowledge and appreciate the aid of Trustees of the Wallace Collection, London, particularly Head of Conservation David Edge and Senior Furniture Conservator Jürgen Huber. Gratitude is also owed to University College London and the steadfast support of Dr. Renata Peters, James Hales, and Kevin Reeves. Additionally, we would like to thank the team at Cryogenesis Limited, UK, which supplied the Cold Jet i3 MicroClean equipment. Last and certainly not least, we would like to thank our families who have supported us throughout this endeavor.

Appendix 1. COATING REMOVAL RESULTS FOR COUPONS

Percent of Coating Removed from Brass and Bronze Coupons

	Shellac	Incralac	Ercalene	Briwax	Renaissance Wax
Brass Coupon 1	Q1: 0%–1% Q2: 0%–1%	—	Q3: 0%–2% Q4: 0%–1%	—	—
Brass Coupon 2	—	—	—	Q1: 95%–100% Q2: 95%–100%	Q3: 95%–100% Q4: 95%–100%
Brass Coupon 3	—	Q1: 0%–1% Q2: 0%–1% Q3: 40%–50% Q4: 80%–85%	—	—	—
Brass Coupon 4 (EXTRA)	Q1: 0%–1%	Q2: 0%–1%	Q3: 0%–1%	—	—
Cupronickel Coupon 1	Q1: 0% Q2: 0%	—	Q3: 0% Q4: 0%	—	—
Cupronickel Coupon 2	—	—	—	Q1: 95%–100% Q2: 95%–100%	Q3: 95%–100% Q4: 95%–100%
Cupronickel Coupon 3	—	Q1: 0% Q2: 0% Q3: 0% Q4: 0%	—	—	—
Cupronickel Coupon 4 (EXTRA)	Q1: 0%	Q2: 0%–1%	Q3: 0%	—	—
Averages	.25% (average per 6 quadrants)	12.9% (average per 10 quadrants)	.33% (average per 6 quadrants)	97.5% (average per 4 quadrants)	97.5% (average per 5 quadrants)

Amount removed is approximate. Ranges are used to compensate for this. Averages are taken from the median of ranges.

Percent of Coating Removed from Mild Steel Coupons

	Paraloid B-72	Paraloid B48-N	Renaissance Wax	Petroleum Jelly
Mild Steel Coupon 1	Q1: 40%–50% Q2: 20%–30%	Q3: 0% Q4: 0%	—	—

Mild Steel Coupon 2	—	—	Q3: 95%–100% Q4: 95%–100%	Q1: 50%–55% Q2: 95%–100%
Mild Steel Coupon 3 (EXTRA, Blast First, Then Heat)	Q1:15%–20%	Q3: 0%–1%	Q4: 95%–100%	Q2: 95%–100%
Mild Steel Coupon 4 (EXTRA, Blasting at 90°Angle)	Q1: 20%–25%	Q3: 0%–1%	Q4: 95%–100%	Q2: 95%–100%
Averages	27.5 % (average per 4 quadrants)	.25% (average per 4 quadrants)	97.5% (average per 4 quadrants)	86.2% (average per 4 quadrants)

Amount removed is approximate. Ranges are used to compensate for this. Averages are taken from the median of each range.

NOTE

1. The coupons were bought as "phosphor bronze"; however, compositional analysis undertaken with a pXRF after the experiments were completed revealed that the bronze coupons were cupronickel.

REFERENCES

Air Concern Ltd. 2014. *CO_2 meters*. Accessed August 6, 2014. http://www.airconcern.co.uk/indoor-air-quality-instruments-co2-meters-c-1_132_137.html

Brush, M. B. 2010. Using dry ice for spray-paint removal on weathering steel. *Association for Preservation Technology Bulletin* 41 (1): 1–5.

Caple, C. 2000. Cleaning. In *Conservation skills: Judgement, method and decision making*. London: Routledge. 90–105.

CleanLink. 2014. *Chemical-free cleaning: Helping to preserve Auschwitz artifacts*. Accessed December 16, 2013. http://www.cleanlink.com/casestudieswhitepapers/details/ChemicalFree-Cleaning-Helping-to-Preserve-Auschwitz-Artifacts--25626

Cold Jet LLC. 2004. *Technical papers: The fundamentals of dry ice blast cleaning*. http://old.coldjet.com/tech-fundamentals.html

——2014a. *Environmental facts about dry ice blasting.* Accessed September 3, 2014. http://www.coldjet.com/en/environmental/facts.php

——2014b. *Frequently asked questions (FAQ).* Accessed September 2, 2014. http://www.coldjet.com/en/information/faq.php

——2014c. *i3 MicroClean.* Accessed August 31, 2014. http://www.coldjet.com/en/products/product-catalog.php?id=6&type=machine

——2009d. *The new i3 MicroClean*. Accessed August 31, 2014. http://www.coldjet.com/minisites/i3microclean/en/

——2014e. *Two hose vs. one hose systems*. Accessed August 31, 2014. http://www.coldjet.com/en/information/two-hose-vs-one-hose.php

——2014f. *What is dry ice blasting (cleaning)?* Accessed January 20, 2014. http://www.coldjet.com/en/information/what-is-dry-ice-blasting.php

Cold Jet New Zealand LLC. 2014. *Cold Jet i3 MicroClean precision dry ice blasting*. Accessed March 30, 2014. http://www.coldjet.co.nz/dry-ice-blasting-machines/cold-jet-i3-microclean

Continental Carbonic Products Inc. 2015. *Benefits of dry ice blasting*. Accessed August 5, 2014. http://www.continentalcarbonic.com/benefits-of-dry-ice-blasting.html

Cryogenesis Ltd. UK. 2014a. *Dry ice blasting: Frequently asked questions*. Accessed April 11, 2014. http://www.cryogenesis.co.uk/faq.php

——2014b. *What is dry ice cleaning?* Accessed January 20, 2014. http://www.cryogenesis.co.uk/dry-ice-cleaning.php

Garcia, S. D., D. Gilroy, and I. D. MacLeod. 1998. Metals. In *A practical guide to the conservation and care of collections,* eds. D. Gilroy and I. Godfrey. Perth, Australia: Western Australian Museum. 113–126.

Grossbard, E. 1992. The care and conservation of metal artifacts. In *Conservation concerns: A guide for collectors and curators*, ed. K. Bachmann. Washington, DC: Smithsonian Institution Press. 101–104.

Hailstorm Industrial Cleaning Solutions. 2009. *Dry ice blasting comparison.* Accessed December 16, 2013. http://hailstormsolutions.com/dry-ice-comparison/

Harris, R. 2006a. Arms and armour. In *The National Trust manual of housekeeping: The care of collections in historic houses open to the public*. Oxford: Butterworth-Heinemann Ltd. 320–329.

——2006b. Metals. In *The National Trust manual of housekeeping: The care of collections in historic houses open to the public*. Oxford: Butterworth-Heinemann Ltd. 308–319.

Health and Safety Executive. 2014. *General hazards of carbon dioxide*. Accessed September 2, 2014. http://www.hse.gov.uk/carboncapture/carbondioxide.htm

Higginson, E., and Prytulak, G. 2012. Dry ice (CO_2) blasting tests at the Canadian Conservation Institute. *Proceedings of the Canadian Conservation Institute 38th Annual Conference and Workshop*. Peterborough, Ontario, Canada. Accessed December 4, 2013. https://www.cac-accr.ca/files/pdf/e-cac-conference-2012.pdf

Liu, Y., H. Maruyama, and S. Matsusaka. 2011. Effect of particle impact on surface cleaning using dry ice jet. *Aerosol Science and Technology* 45 (12): 1519–1527.

Lizarraga, D. 2012. *ASM basket research benefits museum collections worldwide*. http://www.statemuseum.arizona.edu/research/asm_basket_research.shtml

Otto, C., S. Zahn, F. Rost, P. Zahn, D. Jaros, and H. Rohm. 2011. Physical methods for cleaning and disinfection of surfaces. *Food Engineering Reviews* 3 (3): 171–188.

Posner, K. 2012. *Conservation comes outdoors for Henry Moore's "Bronze Form."* The Getty Iris. http://blogs.getty.edu/iris/conservation-comes-outdoors-for-henry-moores-bronze-form/

Scott, D. A. 2002. Conservation treatments for bronze objects. In *Copper and bronze in art: Corrosion, colorants, conservation.* Los Angeles: Getty Publications. 352–397.

Silverman, R. 2008. Fire and ice: A soot removal technique using dry ice blasting. *Archival Products News* 15 (3): 1–8.

Spur, G., E. Uhlmann, and F. Elbing. 1999. Dry-ice blasting for cleaning: Process, optimization and application. *Wear* 233-235: 402–411.

Sullivan, K. 2013. *USS* Monitor *Center: Dry ice blasting*. The Mariners' Museum and Park. https://www.marinersmuseum.org/blogs/ussmonitorcenter/?p=4246

US Department of Energy. 2014. *Carbon capture, utilization and storage*. Accessed August 24, 2014. http://www.energy.gov/carbon-capture-utilization-storage

van der Molen, R., I. Joosten, T. C. P. Beentjes, and L. Megens. 2010. Dry ice blasting for the conservation cleaning of metals. In *Metal 2010: Proceedings of the Interim Meeting of the ICOM-CC Metal Working Group*, eds. P. Mardikian, C. Chemello, C. Watters, and P. Hull. Clemson, SC: Clemson University. 96–103.

Veloz, N. F. 1993. Practical aspects of using walnut shells for cleaning outdoor sculpture. *Association for Preservation Technology Bulletin* 25 (3/4): 70–76.

Yara CO_2 and Dry Ice. 2014. *Dry ice blast cleaning*. Accessed March 10, 2014. http://www.yara.ie/co2-and-dry-ice/cryoblasting/

Zhou, W., M. Liu, S. Liu, M. Peng, J. Yu, and C. Zhou. 2012. On the mechanism of insulator cleaning using dry ice. *IEEE Transactions on Dielectrics and Electrical Insulation* 19 (5): 1715–1722.

SOURCES OF MATERIALS

Brass and Mild Steel Coupons
http://www.ebay.co.uk
http://www.ebay.co.uk/usr/hardware0utlet?_trksid=p2047675.l2559

Cold Jet i3 MicroClean Single-Hose Dry Ice Shaving Unit
Cryogenesis Ltd. UK
Units N1/N2
Riverside Industrial Estate
Littlehampton, West Sussex, UKBN17 5DF
http://www.cryogenesis.co.uk/newsfeed/products
Cold Jet Distributors: http://www.coldjet.com/en/company/distributor-locator.php

Cupronickel Coupons
Metals Supermarkets
11 Hanover West Industrial Estate
161 Acton Ln.
London, UK NW10 7NB
http://metalsupermarkets.co.uk/park-royal/

Hitachi S3400N Scanning Electron Microscope
Hitachi Hi-Technologies Corporation
http://www.hitachi-hightech.com/eu/product_detail/?pn=em-su3500

Incralac
Conservation Support Systems
PO Box 91746
Santa Barbara, CA 93190-1746
http://www.conservationsupportsystems.com/main

Paraloid B-72, Paraloid B48-N, Ercalene, and Renaissance Wax
Conservation Resources UK Ltd.
Unit 15 Blacklands Way
Abingdon-on-Thames, Oxon, OX14 1DY
http://www.conservation-resources.co.uk/index.php?main_page=index

CASSY CUTULLE attended the University of Massachusetts in Boston from 2006 to 2010, graduating summa cum laude with a BA in archaeology and history and a minor in art history. She carried out graduate studies at University College London (UCL) from 2011 to 2014, where she obtained an MA degree in principles of conservation, completed with a dissertation on the conservation care of Native American objects. She recently completed an MSc degree in conservation for archaeology and museums with a research project that explores the use of dry ice blasting in museums. Cassy also completed practical internships at the Wallace Collection and the Horniman Museum alongside voluntary work at UCL's Institute of Archaeology, UMass Boston, and the Catalhöyük Research Project. Recently, she volunteered as an objects conservator at the Harvard Semitic Museum and worked as a Laboratory Consultant and Contract Conservator for the Collection of Historical Scientific Instruments at Harvard University. Cassy is now the Chief Objects Conservator for Kyrenia Ship Project in Nicosia, Cyprus. Address: 14 Jones Rd., Apt. 3, Revere, MA 02151-5438. E-mail: c.cutulle.11@ucl.ac.uk

SEOYOUNG KIM earned an MA in conservation of historic objects at De Montfort University, Lincoln. She completed the Kress Postgraduate Fellowship at the Saint Louis Art Museum, St. Louis, Missouri. She worked for Glasgow Museums, Scotland, UK, from 2003 to 2008 as Assistant Conservator (metals, arms, and armor), and worked for the Wallace Collection from 2008 to 2014 as Metalwork, Arms, and Armor Conservator. She joined Kingston Museum as a Curator in 2014. Seoyoung is an accredited member (ACR) of the Institute of Conservation. Address: Kingston Museum, Wheatfield Way, Kingston upon Thames, Surrey, KT1 2PS, UK. E-mail: seoyoung.kim@kingston.gov.uk