JEN JUNG KU AND FEI WEN TSAI

Study on the Influence of Gunpowder Residues Found in Paper-Based Materials

INTRODUCTION

The use of gunpowder has become a new method of artistic expression since around the 1950s. The application of gunpowder in art began as artists explored new possibilities outside the boundaries of traditional art forms and materials. Since the aging speed and deterioration mechanisms of gunpowder are complex by nature, the safekeeping of such artworks has posed a new challenge to the field of art conservation. As there has been an increase in the number of gunpowder artworks, it is important to establish a better understanding of gunpowder and its use as an artistic medium, and to develop a proper standard for the preservation and conservation of such artworks. With this in mind, this project uses materials science to analyze gunpowder as a contemporary art medium and hopes to provide a starting point for the study of gunpowder-art conservation, which will assist museums and collectors in the better preservation of their gunpowder art collections.

The focus of this paper is on gunpowder artwork and its related derivative materials. Because of the uncontrollable nature of gunpowder, it was not possible to control the surface condition of each paper sample created. In order to compensate for this and reduce possible error in the result, 11 samples were used in each experiment group. Each sample was measured 11 times using a color spectrophotometer, and the average color difference value was calculated.

Through literature collection, sample creation, accelerated-aging experiments, analysis and diagnosis of the experiment samples, the goal of this project is to evaluate and understand the deterioration mechanisms and effects of gunpowder residue on paper, providing references for future studies.

Presented at the Book and Paper Group Session, AIC's 40th Annual Meeting, May 8–11, 2012, Albuquerque, New Mexico.

GUNPOWDER AND ART

In the past, artists used mostly paints and canvases, but contemporary art is often multimedia, and artists are expressing their ideas through many nontraditional materials. Compared to traditional art media, gunpowder is a completely new material, and gunpowder art can be both physical and conceptual. Some contemporary artists use specific sites where explosions happened or land burned to create conceptual art pieces referring to ideas such as violence, military crises, and conflicts in a metaphorical manner. However, in Asian cultures the use of firecrackers implies the dispelling of misfortune and represents people's hope for peace and unity. Conceptual works like these can use gunpowder indirectly, by recording the loud sound of an explosion on tape or capturing the moment of explosion with video or photography. Many artists also use gunpowder directly, as a physical medium, applying it onto paper and canvases to create drawings. This project focuses on the latter kind of gunpowder art, in which gunpowder is used physically in the creation of an artwork.

LEADING GUNPOWDER ARTISTS

1. *Edward Ruscha:* Ruscha is an American pop artist who began a series of new-media artworks in the 1970s, incorporated nontraditional materials such as gunpowder, blood, fruit and vegetable juices, lubricating oils, grass extracts, etc. His gunpowder mixture consisted of saltpeter, sulfur, and charcoal, and had a unique, rough texture that he used to imply ideas of violence and war. Using this gunpowder, Ruscha made elegant drawings of words, creating a powerful contrast between the physical material and the visual imagery.
2. *Matthew Stromberg*: Stromberg, a professor at Savannah College of Art and Design in Georgia, began his exploration of gunpowder in art in 2007. His work incorporates different types of gunpowder on cardboard or thick watercolor paper.

3. *Aoife van Linden Tol*: Van Linden Tol is an Irish artist who received professional training in explosives through the International School for Security and Explosives Education. In recent years, her solo exhibitions in Berlin and London explored the themes of nature, violence, and time. Her work utilizes chemical and physical reactions of powerful explosives to express the intense experiences of pain and love. Her application of explosives is not limited to paper and canvases; she has also utilized three-dimensional objects such as books, metal objects, photographs and other ready-made objects.
4. *Robert Weibel*: An American contemporary artist and printmaker, Weibel has focused on public art projects and paper-based gunpowder drawings in his recent works. Metals and plastics are sometimes used in his work to enhance the definition of drawings.
5. *Rosemarie Fiore*: A New York–based contemporary artist who has been working on a series of firework drawings since 2005, Fiore makes her work by exploding and containing different types of fireworks, including colored smoke bombs, jumping jacks, monster balls, fountains, magic whips, spinning carnations, ground blooms, rings of fire, and lasers on a large piece of white paper, creating "bursts of saturated color that are overlapped and collaged" into a final piece (Fiore 2000–2011). Due to the need for multiple explosions and collaging, her works are often heavy and thick.
6. *Cai Guo-Qiang*: Cai is a Chinese contemporary artist who became internationally known through his explosive art in the 1990s. Recently named by the *New York Times* as the world's most highly valued Asian artist (Pomfret 2008), Cai is famous for his gunpowder drawings, explosion sketches, and video recordings of his large-scale installation works. Cai uses gunpowder in two ways: gunpowder drawings and large-scale explosive installations.

Many contemporary artists make new works constantly using gunpowder as their primary medium. Gunpowder is a new type of art medium that still needs experimentation and development, and the new types of artwork it produces are posing an important test for the knowledge and techniques of contemporary archival practices. It is crucial to establish sound preservation and conservation standards based on the materials science of gunpowder. By conducting accelerated-aging experiments and analyzing the deterioration of gunpowder-based artworks, this project hopes to provide further understanding of the characteristics of gunpowder and to assist in extending the life of these kinds of artworks.

THE EFFECTS OF GUNPOWDER RESIDUES ON PAPER IN ACCELERATED-AGING TESTS: EXPERIMENTAL METHODS

The effects of gunpowder residues on paper were simulated in accelerated-aging tests. The test samples were then analyzed using automated color measurements, pH tests, and infrared spectroscopy tests. Because gunpowder is still a fairly new medium in art, there is no available reference data that can be compared with the results of this experiment.

In this experiment, gunpowder was ignited on three different types of paper materials: Toyo filter paper, handmade paper, and Canson sketch paper. The resulting paper samples were separated by their surface conditions into two different groups: those with powder residue only and those with powder residue and burn marks. These samples were then subjected to accelerated-aging tests, and the test results were compared to a control group of plain samples with no gunpowder residues.

Fig. 1. Paper sheets after the gunpowder has exploded, before cutting

Fig. 2. Cutting paper samples

Sample Creation

The gunpowder used in this experiment consisted of 75% potassium nitrate, 15% carbon (charcoal), and 10% sulfur powder (all extra-pure reagents), filtered and mixed. A fuse was placed on a large sheet of sample paper to which gunpowder was applied. A piece of wooden board was then placed on top of the paper and lightly pressed to keep the paper in place and contain the explosion while still allowing enough air to circulate. The fuse was then ignited. The paper was burned and became brittle after the explosion, with multiple holes (fig. 1).

In order to obtain samples without any holes, samples were trimmed from the sheet in the smallest possible size. Each sample needed to be bigger than the aperture of the automated spectrophotometer (1.2 cm) and to have enough space around it for safe handling (an additional 0.9 cm). For this reason, each circular sample was 3 cm in diameter (fig. 2).

Sample Quantity

Because of the uncontrollable nature of gunpowder, it was hard to manage the explosions and unify the surface condition of all paper samples created. Therefore, a large quantity of samples was created and used in the experiment in order to ensure the accuracy of the result. The experiment involved three types of paper, three different levels of damage caused by the gunpowder, and three types of accelerated-aging tests. Eleven samples were used in each of the 27 test groups, resulting in a total of 297 samples for testing and examination.

Accelerated-Aging Tests

Three different accelerated-aging tests were carried out in this experiment, each according to established Chinese National Standards (CNS). The dry-heat aging test was carried out in accordance with CNS 12886, "Test Method for Accelerated Aging of Paper and Paperboard: Dry-Heat Treatment at 105ºC." For the light-and-heat aging test, a UVA 340 μm lamp was used and samples were exposed to ultraviolet light with an intensity of 0.89 W/m^2 at 60ºC (fig. 3). CNS 12887-1, "Test Method for Accelerated Aging of Paper and Paperboard: Wet Heat at 60ºC and 65% Relative Humidity" was used for the wet-heat aging test. While the test temperature was kept at 60ºC, the relative humidity was adjusted to 80% in this experiment in order to simulate the hot and humid climate of Taiwan (fig. 4). Paper samples were aged under these conditions for 0, 36, 96, 120, 240, 480, and 600 hours.

Color Differences and Blackness

The color of each sample was measured before and after the accelerated-aging tests using the automated color spectrophotometer and CIE L*a*b* color parameters, which were developed by the Commission Internationale de l'Eclairage (CIE) in 1976. The aperture of the color spectrophotometer used was 0.375 in. Each sample was measured 11 times, and the average value was calculated. The following tables summarize the definition of L*a*b* color coordinates (table 1) and the color difference values corresponding to human perception (table 2).

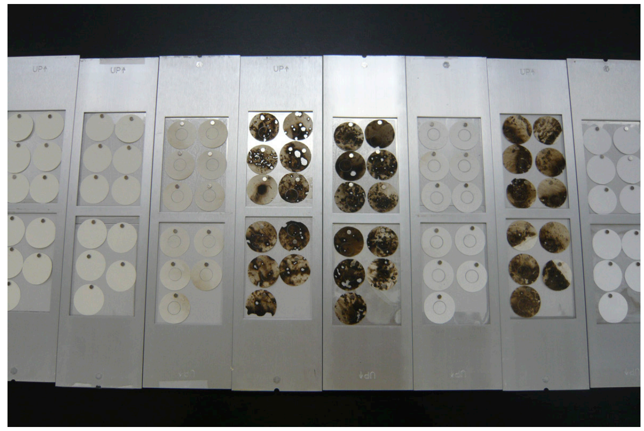

Fig. 3. Light-heat aging test

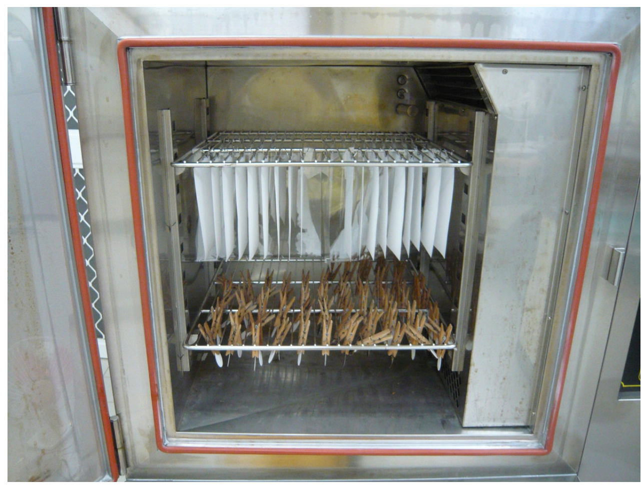

Fig. 4. Wet-heat aging test

The L*a*b* values were also used to calculate the blackness values of samples. The color of a black paper cannot be represented with a single L* value like the color of a white paper. Therefore, the blackness value of the paper was represented using the method suggested by Lan, Zhi, and Ming (1998), who used the formula $BL^* = L^* + |a^*| + |b^*|$ to calculate the blackness value (BL*) of paper.

pH

The pH value of paper indicates its acidity, but pH is determined by the concentration of hydrogen ions in a solution. Precisely speaking, pH cannot be measured for paper since it is a solid and not a liquid. Therefore, when pH values are used to indicate the acidity of papers, the pH value actually indicates the acidity of the solution in which the paper was soaked.

Coordinates	Definitions	Meaning in the Change of Values
L*	light-dark value	$\Delta L^* = (L^{*\prime} - L^*)$; $L^* = 0$–100 +L = more light, –L = more dark
a*	red-green value	$\Delta a^* = (a^{*\prime} - a^*)$; $a^* = -1$ to $+1$ +a = more red, –a = more green
b*	yellow-blue value	$\Delta b^* = (b^{*\prime} - b^*)$ $b^* = -1$ to $+1$ +b = more yellow, –b = more blue
ΔE*	color difference	$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ The larger the ΔE* value, the larger the color difference.
L*, a*, b* = Values **before** the accelerated-aging test **L*′, a*′, b*′** = Values **after** the accelerated-aging test		

Table 1: L*a*b* Coordinates and Their Meanings

Color Difference Values (ΔE*)	**0–0.5**	**0.5–1.5**	**1.5-3.0**	**3.0-6.0**	**6.0-12.0**	**12.0+**
Human Perception	Very little difference	Minor difference	Visibly different	Different	Huge difference	Totally different

Table 2: Color Difference Values and Human Perception

Acidity is one of the most important factors affecting the longevity of a paper. Due to the presence of hydrogen ions, hydrolysis and oxidation reactions can occur more readily in the cellulose and hemicellulose of acidic papers, degrading the sturdiness of the paper. This kind of deterioration is more severe in acidic papers with lower pH. However, when a paper has a very high pH and is extremely basic, its longevity is not enhanced because the speed of oxidative degradation becomes faster for cellulose in a highly basic environment. Therefore, neither strong acidity nor strong basicity is desirable for the preservation of paper materials. In the case of artworks using gunpowder (a basic medium), papers should not become overly basic.

Three levels of gunpowder damage were created on three different types of papers, which were then aged in wet-heat, dry-heat, and light-and-heat conditions for 600 hours. There were also nine groups of control samples used for comparison before and after accelerated aging, resulting in 36 groups of samples for pH testing. The cold-extraction method described in TAPPI T509 om-96 was used to test the pH value of the samples (TAPPI 1996). A cold-extraction method was used because the hot-water extraction method can cause the decomposition of water molecules, which may affect the acidity of the resulting solution. Paper samples were cut into small pieces and soaked in distilled water. A HANNA Instruments HI 8424 Microcomputer pH meter was used to test the pH of the solution.

Infrared Spectroscopy

FTIR with attenuated total reflectance (ATR-FTIR) was used in this experiment for infrared spectroscopic analysis. This technique utilizes the infrared-absorbing characteristics of certain functional groups within molecules to examine chemical compounds and the construction of sample surfaces.

Paper samples from before and after the accelerated-aging tests were placed on the test platform and exposed to the infrared light. After samples had absorbed the infrared light energy, Fourier transform was used to convert the raw data into a full spectrum.

X-Ray Fluorescence Spectrometry

A Seiko Instruments Inc. SEA200 Mobile Element Monitor (Field-X) was used for the XRF analysis of the paper samples (fig. 5). XRF can be used to detect elements with

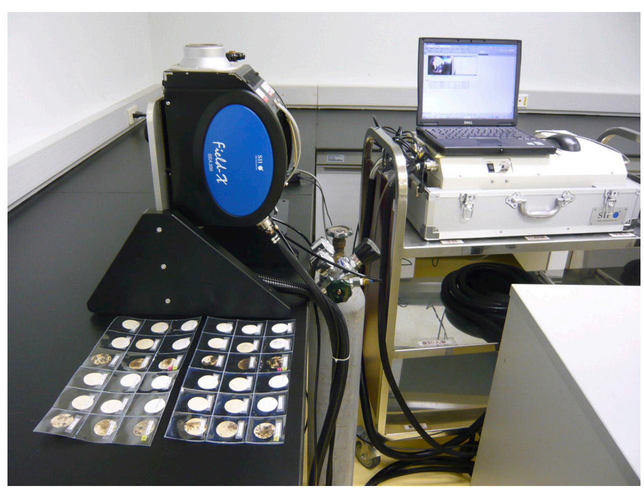

Fig. 5. Samples undergoing XRF analysis

atomic numbers larger than 12 for qualitative and quantitative analysis. Because the molecular mass of the elements detected in this experiment was expected to be small, helium gas was introduced to minimize the noise in the results.

The XRF analysis was carried out on three types of paper samples with three different levels of gunpowder residues before and after each wet-heat, dry-heat, and light-and-heat accelerated-aging test. Results were compared to the samples from the control group before and after accelerated aging.

ACCELERATED-AGING TESTS: RESULTS AND ANALYSIS

Color Difference Analysis

Based on the average color measurements taken before and after the accelerated-aging tests, the $\Delta E^\star$ and $\Delta L^\star$ values of samples from the group with more gunpowder residues and burn marks after the explosion were clearly higher than the $\Delta E^\star$ and $\Delta L^\star$ values of the other sample groups (i.e., the samples with burn marks became lighter). This result was consistent in all three types of accelerated aging tests (figs. 6–8). A possible cause might be that the gunpowder residue on the paper samples fell off during the accelerated-aging tests, resulting in increased lightness. As for the color change of the samples, the $\Delta E^\star$ value of the sample group with gunpowder residue was relatively close to that of the control group, even though there were still differences between different types of papers.

The three types of paper used in this experiment contained different amounts of lignin as well. According to the lignin-detection test, the filter paper was lignin free, the handmade paper contained some lignin, and the sketch paper contained the most lignin. After accelerated aging, color changes in the handmade paper and sketch paper were similar, but the sketch paper, with its higher lignin content, showed more prominent color change and therefore a higher $\Delta E^\star$ value in the light-and-heat aging test than in the wet-heat and dry-heat aging tests (fig. 8). The main cause of this color difference was the photo-oxidation of lignin inside the cell walls of paper fibers—a chain of radical reactions that happens when the photosensitive groups of lignin, such as its α-carbonyl group, absorb ultraviolet light and produce chromophores. Paper samples with lignin content also showed higher $\Delta E^\star$ values than lignin-free paper samples after accelerated aging. In terms of yellowing, the sample groups with burn marks showed higher $\Delta b^\star$ values, and samples with higher lignin content had more severe yellowing compared to lignin-free samples.

Blackness Value Analysis

The blackness value was calculated from the $L^\star a^\star b^\star$ values measured before and after the accelerated-aging tests using the color spectrophotometer. The blackness value was

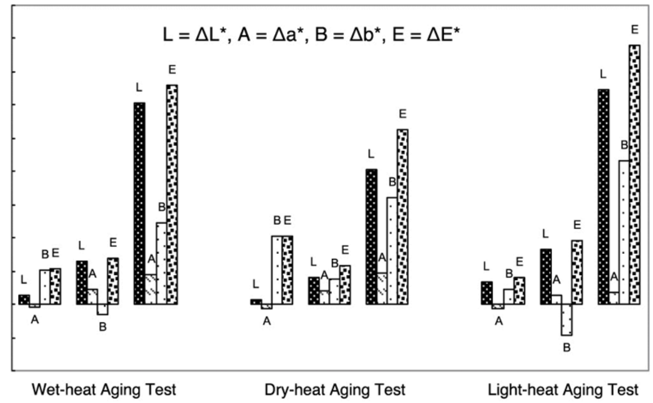

Fig. 6. Comparison of color changes in filter paper samples with gunpowder after accelerated aging (In each accelerated-aging test, levels of gunpowder damage are shown from left to right as none, powder residue, and residue with burn marks.)

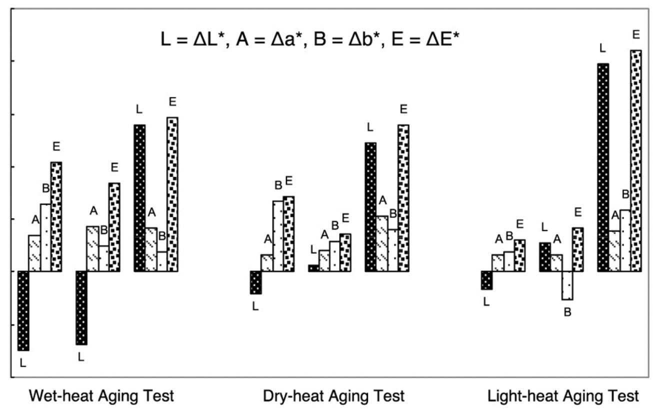

Fig. 7. Comparison of color changes in handmade paper samples with gunpowder after accelerated aging (In each accelerated-aging test, levels of gunpowder damage are shown from left to right as none, powder residue, and residue with burn marks.)

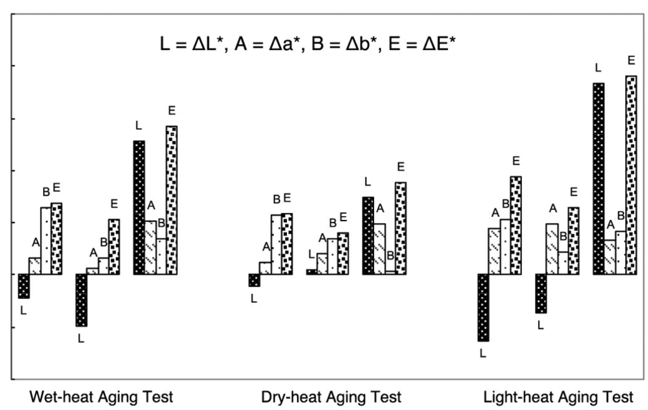

Fig. 8. Comparison of color changes in Canson sketch paper samples with gunpowder after accelerated aging (In each accelerated-aging test, levels of gunpowder damage are shown from left to right as none, powder residue, and residue with burn marks.)

calculated using the formula BL* = L* + |a*| + |b*|. The lower the calculated BL* value, the darker the sample. This value was used to observe the change in the darkness of samples with burn marks. Blackness values of samples with burn marks over the 600 hours of accelerated-aging tests showed that there were no obvious differences in the blackness of Toyo filter paper samples after wet-heat, dry-heat, and light-and-heat aging. The blackness value was a little higher (i.e., the samples became lighter) only after the light-and-heat aging test. Handmade paper samples showed a more obvious increase in the blackness value after the light-and-heat aging test compared to the wet-heat and dry-heat aging tests, and the same was observed for Canson sketch paper samples.

pH Analysis

Figure 9 shows the overall decrease in the pH of the samples after 600 hours of accelerated aging. The pH values at 0 hours into the accelerated-aging tests were higher than the values at 600 hours in all three accelerated-aging tests. Although the pH values became lower after aging, the papers used in this experiment were all basic to begin with, so the pH of samples with gunpowder residues mainly fell in the range of neutral to basic after aging.

In the group of aged samples, the samples with burn marks had higher pH values compared to the others, probably due to the higher amount of gunpowder residue. From the resulting graph, it is possible to see that burnt samples have higher pH values than samples with only powder residue, which have higher pH values than samples without any gunpowder residue.

Infrared Spectrometry Analysis

Figures 10–11 display the ATR-FTIR absorption spectra for the experimental samples, and table 3 summarizes the codes used to represent the sample groups in the spectra.

Figure 10 shows that other than Canson sketch paper, which has a more prominent peak at 878 cm^{-1}, all three types of papers have relatively similar functional groups. Figure 11 contains the spectra for burnt samples of the same papers. In comparison with figure 10, additional peaks are found at 1374 cm^{-1} and 1113 cm^{-1} for A3; at 1377 cm^{-1} and 1110 cm^{-1} for A6; and at 1402 cm^{-1} and 1112 cm^{-1} for A9. These two peaks suggest the presence of potassium sulfate and potassium nitrate (figs. 12, 13).[2]

A comparison of the peaks for the control groups (figs. 14, 16, 18) shows that the peaks were all the same before and after the aging tests, and that no new functional groups appeared in the control samples. As can be seen in figures 15, 17, and 19, no significant changes were observed after aging in samples with powder residues, either. Comparing control samples and samples with gunpowder residues (figs. 14–19) also shows that their absorption peaks were the same, which means that gunpowder residue has little or no effect on the organic components of paper samples.

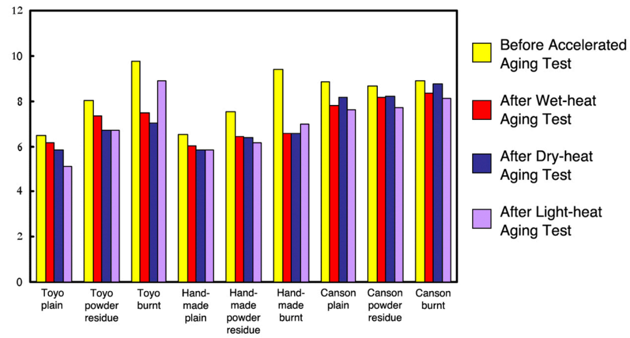

Fig. 9. Comparison of the pH value of nine sample groups

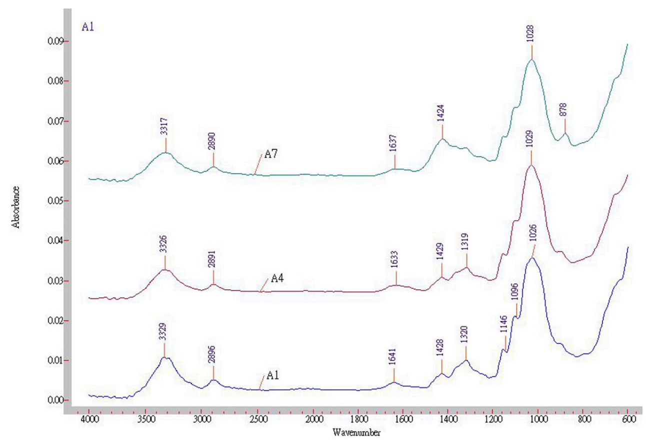

Fig. 10. Control group of filter paper (A1), handmade paper (A4), and Canson sketch paper (A7) before aging

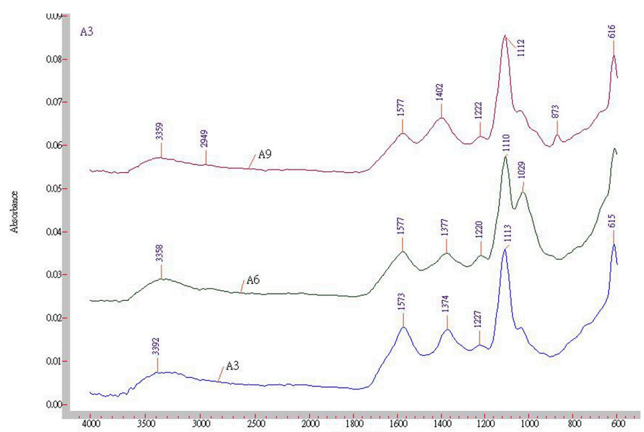

Fig. 11. Burnt group of filter paper (A3), handmade paper (A6), and Canson sketch paper (A9) before aging

Figures 20–23 show the change in absorption peaks for the three different burnt paper samples after aging. There are noticeable peaks at 1022 cm^{-1} for B1, at 1025 cm^{-1} for B6, and at 1032 cm^{-1} for B9 after wet-heat aging (fig. 21); at 1030 cm^{-1} for

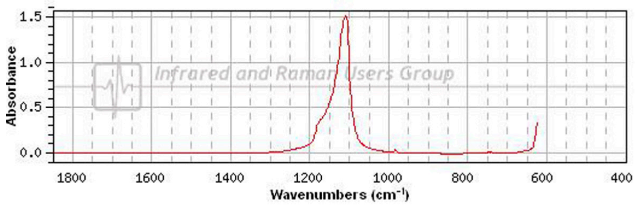

Fig. 12. IMP00167 Potassium Sulfate, Cargille, #5-A, PMA, trans. Courtesy of Infrared and Raman Users Group (IRUG), www.irug.org.

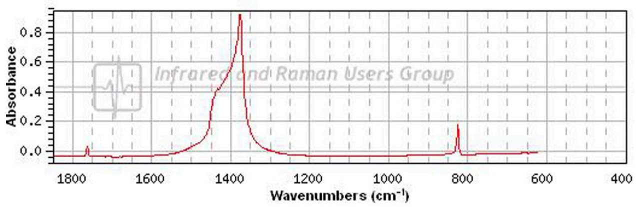

Fig. 13. IMP00168 Potassium nitrate, Cargille, #5-B, PMA, trans. Courtesy of Infrared and Raman Users Group (IRUG), www.irug.org

C6 and at 1029 cm^{-1} for C9 after dry-heat aging (fig. 22); and at 1028 cm^{-1} for D6 after light-and-heat aging (fig. 23). These absorption peaks are very similar to the absorption peaks of the control groups (figs. 14, 16, 18). A possible explanation for this is that the gunpowder residues deteriorated and disappeared after the long period of accelerated aging, causing the absorption peaks of the original base paper to appear again.

While there is a small potassium nitrate peak present in the spectrum for the Toyo filter paper (B3) after wet-heat aging (fig. 21), peaks for both potassium nitrate and potassium sulfate disappeared from other sample groups after the same aging test. After dry-heat aging, on the other hand, the spectra for all of the samples except the Toyo filter paper (C3) showed peaks for both potassium nitrate and potassium sulfate (fig. 22). Absorption peaks for potassium nitrate and potassium sulfate are present in the spectra for all sample groups after light-and-heat aging (fig. 23).

XRF Analysis

XRF results show that the signals for sulfur and potassium in counts per second (cps) were stronger in samples before accelerated aging than after aging. The burnt samples also had stronger signals compared to the control samples and samples with only powder residues, and the strength of the sulfur and potassium signals was proportional to the amount of gunpowder residue. The results after three types of accelerated-aging tests show that sulfur and potassium have stronger cps signal values in the light-and-heat aged samples than in the wet-heat and dry-heat aged samples. In other words, sulfur and potassium have lower sensitivity to light than to other aging factors in this experiment.

RESULTS AND CONCLUSIONS

Materials science has always played an essential role in the field of collections preservation and restoration because the properties of materials themselves can affect the preservation and life expectancy of artworks. Gunpowder as a creative medium is still in its experimental stages, and conservation science still has a limited understanding of its physical and chemical characteristics when used in works of art. Until now, no scholarly papers have been published on the physical and chemical properties of gunpowder in the context of its use as an art medium. This is the first research paper published, either in Taiwan or internationally, on the scientific analysis of gunpowder as an art medium and its effect on papers, in order to establish a preliminary understanding of gunpowder's impact on paper materials.

According to the test results from this experiment, the color difference values obtained from samples with large amounts of gunpowder residue were much larger compared to values obtained from samples with little or no gunpowder residue. This result was consistent in all tests, regardless of which paper type or which accelerated-aging test was used. Therefore, without analyzing what caused the color change in the sample, it is evident that the more gunpowder residue a sample has, the bigger its color difference value will be. Samples with higher color difference values also have a greater increase in their L* (light/dark) values compared to their a* and b* values. Based on preliminary deduction, the main cause for this color change in samples is probably the deterioration or detachment of gunpowder residue from the paper samples. This also means that it is important to ensure the stable adherence of gunpowder to the base material when preserving samples with large amounts of gunpowder residue.

The results of pH testing clearly show that aged samples with gunpowder residue have higher concentrations of hydroxide ions in their test solutions compared to the test solutions of aged control samples without gunpowder residue. The overall pH of samples after accelerated aging was in the range of 7–9. The main reason for this is that the main components of gunpowder are all basic. However, this does not prove that paper containing gunpowder will be preserved better, because there was still a substantial decrease in pH after accelerated aging. It is not possible to determine or hypothesize whether this decrease in pH was caused by the deterioration of the gunpowder itself, the deterioration of the paper, or the interaction between the gunpowder and the paper during accelerated aging. The cause of the pH shifts still requires further investigation.

The medium used in this experiment contains a mixture of substances. ATR-FTIR was used in order to further understand the changes in the samples' composition after accelerated aging. Since the FTIR spectra of the control groups showed no obvious changes after accelerated aging,

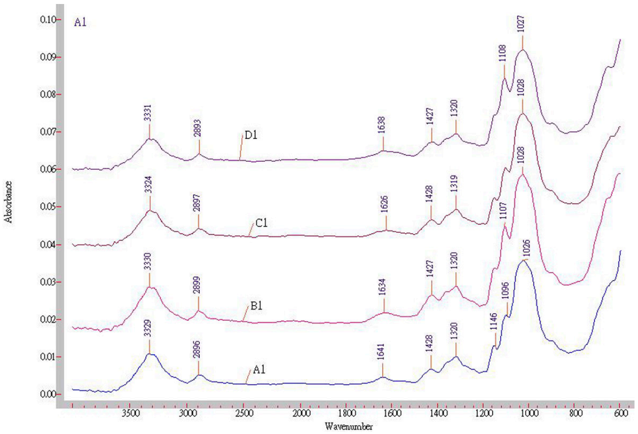

Fig. 14. Toyo filter paper control group (no residue) before and after aging

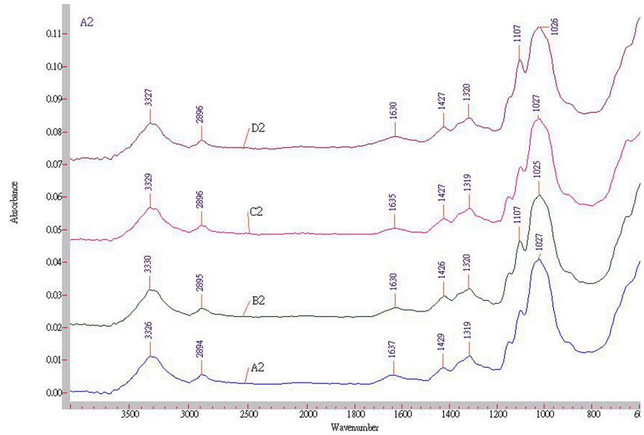

Fig. 15. Toyo filter paper with powder residue before and after aging

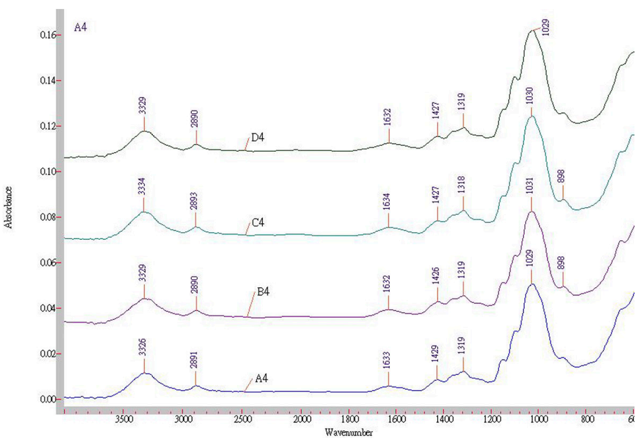

Fig. 16. Handmade paper control group (no residue) before and after aging

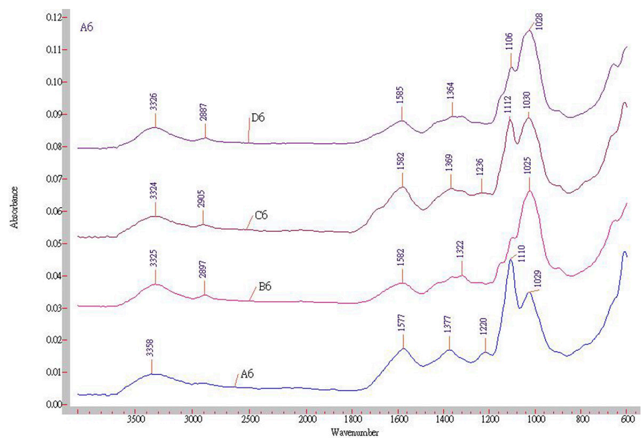

Fig. 17. Handmade paper with powder residue before and after aging

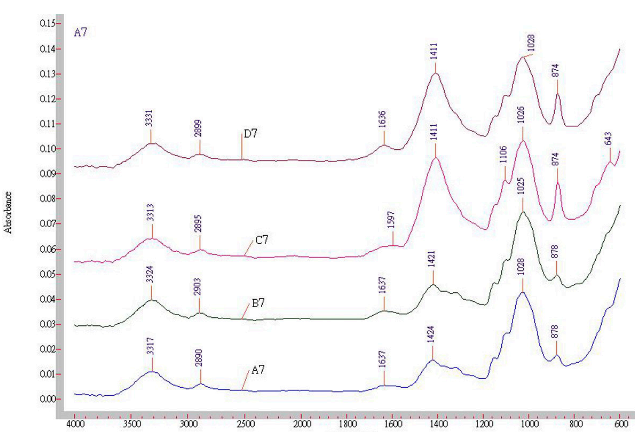

Fig. 18. Canson sketch paper control group (no residue) before and after aging

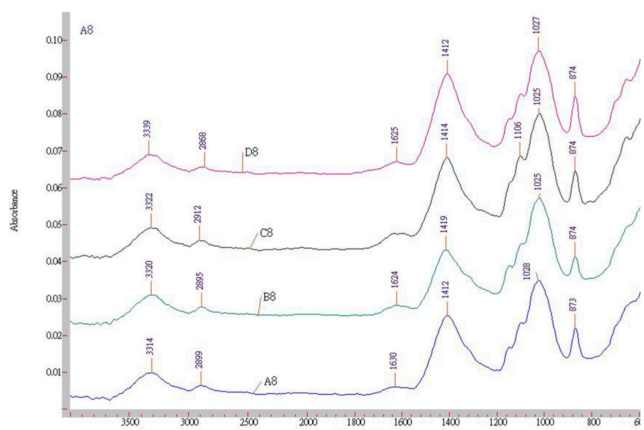

Fig. 19. Canson sketch paper with powder residue before and after aging

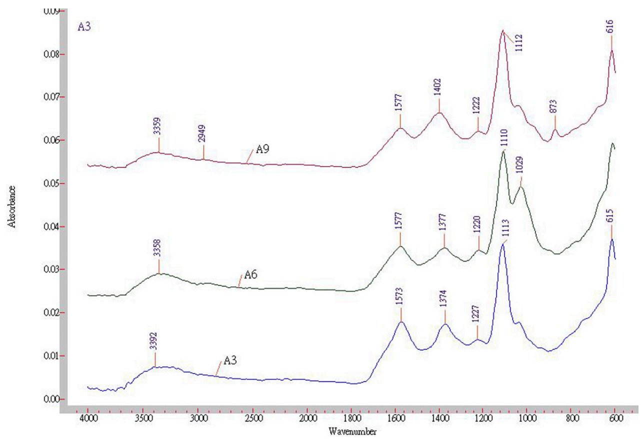

Fig. 20. Samples with burn marks before aging

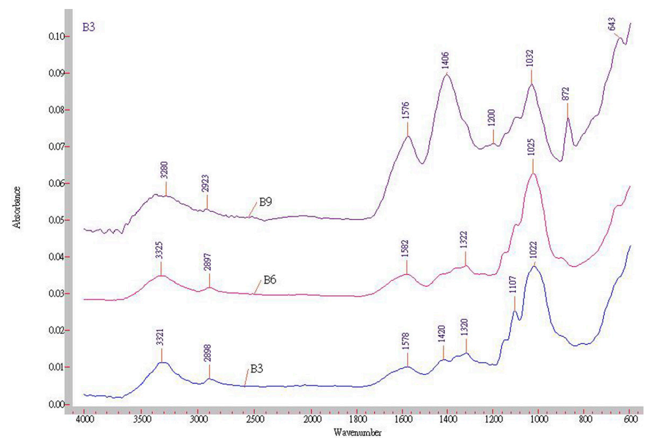

Fig. 21. Samples with burn marks after 600 hours of wet-heat aging

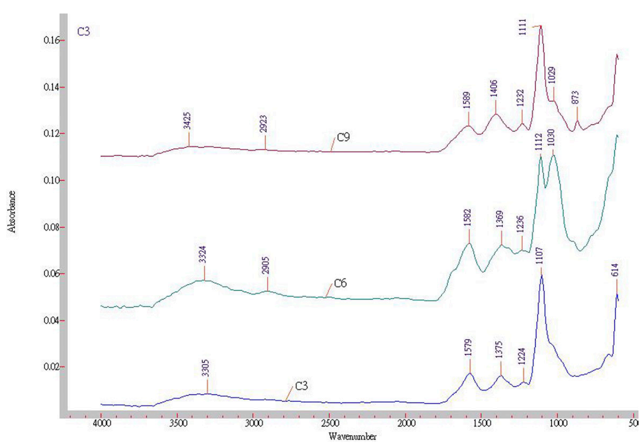

Fig. 22. Samples with burn marks after 600 hours of dry-heat aging

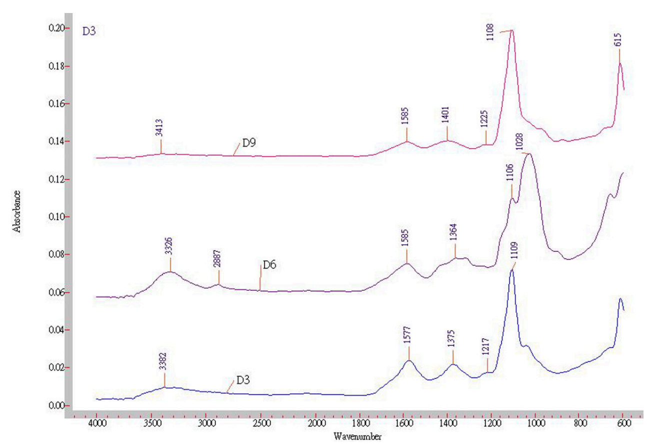

Fig. 23. Samples with burn marks after 600 hours of light-and-heat aging

Gunpowder Damage	Toyo Filter Paper	Handmade Paper	Canson Sketch Paper
A: Control Groups Before Accelerated Aging			
None	**A1**	**A4**	**A7**
Powder Residues	**A2**	**A5**	**A8**
Burnt	**A3**	**A6**	**A9**
B: Sample Groups After 600 Hours of Wet-Heat Aging			
None	**B1**	**B4**	**B7**
Powder Residues	**B2**	**B5**	**B8**
Burnt	**B3**	**B6**	**B9**
C: Sample Groups After 600 Hours of Dry-Heat Aging			
None	**C1**	**C4**	**C7**
Powder Residues	**C2**	**C5**	**C8**
Burnt	**C3**	**C6**	**C9**
D: Sample Groups After 600 Hours of Light-and-Heat Aging			
None	**D1**	**D4**	**D7**
Powder Residues	**D2**	**D5**	**D8**
Burnt	**D3**	**D6**	**D9**

Table 3: Codes Representing Sample Groups in the Infrared Spectra

the differences between the spectra for the control groups and the sample groups with large amounts of gunpowder residue after accelerated aging were probably caused by the change of functional groups in gunpowder.

There were two prominent absorption peaks that appeared in the spectra of samples with gunpowder residues. The characteristics of these two peaks show that the new substances are potassium nitrate and potassium sulfate. Their peaks disappeared or became significantly weaker after accelerated aging. Possibly these two substances degraded or fell off the samples during accelerated aging, causing their absorption peaks to become weak. The absorption peaks for functional groups characteristic of the original paper samples also became more visible in the IR spectra after accelerated aging. From this, it is concluded that there was no apparent interaction between the gunpowder and the paper during the accelerated-aging tests, and that no new substances were produced after the aging process.

Based on this analysis and the results of the aging tests performed on samples containing gunpowder, the deterioration most likely to occur in this kind of artwork is the degradation and detachment of the gunpowder residue. Therefore, finding a way to ensure the stable adherence of gunpowder to its base material is urgently required for the preservation of this kind of contemporary artwork.

Suggestions for the Current State of Gunpowder Art Collections

1. *Collect Information*: Institutions cannot avoid collecting contemporary, new-media artworks. In the case of gunpowder artworks, there are many different kinds of gunpowder used, and when different kinds of gunpowder come in contact with paper materials, the interactions that may take place are not always the same. Differences in these artworks and their characteristics must be taken into consideration when acquiring gunpowder artworks. Aside from the standard acquisition process of registration, cataloguing, and photographic documentation, it is important to keep a detailed, descriptive record of each piece. Only through a complete and coherent database on gunpowder art collections can conservators further investigate the proper ways to preserve gunpowder artworks.
2. *Exchange Information and Opinions:* A gap sometimes appears between artists and conservators in terms of their understanding and opinion of collection and preservation procedures, but this gap can be overcome by active communication. When artists are reluctant to share everything about their works, it often leads not only to improper advice, poor choices, and ineffective treatments where the preservation of artworks is concerned, but also creates waste of both human and monetary resources. Therefore, the work of conservators is not limited to the preservation of artworks anymore. In order to make artists willingly share information about their work, conservators should establish a trusting relationship with artists, which will require not only good communication skills but also sincere attitudes and a genuine interest in the public welfare, which should convince artists to trust and open up to them.
3. *Develop Technology:* The results of materials-science research can affect the significance and integrity of artworks. Many new art media still require further analysis and examination using professional scientific devices and technologies, and the success of this process relies on effective communication and cooperation between researchers and conservators.
4. *Be Aware of Possible Deterioration:* This experiment revealed that the type of deterioration most likely to occur in gunpowder artwork over the short term is the detachment of gunpowder residue from the base material. Therefore, the foremost problem to consider is how to keep the gunpowder stably affixed to the artwork. Since gunpowder and explosives alike can contain hazardous substances such as potassium sulfate and potassium nitrate, which may contaminate the storage environment, it is also important to take into consideration how these substances may interact with other artworks before stabilization. However, as mentioned before, there are many different types of gunpowder artworks, and institutions should discuss them with their researchers and conservators and come to a consensus decision regarding their storage and conservation.

Proposals For Further Research

The road to gunpowder art preservation is long and complicated. In this project, accelerated aging lasted up to 600 hours, but further research should be done using longer aging periods to examine the deterioration conditions. This research focused only on gunpowder (black powder), but there are also other types of explosives that still require research and analysis.

It was discovered through this experiment that the first step in preserving gunpowder artworks of this type is the stabilization of gunpowder, and how to stabilize the gunpowder without changing its physical texture would be another subject worth further exploration. How to physically store these types of works, especially when their sizes are big, is another subject for research. Though little research has been done on the preservation of gunpowder art to date, as the amount of this kind of work increases, it will inevitably be a valuable subject for discussion in the future.

Aside from focusing on gunpowder arts, this paper hopes to raise collecting institutions' and conservation organizations' awareness of the difficult problems associated with preserving contemporary artworks, and to prompt further research in related areas. Much hard work is still required to preserve the metamorphic and vibrant nature of contemporary artworks. For the well-being of collections in Taiwan and elsewhere, an improved understanding of the preservation needs of contemporary art cannot come too soon.

REFERENCES

Fiore, R. 2000–2011. Firework drawings. www.rosemariefiore.com/firework-drawings-archive (accessed 07/18/12).

Lan S. G., Zhi M. S., and Ming H. D. 1988. 以BL*值表示黑紙之顏色 (Representing the color of black paper using BL* values). *Forest Products Industries*.

Pomfret, J. 2008. With stocks in turmoil, Asian art draws buyers. *New York Times*, February 3. www.nytimes .com/2008/02/03/business/worldbusiness/03iht-rtrinvest04.1.9693776.html (accessed 07/18/2012).

TAPPI. 1996. Hydrogen ion concentration (pH) of paper extracts (cold extraction method), TAPPI T509 om-96. Atlanta: Technical Association of the Pulp and Paper Industry.

JEN JUNG KU
Conservator
Research & Collection Division
National Museum of Taiwan Literature
Tainan, Taiwan
tsenjung@gmail.com

FEI WEN TSAI
Assistant Professor
Graduate Institute of Conservation
Tainan National University of the Arts
Tainan, Taiwan
tsaifw@mail.tnnua.edu.tw