Recovering the missing aura — a study on the feasibility of rebinding and the paper strength of fire-damaged books

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Introduction

In June 2019, a series of manuscripts written by a Taiwanese indigenous writer, Sakinu Ahronglong, was delivered to the National Museum of Taiwan Literature (NMTL). Sakinu is a significant indigenous writer in Taiwan; his works not only won influential literary awards in Taiwan, but were also translated and published in English and Japanese. Through these manuscripts spanning decades, one can observe Sakinu's wisdom and the beautiful moments in life. Moreover, it could be seen as an important part of his literary creations. The expected donation of manuscripts included some diaries, essays, notes, sketches, etc. but instead of intact items, only those salvaged from the fire could be seen.

In order to properly plan the conservation procedures for the manuscripts salvaged from ashes, especially with conditions such as burned edges, water stains and mold, this investigation discussed the need of follow-up treatments by observing and analyzing the current condition of the manuscript papers. The preliminary experiments were also designed to verify the feasibility of future treatment strategies. (Fig.1, Fig.2)

Fig. 1 The author, Sakinu, took out the fire-damaged manuscripts and delivered it to the museum staff (Photo credit: Ya-Wen Cheng)

Fig.2 Manuscripts were packed in a beer box when they were sent to the museum

Fig. 5 Manuscript fibers (100X) under polarizing microscope.

Documentation

Classification of Manuscripts:

According to the condition of the fire-damaged paper, it is roughly divided into four types:

- **Category 1**: piles of paper left in large quantities; with front and back covers; can clearly distinguish individual volumes.
- **Category 2**: piles of paper left in large quantities; no front and back cover; unable to clearly distinguish individual volumes.
- **Category 3**: piles of paper left in small quantities; no front and back cover; can not be precisely judged as a book.
- **Category 4**: Incomplete loose pages.

The degree of the remaining paper

Focusing on the category 1 and 2 of fire-damaged paper which are relatively complete, it shows that the remaining areas are approximately 75–83% of the originals. (Fig. 3, Fig. 4)

Paper fiber identification and pH value measurement

The paper fibers observed are composed of mainly pure cotton, (Fig. 5) and their FTIR spectrums also have similar peaks (Fig. 6). In addition, the pH of paper now is about 5-6.

Fig. 6 The FTIR spectrum of the manuscript fibers showed corresponding peaks to cotton, with a match of 99.3%.

Fig. 3 As seen on cover, It is originally 22.8*15.2 cm (346.56 cm2)

Fig. 4 After the images were captured, the areas of remaining pages were calculated by software

Mold growth

After salvaging it from water following the fire damage, mold and mildew are found almost everywhere on the inner pages. The mycelium growth is deeply embedded in the paper fibers. (Fig. 7, Fig. 8)

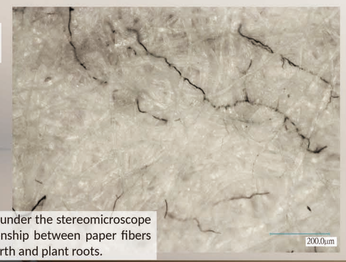
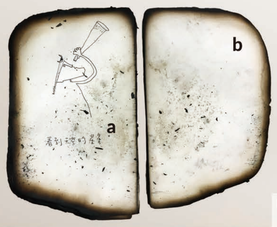


Fig. 7 The 500X image under the stereomicroscope shows that the relationship between paper fibers and mold is just like earth and plant roots.



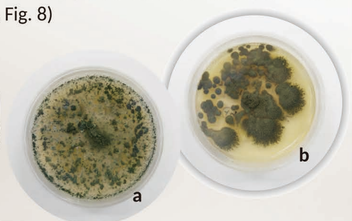


Fig. 8 Samples retrieved from areas with and without observable mold cultured mold growth on the agar mediums

The status of fire-damaged paper fibers

The integrity of the paper fibers affects the performance of structural strength. (Fig. 9)

- **Area A** is the original healthy fiber.
- **Area B**'s fibers have been yellowed by fire, but are still intact.
- **Area C** is close to the carbonization location. Although the fibers are seen as completely black, they do not break apart when touched.
- **Area D** is brittle along the paper edges, the surface is carbonized with luster, it is difficult to observe complete fibers, and the area is easily damaged by external force.

Other deteriorations

bleeding of ballpoint pen media, stains, dirt residues, distortion

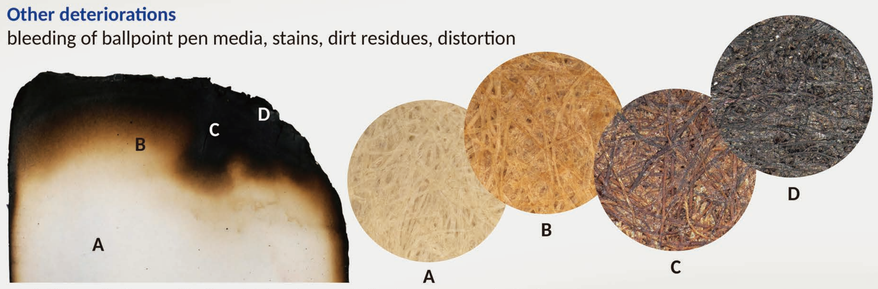


Fig. 9 200X magnified images of the fibers state in each area of the fire-damaged paper under the stereomicroscope.

Discussion

- The category 1 & 2, which have a comparatively complete appearance and content, are evaluated as of value to be collected by the museum. The category 3 & 4 are incomplete manuscripts expected to be used for future pre-treatment tests.
- After the paper was damaged by fire, the absorptive cotton fibers of pH 5–6 will be more sensitive to hydrolysis and acidification.
- While the surface mold can be cleaned by the vacuum, the mold deeply embedded in the paper fibers will be difficult to remove, and may easily recur in the future.
- After the fire damage, the paper fibers in the A, B, and C areas can still be seen with no embrittlement phenomenon when touched. In contrast, area D is without a stable fiber structure and has been completely carbonized. Therefore, future conservation will be focused on the three areas ABC as much as possible.
- The bleeding media of ballpoint pens and signature pens make the result unsuitable for using polar solvents (such as alcohol) on them when doing treatment to inhibit mold.
- Washing is deemed required in order to resolve the above issues, which is not only used to remove harmful residual substances and stains, but also to improve paper distortion. Therefore, the problem of eliminating mildew on paper will be considered first before wet treatment.

Experimentation & Results

This study adopted a two-stage experiment process. The first stage was to evaluate the effect of radiation on mold removal. The second was to irradiate testing paper with the determined radiation dose and wash them. The results evaluated the change and recovery of paper strength.

Mold removal test using Gamma-radiation

Gamma radiation is a kind of electromagnetic energy that can penetrate the irradiated object with no residual radiation and remove fungus and pests by destroying their nucleus (DNA). In this study, the paper was irradiated with low-dose radiation of 0.5, 1, 3, 5, 7, and 10 kGy, and then the sterilization effect evaluated.
(Fig. 10 ~ Fig.12)

The results showed that using 3 kGy was a safe and effective dose to remove mold for these manuscripts. In addition, each paper sample was inspected by FTIR, and there was no noticeable chemical bond change in the fiber spectrum irradiated with all test doses (Fig. 13).

Fig. 10 Two points were taken from each group of samples, and the sterilization effects of the same points were compared before and after irradiation

Fig. 11 Before irradiation (3 days after inoculation)

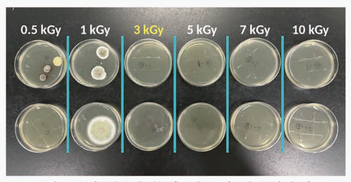


Fig. 12 After irradiation (14 days after inoculation)

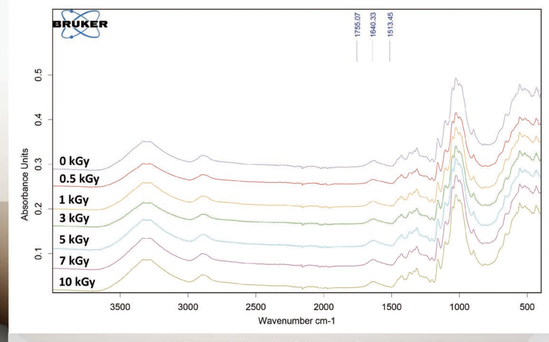


Fig. 13 The chemical bonds of the paper fibers in the FTIR spectrum did not change after each dose of irradiation.

Test of changes in paper strength

It has been studied that radiation may cause the decrease of folding endurance of paper. However, washing is also considered to benefit paper strength. The various factors in this experiment were used to test the changes of folding endurance included fire, 3 kGy Co-60 irradiation, washing, and dry-heat aging for 144 hours (Fig. 14).
For compatibility of results, the same brand of paper with similar paper composition (compared using FTIR spectrum) and density was chosen as test samples. First, the samples were made by simulating the situation of fire damage and water salvage to realize all paper strength changes. At the same time, the blank pages selected from the original manuscripts were used as a reference samples to carry out the experiment together. They were then evaluated to determine whether the changes in properties was consistent and reliable (Fig. 15~Fig. 16).

Changes in chemical and physical properties

According to the FTIR spectrum, the chemical bonds of the paper remain unchanged after being burned and irradiated, but the physical properties have a downward trend (Table 1). It could be believed that the radicals of the cellulose macromolecules were just destroyed and reduced, but did not disappear, resulting in a decrease in the degree of polymerization.

Effects of burning and radiation

From Table 1, the unburnt and irradiated paper has almost no change in the folding endurance for machine direction (MD). In contrast, it decreased significantly after burning and irradiation (compare T-A & T-B with T-G & T-H groups). It indicates that fibers' resistance to radiation was much lower after high temperature. The water molecular structure in the fiber was destroyed. However, it is interesting that the burnt paper has increased folding endurance than the unburnt paper in cross-direction (CD) generally. Because the composition of commercial paper contains not just fibers but also additives and sizing, these added macromolecules may cause cross-linking reactions due to high temperature and irradiation, which indirectly enhanced the strength of burnt paper.

Effects of aging

The folding endurance of the aged irradiated paper significantly deteriorated, the pH dropping from 5 to 4. That might be due to the decrease of hydrogen bonds, and or the generation of free radicals (such as hydroxyl radicals) in the irradiated paper as a result of accelerated oxidation and acidification.

The benefits of washing

Radiation and fire affected the hydrogen bonds in the paper fibers. Fortunately, both the paper strength in MD and CD of the unaged paper group were all recovered to their original state by washing, improving even the aged paper.

Credibility of experiment

Comparing the burnt sample paper and the manuscript paper, their folding endurance change ratios in MD after irradiation were similar. The burnt sample paper decreased by 28%, while the manuscript had a decrease of 26%.

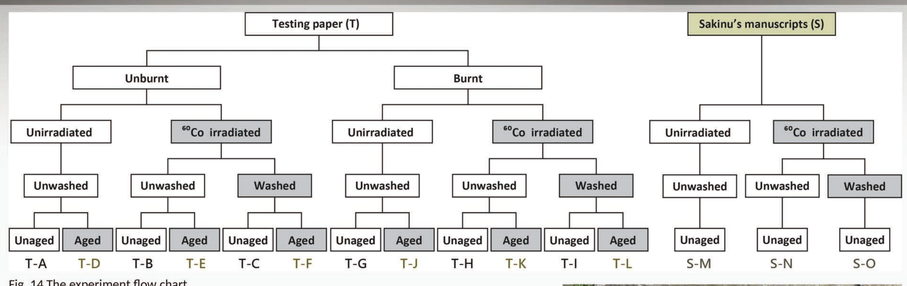


Fig. 14 The experiment flow chart

Table 1 Folding endurance results of each sample

Code	Treatment				Paper fiber direction (Folding times)	
	Burnt	Irradiated	Washed	Oven Aged	MD	CD
T-A		---- Reference ----			322	157
T-B		x			324	139
T-C		x	x		326	151
T-D				x	116	46
T-E		x		x	49	35
T-F		x	x	x	84	40
T-G	x				298	172
T-H	x	x			215	147
T-I	x	x	x		297	178
T-J	x			x	95	98
T-K	x	x		x	29	35
T-L	x	x	x	x	45	55
S-M	x				251	*
S-N	x	x			185	*
S-O	x	x	x		253	*

【S-group are the blank pages of manuscripts. Due to the limited number, only MD is tested】

Fig. 15 Making fire-damaged samples

Fig. 16 Immersion washing for burnt paper

Conclusion & Future works

Taiwan is located in a subtropical climate with high temperature and humidity. To avoid mold growth on manuscripts is a Herculean task. Luckily, through the irradiative experiment, mold can be eliminated completely and contribute to the possibility to further wet conservation.

In the washing experiments, the paper strength could be restored to the original after irradiation. This result contributes to the basis for subsequent book rebinding, especially for treating the first and second categories of manuscripts in the future.

Irradiation might decompose the large molecules of cellulose in cotton fiber into small ones. When the irradiated paper was aged by heat, the folding endurance performed even more unsatisfactorily. It will be recommended that the paper after irradiation should be stored in an environment with a stable relative humidity and avoid an overly dry condition.

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