Physical Condition of Five Historical Land Deeds and Implications for Land Deed Paper Conservation

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Abstract: This work presents five land deeds (S1−S5) collected by the Deng family, the land deed papers were produced by the Deng family, and the content was about the transaction of the Deng family paper production site. Density, whiteness, pH value, and fiber morphology of the deed papers were measured and analyzed, and the physical condition of the deeds was determined. The results showed S1 and S3 were severely damaged, S2 and S4 were moderately damaged, and S5 was mildly damaged. The abovementioned deeds are physical witnesses to the history of Deng papermaking, and have high value as cultural relics and historical documents. It is hopefully this study could be used to inform scientific restoration plans, and provide a reference for the collection and protection of land deeds.

Keywords: land deeds; papermaking; paper conservation

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1 Introduction

Fujian Province has a long history as a papermaking center in China. The abundant bamboo forests and sufficient water sources provide favorable conditions for papermaking. The Deng family from Gutian, Liancheng, Fujian Province, began making paper during the reign of the Qing dynasty's Kangxi emperor (1662−1722). The Deng's family papermaking technology and approach have been passed down for twelve generations. In the 23rd year of the Guangxu reign (1897), Deng Linchang began marketing the paper under the brand name "Meiyutang", which is still used today.

The reason for using this brand name is because the paper produced by the Deng family is smooth and delicate, suitable for writing and printing. In the Qing dynasty, there were hundreds or even thousands of paper mills in Liancheng, but now they have all disappeared, leaving only Meiyutang still producing handmade paper.

This study focuses on land deeds about the transaction of the Deng family paper production site from the Jiaqing reign (1796−1820) to the Republic of China period (1912−1949), collected by the Deng family. These five land deeds are all written on paper made by the Deng, and serve as physical witnesses to the history of Deng's papermaking; they have high value as cultural relics and historical documents. Scientific evaluation (e.g., chemical testing, microscopic analysis) of land deeds can provide data to inform the understanding of historical papermaking and book production practice for Deng handmade paper and present-day conservation and repair of these documents.

2 Materials and methods

2.1 Materials

Five pieces of land deed paper (S1−S5) from the Deng family were analyzed. S1 was created in the first year of the Jiaqing reign (1796), S2 the same year (but on a different date), S3 in the 13th year of the Daoguang reign (1850), S4 in the first year of the Xuantong reign (1909), and S5 in the 17th year of the Republic of China (1928). The five land deeds are shown in Fig. 1.

2.2 Methods

2.2.1 Physical property tests

The basis weight, thickness, chromaticity, and whiteness of the paper were measured using a high-precision electronic balance (JA5003; Shanghai Precision Instrument Co., Ltd., China), large deep throat thousand fraction thickness gauge (SYA1703735; Zhejiang Deqing Shengtaixin Electronic Technology Co., Ltd., China), and 3nh spectrophotometer (YS3060; Shenzhen Sanenshi Technology Co., Ltd., China). Hunter whiteness value (WI) was calculated by substituting the obtained chromaticity value (L^*, a^*, b^*) for the $WI=100-[(100-L)^2+a^2+b^2]^{1/2}$ formula. The measurement environment temperature was 24 ℃, and the relative humidity was 55%.

2.2.2 pH Value measurement

The pH value of the paper was measured using a laboratory pH meter (PHSJ-5;Shanghai Yidian Scientifice Instrument Co., Ltd., China).

2.2.3 Paper fiber tests

2.2.3.1 Optical microscope analysis

The testing instrument is an optical microscope (XSP-8C; Shanghai Precision Instruments Co., Ltd., China). Five land deed samples were selected for analysis, and the fibers stained with Herzberg reagent were observed. Tweezers were used to take a small piece of paper from the blank edge of the land deed and place it on a glass slide. 1−2 drops of deionized water were then dropped on the sample, the fibers were dispersed with a dissecting needle, and then a staining agent was added to evenly stain the back cover of the glass slide for observation.

2.2.3.2 Digital microscope analysis

The use of a Dino lite digital microscope (AM4113T5 X; Taiwan Anpeng Technology Co., Ltd., China) allows for non-destructive, convenient observation of the fiber morphology, yellow spots, aging, defects, and other conditions of paper. Magnification of the digital

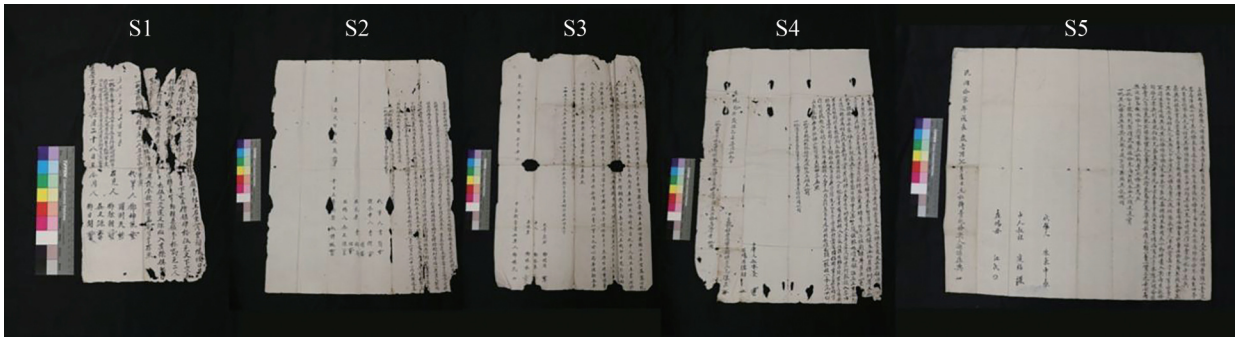

Fig. 1 Images of the five land deeds

microscope was set to 500 times, in units of μm.

2.2.3.3 Scanning electron microscope (SEM) analysis

Paper samples were pasted on the stage using a conductive adhesive. After gold spraying, the micromorphology of the paper samples was observed using a field emission scanning electron microscope (Phenom Prox; Phenom, the Netherlands).

2.2.3.4 Fourier transform infrared (FT-IR) spectroscopy tests

FT-IR spectroscopy is a powerful tool for fiber analysis, which can perform rapid and accurate analysis without damage. It was used to analyze the infrared spectral characteristics of the land deeds and the crystallinity of the paper, explore the differences between land deed papers of different ages collected by the Deng family and provide a reference for the identification of land deed papers.

The experimental instrument is an Fourier transform infrared spectrometer-attenuated total reflection (FT-IR-ATR; Bruker Co., Germany). The blank part of the land deed was clamped face down on the measurement point, and infrared data were measured and processed using Opus software.

Before the paper was analyzed, it needed to undergo 24-h humidity balance to achieve consistency with the measurement environment. The measurement environment temperature was 21.6 ℃, and the relative humidity was 61%.

3 Results and discussion

3.1 Condition of and damage to land deeds

The five land deeds collected by the Deng family had suffered varying degrees of damage. Before conducting scientific testing and repair, it is necessary to first determine the damage level. Due to the archival nature of the land deeds, according to the "Specification for rescue and restoration of paper archives—Part 1: Grading of damage" (DA/T 64.1-2017) standard [1], description of the damage situation and judgment of the damage level were carried out. The results are shown in Table 1.

All five land deeds have wear and stain, to varying degrees. Except for S5, which is only slightly damaged, the deeds have large areas of damage and stain, accounting for over 5% of the total area. S1 and S3 have reached the level of severe damage and urgently need to be repaired and protected.

3.2 Physical properties of land deeds

Table 2 lists the test results of the five land deeds. Based on quantitative and thickness calculations, the densities of the paper were obtained. Density is an indicator of the tightness of paper fibers. The higher the density of paper made from the same fiber, the better its mechanical properties such as burst and tensile strength. Paper density also affects the ink absorption performance of the paper: The higher the density, the slower the

Table 1 Damage level of land deeds

Land deeds	Aging degree	Stain*1/%	Damage and incomplete*2/%	Others	Grading of damage
S1	The mechanical strength of the paper is significantly reduced and there is flocculation phenomenon	12	20	There is a fracture at the crease of the paper	Severe damage
S2	The mechanical strength of the paper has decreased to a certain extent and there is yellowing phenomenon	16	2	There is a fracture at the crease of the paper	Moderate damage
S3	The mechanical strength of the paper is significantly reduced and there is flocculation phenomenon	50	4	–	Severe damage
S4	The mechanical strength of the paper has decreased to a certain extent, with oxidation spots	12	3	–	Moderate damage
S5	Slight brittleness of the paper	5	–	There is a fracture at the crease of the paper	Mild damage

Note *1: The proportion of stained area to the entire page; *2: the proportion of incomplete area to the entire page.

Table 2 Basis weight, thickness, and density of land deeds

Land deeds	Basis weight/(g·m^{-2})	Thickness/mm	Density/(g·cm^{-3})
S1	26.46	0.071	0.37
S2	27.30	0.066	0.41
S3	28.10	0.087	0.32
S4	37.58	0.090	0.42
S5	43.18	0.091	0.48

absorption speed, the longer the ink drying time, and the worse the ink absorption performance [2]. Among the deeds, S1 had the lowest density and S5 has the highest. It can be inferred that the mechanical properties of S5 are generally better than those of the first four land deeds, but that it is slightly inferior in ink absorption. It can also be inferred that if environmental factors are excluded, the longer the land deed is stored, the looser the paper fiber interweaving structure may be. At the same time, if there are phenomena such as insect infestation, it may cause internal damage to the page. The density of S1 is relatively low, as noted, but S5, which was produced later and has a high degree of preservation integrity, has higher compactness and a tighter paper texture structure.

As shown in Table 3, the values of L^*, a^*, and b^* for the five land deeds are all positive, indicating that the whiteness of the papers is still relatively high. Moreover, according to the results of b^*, the papers tend to be rather yellow. S1, S2, and S3 have been circulating for a long time and have slightly heavier yellowing, while S4 has relatively lighter yellowing. It is worth noting that the latest deed, S5, has the largest b^* and the most yellow color. S5 was signed in the 17th year of the Republic of China (1928), later than the others, and it is speculated that its yellowness is due to the use of non-traditional chemicals during the papermaking process.

From the results in Table 3, it can also be seen that based on the WI values, calculated from the L^*, a^*, and b^* values, the whiteness of S5 is lower than that of the other deeds.

Table 3 Chromaticity and whiteness of land deeds

Land deeds	L^*	a^*	b^*	WI
S1	89.39	0.94	8.34	84.56
S2	89.83	0.60	8.15	85.12
S3	89.05	0.89	8.27	84.23
S4	89.68	0.44	6.76	85.51
S5	86.96	1.47	15.77	78.65

3.3 pH Value test results

The measurement of pH value reflect the degree of acidification of the land deed paper and provide a reference for the subsequent selection of paper for deacidification and repair.

From Table 4, it can be seen that the pH values of the five land deeds are all greater than 5.50, indicating weak acidity. Referring to the principle of minimal intervention in historical book restoration and considering the impact of deacidification treatment on paper, no deacidification was carried out on the five land deeds.

Table 4 pH Value of five land deeds

Land deeds	P1	P2	P3	P4	P5	Average
S1	5.99	6.01	5.09	6.12	5.90	5.82
S2	5.86	5.79	6.01	5.65	6.21	5.90
S3	5.68	5.78	5.96	5.75	5.87	5.80
S4	5.60	5.58	5.98	5.61	5.44	5.64
S5	5.64	5.87	5.93	5.99	6.12	5.91

3.4 Fiber test results of land deed papers

3.4.1 Results of optical microscope observation

Fig. 2 shows optical microscope photos of five land deeds at different magnification. It can be observed that the characteristics of the paper fibers are obvious nodular thickening on the fiber wall, longitudinal stripes, pillow-shaped stone cells and vessel, and network-shaped pores on the wall. In addition, the epidermal cells are rectangular in shape, with smooth edges and no dentate marks. There are a large amount of miscellaneous cells and shorter fibers. The average length of fibers within the observation range is greater than 1.89 mm, and the average width is (13.62±1.64) μm. The above observation results are consistent with the description of the microscopic characteristics of bamboo fibers in Ref. [3]. Moreover, the average length and width of the observed sample fibers are within the general length and width range of bamboo fibers. Therefore, it can be inferred that the five land deeds were written on bamboo papers.

3.4.2 Results of digital microscope observation

Observation is mainly conducted from two perspectives, through a digital microscope. First, the width of the

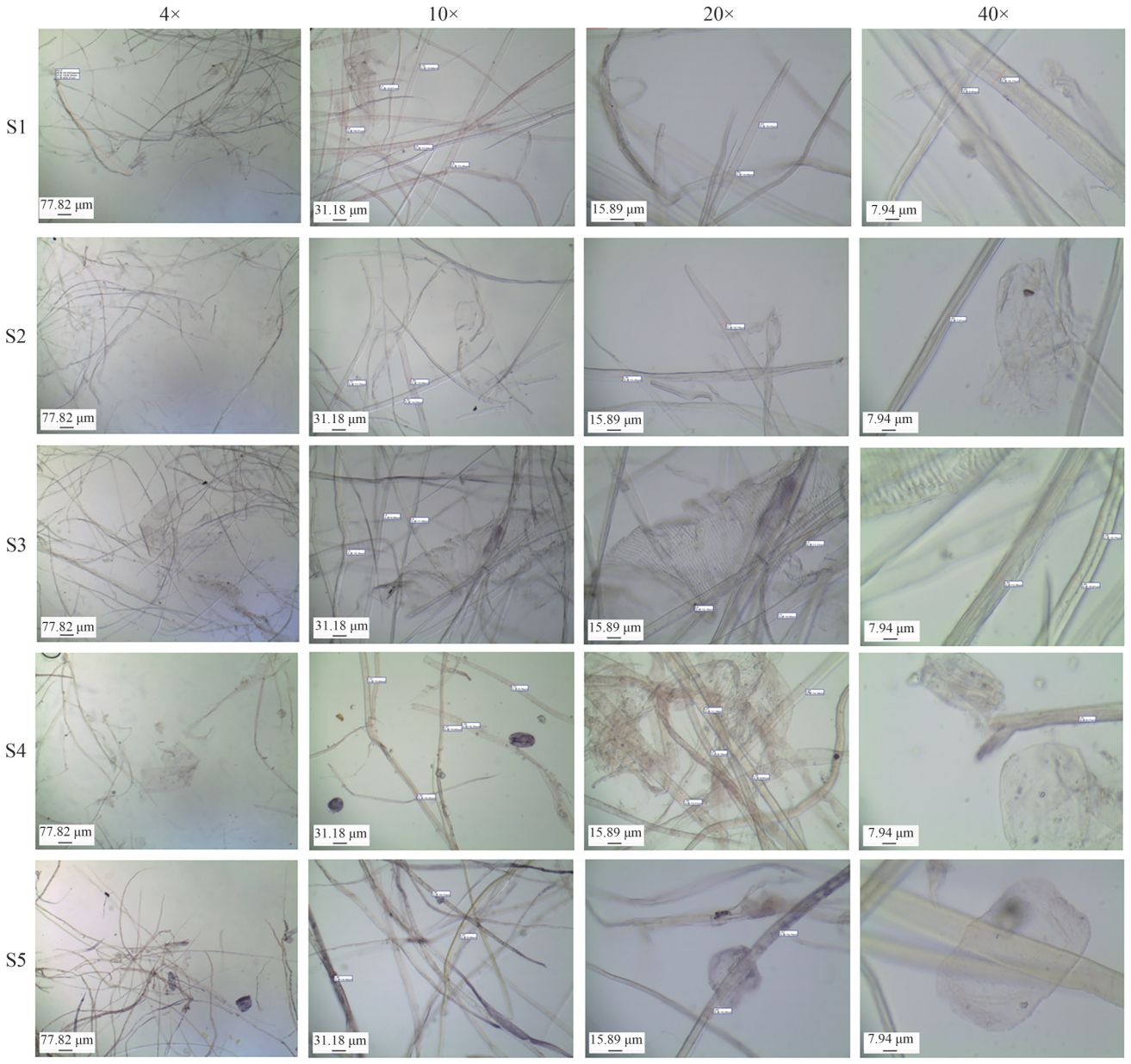

Fig. 2 Optical microscope images of paper fibers under 4×, 10×, 20×, and 40× magnification

fibers was measured to obtain accurate data. Second, the yellow spots and defects on the paper were visually observed.

Using a digital microscope, the fiber width can be measured, calculated, and averaged. Through observation in Fig. 3, it is found that the fibers of the land deed paper are relatively uniform. Therefore, a portion of fibers for each deed was randomly selected for measurement. The average widths of S1, S2, S3, S4, and S5 were (14.91±2.15) (13.70±1.39) (13.64±1.53) (13.68±1.89), and (16.40±1.51) μm, respectively. When receiving the land deed of the Deng family, S4 paper was labeled as Xuan paper. Combining the optical microscope observation results with paper fiber width data, it can be concluded that S4 paper is bamboo paper. It should be noted that the fibers of S5 are significantly wider than the others; in connection with the above speculation, if traditional paper medicine is still used in the paper made during the Republic of China period, the wider fibers may indicate that the pulping method during this period is different from before. The degree of delignification of paper fibers during boiling-down is

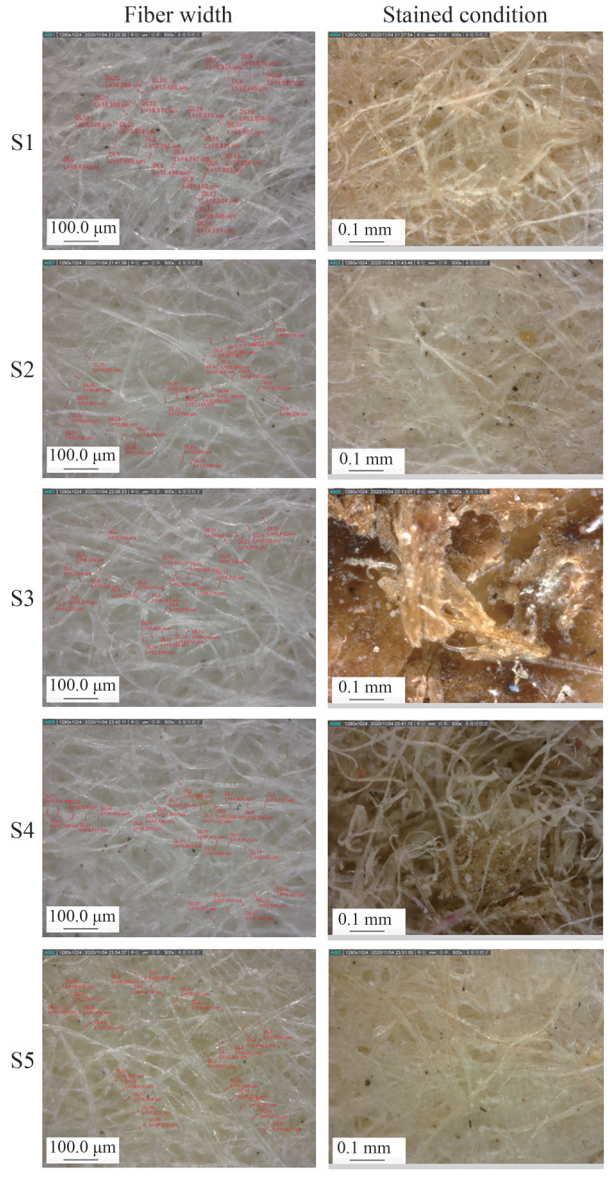

Fig. 3 Optical microscope images for measuring fiber width and stained condition

not sufficient, and residual lignin can also lead to yellowing of the paper. This may help explain the lower whiteness of S5.

Through Fig. 3, the degree of aging and damage of the five land deeds can also be observed. The aging of S3 is the most severe. The yellowed and stained parts cannot help distinguish the fiber shape, with severe clumping and visible defects such as mold; this is significantly different from the defect-free areas. The situation of S5 is the best, with no obvious fiber damage or breakage; the fibers of S2 are slightly damaged, with black impurities distributed in the fibers; there are many black impurities distributed in the fibers of S1; the fibers of S4 have obvious fractures and fragmentation, with some fibers clumping, and a lot of impurities.

3.4.3 Results of SEM observation

Fig. 4 shows the SEM images of the five land deeds. At a magnification of 5000 times, damage was observed on the fiber surfaces of S1 and S4. The fibers of S3 show significant fragmentation, and the damage is significantly more severe than others. We can also observe traces of the papermaking process, such as sizing, filling, and calendering. The fiber gap in S5 is small, and it is not possible to directly observe a single fiber. It can be inferred that the paper has undergone heavy material grinding, and this is the reason why S5 has the highest density among the five deeds. There is a large amount of adhesive dispersed and attached between the fibers of S4, therefore, its calendering is heavier than that of the other four deeds.

3.4.4 Results of FT-IR experiment

Fig. 5 shows the FT-IR spectra of the five land deeds. According to current infrared research results, the 3400 cm^{-1} characterizes the —OH stretching vibrational band within cellulose molecules, which is the characteristic band of all cellulose molecules [4]; 2900 cm^{-1} represents the absorption peak of the —OH stretching vibration between cellulose molecules; 1637 cm^{-1} represents the absorption peak of the stretching vibration of C═O; 1432 cm^{-1} represents the absorption peak of the bending vibration and shear vibration of cellulose; 1375 cm^{-1} represents the absorption peak of the bending vibration of C—H; 1335 cm^{-1} represents the absorption peak of the in-plane bending vibration of —OH; 1163 cm^{-1} represents the asymmetric stretching vibration of C—O—C in cellulose and hemicellulose; 1058–1060 cm^{-1} characterizes C—O stretching vibration in cellulose and hemicelluloses [5]; and 898 cm^{-1} is the β-glycosidic bond vibration and C1 deformation vibration absorption peak [6].

Referring to the infrared spectrum of bamboo fibers obtained by Liu et al[7], a characteristic peak near 993 cm^{-1} in bamboo fibers is observed, while cotton fiber, Manila hemp, or coniferous wood fiber, have a distinct characteristic peak near 1110 cm^{-1}. It can be seen that

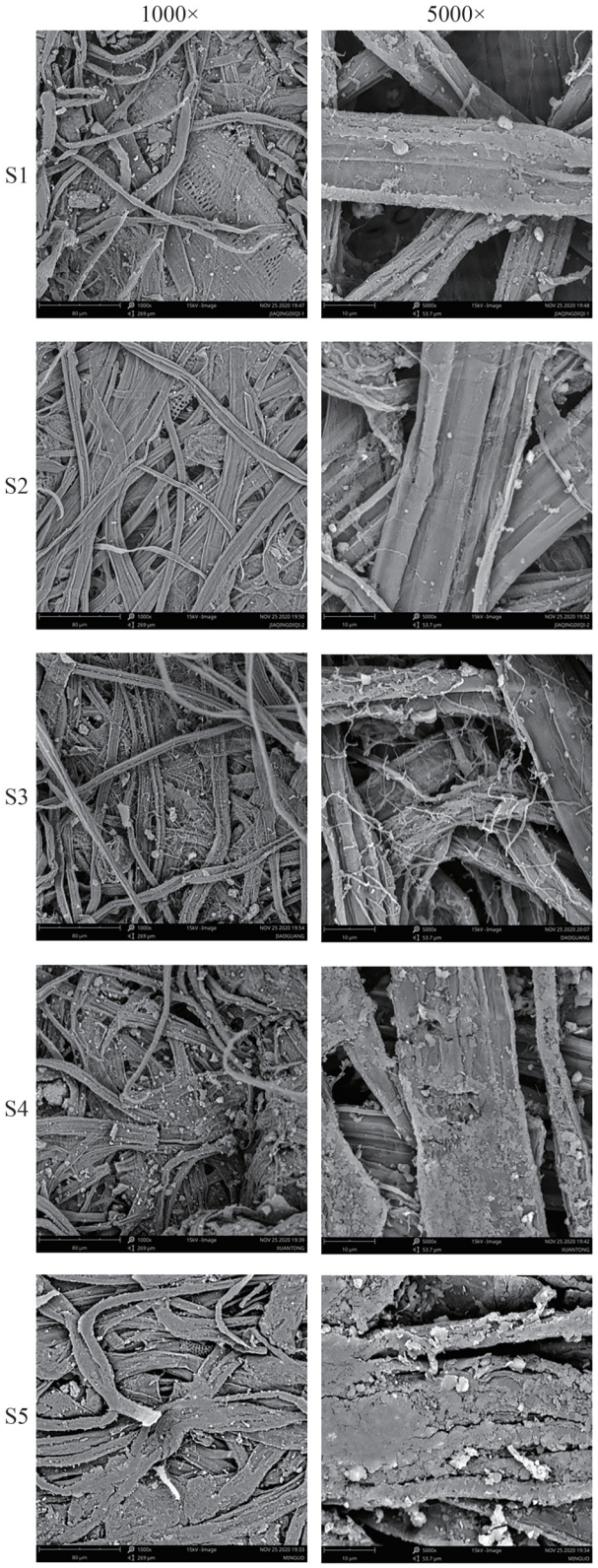

Fig. 4 SEM images of paper fibers at a magnification of 1000× and 5000×

the five land deeds have an average characteristic peak at 995.7 cm^{-1}, while without 1110 cm^{-1} peak in Fig. 5.

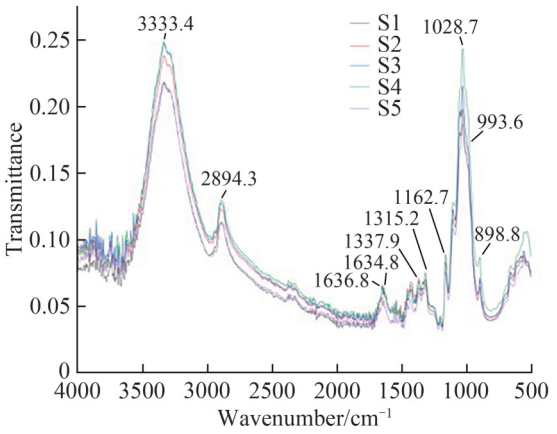

Fig. 5 FT-IR spectra of land deeds

4 Conclusions

This study mainly tested and analyzed the thickness, chromaticity, pH value, and paper fibers of five land deeds (S1−S5) collected by the Deng family. The observed morphologies of paper fibers at different magnifications through optical, digital, and electron microscopes verify the fiber type and sizing during the paper production process. On that basis, scientific description and grading of the damage to the land deed paper produced by the Deng family can be conducted. It can be concluded that S1 and S3 are severely damaged, S2 and S4 are moderately damaged, and S5 is slightly damaged. The land deed papers were produced by the Deng family, and the content on the deeds was about the transaction of the Deng family paper production site. Therefore, the land deeds are physical witnesses to the history of Deng papermaking, and have relics of high cultural, literary, and collection values. Scientific testing preserves scientific data on land deed papers produced by the Deng family from different periods and provides scientific data for the selection of repair paper, repair plans, and long-term preservation of land deeds.

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