Manufacture of Paper for War Maps and Other Applications

The manufacture of robust paper for maps assumed great importance early in World War II. Up to that time, maps used by troops in combat tended to disintegrate rapidly after being subjected to the water, mud, and grime of the battlefield. On the basis of information developed by the NBS Paper Section, the Army Map Service of the Corps of Engineers formulated specifications for paper for the printing of maps. The most critical requirements were very high resistance to tear, high wet tensile strength, high dry tensile strength, high opacity, and superior smoothness. Additionally, the paper needed to be made from commercially available raw materials to meet unprecedented tonnage requirements. The article *Experimental Manufacture of Paper for War Maps* [1] documents the contributions of NBS to this endeavor.

In the NBS Paper Section, this project was spearheaded by Charles G. Weber and Merle B. Shaw. They attacked the problem by preparing many batches of paper under a variety of experimental conditions on a "Fourdrinier" semi-commercial paper-making machine. This machine, invented by Nicholas Robert in France and named after the Fourdrinier brothers in England who commercialized it in 1804, is basically an endless wire screen belt which runs continuously; a paper pulp suspension flows onto the screen at one end and is removed at the opposite end after most of the water has been removed. The partially dried suspension is transferred onto a felt and transported over drying cylinders. A simple Fourdrinier travels at a speed of less than one mile per hour, but a modern, highly automated machine can travel 30 times as fast.

One of the variables tested by NBS was the relative amount of cutting and fraying, which affect fiber strength. These variables are a function of "beating," a process in which an aqueous suspension of paper pulp is passed continuously between a revolving roll and a bedplate. Knives are installed on the roll and initially separated from the bedplate by about 2.5 mm. Operating the beater with a wide bedplate-to-roll separation frays the fibers, with little cutting, and generates a large surface area. Operation with the roll close to the bedplate produces more cutting and less fraying.

In the early 1940s, it was common practice to permit extensive fraying of fibers as this produced a large surface area for fiber-to-fiber bonding and thus a very strong paper. When a papermaker held the paper up to the light, his product looked very uniform, and this had become a simple test for paper quality. However, because of extensive fiber-to-fiber bonding, this paper had a high coefficient of hygroscopic expansion, an undesirable property for military maps. Shaw and Weber found that the recently developed melamine resin could be used as a bonding agent to increase wet strength, and that the resin could take the place of beating to increase dry strength. The reduced need for beating diminished the interfiber bonding and consequently the hygroscopic expansivity of the sheet. At first, paper makers objected to the disordered or "wild" appearance when the paper was viewed by transmitted light, as described above. Once it was recognized that the disordered appearance was not a criterion for the quality of map paper, this test was discarded.

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Ultimately, numerous runs on the Fourdrinier showed that the best paper was obtained by using 100 % strong bleached sulfate pulps with the addition of melamine-formaldehyde resin to increase wet strength, and titanium dioxide to produce the desired opacity [1]. The large scale of the Fourdrinier in the Paper Section facilitated the transfer of this technology to factory production. With the assistance of NBS, many paper mills were able to meet or exceed the specification prepared by the Army Map Service. Production exceeding 5000 tons per month was achieved within 6 months. This was a substantial contribution to the war effort.

Further studies on paper for defense needs continued after World War II. About 1952 the Naval Research Laboratory and the NBS Paper Section cooperated in the development of the first machine-made paper made from glass fiber, without binder or additives [2]. The paper, which resembles soft blotting paper, was found to have numerous important applications, both in defense and civilian life. It was many times more effective as an air filter than commercial filters then on the market. It was found to be a very effective smoke filter in gas masks. All-glass paper is resistant to heat, moisture, chemicals, and microorganisms, and it has excellent electrical properties. It was used in diverse applications, such as mine respirators, gas masks, and filter discs for laboratory crucibles.

The first all-glass paper had a low tensile strength, and thus required extra care in production, storage, and handling. A 1955 study showed that the best bonding was obtained if the beater was maintained at 85 °F and a pH within the range 3.0 to 4.0. Under these conditions the fibers were well dispersed, resulting in a uniform sheet of paper. The secret of the interfiber bonding and the strength of fiberglass paper lies in the reaction of the glass fiber with acid [3]. Most acids react so slowly with glass under normal conditions that there is negligible effect. However, very fine glass fibers expose a very large surface area to the acid, which starts to dissolve the soda and the lime in the glass, leaving on its surface a thin gelatinous layer, rich in silica. When the fibers are pressed together in the papermaking process, this gelatinous layer acts as an adhesive to bond the fibers. Although the pH must be below 4.0 to obtain this effect, the pH of the paper becomes neutral after the acid solution drains from the paper.

Research on paper for currency has been another important NBS contribution. The first work at NBS on currency paper, supported by the Bureau of Engraving and Printing, was initiated in 1924 and conducted by Merle B. Shaw and George W. Bicking [4]. Paper currency had to be redeemed after a few months of circulation, and at that time the cost was substantial. Shaw and Bicking developed a paper that was about twice as strong as the paper then used for printing currency. The wear-resistant quality of paper currency was very much increased.

Until 1957, currency had been printed on flat-bed presses on moist paper, but this process was too slow for the expanding currency needs. New high-speed rotary presses were obtained, and the Paper Section developed a new paper for use in these presses. This new paper was 75 % cotton and 25 % linen with melamine resin, glue, and glycerol as additives, and it was printed dry. On Oct. 5, 1957, the first dollar notes printed on the new paper by the new high-speed rotary intaglio presses using the dry-print method were placed in circulation. A statistical evaluation, made by John Mandel of the NBS Statistical Engineering Laboratory [5], showed the old bills had a median life of approximately 122 days, while that of the new bills was approximately 172 days. This was indeed a substantial improvement of an undeniably short lifetime. The manufacture of currency paper, within the guidelines developed by the NBS Paper Section, has saved the U.S. Government millions of dollars.

Over the years, the Paper Section's standards-related work consisted of (1) the development of methods for evaluating the chemical and physical properties of paper, (2) the development and evaluation of testing machines, especially for active projects, and (3) the statistical evaluation of test procedures. Where possible, the work was directed toward the preparation of test methods for the Technical Association of the Pulp and Paper Industry (TAPPI) or for the American Society for Testing and Materials (ASTM). This effort continued throughout the lifetime of the section, culminating in the establishment of a Collaborative Testing Program in 1969, mostly through the initiative of Theodore Lashof. Paper samples were distributed to participating laboratories, test results were obtained, and data returned to the NBS for analysis. A report was prepared by NBS and distributed to the participating laboratories. Through this program, cooperating laboratories could compare their results with those of other laboratories and, thereby, evaluate their own testing equipment, personnel, or laboratory conditions [6]. Eventually, the great growth of this program necessitated that it be shifted to the private sector. Collaborative Testing Services, Inc., assumed responsibility for the program, which now includes many other materials in addition to paper. Laboratories all over the world participate in this activity.

The NBS Paper Section also has a long history of contributions to the development of standards for permanent record paper and other contributions to the science of preservation of records. In 1929, at the request of the American Library Association and with the support of the Carnegie Foundation, the Paper Section implemented a study of the whole problem of preservation of records. The National Archives, created in 1934, later supplied the principal support, along with the Department of Agriculture, the Social Security Board, and manufacturers of record materials.

We know today that a calcium carbonate filler in paper almost guarantees long-term stability. Although the use of calcium carbonate filler started in 1901, almost 40 years passed before its advantages were recognized. In the 1930s, M. B. Shaw and M. J. O'Leary of the Paper Mill at NBS made 72 papers on the experimental Fourdrinier in a study of sizing and filler materials on the stability of paper. Several papers with an alkaline filler were included in the study at the suggestion of Edwin Sutermeister, who was on the advisory committee for the project. This study showed that the stability of paper was an inverse function of acidity and thus depended on alum content. An alkaline filler gave paper maximum stability [7]. Unfortunately, conventional rosin-alum sizing was not efficient in an alkaline medium, so the process was not favorably received until an alkaline sizing material was developed in the early fifties. When fiber gradually increased in price to the point where calcium carbonate filler was cheaper than fiber, alkaline paper gained wide acceptance. The percentage of alkaline paper on the market has increased in the last 20 years from a few percent to more than 80 %.

In the early 1940s the Library of Congress asked NBS for recommendations for the display of the Charters of Freedom—the Declaration of Independence, the Constitution, and the Bill of Rights. Herbert F. Launer, who had done careful studies of the effect of light on paper [8], suggested an atmosphere of helium in a sealed enclosure at 25 % to 35 % relative humidity, with a light filter that cut off at a wavelength of about 450 nm. These suggestions were followed when the documents were enclosed for display [9]. Work on the preservation of records after 1954 was supported by the National Archives and Records Administration. As NARA was interested in standards, the Paper Section worked with the ASTM to develop six standards for papers suited to permanent record storage [10].

Thus the contributions of the NBS Paper section spanned a wide range of military and civilian applications. In conducting this work, the group identified significant national needs, worked with other government agencies and industry to meet those needs in a cost-effective way, and participated in the development of essential test methods and specifications.

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Bibliography

[1] Charles G. Weber and Merle B. Shaw, Experimental Manufacture of Paper for War Maps, *J. Res. Natl. Bur. Stand.* **37**, 325-330 (1946).

[2] M. J. O'Leary, B. W. Scribner, J. K. Missimer and J. J. Erving, Manufacture of Paper from Glass Fibers, *Tappi* **35**, 289-293 (1952).

[3] M. J. O'Leary, R. B. Hobbs, J. K. Missimer and J. J. Erving, Effects of Mechanical Preparation and pH on the Strength of Glass-fiber Paper, *Tappi* **37**, 446-450 (1954).

[4] Merle B. Shaw and George W. Bicking, Research on the Production of Currency Paper in the Bureau of Standards Experimental Paper Mill, *Technol. Pap. Bur. Stand.* **21**, 89-108 (1926).

[5] E. B. Randall, Jr. and John Mandel, A Statistical Comparison of the Wearing Characteristics of Two Types of Dollar Notes, *Mater. Res. Stand.* **2**, 17-20 (1962).

[6] T. W. Lashof, The NBS-TAPPI Collaborative Reference Program—beginning its second decade, *Tappi* **63** (4), 61-63 (1980).

[7] M. B. Shaw and M. J. O'Leary, Effect of Filling and Sizing Materials on Stability of Book Papers, *J. Res. Natl. Bur. Stand.* **21**, 671-695 (1938).

[8] H. F. Launer and W. K. Wilson, Photochemical Stability of Papers, *J. Res. Natl. Bur. Stand.* **30**, 55-74 (1943).

[9] *Preservation of the Declaration of Independence and the Constitution of the United States,* NBS Circular 505, National Bureau of Standards, Washington, DC (1951).

[10] Six standards for paper for permanent records, *Annual Book of ASTM Standards,* No. 15.09, American Society for Testing and Materials, West Conshohocken, PA (1999).