On the Strength Properties of Kraft Paper

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NOTE

On the Strength Properties of Kraft Paper

By Masakazu HIGUCHI

Out of a certain necessity the compression test of the Kraft paper bags containing potato starch was made, and the tensile strengths of the paper specimens taken from the bags broken at the test were measured. Although we had already as comprehensive works on paper strength properties K. Ueno's "Kami no Kyodo" (1955, Maruzen Co., Tokyo) and H. F. Rance's "The Mechanical Properties of Papers," the Part B of "The Mechanical Properties of Wood and Paper," edited by R. Meredith (1953, North-Holland Publ. Co., Amsterdam), the writer could not learn such strength properties from them as the compressive strength of the filled paper bag related to the mechanical behavior of the contents of the paper bag.

1. **Compressive strength** The compressive strength of the actual bags of three sheet Kraft papers of which the contents were potato starch weighing 22.5 kg, was measured three times; while a number of small scale tests were made in a variety of the contents as well as of the papers. Each test was made with three bags or four which were piled up and layed on the bed of a universal testing machine. The load was applied through the wood plate (about 15 cm deep) put on the top bag.

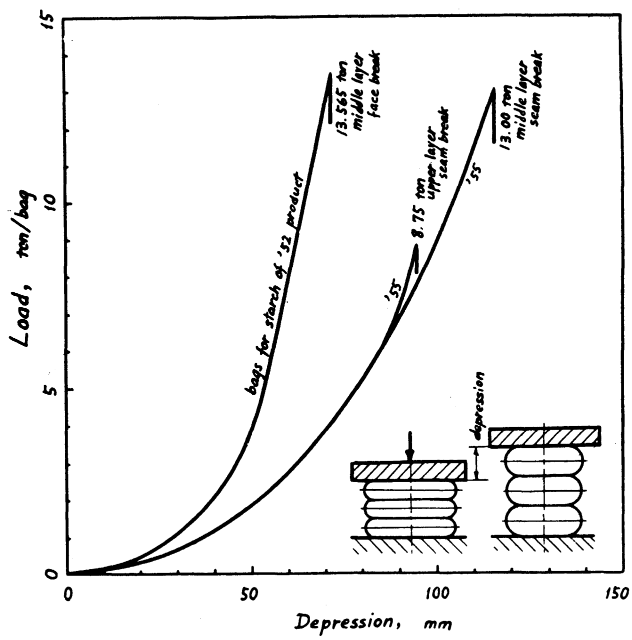

Fig. 1. Compression tests of actual bags

The bag paper does not stretch enough in the early stage of loading, i.e., in the upward concave portion of the load deformation curve; it only begins to become tight all over at the part of steep rise of the curve.

Although there were two tests of the actual bags ceased with bursting at some seam, in one of them the central part of the middle bag and its counterpart in contact were later found broken. It may therefore safely be said that the collapse of the bags will generally begin with the break of the central part in contact with each other. It may be an exceptional case that in the other test breaking occurred at the seam of the upper bag at the load of compression of 8.75 tons (rather small value). Since it is usually said that no failure of seams happens if handled ordinarily, and what we were aiming at was the strength of the paper, we took no notice of the strength of the seam. Thus, we prepared a number of paper bags of small size with strong seams and confirmed the strength properties of the paper bags by the similar tests.

As known from the photo, the permanent set of elongation is spread over a certain area near the center of the face of the bag and the face is sagged. It seems therefore that the paper of the bag is not subjected to hydrostatic pressure, but is stretched at the face

Photo showing the face breaks of middle layer bags of similar miniature test

This test was done with four layers of two sheet Kraft paper bags containing wheat flour; sagging along with breaking is observed in the central parts facing each other.

by the frictional force between the paper and the contents, which force does not act at the part near the side of the bag. The circumstances can be ascertained by using slick paper for bags and reducing the friction; the bags of cellophane as well as of paraffine paper break in the first place at the side of them along the length.

Besides, it is reasonable that the break in the bag face runs along the length in contradiction to the burst through a burst strength tester: Fundamentally speaking, the paper is to be considered to break at its respective proper limits of extension along the direction of the fiber or across it. The content of the bag is evidently more mobile across the direction of the length near the middle of the length of the bag in the later stage of compression and hence the paper also will be stretched the more in that direction, while the extensions of the paper specimen in burst strength testing are approximately equal in both directions and hence the specimen bursts in the first place in the direction of less extensibility, or across the fiber.

The load-deformation curves for small sized bags which are of geometrically similar form and of capacity of one hundredth of the bags of full size are quite similar to

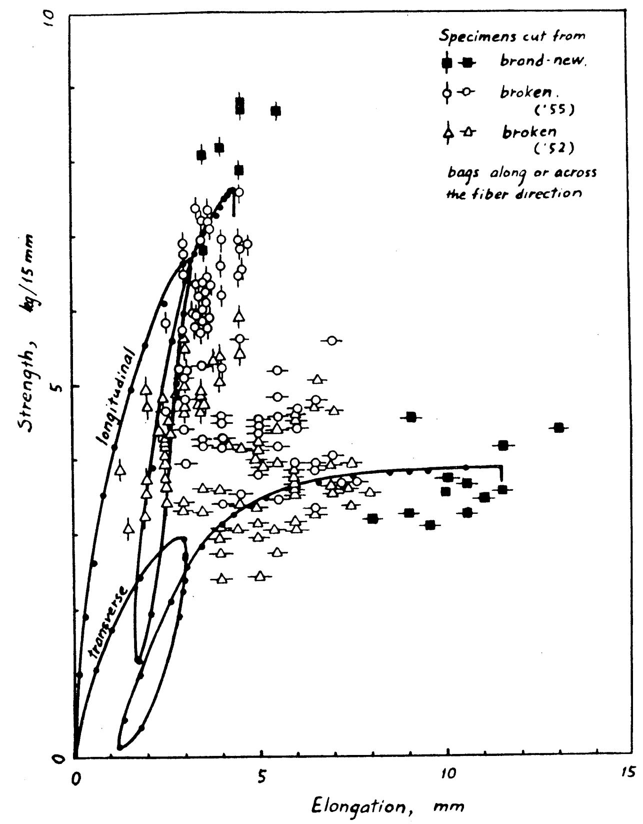

Fig. 2 Tensile tests of paper specimens

According to JIS P 8113 with the exception of the conditions of temperature (13~18.5°C) and relative humidity (55~67%)

those shown in Fig. 1. The loads to break these bags were, as a matter of course, reduced and were 2.29~2.64 tons for three sheets of Kraft paper and about 1.64 tons for two sheets. These figures suggest such relations as

$$13 \text{ or } 13.565 \doteqdot 100^{1/8} \times (2.29\sim2.64)$$

and

$$1.64 \doteqdot \frac{2}{3} \times (2.29\sim2.64),$$

the latter of which simply means that the bearing load is reduced proportionally to the number of sheets; the other factor $100^{1/3}$ in the former expression is possibly to be inter-

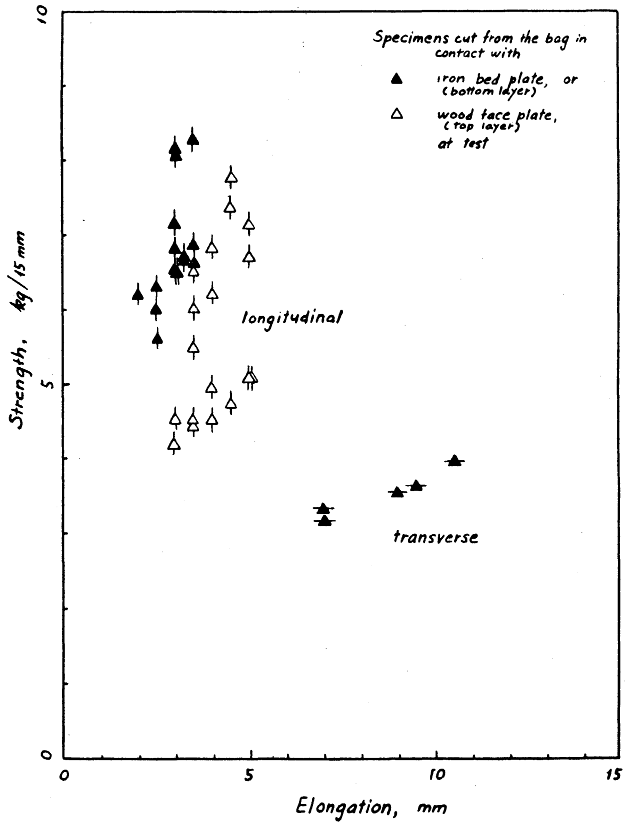

Fig. 3. Tensile tests of paper specimens

Test temperature 15°C, relative humidity 64%

preted as $100^{2/3}\times 100^{-1/3}$, 100 being the capacity ratio; that is, the bearing strength of the heap of the same number of bags, when compressed, may be taken to be proportional to the face area of the bag and approximately inversely proportional to the depth of it because its area and depth vary as $100^{2/3}$ and $100^{1/3}$ respectively in the present case. The extension itself of the bag paper, therefore, may be regarded as most roughly proportional to the depth of the bag.

Although the result is also derivable from the interpretation that the bag bursts as the water pipe does when subjected to hydrostatic pressure, it applies only in the case of little friction between the paper and the contents. In general, the powder acts so as to take with the part of the paper pressed between and to give rise to the localized extension there as inferred above. That the formula gives rather large value than the measured will be due to the smaller gradient of the distribution of extensional strains near the part of contact in the large sized bags.

2. **Tensile strength of the preloaded paper** Fig. 2 shows the strengths and the elongations at break of the specimens taken from the bags broken by the compressive tests.

For comparison the tensile testing was also done for the specimens from some brand-new bags. As to these the load-extension diagrams were obtained and two of them are reproduced in the same figure.

The paper specimens from the broken bags showed the considerable decrease both in extensibility in the direction across as well as in breaking strength in the direction along the fiber direction.

The decrease in extensibility is attributable to the permanent set of elongation owing to previous tension. The elongation ought to diminish as much as sets. The distinguished decrease in strength along the fiber direction is due probably to the lowering of the degrees of orientation and entanglement of the fibers which contribute to the strength. The ef-

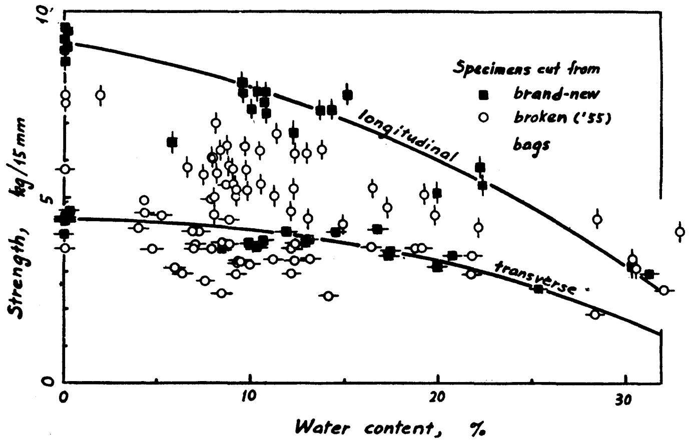

Fig. 4. Relationship between paper specimen strength and water content

Test temperature 18°C, presoaking about 20 hours

Here the water content 0% does not mean the state of absolute dryness, but the state of one hour drying at 110° C.

fect of previous tension may be expected to act as if when we, pulling crosswise now and then, unloose the tangled thread. It probably acts so as to remove the difference of properties dependent on the direction and to equalize the strengths.

For reference, the specimens taken from the bags in direct contact with the surface plates of the testing apparatus were examined as well and the results are shown in Fig. 3. Comparing with strength properties shown in Fig. 2, we find less decrease in extensibility across as well as of strength value along the fiber direction. It can be said that in spite of the identical compressive loading, the specimens from the portion in contact with the rigid plate (especially with the iron plate) suffered little effect of the previous tension on account of the rigidity resisting enough to the frictional pulling force by the contents.

3. **The influence of the water content on the tensile strength** Additional tests were made for the decrease owing to the water content in the tensile strength of the paper subjected to pretension, the results of which are shown in Fig. 4. The specimens from the

paper bags, brand-new as well as broken by the compression tests, were left in a room after soaked in water for about twenty hours, untill the water contents decreased to the quantities of our choice.

The two curves drawn in the figure indicate the relations of the breaking strengths of the specimens to the water content; the upper is for the specimens cut along the fiber and the lower for those across it. The tendency of monotonical decrease in strengths with the water content, with a few exceptions, is observed. Here, the water content of 0% does not mean the state of absolute dryness, but the state of the specimens set for tensile testing after one hour drying at 110°C. The range of the least moisture content in which the strength of the paper is said to decrease after it reaches a maximum, may possibly be found at the left side of the diagram beyond our scope of test.

4. **Summary** The ultimate bearing strength of the heap of filled paper bags was determined, and the tension tests were made for the paper specimens from the broken bags for the purpose of investigating the decrease in strength. The similar small paper bags of one hundredth capacity of the actual bag were also tested and a proportionality law was given for the rough estimation of the compressive load which the paper bag full of such powder as potato starch would bear:

$$\text{(The ultimate load)} \propto \text{(capacity)}^{1/3} .$$

In spite of the form of the expression to suggest such a burst as the water pipe suffers under hydrostatic pressure, the break of our paper bags is found due evidently to the stretching by the frictional force between the paper and the contents at the central portion of the bag face, with the exception of the break at the side of the bag made of very slick paper.

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