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RELATION BETWEEN HANDLE AND BENDING PROPERTIES OF PAPER AND PAPERBOARD

Yasuji Kazumori* and Takashi Kadoya**
* Central Research Laboratory, Hokuetsu Paper Mills, Ltd.
** Division of Pulp and Paper Science, Faculty of Agriculture, The University of Tokyo, Tokyo, Japan

Abstract

The relation between `handle´ and the bending properties of paper and paper-board is investigated statistically. The handle of paperboard was recognised to be explained by bending stiffness. In contrast, the handle of paper is complicated compared with that of paper-board, and cannot be explained by bending stiffness alone. The highest correlation coefficient is obtained for paper by applying the formula

$$Sm^2/d$$

where Sm is the maximum bending moment at the curvature of $2.5cm^{-1}$ and d is the thickness of the paper.

A simple method of observing the liveliness of paper is also proposed.

Introduction

The quality of paper and board products is widely evaluated by handle even today in Japan. For the evaluation of the quality of paper, bending stiffness has been said to be the most important factor. However, it is also known that bending stiffness is not always an adequate measure to express handle. There is a great number of papers that have the same bending stiffness, that is to say the same value of EI, but have different ratios of E to I, where E is the modulus of elasticity and I the moment of inertia of cross section for the sample respectively. Furthermore, bending recovery characteristics which might affect the handle have not been investigated so far for paper. In this paper, the relation between the subjective evaluation by handle and typical test parameters such as Taber and Clarke stiffness, and the results obtained by a specially designed apparatus is investigated.

Experimental

Bending tests

A Taber stiffness tester was used for the measurements on paper-board and hand-sheets, and Clarke and Taber stiffness testers and a KES-FB2 pure bending tester for those on commercial paper. All bending measurements were expressed as $L^3/100$, S15, Sk and Sm respectively. Sk and Sm are shown in fig 1.

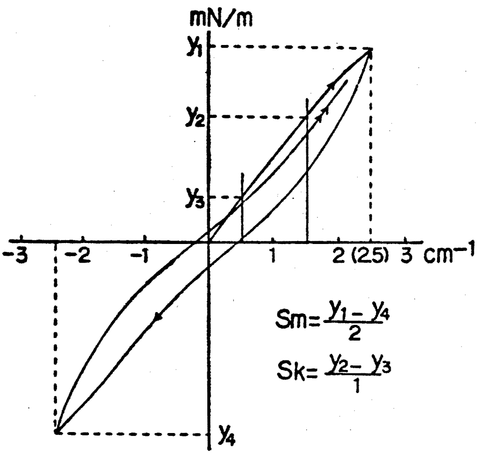

Fig 1—Typical bending moment hysteresis curve of paper obtained by KES-FB2 pure bending tester.

Sensory evaluation

Sensory rank on handle was obtained according to paired comparisons or ranking tests. The relationship between bending properties and handle was judged from Spearman's rank correlation coefficient.

Measurement of immediate bending recovery time

Immediate bending recovery time was measured with the device illustrated in figure 2. The dimensions of the test specimens are 135 x 50 mm. Specimens are lapped around the vertical cylinder to avoid any dead load effect, as shown in the figure.

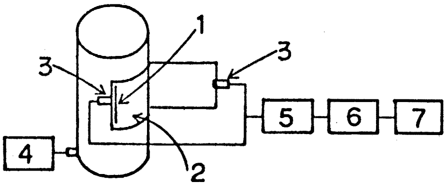

Fig 2—Device for measuring liveliness of paper. (1) air suction slit (2) test specimen (3) recovery time measuring sensor (4) vacuum pump (5) amplifier (6) transient time converter (7) recorder

Results and discussion

Relation between bending stiffness and handle

Though bending stiffness is the most important factor in handle, it is also known that bending stiffness is not always a measure adequate to represent handle. There is a great number of papers that have the same bending stiffness, that is EI, but different ratios of E to I. As it is thought that an evaluation of handle may change according to the ratio of E to I, sensory tests of the above-mentioned samples were performed in order to clarify the relationship between bending stiffness and handle. Figure 3 shows that sensory rank concerning handle does not correspond with the change of Taber stiffness. Comparison of sheets containing 0 % and 50 % of hardwood bleached kraft pulp respectively, revealed that their Taber stiffnesses are almost the same, while their sensory ranks are obviously different. The sensory evaluation of handle is not always constant even if bending stiffness EI is. A similar result was also obtained for machine-made papers. They showed the same stiffness, but the elastic modulus of one sheet was about two times greater than that of the others. These results indicate that the handle of paper is not always defined only by stiffness.

It is rare that sheets having such extremely different properties are compared. The relationship between handle and bending properties is further investigated for commercial paper.

Three types of bending tester using different measuring principles were applied: a Taber stiffness tester, which measures relatively small deformation by an external force to give EI: a Clarke stiffness tester which measures the deformation caused by a dead load to give EI/W, where W is the basis weight of the paper: and a KES-FB2 pure bending tester which measures a relatively large deformation caused by pure bending.

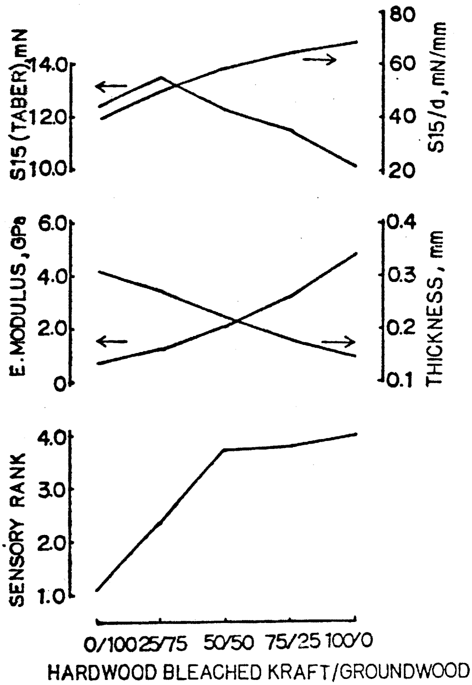

Fig 3—Relation between sensory rank and mechanical properties of handsheet ($W = 120\ g/m^2$).

Table 1 shows the rank correlation between handle and bending properties and so on. The values of $L^3/100$ made with the Clark tester showed the lowest correlation coefficient among the three methods. The highest correlation coefficient is obtained from the relation between handle and the formula Sm^2/d, where Sm is maximum bending moment at the curvature of 2.5 cm^{-1}. Under such test conditions, the specimens are all subjected to plastic deformation as shown in figure 1. The expression Sm^2/d is similar to the previous results reported by Brecht[(1)] in a sense, i.e. the square of the bending moment obtained at relatively large

	Spearman's rank correlation coefficient				
	S1(8)	S2(6)	S3(7)	S4(7)	mean
TABER					
S15	0.476	0.600	0.643	0.429	0.537
S15/d	0.571	0.714	0.643	0.786	0.678
$S15^2/d$	0.571	0.543	0.643	0.643	0.600
KES-FB2					
Sk	0.798	0.800	0.732	0.321	0.663
Sk/d	0.857	0.771	0.464	0.643	0.684
$Sk/^2/d$	0.786	0.714	0.661	0.250	0.603
Sm	0.798	0.714	0.643	0.321	0.619
Sm/d	0.714	0.886	0.375	0.875	0.712
Sm^2/d	0.883	0.771	0.643	0.679	0.732
CLARKE					
$L^3/100$	-0.071	-	0.643	0.429	0.333
TENSILE					
Modulus	0.726	0.800	-0.071	0.857	0.578

S1:wood free paper, $66g/m^2$ S2:wood free paper, $105g/m^2$
S3:woody paper, $69g/m^2$ S4:S1+S3
( ): number of specimens d:thickness
Number of judges is 7 or 8 persons.

Table 1
Rank correlation between sensory test result and bending properties of paper

deformation divided by sheet thickness shows a high correlation with handle. When sheets having the same bending properties are compared to each other, it is considered that handle may relate to the elastic modulus or strength properties. In other words, judges probably extract information about strength as well as bending properties through touching or snapping the sheets.

On the other hand, the Taber stiffness expresses the handle of paperboard satisfactorily, as shown in table 2. The highest correlation coefficient is obtained between the geometric mean of the Taber stiffness and the handle.

	Spearman's rank correlation coefficient				
	S1(6)	S2(7)	S3(7)	S4(7)	mean
MD					
S15	0.600	0.929	0.143	0.732	0.601
S15/d	0.428	0.929	-0.107	0.482	0.433
$S15^2/d$	0.600	0.929	0.036	0.661	0.556
CD					
S15	0.886	0.964	0.571	0.768	0.797
S15/d	0.886	0.964	0.857	0.518	0.806
$S15^2/d$	0.886	0.964	0.607	0.839	0.824
MD x CD					
S15	0.943	0.964	0.821	0.875	0.901
S15/d	0.828	0.964	0.607	0.625	0.756
$S15^2/d$	0.943	0.964	0.821	0.768	0.874

S1.190g/m^2 S2.210g/m^2 S3.310g/m^2 S4.400g/m^2
() number of specimens
Number of judges is 11 persons.

Table 2
Rank correlation between sensory test result and bending properties of paperboard

The reason is assumed to be as follows: when judges compare the bending properties of a pair of paper-board samples, they examine the properties along the same direction of both sheets, that is, machine direction to machine direction and cross

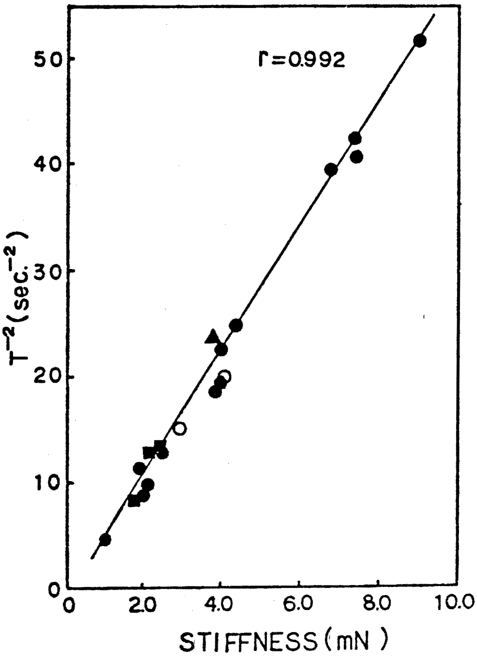

Fig 4—Liveliness of machine-maae paper as a function of bending stiffness.
Wood free paper (●), wood contained paper (■), kraft paper (▲), latex treated paper (o).

direction to cross direction. Therefore, it is assumed that they will take the results of one direction in which stiffness has the largest difference in perceived value as the basis for evaluation of handle. Based on this assumption, a paired comparison was performed objectively by comparing the Taber stiffness values of each sheet. The correlation coefficient between objective rank and sensory rank was calculated to yield the value of 0.901. The high correlation coefficient may support the above explanation. The differential threshold of bending stiffness was also determined by a constant method. It was about 5 % based on a Taber stiffness value of 130 mN in the case of paper-board of 250 g/m^2 basis weight.

Liveliness of paper

The term `liveliness´, which implies bending recovery characteristics, is one of the most important factors in fabric handling. It is often expressed as a bending recovery speed, but does not have a strict definition. As a result, there is a wide variety of ways of measuring it.

The liveliness of paper was measured according to the method illustrated in figure 2, and the speed of bending recovery was also observed using a stroboscope. The immediate bending recovery time was between 100 and 400 ms in this test. Figures 4 and 5 show the relationship between the Taber stiffness and the inverse square of the immediate bending recovery time.

Liveliness is seen to be highly correlated with bending stiffness.

Most of the test specimens for figure 4 were commercial wood free paper and the liveliness of those sheets depended on bending stiffness very closely. For handsheets prepared from several pulps, bending recovery characteristics are somewhat different from one another, and become more remarkable as bending stiffness increases. The bending recovery speed of groundwood sheets is lower than that of the other sheets, even at constant stiffness. The difference is pronounced, especially for higher stiffness values.

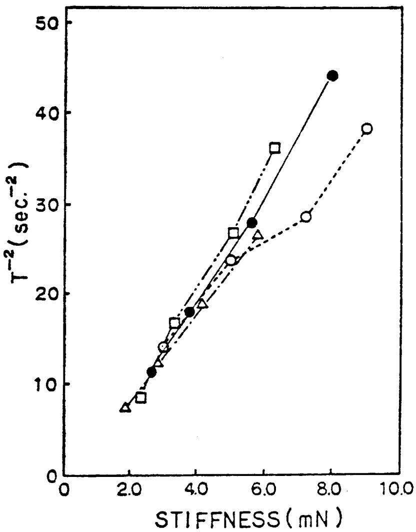

Fig 5—Liveliness of handsheet from several kinds of pulps as a function of bending stiffness. Groundwood (o), softwood (□), hardwood bleached kraft (●), softwood bleached sulfite (△).

This may be because groundwood sheets are thicker than and differ in plastic behaviour from wood-free paper. Stroboscopic observation showed that the recovery time of the free end of a groundwood specimen was not the same as that of its centre. Visco-elastic analysis of the fibres, as discussed by Onogi[(2)] in connection with fabric handling, should be useful in clarifying the differences in bending recovery behaviour. A more detailed and fundamental study will be necessary to elucidate the bending recovery characteristics of paper.

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