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NOTE

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Tearing test for paper using a tensile tester

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Abstract As a simulation of the Elmendorf tearing test, a tearing test method using a tensile tester was proposed with the same mode of fracture, mode III. Tear indices by both tests were highly correlated for various machine-made papers and laboratory handsheets. The relation between tensile strength and tear strength using the tensile tester was similar to that between tensile and Elmendorf tear strengths in single-ply mode for both softwood and hardwood pulp sheets. The proposed tearing test is convenient especially for imaging techniques such as thermography, and can help give new insights into the tearing process of paper.

Key words Elmendorf tear · Fracture · Paper · Tearing · Test methods

Introduction

The tear strength of paper, as measured by the Elmendorf tester, is one of the most important mechanical properties of paper. Although other tearing tests, such as the in-plane tearing test, were developed as alternatives,[1,2] Elmendorf testing is still used for routine evaluation of runnability in paper mills.[3] Furthermore, it has been applied as an index of aging of paper regarding its delicate character.[4] There are few reports, however, of studying Elmendorf testing itself,[5] partly because Elmendorf tearing is the retardation of a swinging pendulum, giving complex straining rates and angles. This is inconvenient for continuous checking of the crack tip status by such imaging techniques as thermography.[6]

In this report, a tearing test based on the trouser tearing test[7] is proposed to simulate the Elmendorf tearing test. The proposed test is able to perform out-of-plane tearing at various strain rates on a plane using the Instron tensile tester. The results of the proposed and Elmendorf tearing tests are compared using a variety of machine-made papers and laboratory handsheets.

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Experimental

Materials

Commercial papers [machine-glazed (MG) paper, glassine paper, filter paper] were employed as typical machine-made papers. Their basic properties in both machine and cross-machine directions are given in Table 1.

Laboratory handsheets were made from commercially available bleached softwood and hardwood kraft pulps according to TAPPI test method T 205. The pulps were screened in advance using a classifier with a 100-mesh screen to remove fines and then were beaten to various degrees with a PFI mill. The thickness of the sheets was measured according to TAPPI test method T 551 (soft platen method). Their basic properties are given in Table 2. Judging from the density and scattering coefficient, the handsheets represent unbeaten, lightly beaten, moderately beaten, and heavily beaten pulp sheets.

The geometry and size of the specimens for Elmendorf and the proposed tearing tests are shown in Fig. 1. All specimens were conditioned and tested under standard atmospheric conditions (23°C, 50% relative humidity).

Instrumentation

The tearing (tensile tester tearing) test was carried out using an Instron-type tensile testing machine (Shimadzu

Table 1. Basic properties of machine-made papers

Parameter	Machine-glazed paper		Glassine paper		Filter paper (MD)
	MD	CD	MD	CD	
Basis weight (g/m²)	41	41	30	30	100
Thickness[a] (μm)	55	55	22	22	174
Density (kg/m³)	745	745	1360	1360	575
Tensile index (kNm/kg)	83	26	96	36	29

MD, machine direction; CD, cross-machine direction
[a]Thickness was measured following TAPPI test method T 551 (soft platen method)

Table 2. Basic properties of handsheets

	Results, by degree of beating (PFI mill revolutions)			
	0	2000	10000	100000
Bleached softwood kraft pulp				
Freeness (ml CSF)	702	658	329	20
Density (kg/m³)	509	675	820	1090
Tensile index (kNm/kg)	21	71	107	128
Scattering coefficient (m²/kg)	39.5	30.3	22.9	10.8
Bleached hardwood kraft pulp				
Freeness (ml CSF)	659	623	433	25
Density (kg/m³)	410	566	679	886
Tensile index (kNm/kg)	8.1	36	63	83
Scattering coefficient (m²/kg)	50.2	40.6	36.1	31.3

CSF, Canadian standard freeness

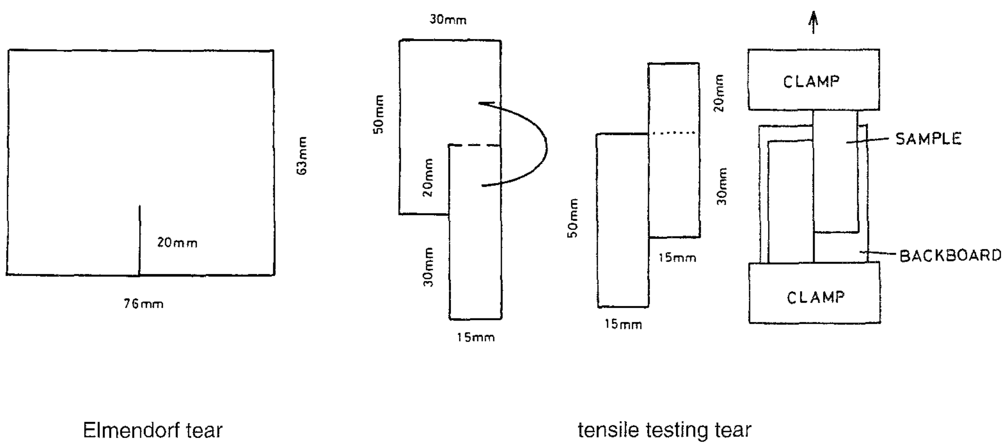

Fig. 1. Geometry and size of test specimens and specimen preparation for the tearing test using the tensile testing machine

Autograph AGS 100) with a span distance of 50mm and a crosshead speed of 500mm/min. The experimental arrangement for the tearing test is shown in Fig. 1. Specimens were torn by the movement of the crosshead at a constant speed along the plane of the backboard. The torn length of the specimen is 30mm, and the time needed for testing was 7.2s. The work done by testing was divided by the tearing length (2 × 30mm) and the basis weight; the tear strength is represented (in Nm²/kg) as the tear index (tensile testing).

Elmendorf tearing was carried out according to TAPPI test method T 414; that is, the number of plies torn simultaneously varied to obtain readings within a certain range on the tester scale. The torn length of the specimen was 43mm, and the time needed for testing was about 0.2s. The averaged tearing force was divided by basis weight, and tear strength is represented as the tear index (in Nm²/kg) (Elmendorf).

Results and discussion

Tensile tester tearing

Tearing often proceeded with some deviation from the center line of the specimen for the handsheets, whereas it was almost along the center line for the commercial machine-made papers. A typical load – tearing time curve is shown for unbeaten softwood pulp sheet in Fig. 2. The load tended

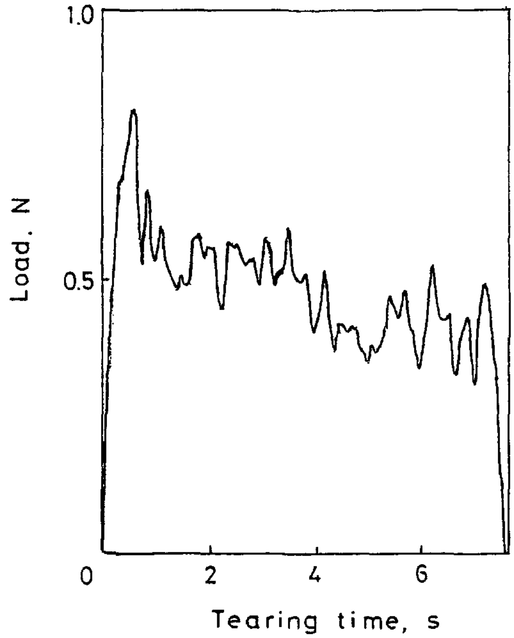

Fig. 2. Typical loading curve during the tearing of unbeaten softwood pulp sheet

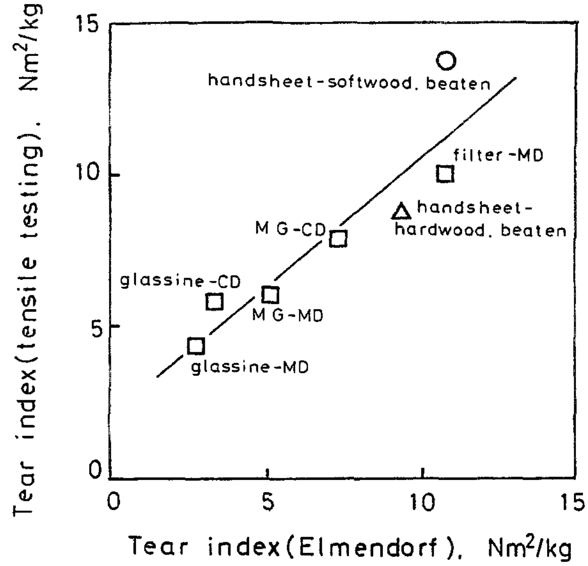

Fig. 3. Relation of tear indices between the Elmendorf test and the tensile test. *MG*, machine glazed; *CD*, cross-machine direction; *MD*, machine direction

to decrease progressively with fluctuation. Handsheet tearing often accompanied delamination, as did Elmendorf tearing. There should be some effect on the tearing process, but little difference was found in the tear indices for less delaminated samples and more delaminated samples.

Comparison of the tearing tests

Although both tests are classified in the mode of type III in fracture mechanics (i.e., out-of-plane fracturing test), some points such as sheet bending, testing time, and number of plies differ between them. The most critical point seems to be the tearing angle followed by the bending energy. Tensile tester tearing has a constant tearing angle of 180° with support of the backboard, whereas Elmendorf tearing has a range of angles without any support. The relation between the tear indices is shown in Fig. 3 for the machine-made papers and some representative handsheets. All data are mean values of ten measurements. Although testing conditions differed between the tearing tests, as mentioned above, a good correlation was found. The results suggest that there is no practical difference between the two methods.

The tensile tearing test was also done at lower crosshead speeds (50 and 5 mm/min) to evaluate the effect of the tearing rate on the tear index. Similar good correlations between them were found with a slight decrease in the tear index (tensile testing) with decreasing speed. The highest straining rate, 500 mm/min, was selected as the standard crosshead speed in this study.

The effect of beating on the tear index (tensile testing) is shown in Fig. 4 as a function of the tensile index for softwood and hardwood pulp sheets. Because the proposed tearing test is a single-ply test, the relation is preferably

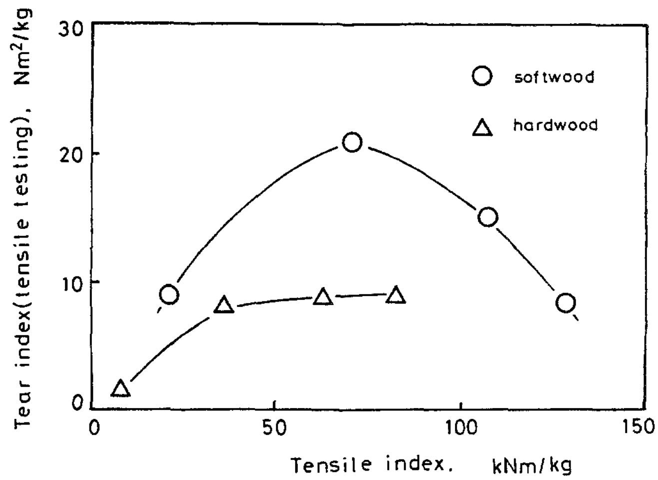

Fig. 4. Relation between the tensile index and the tear index (tensile testing) for the handsheets

compared with that between the tensile index and the tear index (Elmendorf) obtained in a single-ply test.[8] Although there are some discrepancies between single-ply and multiple-ply tear indices (Elmendorf),[8] both the tear indices (Elmendorf) and the tear index (tensile testing) changed with an increase in tensile index in a somewhat similar manner, as follows. For softwood pulp sheets, all tear indices decreased after passing an early peak with an increase in tensile index. The peak tear index at a somewhat higher tensile index is a feature of both single-ply tests. For hardwood pulp sheets, all tear indices increased with an increase in tensile index even for heavily beaten pulp sheet. These results indicate that the tearing test using the tensile tester can be employed as a substitute for the Elmendorf tearing test.

Conclusions

The proposed test method is convenient especially for imaging techniques, as the fracture takes place on a fixed plane; that is, a constant focus can be achieved. Thus, further studies on tear strength or the tearing process are expected with such combinations (e.g., with thermography).[9]

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