The effect of loading rate on the zero-span tensile strength test

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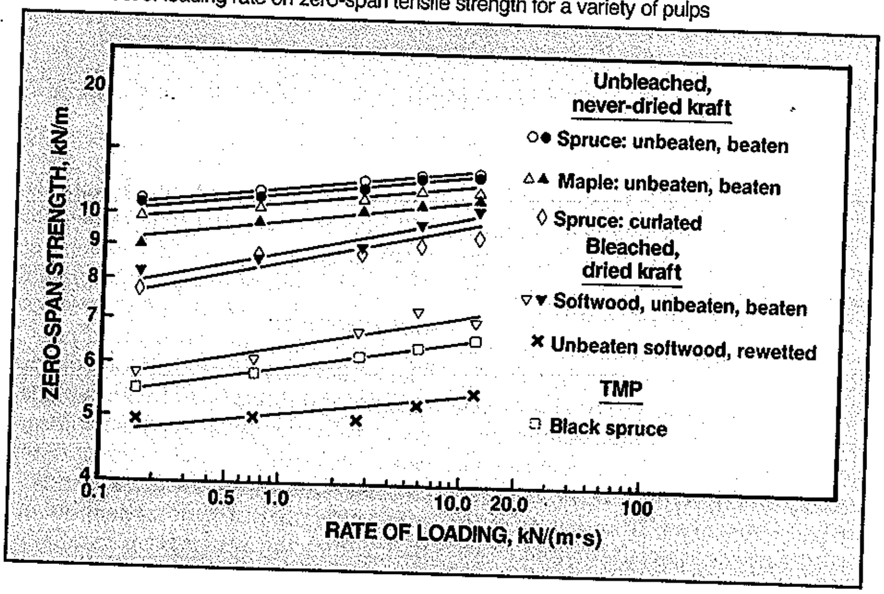
KEYWORDS: Instrumentation • Loading • Tensile strength • Testing

In their studies on the factors affecting zero-span strength, Wink and Van Eperen (*1*) studied the effect of loading rate using the IPC zero-span attachment on instruments that operated both at a constant rate of loading and a constant rate of straining. Data were obtained for loading rates ranging from 0.18 to 7.8 kN/(m•s) for both instruments. Zero-span tensile strength increased with loading rate and plateaued on linear plots after a critical rate of about 3.5 kN/m per second. Based on these studies, it was recommended that loading rate should be standardized at a value of 3.9 kN/(m•s).

At present, there is no official TAPPI Test Method for determining the zero-span tensile strength of paper. TAPPI published a suggested method in 1953 based on the use of the Clark zero-span attachment on a tensile tester (*2*, *3*). This method was revised in 1970, describing both the IPC design and a modified Clark design (*4*). Recently, the method has been classified as a classical method (*5*). It is suggested in this method that the load be applied at such a rate that the specimen breaks in 2.5 ± 0.5 s.

The Pulmac zero-span tester was designed in the early 1970s and combined the high accuracy of the IPC zero-span attachment with the simplicity of a burst tester (*6*, *7*). In this tester, the load is applied by leaking air at 100 psi to the loading cylinder through an adjustable needle valve. The needle valve is set to correspond to a build-up of 45 psi in 3 s, which is equivalent to a loading rate on the specimen of 3.5 kN/(m•s). This value is similar to that suggested by Wink and Van Eperen (*1*).

1. The effect of loading rate on zero-span tensile strength for a variety of pulps



Recently, we tested a variety of paper samples on two Pulmac zero-span testers. One tester consistently gave slightly lower results than the other, and we found that the rates of loading on the two instruments were not in agreement with the suggested standard setting. The instrument giving consistently higher zero-span values had a higher rate of loading. Based on this finding, we decided to re-examine the effect of the rate of loading on zero-span tensile strength.

Experimental procedure

Standard handsheets prepared from a variety of pulps were tested with a recent model of the Pulmac Trouble-Shooter zero-span tester at 50% relative humidity and 23°C. Both dry and rewetted zero-span tensile strengths were determined at rates of loading ranging from 0.16 to 12.0 kN/(m•s). These rates correspond to times to build up 45 psi in the loading cylinder, from 67 s to about 1 s.

Discussion

Figure 1 shows a plot of zero-span tensile strength as a function of loading rate on a log scale. Each data point corresponds to the average zero-span tensile strength of at least 50 measurements. The plots are all linear, and the gradients of the lines for the unbleached, never-dried kraft pulps are similar, regardless of differences in sheet structure (unbeaten vs. beaten) and fiber length (softwood vs. hardwood). In fact, the slopes of the lines are similar to those obtained by

Hardacker for single fibers of Douglas-fir (*8*).

These plots suggest that the changes in zero-span tensile strength with the rate of loading are independent of sheet structure but are more fundamentally a function of the behavior of the constituent fibers. It is surprising to observe plots of similar slope for sheets of dried bleached kraft, curlated unbleached kraft, and thermomechanical pulp, despite differences in the chemistry of these pulps. This similarity suggests that the viscoelastic nature of the interfibrillar matrix does not contribute to the effect of loading rate. We suggest that the behavior exhibited in Fig. 1 arises primarily from the effect of loading rate on the strength of the individual fibrils of cellulose.

The gradients of the lines corresponding to the dried bleached kraft, curlated unbleached kraft, and TMP are slightly steeper than the rest, however, and the only feature they have in common is that they contain fibers that are curled and microcompressed. The reason for this behavior is not known. It could be that at a low loading rate, microcompressions may be more easily removed, resulting in more fiber pull-out and a large drop in zero-span strength. It is also possible that fibers fail as a result of stresses concentrated in the microcompressed regions of the cellulosic fibrils and that these regions may be sensitive to the strain rate.

Conclusions

Changes in the loading rate can account for variations in zero-span strength. The loading rate should be checked on Pulmac instruments, and comparisons in zero-span measurements should only be made at the same rate of loading. The magnitude of the change in zero-span strength with loading rate is the same, regardless of changes in sheet structure, wood species, or fiber chemistry. The change seems to be more pronounced for pulps that contain curled and microcompressed fibers. □

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The authors would like to thank Barbara Admans and Claire Dumouchel in conducting the experiments, Bob Bain of the Physical Testing section for assistance with the instrument comparisons, Wavell Cowan and Phil Gallager of Pulmac Instruments, and Maurice Douek for helpful suggestions. A fellowship provided by Dow Chemical Canada, Inc., is greatly appreciated.

Received for review Dec. 12, 1988.

Accepted Jan. 29, 1989.