# THE INFLUENCE OF FORMATION ON TENSILE STRENGTH OF PAPER MADE FROM MECHANICAL PULPS

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## ABSTRACT

The importance of paper formation is widely appreciated amongst papermakers in relation to sheet appearance, but much remains unclear about its role in paper strength, particularly for paper made from mechanical pulps. This paper addressed the question of how formation affects the tensile strength of such pulps. Two softwoods mechanical pulps from species of differing fibre length and coarseness were fractionated by fibre length and formed into handsheets at standard handsheet consistency and at a headbox consistency. As found by previous workers, handsheets from the shorter fibre fractions gave higher strength. These handsheets also had better formation, as expected from shorter fibres. To isolate the influence of formation from other factors which differ between species and fractions and may cause strength differences, we compared one fraction of one species at differing forming consistencies. This showed that the direct contribution of formation to tensile strength was significant, with poor formation giving lower strength for all fractions. In addition, we compared tensile strengths of whole pulps formed at standard handsheet consistency and headbox consistency at reduced grammages over the range 60-30 gsm.

## INTRODUCTION

It has long been known that poor formation decreases the tensile strength of paper [1]. This has been found experimentally for mechanical pulps as well as chemical pulps [2]. Formation is strongly influenced by forming hydrodynamics, but it is also influenced by fibre properties. In particular, increasing length and coarseness cause poorer formation. This has been found for flocculated suspensions [3], standard handsheets [4,5], and has been predicted theoretically for

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ideal sheets of randomly distributed fibres [6]. In a related study, we have also shown the influence of these two properties on formation of mechanical pulps of differing species [7].

Fibre length and coarseness also influence the tensile strength of paper. Increasing fibre length generally gives stronger paper [4]. However, for mechanical pulps it has been found that the shorter fibre fractions give higher tensile strength than do the long fractions [8,9]. This somewhat surprising result has been attributed to decreased bonding arising from the stiffness of the long fibres [8,9]. However, poorer formation may also account for this diminished strength.

Poor formation decreases strength as a result of stress concentrations caused by the non-uniform mass distribution. It also decreases strength through decreased consolidation [10]. Both effects are described in [1] and well summarized as “a sheet with uneven mass distribution, which has poor strength properties due to local stress concentrations, normally also has a disordered microstructure that in turn decreases bonding”. The relative importance of these roles is generally not known.

These observations raise the larger question of the influence of formation on strength for papers produced from wood species of differing length and coarseness. Might differences attributed directly to these fibre properties be due instead to differences in mass distribution caused by them? The objective of this study was to address this question.

## EXPERIMENTAL PROGRAM

### Pulps

Two commercial TMP pulp of differing properties were examined. One was a northern softwood (NS) mixture of balsam/spruce (75/25) from eastern Canada and the other a southern pine (SP). The pulps were sampled from the composite secondary discharges at the thickeners which contained the accepts of the screening and cleaning systems, mixed with the screened and cleaned refined rejects. This pulp was drawn from the line leading to the papermachine.

The whole pulp (WP) was washed in a Bauer McNett fractionator with a 140 mesh screen to remove fines and additives. This fines-free pulp is called whole pulp screened (WPS). These screened pulps were then fractionated into R14, R16, R30, and R50 fractions. The measured values of length and coarseness, crowding number of the suspensions [11], as well as other pertinent data for the pulps is given in **Table I**.

The shive content whole pulps measured in a flat screen were found to be 1.2% for the SP and 0.24% for the NS pulp. Examination of the pulps under a scanning electron microscope revealed intensely frayed individual long fibres, but few shives in the SP pulp. Accordingly, the high value for shive content of SP does not reflect shives, but frayed long fibres that do not pass through the screen aperture. Similar observations have been made on chemical pulps [12].

### Sheet Forming

Handsheets were formed by two methods. The first was the standard method on the British sheet former (SH). The second was a technique to form sheets at headbox consistency (0.5%) on a modified British sheet former (HC). This technique, described fully in [13], employs a pouring and agitation step, and differing levels of agitation (A1, A2, …A10). Sheets were formed to a nominal basis weight of 60 g/m$^2$, excepting the tests carried out to determine the effect of grammage on breaking length.

### Northern Softwood Mixture (NS)

| **Sample** | **Freeness** | **LWA Length** | **Coarseness** | **Crowding Number** | |
|---|---|---|---|---|---|
| | CSF, ml | Mm | Mg/m | C=0.017% | C=0.5% |
| Whole pulp* | 122 | 1.46 | -- | .78 | 23 |
| Whole pulp** | -- | 1.60 | -- | 1.7 | 26 |
| Fraction R14 | -- | 2.50 | 0.221 | 2.4 | 71 |
| Fraction R16 | -- | 2.13 | 0.203 | 1.9 | 56 |
| Fraction R30 | -- | 1.63 | 0.214 | 1.05 | 31 |
| Fraction R50 | -- | 1.03 | 0.196 | .44 | 14 |

### Southern Pine (SP)

| **Sample** | **Freeness** | **LWA Length** | **Coarseness** | **Crowding Number** | |
|---|---|---|---|---|---|
| | CSF, ml | Mn | Mg/m | C=0.017% | C=0.5% |
| Whole pulp* | 117 | 1.74 | -- | .71 | 21 |
| Whole pulp** | -- | 1.84 | -- | .78 | 23 |
| Fraction R14 | -- | 2.94 | 0.376 | 2.0 | 57 |
| Fraction R16 | -- | 2.50 | 0.389 | 1.4 | 40 |
| Fraction R30 | -- | 1.97 | 0.331 | .99 | 29 |
| Fraction R50 | -- | 1.22 | 0.292 | .44 | 14 |

* Whole pulp including fines and additives (WP).

** Whole pulp with fines and additives (WPS).

**Table I. Pulp Properties**

### Formulation Measurement

Formation measurements were carried out at the University of Toronto using the beta radiography techniques developed by Dodson et al [14]. These gave coefficients of variation (CV) of mass distribution for measuring zone sizes of 0.1 mm to 10 mm as well as values for the intensity and scale of local grammage variations. We describe these measurements for the mechanical pulps of this study in our related paper [7]. For convenience in this study, we have used only values of CV for a zone size of 1 mm as the measure of formation.

## RESULTS AND DISCUSSION

### Whole Pulps

The relationship between breaking length and formation for the whole pulps (WP) and whole pulps screened (WPS) of the two species using differing forming methods are shown in **Figures 1** and **2** respectively. The data are scattered, but it is evident that breaking length increases with improved formation, as expected.

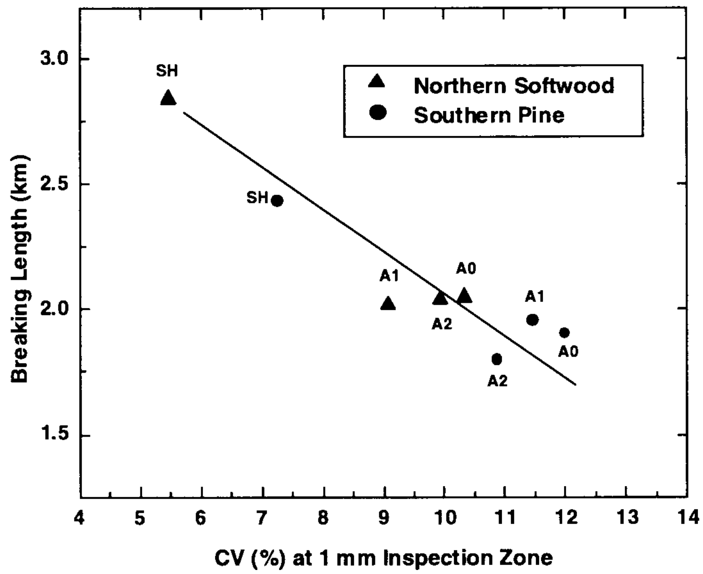


**Figure 1. Effect of formation on breaking length of whole pulps for differing forming methods: standard handsheets (SH) and differing levels of agitation (A0, A1, … A10) at 0.5% consistency.**

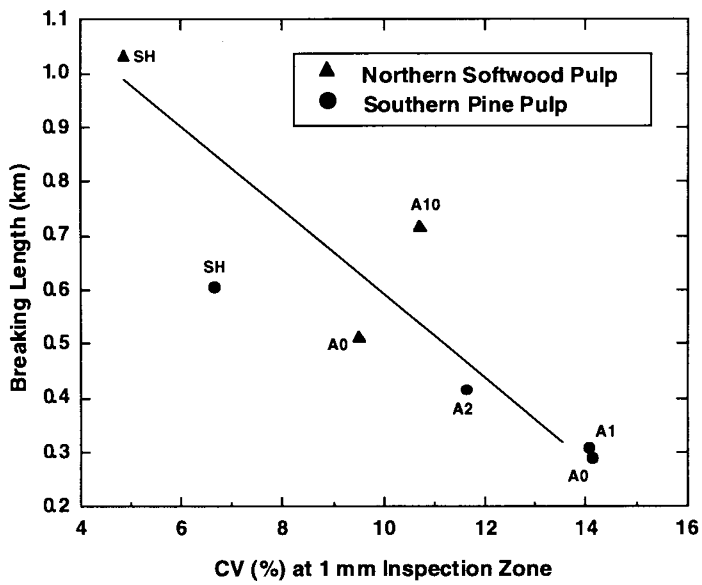


**Figure 2. Effect of formation on breaking length of pulps with fines and additives removed for differing forming methods: standard handsheets (SH) and differing levels of agitation (A0, A1, … A10) at 0.5% consistency.**

## Pulp Fractions

Long fibre fractions make the major contribution to formation, and therefore further tests were carried out on individual fractions. **Figures 3** and **4** show the change in formation for each fraction of each species between SH and HC sheet forming. The lines joining each two data points represent comparisons that have all factors other than formation eliminated. Consequently, the observed differences in tensile strength are due solely to formation differences. In all cases, poorer formation gives lower breaking length.

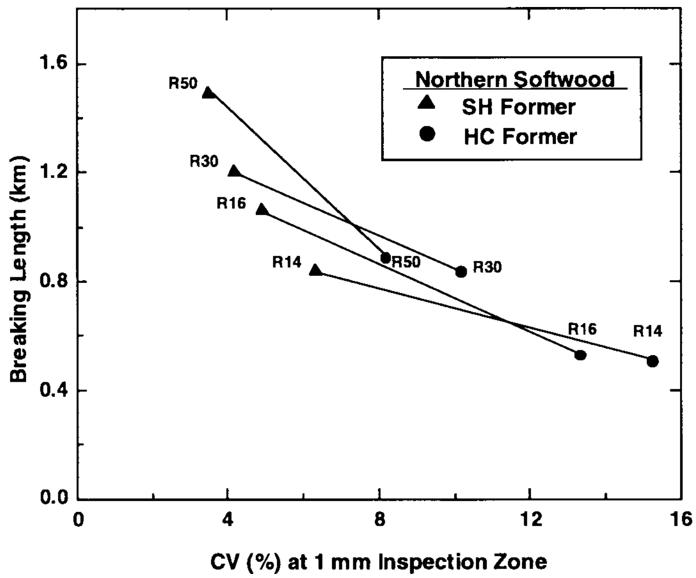


**Figure 3. Comparison of individual fractions of Northern Softwood mixture at two levels of formation. Poorer formation causes lower breaking length.**

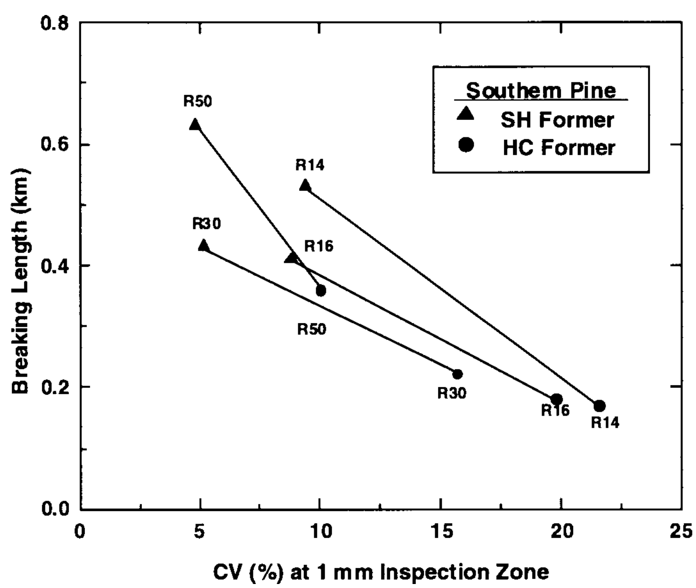


**Figure 4. Comparison of individual fraction of Southern Pine at two levels of formation. Poorer formation causes lower breaking length.**

For a common forming method, **Figures 5** and **6** show that the breaking length of each species increases with decreasing fibre length, as found by previous workers [8,9]. This decreasing length also gives improved formation. However, in this comparison between species, strength differences cannot be solely attributed to formation because other factors, such as specific bond strength, fibre length, and coarseness also differ between the two pulps. Nevertheless, given the demonstrated relationship between formation and strength of single species in Figures 3 and 4, it is reasonable to expect that differences in formation also contribute to the strength differences between species, though it is not possible to specify the magnitude of this contribution.

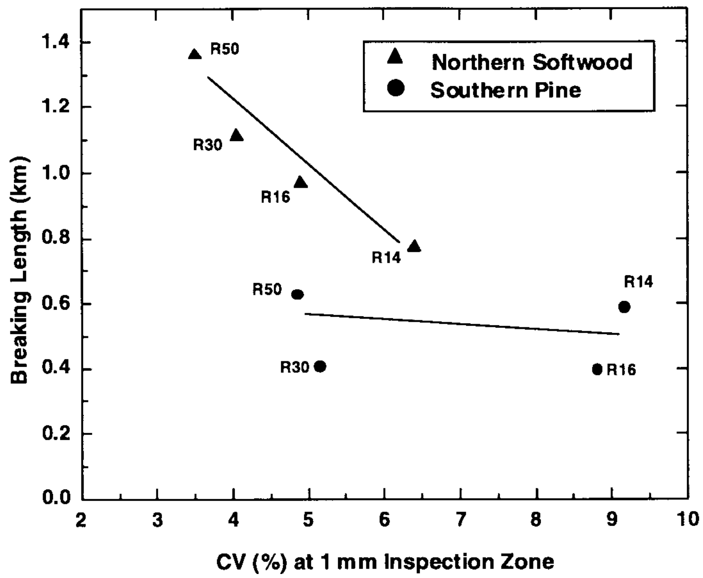


**Figure 5. The effect of formation of different length fractions for standard handsheets.**

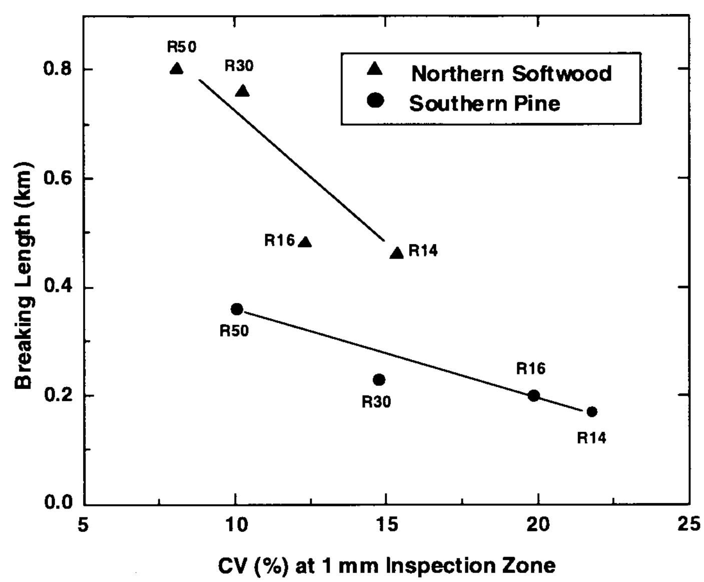


**Figure 6. The effect of formation of different length fractions for handsheets made at 0.5% consistency.**

## Effect of Grammage Reduction

The influence of formation on paper strength is expected to increase as grammage is reduced [15]. To determine this, we extended this study to handsheets of lower basis weights using the forming procedures described. Screened whole pulps (WPS) were used.

**Figures 7** and **8** show that, over the range tested (75-30 g/m$^2$), breaking length decreased with decreasing basis weight despite the fact that breaking length is a tensile strength normalized to basis weight. There is some suggestion of a sharp decrease at 40 g/m$^2$ for NS pulp formed by the standard method, but generally the data follow an approximately linear relationship. This accords with earlier findings for groundwood [2]. In contrast, bleached softwood kraft showed a constant level of breaking length down to about 30 g/m$^2$, followed by a sharp decrease below this level [2].

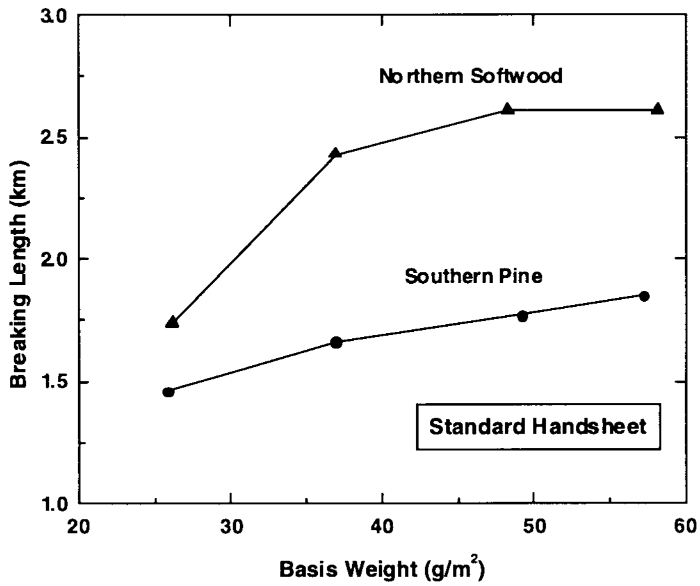


**Figure 7. The effect of basis weight on breaking length for standard handsheets.**

The average level of breaking length decrease over the basis weight range tested was approximately 0.77% for every 1% decrease in basis weight. This is greater than the level of 0.31% found in [2] over a range 55 to 30 g/m$^2$, but smaller than levels reported for commercial newsprint (1.1%) and for laboratory handsheets (1.0%) [15]. The differing forming conditions, for example whitewater recirculation in [2], may account for some of the differences.

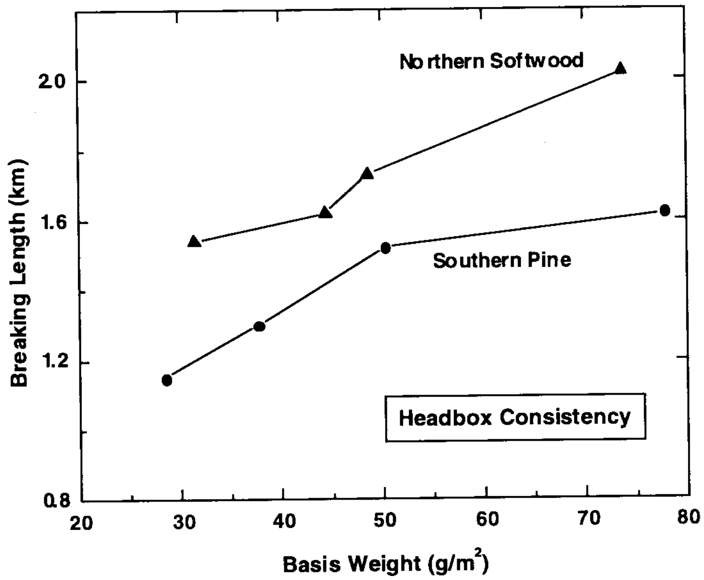


**Figure 8. The effect of basis weight on breaking length for handsheets formed at 0.5% consistency.**

## SUMMARY AND CONCLUSIONS

This study has shown that paper made from the long fibre fraction of mechanical pulp fractions has lower tensile strength than paper from the shorter finer fractions as found in previous studies, but it also has poorer formation. This poorer formation may be a cause of the decreased strength, in addition to the reduced bonded area resulting from stiffer fibres postulated by earlier investigators.

It was further found that paper made from mechanical pulp of low coarseness had a larger tensile strength than did paper from high coarseness pulps, and that this strength difference was maintained at low basis weights. It was postulated that this occurred as a result of better mass distribution as well as increased bonded area and other factors affecting tensile strength.

## ACKNOWLEDGEMENTS

The authors gratefully acknowledge financial support for this study from the Mechanical Wood Pulp Network of Centres of Excellence and the Pulp and Paper Research Institute of Canada.

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Received: May 25, 2000
Accepted: August 14, 2000

This paper was accepted for abstracting and publication in the December 2000 issue of *TAPPI JOURNAL.*

*TAPPI Website: www.tappi.org*