# EFFECT OF SOFTWOODS ON THE WET-WEB STRENGTH OF E. Globulus BLEACHED KRAFT BASED FURNISHES


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## ABSTRACT

The present work analyses the influence of the amount of long fibres on the wet web strength of E. globules pulps. Four pulps, with percentages of a softwood commercial based pulp between 0 and 100%, were characterized with respect to fibre dimensions and drainability. Handsheets with about 50% solids content were made and tested in terms of wet tensile strength and strain. Dry handsheets were also produced and submitted to the conventional physical and mechanical tests, as well as to measurements of dimensional stability (hygroexpansivity). The results reveal that while wet tensile is steadily increased with the addition of the softwood fibres, wet stretch is not significantly improved for softwood percentages higher than 20%. For the dry handsheets, the small influence detected for softwood content superior to 20% was found for both tensile and stretch. Finally, this study shows that the effect of adding long fibres is much more pronounced for the wet than for the dry tensile properties.


## INTRODUCTION

In the papermaking process the frequency of wet-end breaks, which occur in open draws, depends on the machine speed, on the geometry of the open draws and on the dryness of the web, but is mainly affected by the wet-web strength properties (Wharen 1981; Seth et al. 1982; Pikulik 1997). This is why, sometimes, a certain amount of long fibre is added to the short-fibre pulps that are increasingly used to produce printing and writing paper grades. Several studies have been published, regarding the mechanical and wet-web properties of various furnishes and the runnability in the machine (Nyblom and Levlin 1981; Seth et al. 1982; Gurnagul and Seth 1997; Pikulik 1997), but a systematic evaluation of the softwood fibre content on the performance of E. globulus bleached kraft pulps can not be found in the open literature. In fact, a clear understanding of the parameters that influence the wet-web strength of eucalyptus pulps is of utmost importance due to their role on the production of fine papers. This study is the beginning of a more comprehensive work devoted to identifying the critical factors of the wet-web strength of E. globulus pulps. The research carried out so far in laboratory is particularly focused on the effect of the amount of long fibres in the furnish.

The wet-web strength has been usually characterized considering the tensile strength and stretch and using the "failure envelope" approach, based on the values of these two properties measured over a range of moisture contents (Seth et al. 1984). The tensile strength is improved by the fibre-to-fibre interactions, while the stretch is much influenced by the curl and the microcompressions of the fibres. Fibre-to-fibre interactions increase with the solids content, with the fibre collapsibility, flexibility and fibrillation, and also with the amount of fines. At low solids content, fibre interactions are weak since fibres are held together mainly by the forces of surface tension. At high solids content (above 30% w/w) interactions are improved by the hydrogen bonds between fibres (Nyblom and Levlin 1981; Clark 1985; Seth et al. 1984). Curl and microcompressions, which also vary with fibre intrinsic resistance and fibre-wall structure, tend to enhance the wet-web stretch. However, it is believed that the extension of their effect is also conditioned by the intensity of fibre bonding: when the interactions are weak, stretch is mainly controlled by fibre curl (the higher the stretch-to-break the lower the sheet tensile strength); for well bonded fibres, stretch is mostly determined by the presence of microcompressions and short-range curl, and both the strength and strain increase (Seth et al. 1984).

Consequently, there are many parameters that influence the wet-web resistance and that depend either on the composition of the furnish or on some basic papermaking operations like refining and formation. In this work pulps with distinct softwood contents were used, and pulp characteristics like the amount of fines, the length and the coarseness of fibres, as well as their curl and kink indices, were quantified in order to better evaluate the differences in the wet-web strength. The length and the coarseness of fibres were determined since they give an indication of their collapsibility and flexibility: fibres that are longer and fibres with thinner walls in relation to the fibre width are more conformable and therefore the interactions between them increase (Gurnagul and Seth 1997; Jang and Seth 1998). Additionally, measurements of fibre swelling, pulp drainability and conventional physical and mechanical paper properties were performed and the results examined against the percentage of long fibres in the pulps. This study also aimed at understanding the influence of long fibres on the dimensional stability of paper, expressed in terms of hygroexpansivity (Nanri and Uesaka, 1993). Moreover, the relation of this property with the wet-web stretch and with other properties that also depend on the uptake of water by fibres, such as the drainability, was investigated.

## MATERIALS AND METHODS

Two bleached kraft pulps were used in this study: a never-dried E. globulus pulp and a rewetted softwood commercial based pulp, separately beaten in a PFI mill at 10% consistency up to 31 and 21 °SR, respectively. With these two pulps, two blends were prepared, with 20 and 50% (w/w) of softwood fibres. Thus, a set of four pulps, comprising different softwood content, was available for analysis. These pulps were kept at a low consistency with minimum handling to avoid changes to fibre shape, and their drainability and fibre swelling ability were evaluated by calculating the Schopper-Riegler degree (°SR) and the Water Retention Value (WRV), respectively. For each pulp, fibre coarseness, fibre length distribution, length-weighted average fibre length (Ll), as well curl index distribution and mean value (Jordan and Nguyen 1986) were determined by image analysis in the Fibre Quality Analyzer (Robertson et al. 1999). The amount of fines was also quantified with this equipment, considering fines as all the fibrous material with length inferior to 200 _m (Ferreira 2000a).

To measure the wet-web tensile stress and strain, isotropic laboratory handsheets, having 80 g/m2 OD basis weight, were made with the four pulps and submitted to the same dewatering conditions: couching with three blotters and air drying in a conditioned room during the exact time that the reference pulp (the pulp with 20% (w/w) of softwood fibres) took to reach a moisture content of 50%. A vertical tensile testing apparatus equipped with a 50 N cell load and having an elongation rate of 5 cm/min was used with specimen strips 5.0 cm wide and 10 cm between clamps. For each pulp, an average of five measurements results was calculated. The effect of gravity on the water migration may be considered negligible for the range of the moisture content studied here, in spite the fact that strips were held vertically (Seth et al. 1982). Nevertheless, it should be stressed that wet-web strength measurements are not easy to perform, especially for hardwood pulps, since the webs are very weak, and therefore particular care is due when analysing the results.

Air-dried isotropic handsheets, with the same basis weight of the wet ones, were also produced according to the ISO 5269/1 standard, so that pulp properties like bulk, air permeability, stretch and tensile and tear strengths could be quantified by the standard procedures. Tensile tests were performed in a horizontal apparatus.

With regard to the dimensional stability of paper, it was used a new device previously designed and constructed so that changes in the in-plane dimensions of paper, when submitted to different humidity conditions of the surrounding environment, can be quantified for several test pieces simultaneously (Ferreira et al. 1998). This device consists of three parts: a humidity chamber equipped with a laser based motion sensor for measuring the increase in the length of the test specimens, an air conditioning system and a computer based data acquisition and control unit. For each pulp, five strips 2 cm wide and approximately 10 cm long were prepared using the aforementioned dry handsheets and held vertically with clamps in the humidity chamber. The hygroexpansivity measurements were then performed based on the SCAN-P 28-88 standard: the test pieces were preconditioned at 22 ± 2% relative humidity, for one hour; after that, the relative humidity was raised to the starting point of the test, 33 ± 2%, and one and a half hour later raised again to 66 ± 2%. The specimens were kept at this value relative humidity for four hours and, finally, the hygroexpansivity coefficient of each one, _33_66, was computed as:

$$\beta_{33\rightarrow 66} = \frac{\Delta R \cdot (L_2 - L_1)}{(R_2 - R_1) \cdot L_0} \times 100 \qquad (1)$$

where Lo is the initial length of the specimen (in the conditioning atmosphere, at 23°C and 50% relative humidity), L1 and L2 the lengths recorded at the end of the 33% and 66% relative humidity stages, respectively, _R the nominal increase in relative humidity (33%), and R1 and R2 the lower and the upper relative humidity as measured by the moisture sensor inside the chamber. For each pulp, the coefficient reported corresponded to the average result of the five test pieces utilized.

## RESULTS AND DISCUSSION

Table 1 summarizes the characteristics of the four pulps analysed in this study and Figure 1 presents the fibre length distributions of pulps A and D, the pulps which include 0% and 100% of the commercial softwood based pulp, respectively.

**Table 1. Pulp characteristics at different softwood content.**

| Pulp | A | B | C | D |
|---|---|---|---|---|
| Softwood Content (%, w/w) | 0 | 20 | 50 | 100 |
| Schopper-Riegler number (°SR) | 31 | 29 | 26 | 21 |
| Water Retention Value (WRV) | 106.6 | 111.5 | 63.5 | 60.5 |
| Fines Content (%, w/w) | 13.04 | 15.18 | 16.95 | 27.56 |
| Average Fibre Length (Ll, mm) | 0.671 | 0.822 | 1.146 | 2.148 |
| Coarseness (mg/100 m) | 7.4 | 8.8 | 9.9 | 16.3 |
| Curl Index (length weighted) | 0.064 | 0.064 | 0.066 | 0.106 |

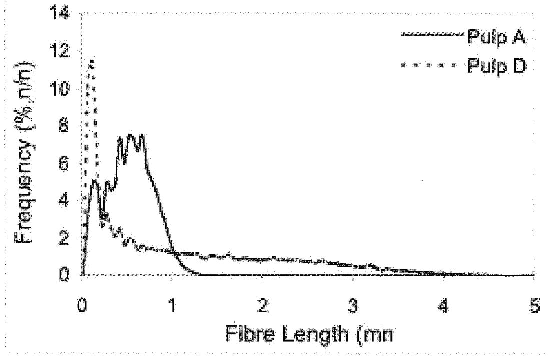


**Figure 1. Fibre length distributions of pulps A and D, as measured by the Fibre Quality Analyzer.**

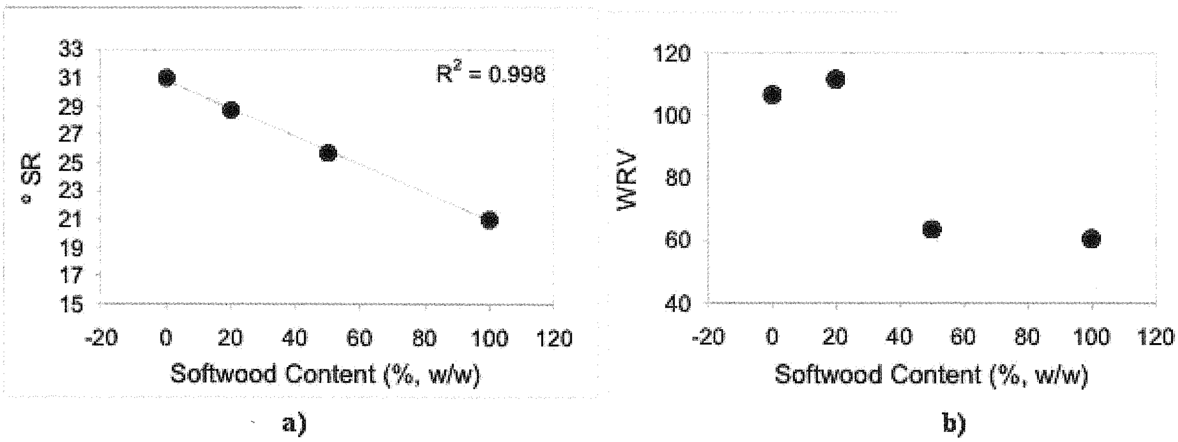


**Figure 2. Schopper-Riegler degree (a) and water retention value (b) at different softwood content.**

As can be seen in Table 1 and in Figure 1, the amount of fines in pulp D is unexpectedly high when compared to that of pulp A. These fines may be either primary fines present in the unbeaten pulp or fibre ends formed by the cutting action during beating. In fact, the softwood pulp D required a larger amount of energy to reach 21 °SR (1700 revolutions) than the E. globulus pulp to reach 31 °SR (1000 revolutions). This reflects the coarseness (see Table 1) and stiffness of the softwood fibres, which promote the cutting action during beating.

The drainability of the four pulps clearly reflects the different softwood percentages: the Schopper-Riegler number decreases linearly with the amount of the softwood beaten pulp (Figure 2a)). Fibre swelling ability, expressed in terms of the Water Retention Value (Figure 2b)), also reveals a decreasing tendency, in spite of the anomalous value corresponding to pulp B (probably originated by some experimental error, namely related to the weighting operations of the method).

Table 1 also shows that pulp freeness augments (i.e., °SR diminishes) with the amount of fines, in opposition to the strong positive influence of fines on the water retention of kraft pulps described elsewhere (Ferreira 2000b). This fact indicates that the most abundant fines, initially present in pulp D, are perhaps too small to fill voids between fibres and to promote water retention. Thus, the drainability of these four chemical pulps is mainly controlled by fibre swelling (Nyblon and Levlin 1981) as well as fibre fibrillation and conformability. Accordingly, a closely linear relation between fibre dimensions (length-weighted average fibre length and coarseness) and softwood content can also be found using the values of Table 1. With regard to the curl index, no significant differences are detected between pulps A, B and C. However, pulp D exhibits a clearly higher curl index, similar to those reported in the literature (Gurnagul and Seth 1997).

The results of the wet strength measurements are listed in Table 2, which also includes the solids content of the wet handsheets tested.

**Table 2. Wet-web properties of pulps at different softwood content.**

| Pulp | A | B | C | D |
|---|---|---|---|---|
| Solids Content (%, w/w) | 49.3 | 50.0 | 50.4 | 51.6 |
| Wet tensile Index (Nm/g) | 2.28 | 2.67 | 3.53 | 4.97 |
| Wet stretch (%) | 4.65 | 5.04 | 5.13 | 5.18 |

Although the same dewatering procedure has been applied when preparing the wet handsheets, slightly different moisture degrees were obtained, certainly due to the distinct composition of each pulp. As referred to above and as expected, drainability is improved by the larger softwood fibres, which originate more open web structures, and thus higher solids content levels are achieved. Figure 3a) depicts the linear increase of the wet tensile index with the pulps softwood content. This tendency is explained by the increase of the solids content and mainly by the presence of the softwood fibres, which are larger and establish more fibre-to-fibre interactions. In fact, comparing pulps A and D (Table 1), it is visible that the fibres of the latter, in spite of having approximately double coarseness, are three times longer, and thus are more likely to collapse (Gurnagul and Seth 1997). Moreover, a minor contribution of the amount of fines to the increase of the wet tensile strength may also be expected. The increase of both the wet tensile strength and the drainability (Figures 2a) and 3a)) contradicts the findings of other authors, but it is known that the influence of drainability on the wet tensile strength is small when the comparison between pulps is made after a constant dewatering procedure, as it was in this study (Nyblon and Levlin 1981).

As for the wet stretch, Figure 3b) shows that this property increases with the wet tensile index (and therefore with the softwood content), what is consistent with the moisture degree of the test specimens and with the extent of

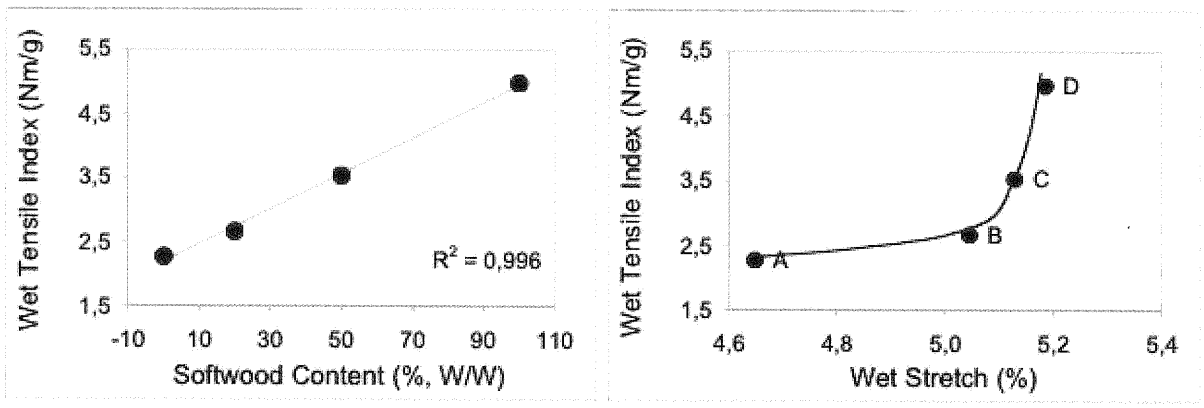


**Figure 3. Wet tensile strength at different softwood content (a) and wet tensile versus wet stretch (b) (A, B, C and D correspond to the pulps listed in Table 1).**

fibre bonding (Seth et al. 1984). Indeed, the addition to the E. globulus fibres of the softwood fibres, with an average curl index 60% superior (Table 1), promotes fibre stretch due the removal of latency during web straining. However, considering that the solids content of the four pulps is always close to 50% and that fibres are not severely curled, only short-range curl is removed (Seth et al. 1984), and this explains the limited increase in wet stretch (4.7 - 5.2 %). On the other hand, it is important to notice that the effect of the softwood content is not so relevant for percentages superior to 20% (w/w) (pulps B, C and D), denoting that there is a limit to the influence of the softwood fibres on the web straining.
The results of the measurements performed on the dry handsheets are given in Table 3 and confirm the positive role of the softwood based pulp either on the structural and on the mechanical properties.

**Table 3. Dry handsheet properties of pulps at different softwood content.**

| Pulp | A | B | C | D |
|---|---|---|---|---|
| Bulk (cm3/g) | 1.53 | 1.49 | 1.50 | 1.43 |
| Air Resistance (s/100ml) | 10.65 | 12.25 | 18.90 | 31.14 |
| Tensile Index (Nm/g) | 76.65 | 79.50 | 80.25 | 81.45 |
| Stretch (%) | 3.63 | 3.72 | 3.72 | 3.72 |
| Tear Index (mNm2/g) | 11.1 | 11.8 | 13.5 | 14.4 |
| Hygroexpansivity Index ( 33 66, %) | 0.262 | 0.232 | 0.249 | 0.250 |

Nonetheless, when the softwood content exceeds 20% (w/w) the increment of both the tensile strength and stretch is attenuated (Figure 4), partially in contradiction to the case of the wet webs, where only the results of the stretch reveal this tendency.

With regard to the hygroexpansivity index, Figure 5 indicates that more experiments are needed in order to find out which point (A or B) requires correction. In fact, the above results of the tensile tests (Figures 3 and 4) suggest a positive correlation between hygroexpansivity and softwood content, and this is not clear from Figure 5. Only after this correction, dimensional stability can be correlated to web drainability, as previously intended.

Relating now the tensile properties of the air-dried and wet handsheets, Figure 6 shows that the differences between the four pulps are much more pronounced for the wet than for the dry handsheets. Therefore, the presence of long fibres in the furnish seems more important in controlling the strength of the wet web than in controlling that of the final product.

## CONCLUSIONS

This study confirms the positive effect of adding softwood long fibres on tensile wet properties also to an E. globulus kraft pulp, by evaluating different pulps at the same dewatering conditions. However, the results obtained were also influenced by the different beating degree of each pulp as well as by the large amount of fines of the softwood based pulp. With regard to the handsheets hygroexpansivity, more measurements are needed before correlations with the softwood content can be established.

By comparing the tensile results of the wet and the dry handsheets, it may be concluded that, on the one hand, the benefits of the softwood pulp at amounts larger than 20% (w/w) are attenuated, specially for the tensile stretch; on the other hand, the influence of this pulp is much more notorious in the wet than in the dry state.

## ACKNOWLEDGMENTS

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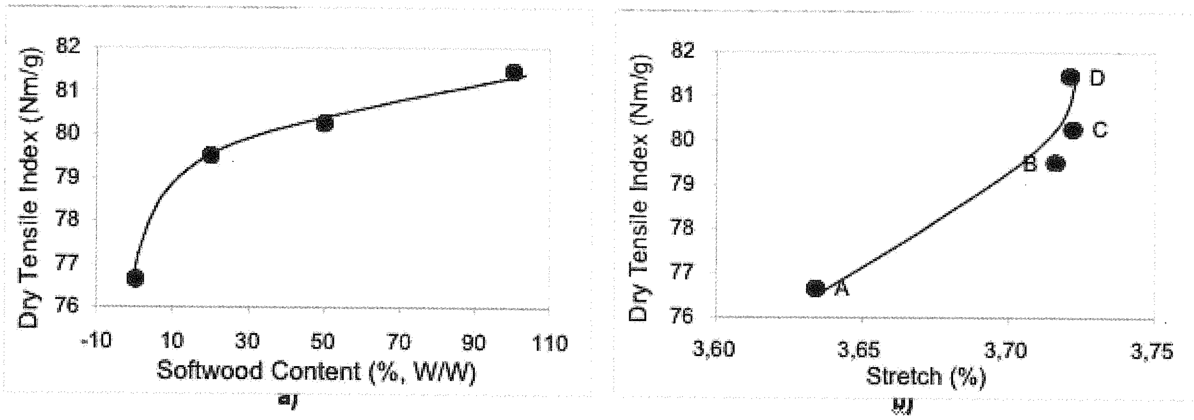



Figure 4. Dry tensile strength (a) and stretch (b) at different softwood content (A, B, C and D correspond to the pulps listed in Table 1).

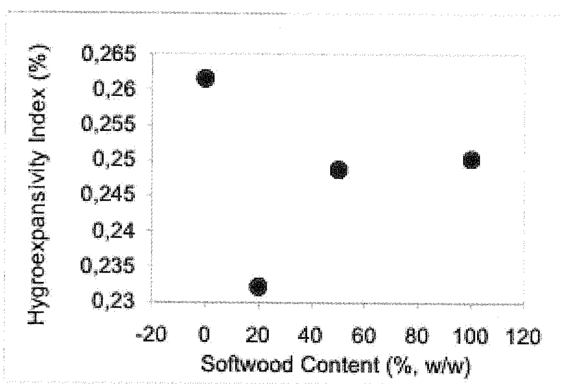
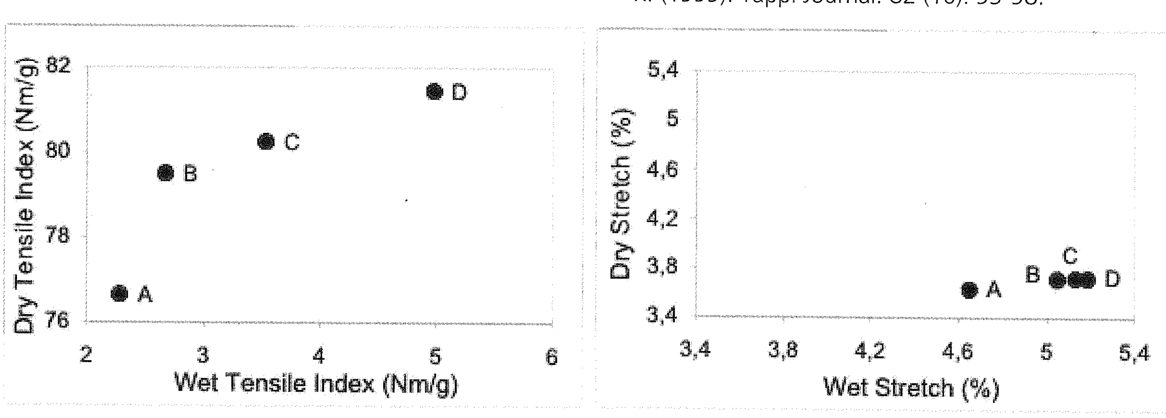



Figure 5. Dry handsheets hygroexpansivity index at different softwood content.




a) b)

Figure 6. Comparison between the dry and the wet tensile properties at different softwood content (A, B, C and D correspond to the pulps listed in Table 1). a) tensile strength; b) stretch.

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