VTT Technical Research Centre of Finland

The Relationship between Sheet Contraction and Elongation of Paper for Improved Formability

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Summary

Elongation is a key property for several packaging applications. The relationship between shrinkage and elongation of paper was investigated over a wide range, in order to understand and develop high extensibility for paper. The same dimensional contraction brought about by shrinkage can be strained out in tensile testing. However, percentage-wise the elongation is greater than the shrinkage due to different reference points, and the difference increases strongly at higher shrinkage levels. Elongation of paper can be explained mainly by two factors: the shrinkage and the net elongation of paper.

Figure 1. *A sample of a tray with requirement of high extensibility.*

Relationship between elongation and shrinkage

Reduction of length of a sheet due to in-plane compaction and drying shrinkage is well-known trivial behavior. However, the mathematical non-linear relationship that describes the effect of shrinkage (including creping, compaction and drying shrinkage) on elongation at break is not so well recognized, due to typically small in-plane length changes of paper. Elongation of shrunken paper in percentage units can be presented as

$$Elongation = \frac{\Delta S}{100-\Delta S} + \varepsilon_{Restrained} \qquad (1)$$

Where **ΔS** is the shrinkage (the percentage length reduction), "**100**" refers to the length before the shrinkage and $\boldsymbol{\varepsilon_{Restrained}}$ is the percentage elongation of a corresponding completely restrained dried sheet.

The *Eq 1* is not an empirical equation. It can be used as a reference providing that **ΔS** and $\boldsymbol{\varepsilon_{Restrained}}$ are known. The elongation obtained from the first part of *Eq 1* has a different reference length ("**100-ΔS**") than the shrinkage percentage **ΔS**, although the shrinkage and subsequent elongation could be exactly the same on an absolute length scale (e.g. a mm-scale) as shown in Figure 2.

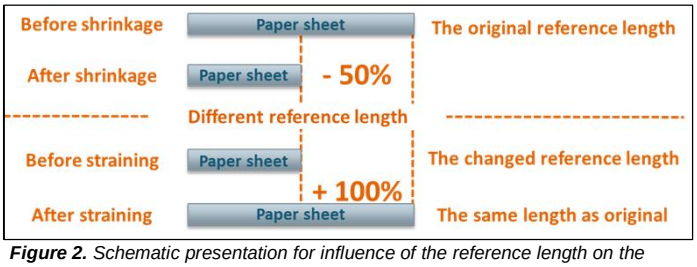

Figure 2. *Schematic presentation for influence of the reference length on the relationship between shrinkage and elongation.*

Importance of the relationship

A significant "advantage" on elongation due to the nonlinearity can be obtained when the shrinkage of the structure is more than 20% as shown in Figure 3. On the other hand, the role of this nonlinearity is minor at low shrinkage levels.

$\boldsymbol{\varepsilon_{Restrained}}$ can be regarded as a "net elongation" of the unshrunken fiber network that in addition to the structural factors also depends on the fiber and bonding properties.

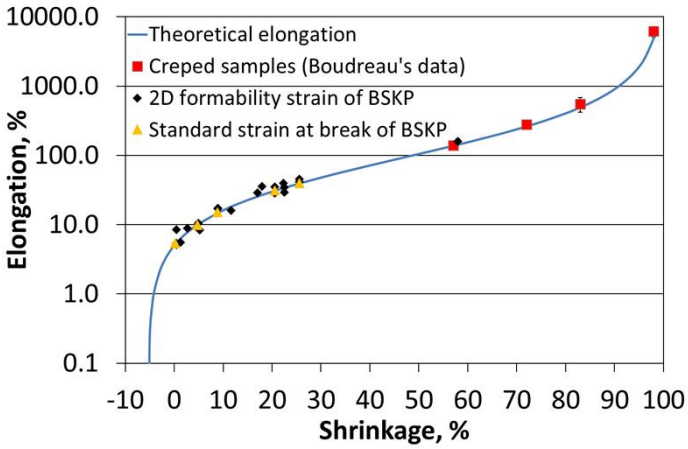

Figure 3. *Theoretical elongation and elongation of laboratory samples as a function of shrinkage, logarithmic scale for elongation. Bleached softwood kraft pulp (BSKP) data from this study. Boudreau's data re-plotted.*

The reason for the unfamiliarity of this theoretical relationship until now has been the low elongations (less than 10%) of investigated paper samples and the lack of results with very high elongation (above 30%), in combination with often missing information concerning sheet shrinkage.

Conclusions

- Elongation of paper sheets depend only on the elongation of completely restrained dried sheet and on prior shrinkage, but not on the method that generated the shrinkage.
- The proposed equation (*Eq 1)* reveals that the more a paper sheet shrinks, the more advantage of elongation can be obtained in straining, because the reference point in calculating the percentage elongation is different from the original pre-shrinkage length.
- Another new concept, 'net elongation' (paper elongation minus paper shrinkage) enables the examination of the interrelationship between the effects of refining, drying shrinkage, restrained drying and elongation of paper.

Literature

Kouko J, Retulainen E (2018), "The relationship between shrinkage and elongation of bleached softwood kraft pulp sheets," Nord Pulp Pap Res J 33(3):522-533.

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