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A COMPARISON BETWEEN INDUSTRIAL AND LABORATORY BEATING WITH REGARD TO FIBRE DEVELOPMENT

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Summary

The effect of industrial beating on tensile strength properties has been compared with laboratory beating and the differences observed have been explained in terms of fibre properties.

Tensile strength development is less pronounced for industrial beating than for laboratory PFI- mill beating. Beating in the laboratory Escher-Wyss conical refiner was found to develop strength to an level intermediate between those of the other two.

The fibre characteristic causing these differences was found to be the ability of the fibres to transmit load in the sheet. Fibre deformations introduced during pulping and bleaching are to a large degree removed by PFI-mill beating. Industrial beating shows very little effect in this respect. Tensile strength development could be explained wholly by changes in fibre swelling (water retention value) and in the ability of the fibres to transmit load. The latter property was evaluated by zero-span measurements on rewetted sheets.

Introduction

It is common experience that the strength development during industrial beating is not on a level with what can be achieved with laboratory beaten pulps. This is especially noticeable in the maximum tensile strength that can be developed during beating. This effect has not been satisfactorally explained in the literature.

The effect of beating on pulp quality has been studied extensively as beating has always been an important part of papermaking. Many different actions on the fibres has been defined(1). In general it is agreed that an increase in fibre swelling and thus improved fibre flexibility are the key factors for improving bonding and the strength properties of the paper. Other factors mentioned in connection with the beating action are fines production, fibrillation and fibre shortening. In recent years it has also been pointed out that during laboratory beating fibres are straightened due to the removal of kinks and crimps, so that the ability of the fibres to transmit load is improved (2). Page attributes most of the tensile strength development obtained during beating to this effect.

A lot of work relating beating theory to industrial beating is quite contradictory. On some occasions the specific edge load theory can be applied satisfactorily, but there are also occasions when it is found that this is not enough. It is the author's belief that before beating theories can be improved, a better understanding of what happens to the fibres during beating is needed. In the present investigation, industrial and laboratory

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beating are compared from the point of view of changes in fibre character. Here data are reported for a dried bleached softwood kraft market pulp. Similar results has been obtained for never-dried pulps and for hardwood pulps. Studies of more pulps over a wider range of beating conditions are presently under way.

Experimental

Beating was performed on a laboratory scale using standard conditions in a PFI-mill. Industrial beating was done in one pass through the Beloit double disc refiner incorporated in the experimental machine at STFI, the FEX-machine. In order to achieve a constant specific edge load at the different energy levels, production through the refiner was varied. Beating was also done in the Escher-Wyss Kleinrefiner which is known to give more industrial-like beating conditions but can still be used on a laboratory scale. An increase in energy input in this refiner is obtained by increasing the beating time. Two levels of specific edge load were used in the Escher-Wyss refiner, 0.5 and 3.0 Ws/m. In the Beloit refiner, the specific edge load was 2.0 Ws/m. The pulp used was a commercial sheet-dried bleached kraft pulp.

The beaten pulps were evaluated using SCAN-standard laboratory sheet-making procedures and the sheets were tested for tensile strength and related properties. The influence of beating on fibre swelling and fines generation was evaluated by measuring SR and WRV. Fibre length was measured using the Kajaani FS 200 and fibre shape was evaluated by curl measurements using an image analyser. The ability of fibres to transmit load can be detected using zero-span measurements as has been pointed out by Perez et al(3). Zero-span-testing was performed in a Pulmac zero-span-tester and the numbers used were those obtained at "zero" span-length. The measurements were made both on dried sheets and on sheets dried and rewetted. It was found that the value obtained for the dried sheet was influenced by the bonding level of the sheet and that it was better to use the value obtained for the rewetted sheet as an indicator of the fibres ability to transmit load.

Result and Discussion.

In the following, the influence of beating on pulp properties is discussed. The different types of beating are compared using SR as the basis of comparison. This is done primarily because SR is a much used parameter for evaluating beating and not because of any scientific preference for this parameter.

Paper properties

The tensile strength development is different in the three types of refiners. The PFI-mill gives the highest strength level and the industrial refiner the lowest. The Escher-Wyss refined pulps fall between the other two, Fig 1. For the pulp used, no effect of specific edge load was observed when beating in the Escher-Wyss refiner. The sensitivity to specific edge load in the Escher-Wyss refiner is a pulp characteristic and can be very different from pulp to pulp (4)

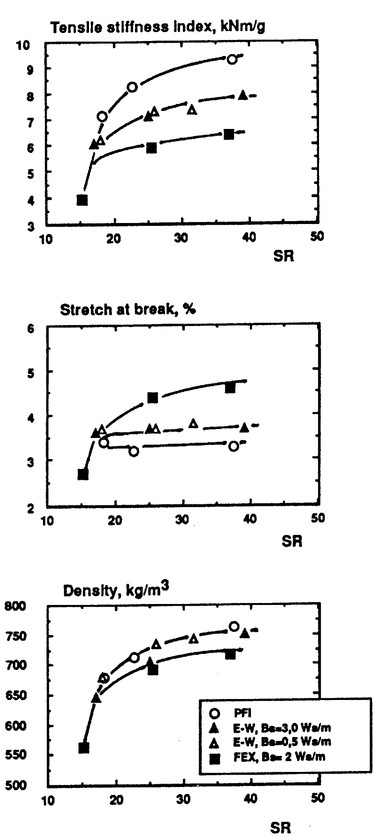

Fig 1. Influence of different types of beating on handsheet properties.

The same type of development is observed for tensile stiffness index as for tensile index. Different levels of stretch to break are also obtained depending on the type of beating applied but in this case in the reversed order to that observed for tensile stiffness index and tensile index. The variation in tensile strength and in stretch to break compensate for each other in the development of tensile energy absorption index. In this property no effect of type of refiner can be detected.

Density at a given SR does not differ greatly for the different types of beating so density differences cannot explain the differences observed for tensile index etc. There is however a tendency for beating at higher specific edge loads to give a lower density at a given SR level.

Fibre swelling and fines generation

SR and water-retention-value, WRV, are influenced by both fibre swelling and fines generation. It is not possible to differentiate between these two effects in this study. About the same WRV-values are obtained at a given SR-value for the different ways of beating Fig 2.

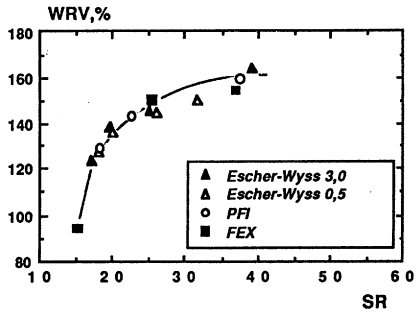

Fig 2. Water retention value increases in a similar manner for all four beating series.

The large differences in tensile strength levels between the different types of beating can thus not be explained by differences in fibre swelling.

Fibre shortening

Fibre shortening is known to be influenced by the specific edge load during beating, the higher the specific edge load the more fibre shortening can be expected. Similar observations are presented here, Fig 3. Fibre shortening takes place primarily when beating in the Escher-Wyss refiner at a high specific edge load. In the Beloit-refiner (FEX) only small changes in fibre length can be detected. The specific edge load in the Beloit refiner was 2 Ws/m compared to 3 Ws/m for the Escher-Wyss. For the PFI-mill beating and the low specific edge load beating in the Escher-Wyss an increase in fibre length is in fact observed initially. This is attributed to a fibre straightening effect.

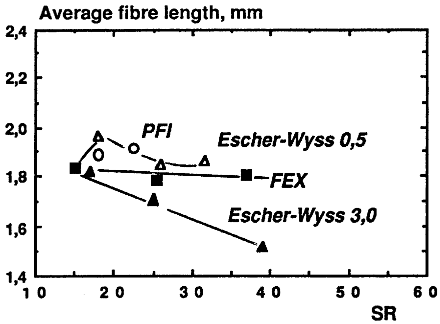

Fig 3. A reduction in fibre length during beating is observed mainly in the case of the Escher-Wyss refiner at a high specific edge load. The initial increase observed for the PFI-beating and for the Escher-Wyss at low specific edge load is probably due to straightening of the fibres.

The fibre shortening cannot however explain the tensile strength development shown in fig 1.

Fibre deformation

It has been shown that when they leave the pulp mill, fibres are curled and kinked and contain crimps and microcompressions (5). Scanning electron micrographs illustrates this very clearly for the pulp used in this study, Fig 4. The micrographs also show that after PFI-mill beating the fibers has been straightened. To some degree this is also the case for the pulps refined in the Escher-Wyss refiner at low specific edge load. For the pulp treated in the Beloit refiner no such effect can be observed.

The observations from the micrographs are confirmed both by the curl measurement and by the zero-span measurements. Zero-span data show a development similar to that of the tensile stiffness index and the tensile index, Fig 5. The PFI-mill beating improves the fibre load transmitting ability quite considerably, in accordance with the suggestions made by Page. Very little effect is however obtained when the beating is done in the industrial refiner. Beating in the Escher-Wyss gives results somewhere in between, the low specific edge load being a little better than the high specific edge load.

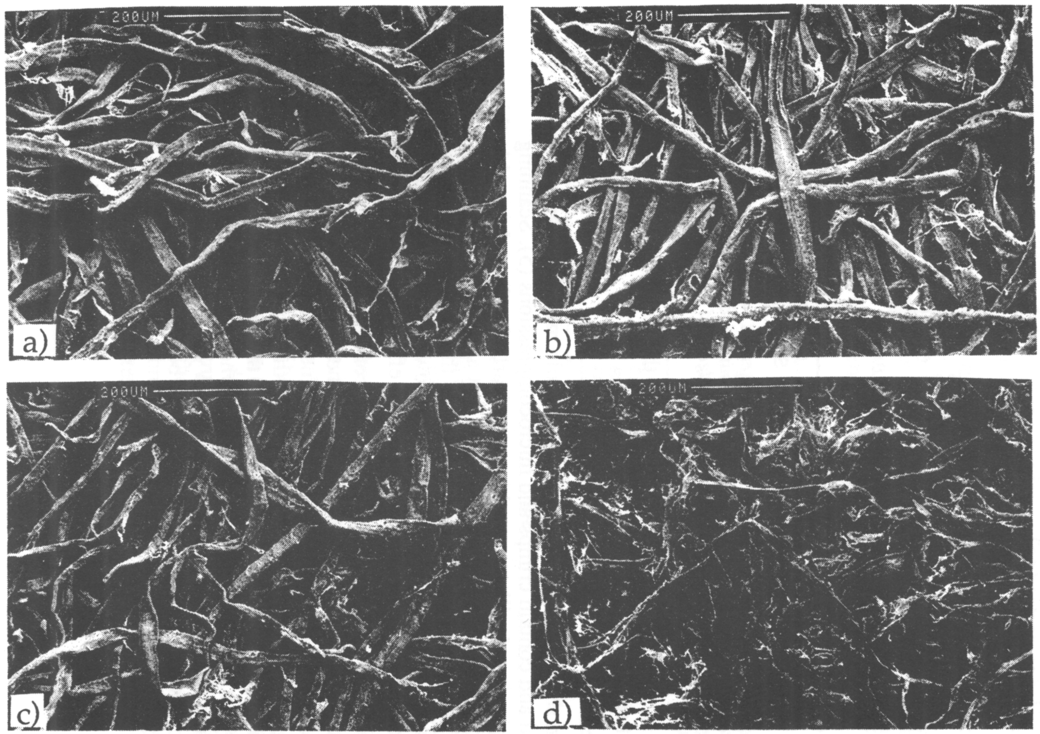

Fig 4. Scanning electron micrographs of a) unbeaten pulp, b) after beating in the PFI-mill, c) after beating in the Escher-Wyss refiner at low specific edge load, d) after beating in the industrial refiner, Beloit refiner in the FEX system. Curl and kinks present in the unbeaten pulp are to a large extent removed by beating in the PFI-mill, to some extent after the Escher-Wyss refiner but are still present after beating in the industrial refiner.

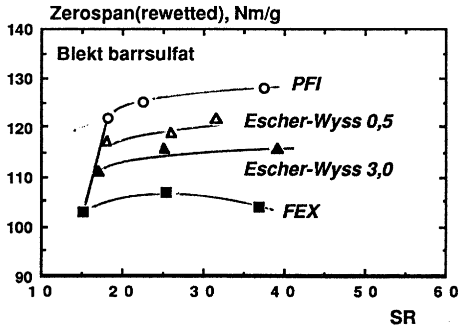

Fig 5. Zero-span tensile strength measured on rewetted sheets increases considerably for PFI-mill beating but hardly changes at all for beating in the industrial refiner (FEX). Beating in the Escher-Wyss improves the zero-span tensile strength to a lesser degree than PFI-mill beating.

Curl measurements confirm these results. There is a good correlation between zero-span-values and fibre curl, Fig 6. The correlation is however not general but varies from pulp to pulp.

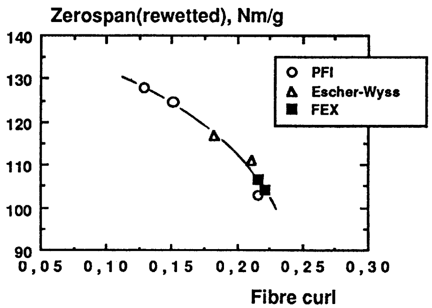

Fig 6. There is a direct correlation between zero-span measured on the rewetted sheets and the degree of fibre curl.

These results thus suggest that the strength development during beating of commercially produced pulps can to a considerable extent be explained by the change in fibre shape and fibre load transmitting capabilities. They also indicate that the ability of the refiner to develop the load transmitting capability of the pulp fibres may be the primary reason for the differences observed between laboratory and industrial beating.

Fibre swelling and fibre load transmitting capability determines tensile strength.

If figures 1, 2 and 5 are compared it can be concluded that both the increase in fibre bonding ability(or fibre swelling) as detected by WRV-measurements and the increase in fibre load bearing capability influence the tensile strength development. Multiple linear regression analysis confirms these results, Table 1. The tensile index and tensile stiffness index development can be explained wholly by WRV and zero-span changes. The coefficient of determination (R^2) is 0.98 and 0.94 respectively. The fibre length does not contribute to the tensile strength development according to the statistical analysis but may contribute somewhat to tensile energy absorption index and stretch at break. In table 1, for the multiple regression analyses only coefficient of determination is given for the best combination of variables.

Table 1. Coefficient of determination (R^2).

	Simple linear regression			Multiple linear regression		
Variable	WRV	Zero-span	Fibre length	WRV+ Zero-span	WRV + Fibre length	WRV+ Zero-span+ Fibre length
Tensile index	0.77	0.60	0.04	0.98		
Tensile stiffness index	0.59	0.73	0.03	0.94		
TEA index	0.94	0.17	0.07		0.97	
Stretch at break	0.35	0.10	0.03	(0.74)		0.90
Density	0.90	0.38	0.08	0.97		

Conclusions

The effect of the load transmitting capability of the fibres on the tensile strength properties of the paper sheet has been shown to be large in accordance with what was pointed out by Page at the Eight Fundamental Research Symposium, 1985 (6). It has also been shown that the load transmitting capability of the fibres can to a large extent be improved by laboratory beating but that only limited improvements can be expected as a result of industrial beating. Further studies will show whether industrial refiners vary in their ability to improve fibre properties in this respect.

An implication of these results is that in an industrial situation, the extent to which the load transmitting capability of the fibres has been retained in the pulp mill may be very important. It has earlier been shown that the fibres are deformed both in pulping (7,8) and in bleaching (5).

Another consequence is that beating results will be influenced by the quality of the ingoing pulp. These quality differences cannot be detected by a standard laboratory beating procedure as the fibre straightening effect obtained under laboratory conditions bring all pulps to the same level independent of the original degree of fibre deformation.

Literature

1. Ebeling K., "A critical review of current theories for the refining of chemical pulps", Symposium on Fundamental Concepts of Refining, Appleton 1980.
2. Page D.H., "Mechanism of strength development of dried pulps by beating", Svensk Papperstidn., 88(3).R30,1985.
3. Perez M., Kallmes O.J., "The role of fiber curl in paper properties", Tappi 48(10), 601, 1965.
4. Levlin J-E., "The response of different fibre raw materials to refining" Preprints Vol II, New Technologies in Refining, Birmingham, England, 1986.
5. De Grace J.H., Page D.H., "The extensional behaviour of commercial softwood bleached kraft pulps" Tappi 59(7), 98, 1976.
6. Page D.H., Seth R.S., Jordan B.D., Barbe M.C., "Curl, crimps, kínks and microcompressions in pulp fibres - Their origin, measurement and significance" Transactions of Eight Fund. Res: Symp. 1985, Mechanical Engineering Publications Ltd., London.
7. MacLeod J.M., Cyr M., Embley D., Savage P., "Where strength is lost in kraft pulping of softwoods" J Pulp Paper Science 13(3), J87, 1987.
8. Sotobayashi H., Suzuki E., Iwase H., Naito T., "Effect of mechanidal treatment at the end of cooking stage on the physical properties of sulfate pulp" Paper presented at Wood and Pulping Chemistry Conf, Tsukuba, Japan, 1983.

Transcription of Discussion

A COMPARISON BETWEEN INDUSTRIAL AND LABORATORY BEATING

Ulla-Britt Mohlin (Prepared Contribution)

Prof.T. Lindstrom, MODO

You talk about high consistency refining, and all of us here today agree that this curls fibres, whereas low consistency refining has a de-curling action. As Derek Page says, the fibres are subjected to tensile stresses during refining, offering an explanation for this type of behaviour. Now we present data from a PFI mill, which is more like a high consistency equipment, and here I have greater difficulty in envisaging tensile stresses in this situation. Then you claim that in the industrial refiner, where I would expect the de-curling effect, you don't have it. What is your explanation for this?

U.B. Mohlin

I think that the straightening effect gained from the PFI mill results in a very even treatment of the fibre, i.e. a very uniform swelling effect, which will increase the mobility within the fibre wall and that you will from this swelling effect be able to get a straightening effect, and also remove kinks and micro-compressions. I do not think that you will need tensile stress on the fibre to take these kinks away. You get this from inside the fibre by swelling. I have not been able to prove it, but that is my current model of it. However, with the low consistency refiner, we do not get the straightening effect. We have done the refining by one pass through the refiner. Therefore, the time the fibre spends in the refiner is so short that you would not be able to see any straightening effects. You get more straightening in the Escher-Wyss refiner, which is set up for multi pass.

Prof. T. Lindstrom

I would like to have a comment from D. Page on the subject of the de-curling effect in the PFI mill.

D.H. Page

There is no reason why fibres should not be undergoing considerable tensile load as they are fed into the nip.This is confirmed by the work of McKenzie who took photographs of flocs being broken essentially in tensile in the PFI mill. The second point may be more related to the fact that when you put fibres through a commercial refiner, many of them are untreated. So, if you produce a certain water retention value, you will have a lot of highly beaten fibres and some which are unbeaten and therefore not decurled. Everything fits beautifully.

K. Ebeling, James River Corporation

In the industrial refiner, fibres go through mainly as flocs, and many of them receive little if any treatment. This is why you do not see any straightening out of the curved structure. The PFI mill is a combing device, especially if you lay down the fibres evenly.

P. Luner, ESPRI

Have you made any attempt to see how much fines are produced under the different beating conditions, and whether you tried to determine the WRV without the fines.

U.B. Mohlin

We have carried out studies following those described here, where we looked at the water retention value on the fibre fraction, and you produce more fines in the commercial refiner than in the PFI mill. In that study, my correlations improved if I used the water retention value of the decrilled pulp instead of the whole pulp.

R.C. Williams, James River Corporation

These very high strength results from the PFI mill have been seen for many years, but I wonder if anyone has tried to characterise the fundamental differences between the PFI and commercially available refiners in terms of hydraulics and bar to bar mechanics. Has this been done? Are there any large PFI mills available?

U.B. Mohlin

One point I would like to make is that you cannot just go in and look at the results you get in different types of refiners without considering the type of pulp you use. Therefore, even if you can explain the way that different refiners act on the fibre in the sense of the hydraulic behaviour you must look at the fibre you put in, i.e. whether it is a straight or curly fibre. This will give you different results with different refiners.