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Effects of Dry Strength Resin and Surfactant Addition on the Paper Made from Pulps with Different Freeness Level

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Abstract: This study was aimed to compare the positive effects of a Dry Strength Resin (DSR) addition to the negative effects of a surfactant (debonder) addition on the paper properties which were made from pulps with different freeness levels. Unbleached intercontinental pulps beaten to different degrees were used to make a variety of handsheets. Pulps used were analysed by Kajaani FS-200 to reveal the detailed properties of stock such as fine, fibre length and coarseness. Handsheets were tested for some key physical properties and also analysed under a scanning electron microscopy. It was found that DSR addition increased the retention and produced a denser sheet whereas debonder addition gave very fluffy sheets with lower retention. When completely opposite effects of DSR and the debonder were compared, DSR was found to be more effective on its job especially on the beaten pulps. Tensile index values of surfactant added paper were found to be reduced to some extent with the parallel reduction of fine retention which was assumed that fines do help paper strength in this experiment. No significant effects on the zero span tensile indexes were observed by any of the chemicals addition.

Key words: Beating, dry strength, surfactants, coarseness, contact area

INTRODUCTION

A small piece of paper is mainly composed of thousands of cellulose fibers which are primarily attached together by hydrogen bonds. Apart from cellulose fibers, depending on the product type, paper also contains a number of different additives such as fillers, pigments and chemicals in different proportions and at different loading levels. The most important factors which actually govern the paper strength are known to be the strength of constituting individual fibers and the strength of interfiber bondings.

Beating of wood fibres is a common practise in papermaking process in order to produce a stronger sheet. It creates a wider surface area on cellulose fibers which directly leads to the increased number of hydroxyl groups on fibers. Beating also creates fines depending on pulps being used and operation parameters such as beater performance and conditions. The increased demand for the chemical loading would be perhaps given here as the first and the common problem associated with the fines in papermaking. There are a number of works carried out on the relationships of beating and paper strength in the literature which discussed and showed detailed conclusions about the links between the beating and paper strength (Ölander *et al*., 2005; Stationwala *et al*., 1996; Laivins and Scallan, 1996; Nazhad *et al*., 2003; Xu and Pelton, 2005; I'Anson *et al*., 2006).

Dry strength additives (DSA) are mainly polymeric long chains molecules which helps fibres tight together strongly by in a sense creating bridges between them or wrapping them up together. It is intended to increase the relative bonded strength actually rather than that of area. But in the case of beaten pulps, for DSA, there is a risk of being adsorbed inside the fibres, meaning inside the lumen through pores and/or cavities and cracks on the fibre walls. Increased surface area on stock (by means of refining, filler addition or/and higher fines content present) were reported to increase the demand of internal sizing loading to meet the required sizing qualities of paper (Karademir *et al*., 2005). Furthermore fines may take a considerable amount of chemicals on them which results in a higher demand on the loading level. It may also effect the paper formation badly if some flocks are formed bigger than acceptable level specified for that particular paper being produced. There are some other factors too which need to be carefully monitored and set to perform a successful chemical addition. Dry strength additives do not only function as strength promoters but also help increase the retention (Jenkins, 1995).

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Surfactants are molecules having dual affinity. Therefore they have a tendency to accumulate at the interfaces between polar or non-polar phases. Surfactants are widely used to disperse emulsion particles, stabilize foams. But they can be a serious problem if they actually stabilize undesirable foams, create problems in sizing operations and reduce especially fines retention. Furthermore and probably most importantly in our case here, surfactants interfere with the dry strength of paper and that is why these classes of chemicals are also in many places called as debonders. Surfactants act like in a sense separators between adjacent fibres thus weaken the interfiber bondings hence papers dry strength.

This study was designed to reveal how pulp freeness is affecting the performance of both DSR and surfactant used. Special attention was given to the fibre coarseness as well as the fine content of pulps used since there is some discussion in the literature about the effects of fines on specially paper strength properties.

MATERIALS AND METHODS

Unbleached intercontinental pulp was used in this study. Pulps with different freeness levels were prepared by beating in a PFI mill using the standard method described by ISO 5264-2. Kajaani FS-200 was employed for analysing the pulp properties such as coarseness, fines, fibre length and so on. A set of handsheets at 70 g m^{-2} were prepared at a British standard handsheet former which was followed by wet pressing the sheets at 350 kPa for 5 min, allowing air drying for one day and conditioning at least two days prior to testing. Some results from pulps analysed and handsheets tested were presented in Table 1.

Hercobond (Hercules, UK) was used as a Dry Strength Resin (DSR) and added to handsheets as 0, 0.01, 0.05, 0.1, 0.5 and 1% on oven dry fibre. Lenor, commercial washing up liquid containing surfactant, was used as debonders. Actual surfactant on oven dry fibre was calculated and added at the same level of DSR addition.

Handsheets prepared with DSR and surfactant additions were kept in a conditioned room at least two days prior to testing. Handsheets were tested according to ISO standards to reveal their air permeability, light scattering, opacity, tensile index and zero span index properties.

RESULT AND DISCUSSION

Effects of beating on pulp properties: Changes occurred on pulp properties as a result of beating are presented in Table 1 along with the resultant paper's properties. Compared to first beating, second beating had a greater effect which caused dramatic changes on pulp properties especially on the number of fibres, fines content and coarseness. Increase in the number of fibres and fine content directly indicates the fibre splitting along the length, some cuttings and fibrillation as well as some outer layer tears generating fines which all are attributed to the mechanical modification of cellulose fibres. Coarseness value of pulp is a most commonly used pulp parameter which represents the general state of any pulp and combines many properties all together. Lower coarseness value indicates that the pulp actually consists of many finer, thinner and flexible cellulose fibres which are relatively easy to form a well compact sheet compared to coarser pulps (Page, 1969; Clarke *et al.,* 1985; I'Anson *et al.,* 2006). Findings here are well in line with the literature reported elsewhere.

Effects of beating on paper properties: The most significant changes were observed to have occurred on both the air permeability and the tensile index values of sheets as seen both in Table 1 and Fig. 1. While the

Table 1: Some properties of pulps used and handsheets tested

Parameters	Unbeaten (°SR:14)	Beating 1 (°SR:40)	Beating 2 (°SR:60)
Arithmetic average (mm)	1.11	1.09	0.98
Length weighted average (mm)	2.52	2.50	2.37
Weight weighted average (mm)	3.07	3.08	3.05
Number of fibres	21789	22441	31634
Fines (%)	2.65	2.80	3.17
Coarseness (mg m^{-1})	0.412	0.408	0.322
Apparent density (g cm^{-3})	0.50	0.62	0.71
Air permeability (mL min^{-1})	5114	211	11
Light scattering coefficient (m^2 kg^{-1})	32	22	14
Opacity (%)	98	97	92
Tensile index (N mg^{-1})	13	64	89
Zero span index (N mg^{-1})	186	190	209

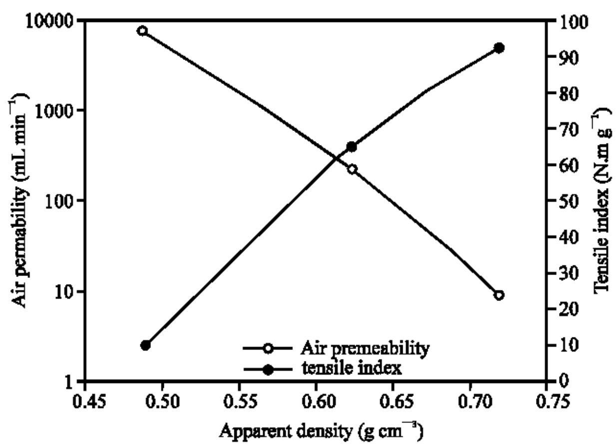

Fig. 1: Correlations between the apparent density and both tensile index and air permeability of sheets as a result of beating

apparent density increased, the air permeability showed a rapid decrease whereas the tensile index gained a very good improvement. This basically shows that the beating actually transformed the long round cellulose fibers into some collapsed, flexible, flat strips with some fibrillated surfaces. It is quite reasonable to understand that fibers like those mentioned above would easily develop a larger bonding area and bonding strength and a very compact, firm sheet where air passages would be at a minimum level. Increase in light scattering shows the improvement on sheet surface properties, meaning that smoother surface was obtained.

A Scanning Electron Microscopy (SEM) was employed to see the surface morphologies of sheets made from pulps with different freeness levels. While Fig. 2 indicates a sheet with rougher surface consisting of relatively loosely attached fibers, Fig. 3 and 4 implies a sheet with flattened fibers. Not many fines were, however, visible on the images.

Effects of dry strength resin and surfactant addition: Five sets of handsheets were made from each pulp with DSR addition and surfactant addition separately. Density of sheets tested showed some improvements with DSR addition whereas some decrease was noticed with surfactant addition as shown in Fig. 5. Extent of changes observed were in the same order of beating, the more beaten pulp was used the more changes were noticed.

DSR addition, as expected, probably increased the fine retention especially on beaten stock and help creating a denser sheet as this is supported by the results where changes on beaten stocks are more dominant. Surfactant addition seems to have no contribution to sheets density. In fact, some decreases in sheets density were observed, indicating that it did not promote the retention at all. Some decrease on tensile index as a result of surfactant addition would be assumed to be supporting some previous works regarding the effects on fines on paper strength (Retulainen *et al*., 1993; Hawes and Doshi, 1994). Surfactant reduced the fine retention and this was reflected as some decrease on paper strength. In addition, it is believed that surfactant repelled the charged surfaces apart and makes sheets little fluffy. The soft and fluffy feeling on surfactant added sheets were actually tested personally by touching and handling the paper surfaces.

Significant increase on the tensile strength by DSR addition is shown in Fig. 6. In general, the positive effects of DSR are more prominent on the beaten pulps which were attributed to the increased contact area and contact strength between fibers. As discussed on paper density, DSR certainly increasing the fine retention. Fines were reported to be improving the paper strength by some

Fig. 2: SEM image of sheet made from the pulp having (14 °SR)

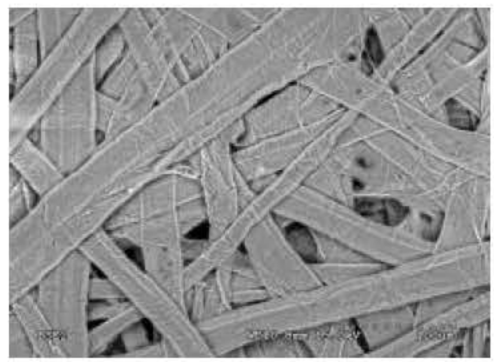

Fig. 3: SEM image of sheet made from a beaten pulp (40°SR)

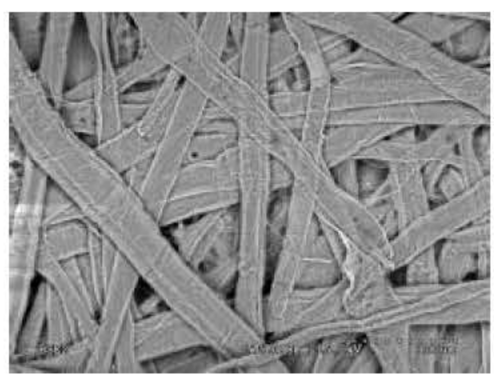

Fig. 4: SEM image of sheet made from a heavily beaten pulp (60 °SR).

researchers (Retulainen, *et al*., 1993; Hawes and Doshi, 1994; Retulainen *et al*., 2002). Furthermore Xu and Pelton (2005) recently reported that fines would help the strength of even filler loaded paper as acting a bridging role

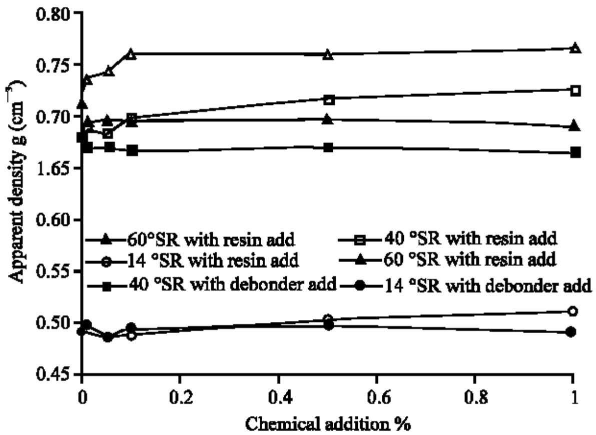

Fig. 5: The effects of chemicals addition on the density of papers

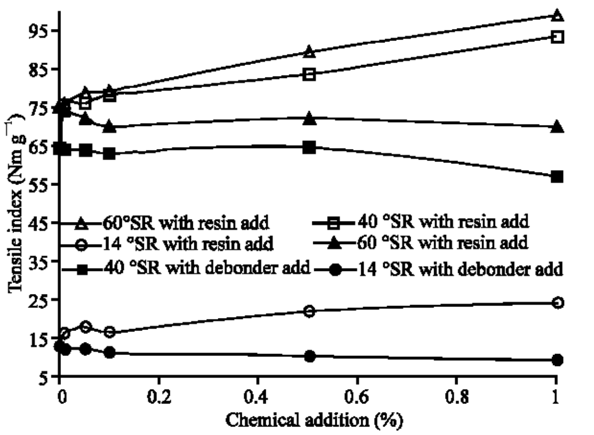

Fig. 6: The effects of chemical addition on the tensile index of papers

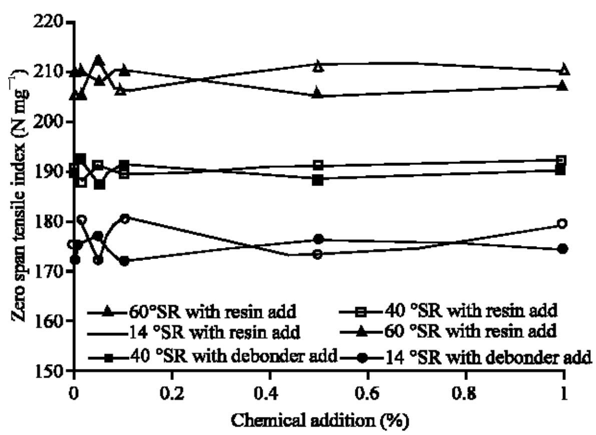

Fig. 7: The effects of chemical addition on the zero span tensile index of papers

between filler-induced voids present in the fibre/fibre binding domain. In addition to that, DSR is believed to have played an adhesive role between adjacent fibrillated fibers hence bound them strongly. It is believed that the fibre coarseness was more effective here on the increase of tensile index then the fines generated as a result of beating. A stronger interfiber bonding seems to be developed between finer and fibrillated fibers with the DSR. Although fines reported as a strength promoting materials, it was thought that fines in our experiments would have hindered the DSR. It is from the fact that they have a bigger surface area and capacity to adsorb any added chemicals to the stock hence reduce the chemical performance. In the case of unbeaten pulp, simple due to the coarser fibers, the contact area as well as interfiber bond strength is believed to be developed on a smaller extent compared to that of beaten pulps. Lower fine content on the other hand would be perhaps regarded a positive factor for unbeaten pulp to give a stronger sheet. However the increase on tensile index could not be achieved such a significant level. This indicates that DSR addition somehow compensated the negative effect of fines and the fibre coarseness were the key factor in the development of tensile index value of tested papers.

No significant improvements on tensile index of papers were obtained by the surfactant addition. In fact negligible decrease was observed.

Zero span tensile indexes were remarkably increased as a result of beating as seen in Fig. 7. However no significant increases as a result of both chemicals additions were obtained. It suggests that changes in tensile indexes (Fig. 6) were only attributed to the changes on interfiber bond strength and area. Chemicals additions seem to cause no positive or negative effects on individual fibers strength properties.

CONCLUSIONS

This study was carried out to find out the opposite effects of dry strength resin and surfactant addition on the some properties of paper. Beating was found to be reducing fibre coarseness and creating some fines. Although fines were reported by some workers as strength promoter, it is believed to be more obvious if no chemicals added to paper. Due to the bigger surface area of fines, they were believed to be counteracted with the DSR by probably absorbing them. DSR increased the retention, giving denser paper with lower air permeability. Whereas surfactant reduced the retention producing a sheet with higher air passages. In the absent of fines in surfactant added paper, some decrease on paper tensile index were seen which would imply that fines really help paper strength to some extent. But overall fines are believed to interfere with the chemicals as adsorbing them and reducing their performances. Both chemicals used here had no effects on zero span tensile index that is to say that increase or decrease on the paper strength here with chemicals addition was strongly connected to the interfiber bonding strength.

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