Influence of felt structure on water removal in a press nip

Torbjørn Helle and Trond Forseth

ABSTRACT: Pressing experiments were performed on a pilot paper machine using nine different felts. All felts were constructed from the same base but differed in terms of batt basis weight and surface smoothness. Sheets were pressed at low speeds (5–40 m/min) in a single nip to solids contents of 28–38%. The effect of machine speed on sheet formation was isolated by using sheets cut from never-dried, never-pressed webs (35 g/m², 20% solids) produced on a pilot paper machine prior to the pressing trials. At constant felt basis weight, fine batt-surface fibers produced a higher-solids sheet. At constant batt surface texture, thicker felts produced a higher-solids sheet. The effect of felt structure on dewatering was diminished for thicker paper webs. Foil replicas of the compressed felts illustrate the nonuniformity of various felt structures at mid nip.

KEYWORDS: Batt on base felts, dimensions, felts, fiber dimensions, fineness, machinery, nip, paper machines, papermaking equipment, press felts, presses, pressing, separation, thickness, water removal, woven fabric.

Knowledge about the fundamentals of wet pressing has advanced significantly in recent years, leading to rapid progress in press design and innovative developments such as wide-nip pressing. MacGregor's excellent and comprehensive survey of the extensive literature on wet pressing summarizes the current understanding of the various mechanisms of pressing *(1)*.

Despite the advances in press design, there is a discrepancy between the solids contents achieved in commercial practice and the solids achieved in the laboratory at the same nip pressures. Uneven load transfer from the press felt to the wet web in the nip is an important contributor to poor pressing efficiency. Asymmetrical load transfer is a consequence of the inevitable nonuniformities in press felt structure. Such nonuniformities are caused by variations in the felt base, in the distribution of the batt material, and even in the batt fibers themselves. The problem has recently been analyzed in a study by McDonald and Pikulik *(2)*.

The objective of the present study was to develop quantitative relationships between the nonuniformities of the felt structure and the water-removal efficiency in a press nip. The experimental design involved the use of nine felts with controlled differences in the basis weight and the surface smoothness of the batt layer. The pressing experiments were carried out on a pilot paper machine using sheets cut from unpressed, never-dried webs that had been produced under constant conditions and reeled prior to the pressing trials.

It is reasonable to ask whether studies carried out on small, slow paper machines can provide valid information for pressing processes at higher speed. From the literature *(1, 3)*, it appears that the basic pressing mechanisms are the same in low- and high-speed operation. The same sources indicate that differences in pressing at high and low speeds can be well accounted for by the inevitable differences in pressing time (nip residence time, time for web rewetting, etc.). We therefore concluded that tests carried out on a

Helle, professor of paper technology, and Forseth, graduate student, are affiliated with the Department of Chemical Engineering at the University of Trondheim, The Norwegian Institute of Technology, N-7034 Trondheim, Norway.

low-speed machine could provide valid insights into performance on high-speed commercial paper machines. However, the results should be evaluated bearing in mind the low speeds at which these tests were conducted.

The experimental study

Objectives

The experiments were designed to measure the effect of felt macrononuniformities on water removal. A series of related felts with controlled differences were provided for use in this study. Felt characteristics are explained later in this report.

To ensure similarity to commercial practice, the experiments were performed on a pilot paper machine using unpressed, never-dried paper webs made on the machine in separate runs. Paper was made from the same stock of bleached softwood kraft pulp at two different refining levels.

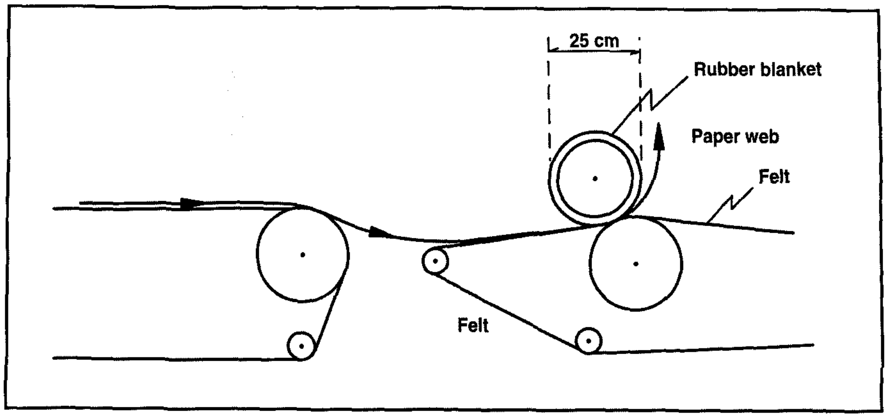
The effect of paper-machine speed on pressing was examined by running unpressed sheets through the nip at three different machine speeds.

Paper machine and press

The pilot paper machine has a fourdrinier forming section with a wire width of 60 cm. The machine is equipped with a suction couch and two solid-roll presses, the second one reversed, and a dryer section with steam-heated drying cylinders. The operating speed range is 5–60 m/min, which of course is far below modern commercial practice.

Only the first press was used during the study, and the web was passed through the nip only once. **Figure 1** is a sketch of the pilot press used in the study. The solid-roll press is equipped with a hard top roll of diameter 25 cm. A linear press load of 15 kN/m was applied across the felt width (45 cm) during the trials. Because the paper samples (40-cm width) did not cover the whole width of the felt, the actual load on the paper samples was slightly more than 15 kN/m.

1. First press on pilot paper machine. Web was supported through the nip by elastic rubber blanket.



Most trials were run at machine speeds of 5 m/min, 10 m/min, and 40 m/min. The press impulses were approximately 200 kPa·s at 5 m/min, 100 kPa·s at 10 m/min, and 25 kPa·s at 40 m/min. During the trials, the solid top roll was covered with an elastic rubber blanket, as seen in Fig. 1. The blanket was used to level out the pressure-load variation exerted by the felt onto the paper, thus raising the overall solids level of the web after pressing. The special effects of the rubber blanket on pressing efficiency are discussed elsewhere *(4)*. Tests proved that the rubber blanket did not bias the factors analyzed in this study.

Press felts

A major felt supplier manufactured a special series of felts for the trial. All felts shared a common base with a basis weight of 350 g/m^2. The felts differed with respect to (a) the amount of batt put onto the base and (b) the fineness of the fibers in the top batt layer. **Figure 2** depicts the basic structures of the applied felts, and **Fig. 3** provides details about the fibers used in the felts.

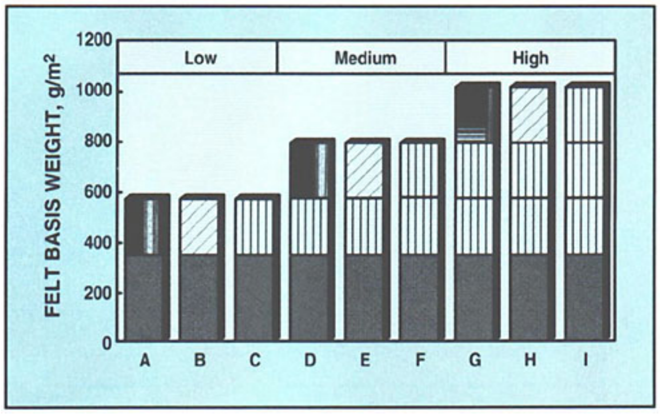
As seen in Fig. 2, the felts had 1–3 batt layers, each with a basis weight of 220 g/m^2. Thus the batt-layer basis weights were 220 g/m^2, 440 g/m^2, or 660 g/m^2. The outermost batt layer was manufactured from one of three different grades of fibers: superfine (23-μm diam.), medium (35-μm diam.), or coarse (55-μm diam.), as seen in Fig. 3. These fiber dimensions cover the range of dimensions commonly used for batt material.

Felts of equal basis weight had different fibers in the surface batt layer, as seen in Fig. 2. This represents a change in felt design and thus implies a change in such design-dependent variables as void fraction and felt compressibility. These characteristics were not analyzed in this study.

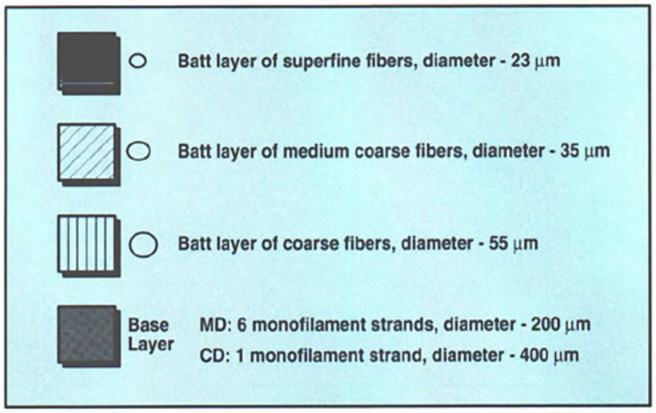
Figure 4 shows the batt-fiber cross-sectional dimensions in perspective relative to the dimensions of the paper web. The curve depicts the thickness of a 35-g/m^2 wet web at varying solids content, assuming no air in the web, a reasonable assumption for the nip situation. Comparing the sizes of the batt fibers and the thickness of the wet web, a nonuniform transfer of the press load from the felt to the sheet appears to be a reasonable assumption.

All felts were 100% synthetic. The manufacturer conditioned the felts using standard procedures in an effort to eliminate or reduce break-in effects. Because the felts were new, the possibility of break-in changes during operation cannot be dis-

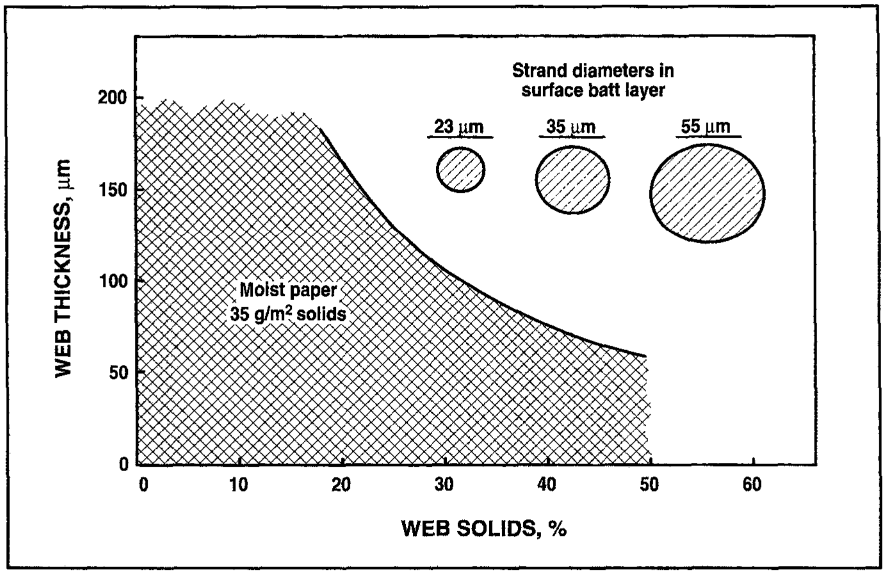
2. Structure of the nine felts (A–I) used in this study. Base was identical for all fabrics. Batts varied in terms of basis weight (220 g/m², 440 g/m², 660 g/m²) and surface smoothness (fine, medium, coarse).



3. Base-layer and batt-layer compositions of Felts A–I in Fig. 2



4. Web thickness at mid nip over a range of solids contents for a 35-g/m² sheet. Fiber cross sections are drawn to scale of web thickness.



I. Characteristics of machine-made papers used in press trials

Level of refining	Stock freeness, °SR	Basis weight, g/m²	Solids content, %
Lightly beaten	14.5	35	19.2
Well beaten	32	36	19.5

counted. However, the study showed no changes in pressing effects.

For easy and continuous operation on the paper machine, the felts included in the study were made into two endless structures by splicing the pieces (length 80 cm) end-to-end, using a thin nylon fabric overlapping each felt piece end. The spliced felt structure was then operated on the machine in the ordinary way.

The first step in each trial series was to moisture-condition the felts. We did this by soaking the felts and then running them in the paper machine for 30 min at a load of 15 kN/m at a speed of 20 m/min. Felts were sprayed with an appropriate amount of water during operation. Separate control runs proved this to maintain a constant moisture content of the felt and pressed paper samples during the run. This finding is in accordance with the findings of Busker and Cronin *(3)*, who concluded that "ingoing felt moisture is very limited in controlling outgoing sheet moisture."

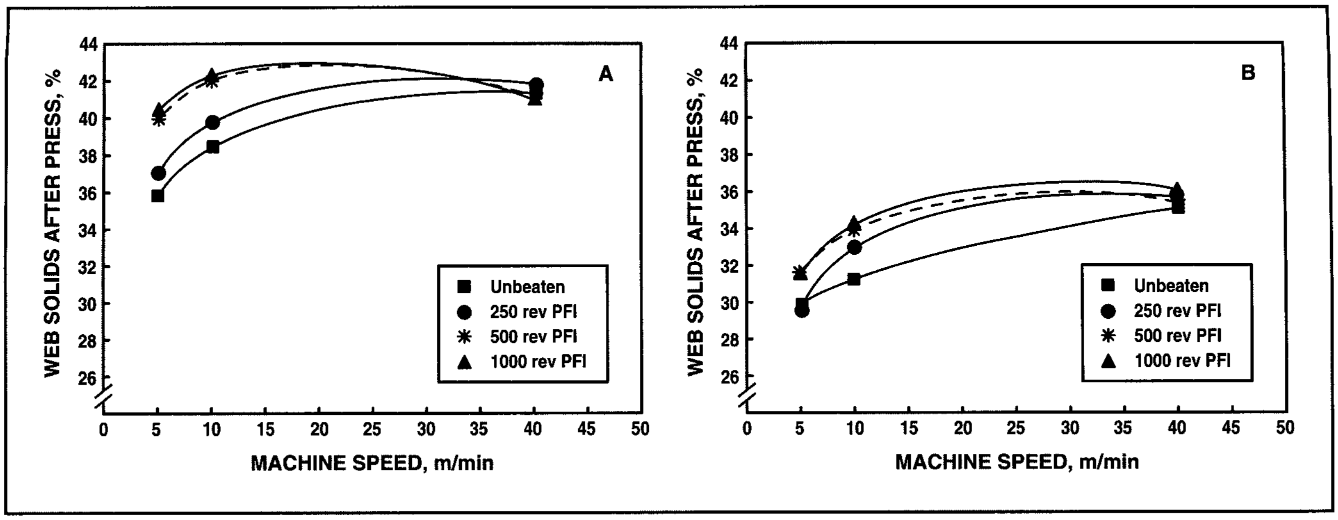
Paper

The first trial was carried out using handsheets. All other trials used unpressed, never-dried webs produced on the pilot paper machine prior to the pressing trials.

Most similar studies on the process of pressing have used either dried machine-made paper samples that subsequently were rewetted before the actual trial, or they have used never-dried handsheets. Both methods have drawbacks. Rewetted paper contains less bound water than never-dried virgin paper, while handsheet structure is different from that of machine-made papers.

The structure of machine-made paper is affected by the speed at which it is produced, so a variation in

5. Web solids after pressing as a function of machine speed for: **A**, heavyweight handsheets (75 g/m²); **B**, lightweight handsheets (37 g/m²). Solids content before pressing was about 20% for all handsheets.



machine speed will lead to variation in paper structure. We isolated the effect of machine speed on pressing by using paper produced separately at constant conditions.

The never-dried, machine-made paper used in the press trials was made in the following way: Commercial, dry-lap, bleached Scandinavian softwood kraft pulp was pulped in a Grubben pulper for 5 h and refined in a Claflin wide-angle conical refiner to one of two freeness levels (14.5°SR or 32°SR). The paper was formed on the paper machine into a web of 40-cm width at 20 m/min. After leaving the couch roll, the wet web was reeled directly and wound onto a core resting on the first press felt, ahead of the first press. The reels were packed in plastic bags and stored in a refrigerated room until the press trials.

This method provided an abundance of never-dried wet paper for the trials. The paper, produced at two levels of freeness, was uniform in structure, solids content, and basis weight, as seen in **Table I**. Control tests during the study proved the paper to be very uniform throughout the reels and to remain so during the trial period.

In the press trials, paper samples of roughly 25 cm x 25 cm were cut from the center of the web taken from the reeled wet paper and laid carefully, avoiding wrinkles, onto the felt ahead of the press. The samples always adhered to the top roll, from which they were removed immediately after passing the press nip. The samples were put into air-tight boxes, weighed, dried, and weighed again to determine solids content.

Three parallel samples were tested at each experimental point. Very good reproducibility was experienced. Only averages are reported here. The sequence of felts tested in a series was randomized.

All the experimental results show the web solids after one passage of the press nip. The effects of passing the web through the nip several times are reported elsewhere *(4)*.

Pressing results

Effect of pressing on handsheets

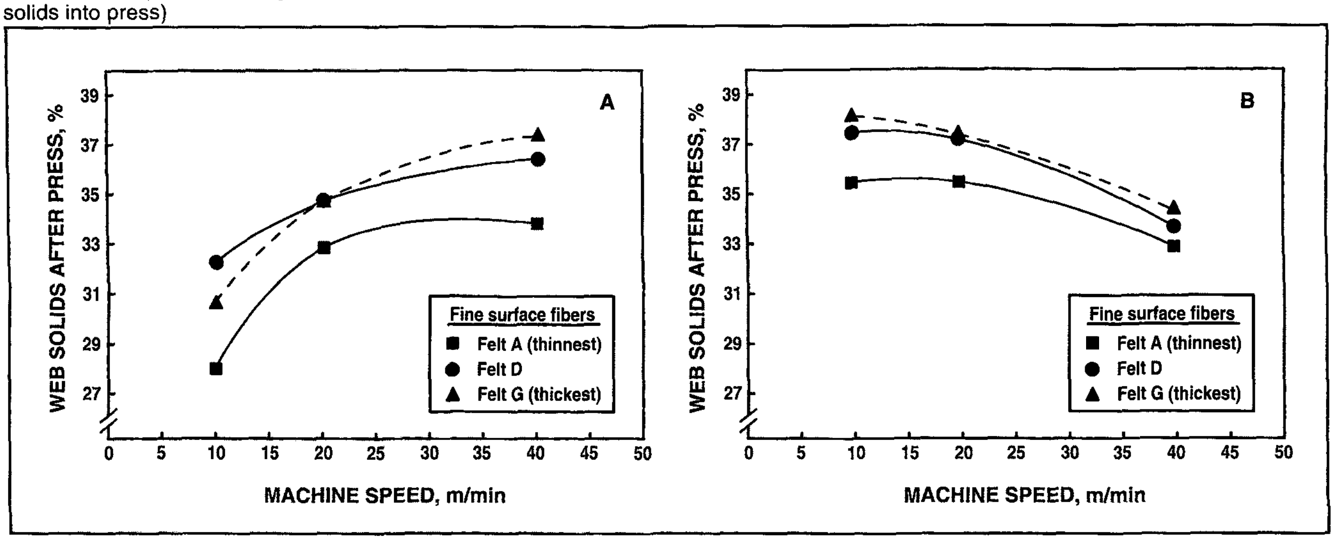
An initial trial was run using handsheets produced from lightly beaten pulp. The purpose of this trial was to establish the general shape of a pressing sequence for different papers at different machine speeds. The results are shown in **Fig. 5** for heavyweight (Fig. 5A) and lightweight (Fig. 5B) handsheets.

Handsheets were made from the same softwood kraft pulp as used in the main study. Handsheets were produced from unbeaten pulp and from pulp lightly beaten in a PFI laboratory beater at 250 rev, 500 rev, and 1000 rev. Sheets of 75 g/m² and 37 g/m² and solids content of about 20% were made and passed through the press at different speeds. In this case, the normally operated felt of the press (Groovetex Needled 6200-29x1 from Nordiskafilt) was applied, and not the test felts described in Figs. 2 and 3. The felt was premoistened using the previously described procedure for the test felts. This technique assured uniform moisture content of the felt and parallel samples throughout the run, as confirmed by controls.

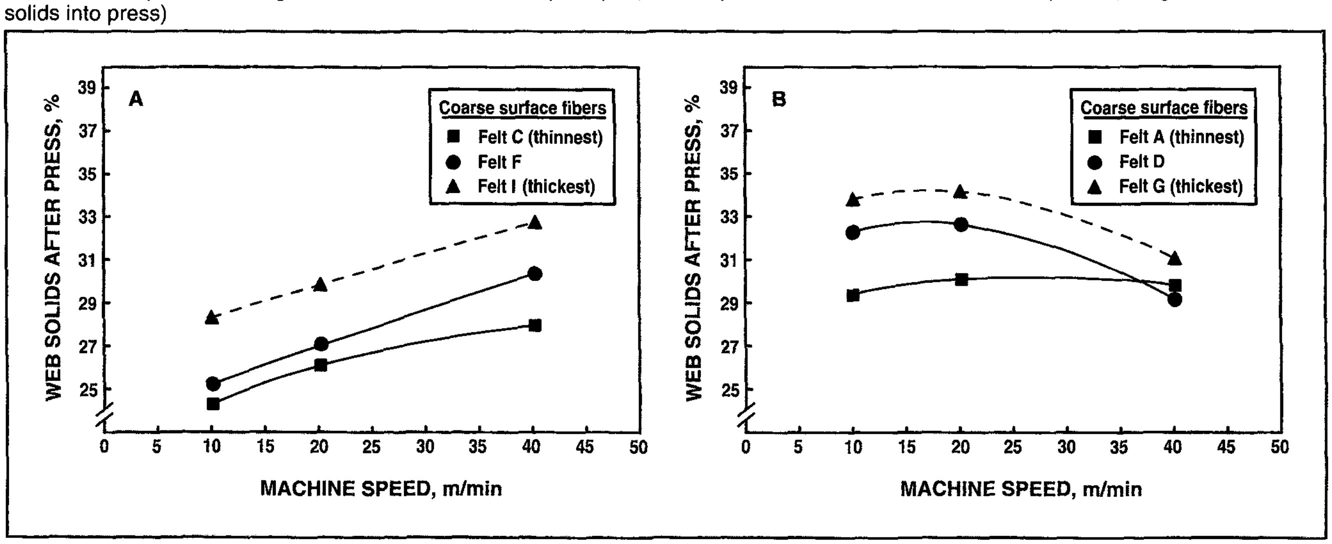
Figure 5A shows that the shapes of the curves for the heavier-weight handsheets (75 g/m²) differ significantly. The curves for the unbeaten and 250-rev stocks rise continuously, while the curves for the 500-rev and 1000-rev sheets rise, pass through a maximum, and then drop. The shapes are well explained by the following assumptions.

- The sheets produced from free stocks (0 and 250 rev PFI) contain fairly stiff fibers. The low web

6. Effect of batt thickness (superfine surface fibers) on pressed-web solids as a function of machine speed for: **A**, sheets produced from high-freeness kraft (14.5°SR, 36 g/m^2, 19.2% web solids into press); **B**, sheets produced from low-freeness kraft (32°SR, 35 g/m^2, 19.5% web solids into press)



7. Effect of batt thickness (coarse surface fibers) on pressed-web solids as a function of machine speed for: **A**, sheets produced from high-freeness kraft (14.5°SR, 36 g/m^2, 19.2% web solids into press); **B**, sheets produced from low-freeness kraft (32°SR, 35 g/m^2, 19.5% web solids into press)



solids at low machine speed can be explained by sheet rewetting as it exits the nip.

- The sheets produced from the more highly beaten stocks (500 rev and 1000 rev PFI) contain flexible fibers. The inability to achieve maximum dryness at the higher speed is an indication of flow-limited pressing, with the network of intertwined fibers resisting the flow of water from the sheet.

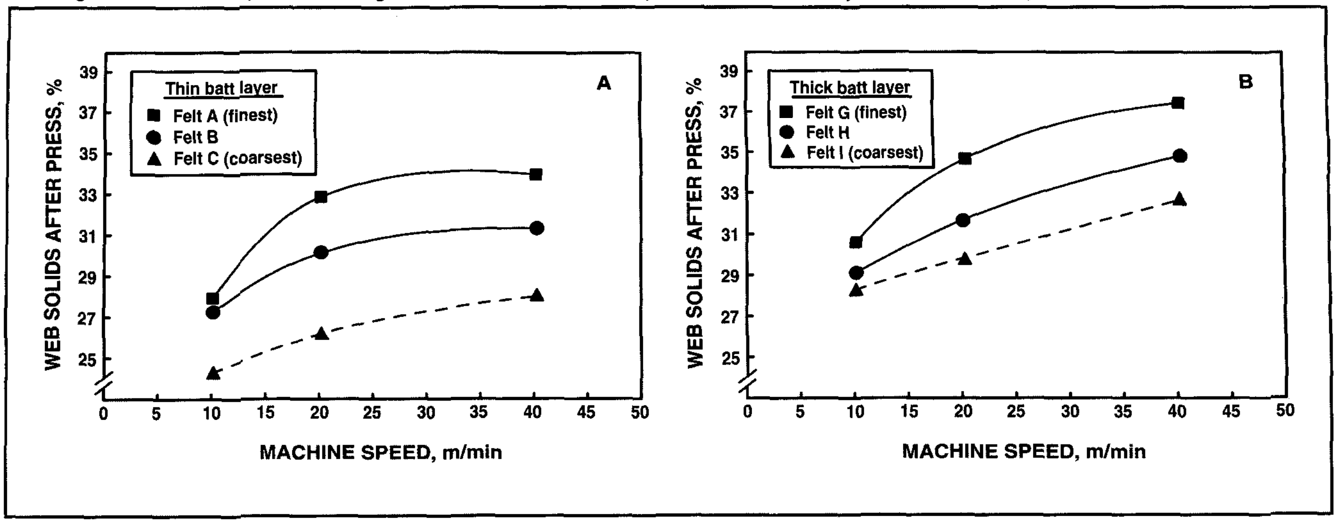
The curves for the lower-weight sheets (37 g/m^2) in Fig. 5B are all rising, indicating that none of the papers have reached the point where pressing is flow-limited.

Effect of batt-layer basis weight

Figure 6 depicts the effects of batt-layer basis weight on water-removal efficiency for paper made from free stock (Fig. 6A) and from well-beaten stock (Fig. 6B). The three felts have the same outer batt layer of superfine fibers, with Felt A the thinnest felt (220-g/m^2 batt layer) and Felt G the thickest felt (660-g/m^2 batt layer). Felt G provides a gain of 3–4% solids for the free stock (Fig. 6A) and 2–3% for the well-beaten stock (Fig. 6B) compared with Felt A.

The drop in solids content at increasing machine speed for the well-beaten stock (Fig. 6B) indicates that the pressing process is flow-limited. For the free stock (Fig. 6A), the low web solids level at low speeds indicates significant rewetting. For these sheets, the pressing process appears to be pressure-limited over the whole speed range under study.

8. Effect of batt surface smoothness (constant batt basis weight) on pressed-web solids as a function of machine speed for sheets produced from high-freeness kraft (14.5°SR, 36 g/m², 19.2% web solids into press). **A**, thin batt layer; **B**, thick batt layer.



9. Effect of batt surface smoothness (constant batt basis weight) on pressed-web solids as a function of machine speed for sheets produced from low-freeness kraft (32°SR, 35 g/m², 19.5% web solids into press). **A**, thin batt layer; **B**, thick batt layer.

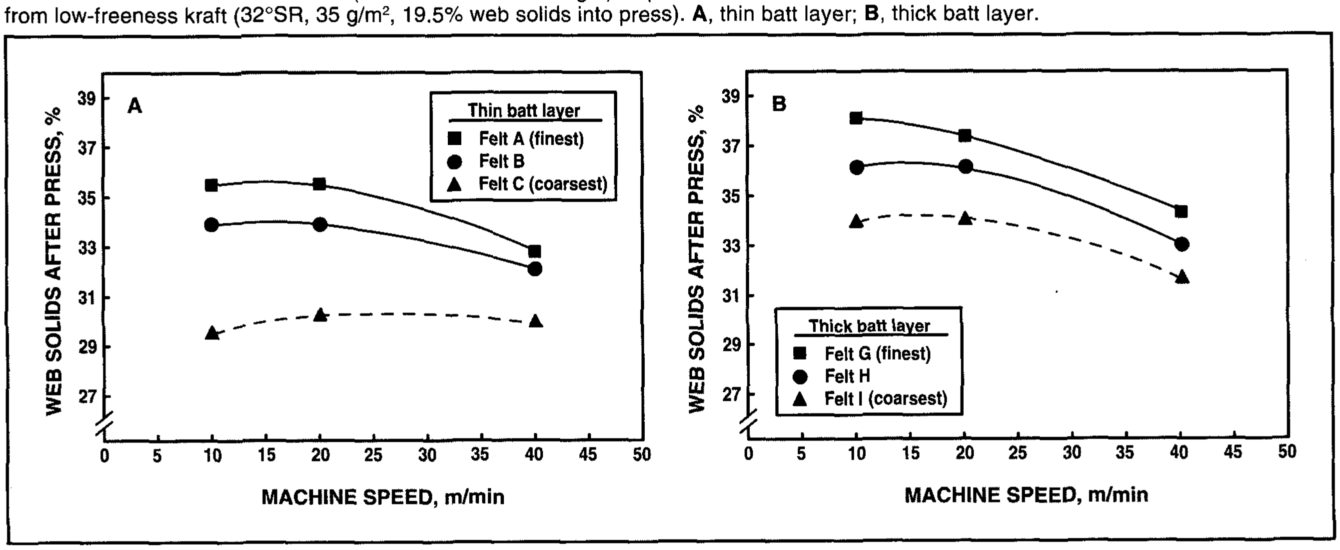


Figure 7 provides a similar comparison of felts with varying batt-layer basis weights. In this case, however, the surface of the batt layer was made of coarse fibers, with Felt C the thinnest felt (220-g/m² batt layer) and Felt I the thickest felt (660-g/m²).

Comparison of Figs. 6 and 7 shows that the web solids achieved by the superfine-top-layer felts (Fig. 6) significantly exceed the web solids obtained with the coarse-fibered felts (Fig. 7). This difference is just what would be expected, based on the previous discussion about the importance of uniform transfer of load from the press roll through the felt to the sheet.

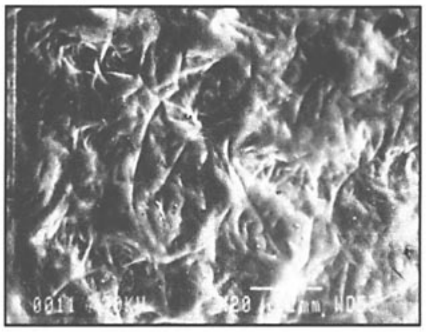
The general shapes of the curves in Fig. 7 resemble those in Fig. 6. However, the effect of batt-layer thickness—the spread in solids content after pressing—is generally somewhat larger for the felts with the coarse-batt-fiber surface.

Effect of fiber coarseness in batt surface layer

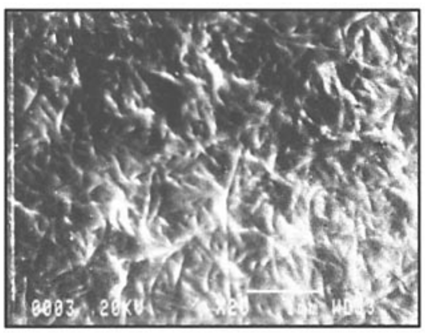
Figure 8 compares the solids contents of paper produced from high-freeness stock after pressing against felts having the same batt-layer basis weights but with varying fiber coarseness in the outer batt layer. Felts A, B, and C have thin batt layers (Fig. 8A), while Felts G, H, and I have thick batt layers (Fig. 8B). Differences in post-press solids content of up to 6% were observed, with the fine-fibered batts providing the highest solids. The largest differences occurred with thin felts, as might be expected.

Figure 9 depicts a similar series of paper solids levels after pressing with the same set of felts. In this

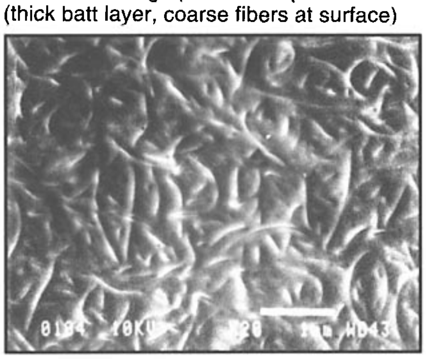
10. SEM micrograph of felt replica of Felt A (thin batt layer, superfine fibers at surface). Bar represents 1 mm. Replica was made by pressing rubber-backed felt against a ductile, very thin tin foil



11. SEM micrograph of felt replica of Felt G (thick batt layer, superfine fibers at surface)



12. SEM micrograph of felt replica of Felt I (thick batt layer, coarse fibers at surface)



case, however, the paper was produced from well-beaten stock. As in Fig. 8, there were differences of up to 6% in post-press solids content, again with fine-fibered batts providing the highest solids.

The generally parallel run of the curves in Figs. 8 and 9 indicates that the felts do not appreciably affect the question as to whether or not the pressing process is pressure-limited (Fig. 8) or flow-limited (Fig. 9). This question is primarily determined by factors such as stock freeness, the amount of water to be removed, basis weight, press geometry, and machine speed.

Replicas of press felts

The dewatering press load is transferred to paper from a compressed felt in a press nip. Therefore, the surface uniformity of the felt in its compressed state is of special interest.

We obtained a visual impression of the compressed felt surface structure as it appears in the nip by making felt impressions on thin tin foils. This was done by placing the foil on the rubber press roll and then passing the foil through the press nip. The foil replicas were examined by scanning-electron microscopy (SEM).

Figure 10 shows the micrograph of the replica for Felt A, the fabric with a thin batt layer and superfine fibers. The coarse pattern of the base weave is clearly evident, proving that the batt-layer thickness is insufficient to cover the knuckles and interstrand voids of the base weave. (Because all the experimental felts (A–I) of this study shared the same base weave, the effect of the base felt cannot be identified in the experimental findings.) **Figure 11** depicts the replica of Felt G, the felt with a thick batt layer and superfine fibers in the surface. The surface of this felt appears much more uniform than that of Felt A in Fig. 10, demonstrating that the thick batt layer provides a more uniform (although incomplete) coverage of the base weave. Finally, **Fig. 12** presents the replica of Felt I, the fabric with a thick batt layer and coarse surface fibers. Comparison with Fig. 11 illustrates the effect of differences in surface smooth- ness.

Discussion and comments

The pressing study was performed at speeds far below those applied in modern commercial practice. Previous studies *(3)* have shown that results achieved at low speeds fit well with results from higher-speed trials (taking into consideration differences in press-nip dwell time, etc.). Nevertheless, the validity of the findings for high-speed operations is uncertain.

The trial results presented in this report demonstrate the nonuniformities of felt structure and some effects on water-removal efficiency. The batt-layer basis weight, felt structure, as well as the batt fiber fineness all affected water-removal efficiency.

The effects of other press-felt nonuniformities were not analyzed. For example, we made no attempt to quantify the effect of the base structure on the compressed fiber uniformity, although this effect can be seen qualitatively in Figs. 10–12 and is reflected by the effect of batt-layer thickness. Another factor not looked into is the nonuniformities of the batt distribution, for instance caused by the needling stitches. It can easily be shown *(5)* that the needling process causes uneven distribution in the number and orientation direction of the surface batt fibers.

Our results show that for a given set of conditions, a thicker batt layer provides a higher web solids content off the press. However, this should not lead to the conclusion that the batt layer should be thick to raise press efficiency. Among the variables applied here, batt-layer thickness is the main factor affecting the surface smoothness of the compressed felt in the nip. The key point for efficient water removal in the press nip is probably to transfer a uniform press load to the paper. Felt manufacturers are well aware of this, as evidenced by the development of "laminated" felts, which are constructed by combining several fabrics. These felts combine low caliper with smooth surfaces.

Our results also demonstrate the strong effect of batt-fiber coarseness on water-removal efficiency, with finer fibers providing superior water removal. Again, the effect on felt smoothness is the critical factor. The qualitative effect of the batt-fiber coarseness is well recognized and is reflected in the tendency to have finer-surface batt fibers in the third press nip.

Going to even finer batt fibers than applied in this study appears to be an attractive option. However, this presents practical limitations, since finer batt fibers entail increased wear loss, increased batt compaction, and thus reduced permeability. It is a challenging situation, where the answer may lie in radically new materials and approaches.

The quantitative effects of the felt structure on post-press paper solids observed here may be larger than in most industrial operations. For one thing, the paper used in the trials had low basis weight. For paper webs of higher basis weights, the web itself acts as a pressure-load-levelling material *(4)*. In the present study, only one nip passage was used. It might be suspected that repeated passages through press nips, similar to conditions on a paper machine, would tend to reduce the effects of the felt nonuniformity occurring at each press nip. However, studies involving multiple nip passages have concluded that this is actually not the case *(4)*. The poor water-removal efficiency caused by the nonuniformity of felt surfaces remains even after several nip passages. TJ

Literature cited

1. MacGregor, M. A., *BPBIF Transactions of the 9th Fundamental Research Symposium*, Vol. 2, Mechanical Engineering Publications, London, 1989, p. 511.
2. McDonald, J. D. and Pikulik, I. I., *TAPPI 1992 Engineering Conference Proceedings*, TAPPI PRESS, Atlanta, p. 869.
3. Busker, L. H. and Cronin, D. C., *CPPA 1982 International Water Removal Symposium Proceedings*, Tech. Sect. CPPA, Montreal, p. 25.
4. Helle, T., *TAPPI 1993 Engineering Conference Proceedings*, TAPPI PRESS, Atlanta, p. 757.
5. Helle, T., unpublished results.

Nordiskafilt (Halmstad, Sweden) is gratefully acknowledged for supplying the applied felts. The financial support of the Royal Norwegian Council for Scientific and Industrial Research is greatly appreciated.

Received for review Jan. 27, 1993.

Accepted Sept. 13, 1993.

Presented at the TAPPI 1993 Papermakers Conference.