

High-intensity pressing and sheet-finish problems

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The industrywide push for higher production rates for all paper and board grades requires faster machine speeds and more-intense wet pressing. There are now well over 100 high-intensity press nips (shoe presses and highly loaded hard-nip and long-nip roll presses) operating worldwide. As most operators will attest, high-intensity pressing is associated with a higher incidence of sheet-finish problems. These problems take various forms such as large-scale buckles and cockles, felt and roll cover marks, and small striations that give the sheet surface the appearance of wrinkled skin.

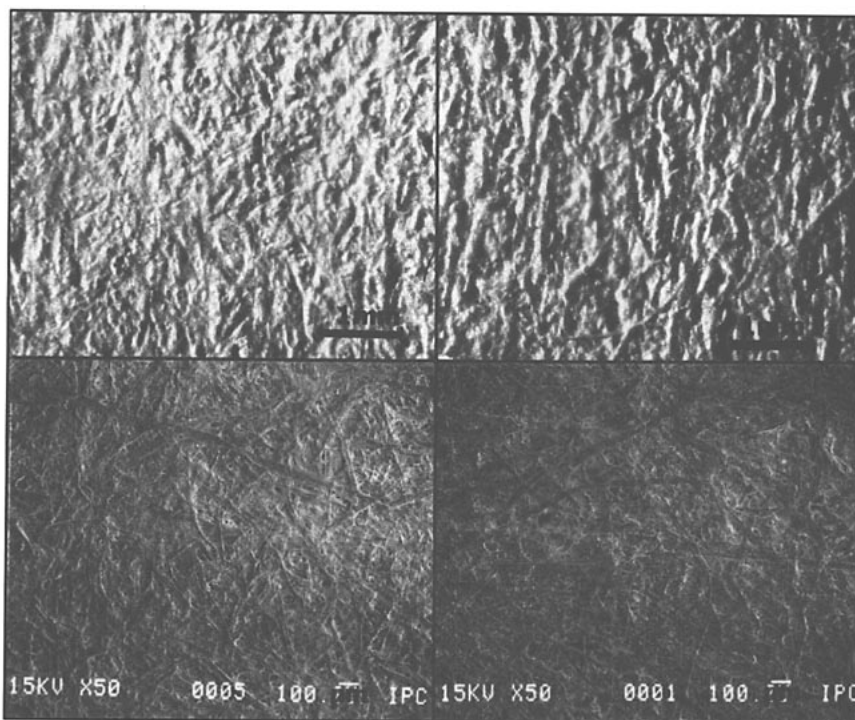
Efforts to maintain acceptable sheet finish generally are focused on the press section, especially the press-felt design. Despite progress, sheet finish continues to be a matter of concern, especially with high-intensity presses becoming more common.

This informal technical note outlines some of our exploratory work on the subject of sheet finish as it relates to wet pressing. The work is presented in the hope that it will stimulate further discussion while offering a few suggestions for attacking the problem.

The sheet-finish problem

Figure 1 shows one of many situations where we encountered finish

1. Effect of pressing intensity on surface finish for a wood-free coating raw-stock paper. Upper photos [sheets under grazing illumination in the cross-machine direction (CD)] demonstrate difference in roughness. Lower photos (scanning electron microscope) show that the rougher paper has a denser surface. Pulp and paper machine conditions were the same for both papers, except that the sample on the right was wet pressed at greater intensity (smaller, harder, more highly loaded presses).



problems with high-intensity pressing. The furnish, basis weight, and machine speed were virtually identical for these side-by-side paper machines. The main difference was that the paper on the right was wet pressed at greater intensity (higher loads and smaller rolls with harder covers).

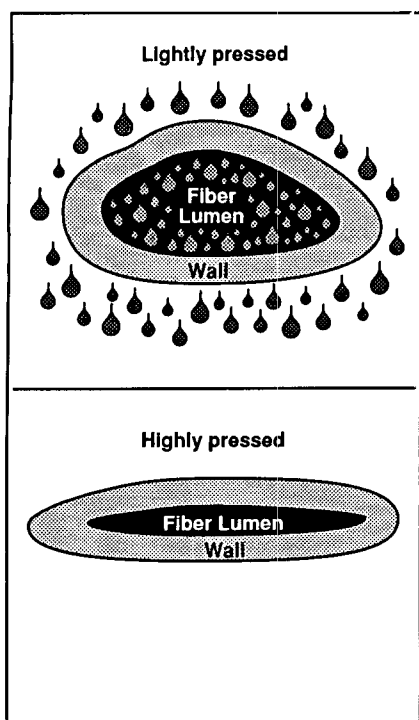
Figure 2 shows the surface finish on a linerboard that was pressed using a shoe press. These two samples, both from the same machine, represent the "best" and "worst" from a visual ranking standard that we developed. The sample on the left is what the

manufacturer would prefer to produce all the time and all across the machine. However, the sample on the right is typical of what is often produced, even though the operating conditions for both samples are supposedly the same.

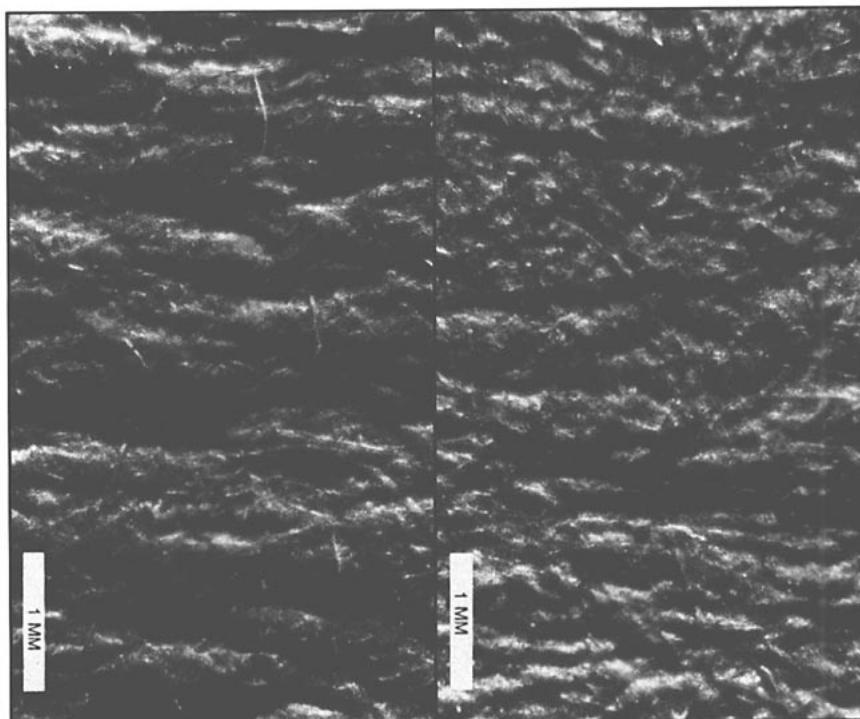
Notice the wide range of disturbance sizes, from buckles of several millimeters (photo at upper right), down to tiny fissures of several hundred micrometers (magnified view in photo at lower right). These disturbances have a strong machine-direction (MD) orientation. We have

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3. Two fiber states after pressing. Less-densified fiber at the top will shrink a different amount than the highly densified fiber at the bottom.



2. Linerboard surfaces (sheets under grazing illumination in the CD) after being wet pressed in a shoe press. Sample on left is "best" from our visual ranking standard; sample on right is "worst." Both samples were produced on the same machine. Lower photos show that disturbances extend down to the level of tiny microstriations.



found that almost all paper and board exhibit this directionality to some extent.

We are using both image analysis and stylus-based methods to objectively measure the severity of these surface disturbances on commercially manufactured paper and board. Preliminary indications are that furnish conditions, pressing intensity, and felt life seem to play an important role. We have also observed that paper with strong small-scale variations tends also to have strong large-scale variations. Our next objective is to collect enough data to correlate these finish measurements with various operating parameters in the pulp mill and the paper mill. We hope to determine which parameters have the greatest impact on sheet finish.

Mechanisms producing out-of-plane sheet surfaces

Some of us believe that the fundamental driving force behind the out-of-plane surfaces shown in Figs. 1 and 2 arises from shrinkage gradients in the paper. These gradients are present to some extent in all machine-

made papers, not just the two examples shown here. Therefore, our observations may be of interest to people making other grades of paper, especially printing grades.

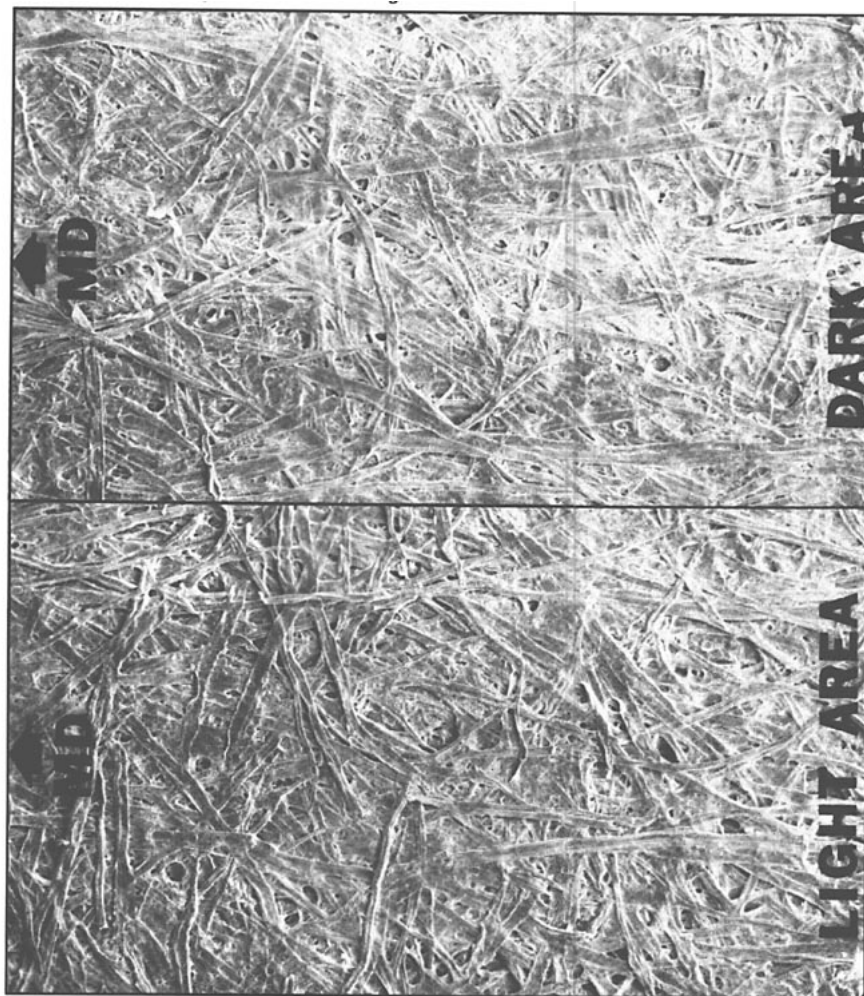
Shrinkage in the cross-machine direction (CD) can lead to "microcreping" in machine-made paper, a topic discussed long ago by Steenberg (1). However, only recently was the shrinkage difference *between paper planes* mentioned as the fundamental cause of "microstriations" (2). We suspect that microstriations are often unknowingly categorized as graininess, but to us they are unique because the interaction in the sheet thickness direction (*z* direction or ZD) is an essential ingredient in the phenomenon. The theories proposed in the following paragraphs are based on fundamental principles and certain experimental evidence, but further research is needed to provide a thorough understanding of the phenomenon.

Evaporative drying and paper shrinkage should be thought of as a three-dimensional process that occurs over a wide range of sizes down to individual fibers. Web shrinkage in

the MD can be controlled by the draw settings on the paper machine. However, there is limited opportunity for controlling CD shrinkage on conventional paper machines. The third and generally overlooked dimension is the significant shrinkage, or densification, that occurs in the web thickness or ZD during evaporative drying. We have measured in excess of 25% ZD shrinkage for various commercial papers. This shrinkage, like CD shrinkage, is due to the widthwise fiber contraction and surface-tension forces that are present in the sheet during evaporative drying. However, the papermaker has absolutely no control over the ZD shrinkage during the conventional drying process.

The shrinkage behavior of a paper depends on the initial state of its constituent fibers. A network consisting of fibers like the one on the right in Fig. 3 has lower shrinkage potential (3). The fiber on the right is more densified, with much less water in the cell walls, the lumens, and its surroundings than the fiber on the left. The densified fiber tends to dry first and shrink less, especially when in contact with a hot dryer surface. The

4. Linerboard with hydraulic marking from the grooved backing roll of a shoe press. The dark lines in the linerboard correspond to the groove spacing (marked with the pinholes in the upper photo). When viewed more closely (lower photos), the dark lines in the linerboard can be seen to correspond to denser surfaces, where the ratio of absorbed to reflected light is higher. Even though density variations are confined mainly to surface layers, the sheet is still pulled out of plane by differential shrinkage stresses.



fiber on the left, because it dries later and can shrink more, will transfer stress to nearby, more-densified fibers as it dries.

How can a sheet have fibers with such large differences in density and moisture content? It is now recognized that the press section is one place where these sharp gradients can be generated, depending on the pressing intensity for that furnish. The gradients occur over a large range of dimensions, starting at the CD profile and extending down to individual fiber groupings (4, 5). When a sheet with sharp density and moisture gradients arrives at the dryer section, we believe that evaporative stress ultimately leads to nonuniform stress distributions, which pull the sheet out of plane at many dimensions down to the tiny sizes shown in Figs. 1 and 2.

Finish problems, especially the wrinkled appearance, seem to be more noticeable with intense pressing. The peak pressure or the press impulse for today's presses are usually many times greater than for older roll presses, and this certainly can promote mechanical marking. In addition, high press impulse and/or high peak pressure also lead to premature felt collapse, which means that the nip runs in a saturated condition for a much longer portion of the felt life cycle, usually without the operator even realizing it.

We now suspect that nip saturation makes an important contribution to sheet-finish problems, especially the microstriations we are observing. In any press type, saturation occurs in the region where essentially all the voids in the compressed sheet, felt,

and the underlying vents are occupied by a liquid continuum. In passing through this saturation zone, the water is rapidly accelerated with respect to the fiber networks in the sheet and the felt (6, 7). The momentary sharp fluid pressure pulse, or "water hammer," forces water in the sheet plane to either side of the peak pressure location, where it suddenly must find (or create) a tortuous path out of the paper. This path is generally downwards and along the MD, but it also has a CD component that is determined by the underlying vents (yarns, grooves, holes). We think the resulting momentary high-velocity water movement inside the sheet manifests itself as a concentrated fluid shear stress at the flow-exiting surface. This shear stress creates a thin, dense "skin" (2) and further intensifies any pressure gradients associated with underlying yarns and vents. We feel strongly that these density and moisture gradients, coupled with nonuniform evaporative drying, are ultimately responsible for the rough surfaces seen in Figs. 1 and 2.

The dense skin is probably created in later nips that are operating in a saturated condition. When these are single-felted nips, the result can be a very two-sided sheet. The sheet isn't necessarily destroyed by catastrophic crushing just because the nip is saturated. For example, on various occasions, we have observed water ejecting from the inlet of a roll press without any physical sign of sheet crushing. In the case of one shoe press, we have even seen water ejecting from the grooves of the top roll with no measurable loss in sheet strength.

Catastrophic crushing is less likely in later nips because the fiber network is already well into the nip and held tightly by compressive stress before passing through the saturation zone. Compared with the roll press, we experience far less sensitivity to catastrophic crushing with the shoe press, probably because the fluid pressure pulse is located further into the nip and because the pulse may not be as high or sharp. Even so, we think nip saturation is a common occurrence in the shoe press, and this can result in the proposed "skin effect."

Based on all the evidence collected so far and supported by wet-pressing theory, our view (not necessarily held

by all) is that many "marks" seen in a high-impulse-pressed sheet—shell marks, groove marks, yarn marks, and microstriations—are actually hydraulically induced, or at least reinforced, and are not solely a result of mechanical imprinting. Dark furnishes such as linerboard are particularly susceptible to marking. These grades are generally subjected to more-intense pressing, and light reflecting from differently densified parts of a dark surface is easier to perceive than it is for a white surface. **Figure 4** shows linerboard with hydraulic marking from the grooved backing roll of a shoe press.

We are certain that a densified surface is created during intense pressing and are convinced that this leads to a rough surface. However, it must be stressed that our thoughts on the exact mechanisms for creating this sharp density gradient have not been unequivocally established by controlled experiments. We are hopeful that research in this area will eventually be undertaken.

Attacking the sheet-finish problem

Our evidence shows that variations in furnish type and condition have the greatest influence on the sheet-finish problems described here. However, this area needs further study using the image-analysis and stylus-based methods mentioned earlier. The following comments apply mainly to the paper machine operation and do not take furnish variations into account.

When paper is dried under partial restraint, it can only remain flat if the drying stresses remain uniform at all dimensions. Approaching this ideal means that sheet moisture and density gradients arriving at the dryer section, as well as drying gradients during the drying process itself, must all be minimized to exceedingly small dimensions. It is especially important to avoid creating a dense "skin" at the sheet surfaces if microstriations are to be avoided.

In the dryer section of a commercial machine, improved methods of CD restraint would help minimize the shrinkage problems that contribute to poor finish, even for sheets arriving with gradients. In existing machines, this may call for closer attention to maintaining high felt tensions. It may

be possible to design dryer felts that grip the sheet edges better. Drying strategies optimized for sheet finish may help, but this needs more study. Moreover, these remedies will probably not produce dramatic improvements unless the existing situation is abnormally bad. Future machines may benefit from the new single-tier dryer configurations or a potentially revolutionary CD-restraint system now being tested on a linerboard machine in Sweden (8).

We think that the press section continues to offer the most immediate hope for improvement, since sharp moisture and density gradients can easily originate here. The felts and roll covers create in-plane gradients, and the dynamic pressing process inherently causes thickness-direction (ZD) gradients. We believe that there is still room to minimize the in-plane gradients through improved felt design and other methods. Much progress has been made here, but more may be possible. In high-impulse presses (especially the shoe press), even the best felts will fill or collapse if they are not removed soon enough. When felt collapse occurs, the result is nip saturation, setting up the conditions that we propose create the dense skin.

Felts must somehow be designed to simultaneously retain compressed void volume over a longer lifetime while still presenting a mechanically and hydraulically uniform pressing surface to the sheet. Current efforts to develop shoe-press press sleeves with finely distributed recesses for water storage appear promising. In this way, fully developed nip saturation might be avoided, provided that the press shoe is properly designed to avoid sharp pressure gradients and deformation from thermal bending stresses.

Even if all these improvements are implemented, operators must still appreciate that if they wish to obtain the best surface finish, they probably must pay for it with frequent felt changes, as well as greater attention to felt conditioning. Felt removal (as well as felt design) must be based on the likelihood that hydraulic forces from collapsed and filled felts are compounding the finish problems that are commonly attributed to simple "yarn marking." We think it is especially important to avoid nip saturation. Lastly, the papermaker should

also appreciate that even if the perfect felt, sleeve, and shoe combination were to be invented, finish problems could still occur. Wet pressing inherently gives nonuniform thickness-direction gradients when it is performed too intensely for a given furnish and basis weight. If the wet pressing is overly intense, the web will develop ZD gradients even if the pressing surface is perfectly uniform. □

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