Evolution of composite covers for release rolls in the press section

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ABSTRACT: Composite roll covers are used in a wide range of applications from the wet end through the finishing operations. This report focuses on the use of composite roll covers in the press section to facilitate release of the wet web from the roll surface. Sheet-release theory is discussed briefly, followed by a review of roll properties affecting sheet release and wear resistance. Higher operating temperatures, press loadings, and machine speeds are identified as trends favoring the use of composite-covered rolls instead of the traditional granite roll.

KEYWORDS: Composites, coverings, development, forecasts, history, paper machines, physical properties, release, rolls, theories.

Granite rolls have a long history of use in paper-machine press sections because of their excellent release characteristics and wear resistance. Alternatives to the granite roll have been available for several decades in the form of steel rolls covered with composite materials. The filler and binder components of a given composite are selected to provide wear-resistant covers of appropriate hardness, surface chemistry, and other relevant physical properties.

While granite rolls continue to provide satisfactory service, the demand for greater efficiency in the press section has created a need to develop substitute materials as an alternative to granite (*1*). The rate of failure for granite rolls also has increased with paper-machine speeds. In 1987, three catastrophic granite roll failures led to the formation of a Granite Roll Group to analyze the failures, compare granite roll designs, prepare operation and maintenance instructions for press sections, and identify reliable substitutes for granite (*2*). Unfortunately, only three alternatives were examined.

Since these failures, several new material options have been brought to market. Among them are synthetic ebonites, filled thermosets, filled polyurethanes, and specialized metallic and ceramic sprayed coatings. **Table I** lists the materials used to cover release rolls in the press section along with their respective load, temperature, and hardness limitations. **Table II** describes the general requirements for covers used on release rolls in the press section.

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Theory of web release

Because of granite's long history as a successful release-roll material, researchers have developed hypotheses for release mechanisms based on its material properties and surface topography. Four important variables affecting web release have been identified.

1. Liquid film between the web and the roll. The work of adhesion—the energy required to separate the web from the roll—typically increases with decreasing film thickness.
2. Cavitation. The presence of microscopically sharp cavities in the roll surface may serve as nucleating sites for numerous surface phenomena, including condensation, particle separation, and air-bubble formation, all of which can reduce adhesion and facilitate web release.
3. Crack propagation in the liquid film. This is believed to be analogous to the mechanism seen in crack propagation in adhesive joints. Crack propagation may be initiated in the presence of microscopic profile points (fillers) on the roll surface.
4. Surface energy. Surface energy is a crucial consideration in the study of adhesives. The compatibility and wettability of joint materials play a major role in adhesion. By analogy, the surface energies of cover and sheet materials can be regarded as essential factors in assessing the wettability and release mechanisms of center press rolls. Surface energy also can play a major role in a

I. Characteristics of granite press rolls and composite press-roll covers*

Material	Max. load, kN/m	Max. temp., °C	Hardness, °Shore D	Base layer, mm	Top layer, mm
Granite	150	60	100	N.A.	N.A.
Rubber composite	60–100	90	86	7–10	10–15
Polyurethane composite	350	80	91	0.5–1.5	10–15
Thermoset composite	350	110	91	4–7	4–8
Ceramic composite	300	110	100	0.1	1.5–5

*Data generated in laboratory or reported in the literature

roll cover's affinity for pitch and rosin deposits. It is postulated that dispersion of hydrophilic and hydrophobic areas throughout the cover surface will disturb the conditions within the liquid film between the web and roll surface, thus facilitating sheet release.

There is little published literature on web adhesion and release from various types of press rolls (*3–5*). This is largely because of the proprietary nature of the subject and because fundamental studies have not been well defined or understood. Other factors that are known or suspected to influence sheet release include:

- Tendency of the web to conform to the roll surface (influenced by sheet dryness and by the types of fiber and filler in the sheet)
- Electrochemical conditions on the roll surface in relation to those on the web
- Selective affinity of roll surface for specific chemicals (especially pitch and similar resinous components)
- Temperature and pH of the white water
- Dynamic modulus of the roll cover (higher hardness may promote sheet release).

II. Properties of a granite press roll and targeted properties for a composite press-roll cover

Property	Granite	Targeted composite
Runnability	Vibration problems at high speed	No vibration problems up to 2000 m/min
Release	Good to excellent	Excellent
Temp. resistance	60°C	110°C
Abrasion resistance (regrinding interval)	Approx. 6 months	Minimum of 12 months
Residual stresses	Difficult to control	Easy to control
Doctorability	Good; short doctor life	Good; long doctor life

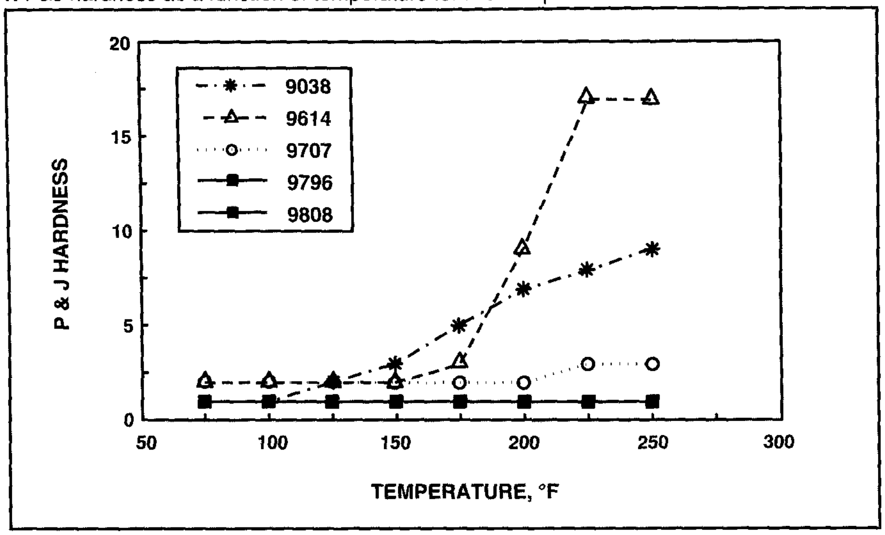
III. Chronological development of composite materials for press-roll covers

Date introduced	Product No.	(Trade name)	Material	Quantity manufactured
1933	9038	(Stonite)	Filled rubber	2000–3000
1950	9614	(Microrok)	Filled rubber	5000–6000
1985	9707	(Dynarok)	Filled rubber	650
1989	9796	(Centerok)	Filled thermoset	20
1991	9808	(Centerok 91)	Filled thermoset	10

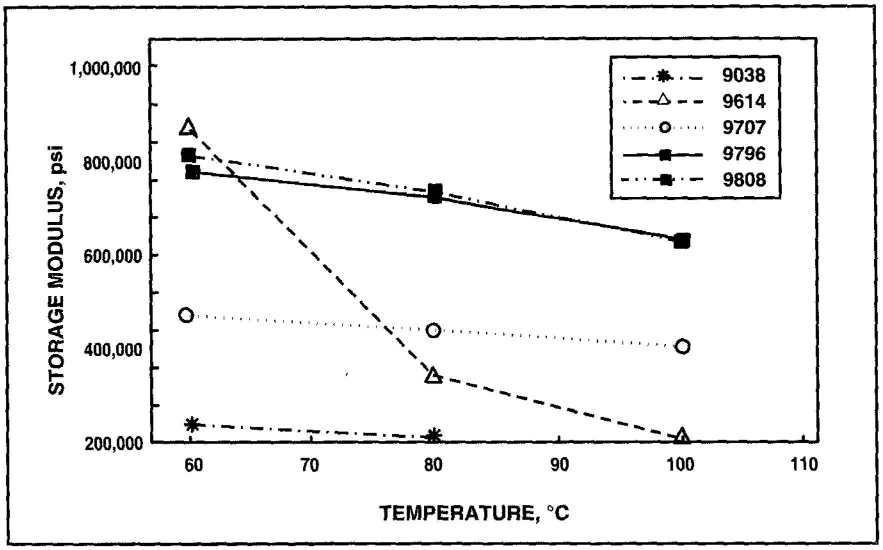
Development of release-roll covers

Over the past 30 years, papermakers, roll-covering suppliers, and universities have attempted to quantify the work of separating a paper web from various cover materials in laboratory environments. None have been very successful. Roll-covering manufactur-

1. P&J hardness as a function of temperature for five composite cover materials



2. Storage modulus as a function of temperature for five composite cover materials



ers have learned that commercial runs on a paper machine are the only reliable way of testing how well a particular cover composition will release a sheet of paper.

In 1933, our company produced the first composite release-roll cover under the trade name Stonite. **Table III** recounts the company's history of release-roll cover developments since then. Compound 9038 was developed to serve as a replacement for granite and contained many of the mineral fillers found in granite. Temperature and wear problems led to the development of a new rubber-filled composite (compound 9614) in 1950. This compound was developed as a release-roll compound with very good wear properties and high dynamic modulus at room temperature. Another family of rubber composite release-roll covers (compound 9707) was developed in 1985 to withstand the higher press operating temperatures that have become commonplace since the advent of steam boxes and increased white-water closure.

In 1989, a new generation of thermoset composites (compound 9796) was designed to withstand very high temperatures, up to 110°C, and provide much improved wear resistance over rubber composites and granite rolls. Another thermoset composite (compound 9808) with greater wear resistance was introduced in 1991.

Roll properties and sheet release

There have been numerous hypotheses to explain the mechanism of sheet release from a roll surface. In an effort to understand the effect of various physical properties on sheet release, we have measured these properties and have attempted to correlate them to field performance. The remainder of this article focuses on five important properties (hardness vs. temperature, dynamic performance, wear resistance, surface topography, and wettability) and discusses them in relation to the properties of granite rolls.

Hardness vs. temperature

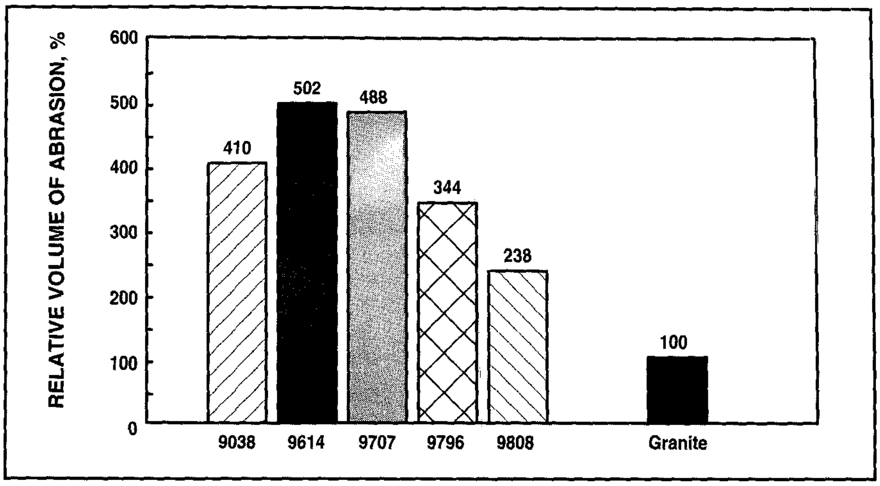
Temperature stability is a critical parameter for release-roll covers. **Figure 1** illustrates the hardness stability (P&J hardness) at elevated temperature for the three rubber composites and two thermoset composites identified in Table III. There is a wide disparity in the thermal stability of the rubber compounds, as can be seen by comparing the results for compounds 9707 and 9614. Temperature stability is a crucial property for a release-roll cover, and the thermal stability of the 9707 roll-cover formulation has made it a success in release applications. Thermoset composites offer even greater temperature stability and higher hardness.

Dynamic performance vs. temperature

Temperatures in the press section have increased with the advent of the steam box and the trend toward closure as mills strive to reduce white-water effluent. The higher temperatures have increased the need for a more dynamically stable roll-cover compound over a broader range of temperature. **Figure 2** demonstrates the chronological progression of dynamic performance for the five compounds identified in Table III.

The necessity that a roll cover maintain its dynamic modulus over the range of desired operating temperatures is obvious. Roll covers that change their physical properties nonuniformly over time (wear, swell, etc.) are not suitable for use as release-roll covers. Nonuniform wear leads to nonuniform release. It has been demonstrated in both the laboratory and in the field that the work of separating a paper web from a granite roll is higher than that between a paper web and a synthetic cover. However, the reason for granite's widespread use is its ability to release a sheet of paper uniformly across the width of the roll surface.

3. Abrasion resistance of five composite cover materials (granite = 100%)



Wear resistance

Wear resistance is a major consideration in evaluating the pros and cons of replacing granite rolls with synthetic-covered rolls. A primary goal for manufacturers of synthetic roll covers is to produce composite materials that rival the excellent wear resistance of granite. **Figure 3** is a bar chart of relative wear using granite as the standard for comparison. While the thermosetting composites provide good wear resistance, granite remains the standard for excellence in this category, at least as measured by this laboratory procedure. Field results have demonstrated superior wear resistance for thermoset composites over granite, as seen in **Table IV**.

IV. Performance characteristics of granite press roll and two composite press-roll covers

Category	*Filled rubber (9707)*	*Filled thermoset (9796)*	*Granite*
Release			
Newsprint			
No waste	Excellent	Excellent	Excellent
With waste	Excellent	Excellent	Excellent
Lightweight coated	Good	Good	Excellent
Supercalendered	Good	...	...
Fine paper	...	...	Excellent
Linerboard	Excellent	Excellent	...
Regrind period, months	6	>11	6
Max. temperature, °C	90	110	60
Doctorability	Good	Excellent	Excellent (short lifetime)
Residual stresses	Somewhat critical	Somewhat critical	Very critical

Surface topography

The uniformity and distribution of microvoids on the roll surface influences wear resistance, wettability, and release performance. Consequently, characterization of surface topography and analysis of its effect on release performance are necessary steps in developing synthetic replacements for granite rolls.

Figures 4–8 are micrographs of rolls surfaced with the five compounds identified in Table III. **Figure 9** is a micrograph of a granite roll surface. The finish for each of the six surfaces is given in the figure captions in terms of Ra (roughness average). Observation of Figs. 4–8 shows the presence of particulate filler in a polymer matrix. These photomicrographs demonstrate that particles can be both ground smooth or removed during the finishing process, leaving behind microvoids. These void areas can be critical to film formation and wettability of the cover surface, as discussed in the following section.

Wettability and surface energy

The shape of a drop of liquid at rest on a solid is controlled by three forces of interfacial tension, as shown in **Fig. 10**. Sessile-drop experiments can be very helpful in understanding the reactions at the white-water–roll-cover interface. Figure 10 illustrates two possible sessile-drop configurations.

The first, under a nonreactive condition, represents the phenomenon of wetting by a steady-state acute contact angle (θ) where $\theta < 90°$. This angle occurs when

$$\gamma_{sv} > \gamma_{sl} > \gamma_{lv}$$

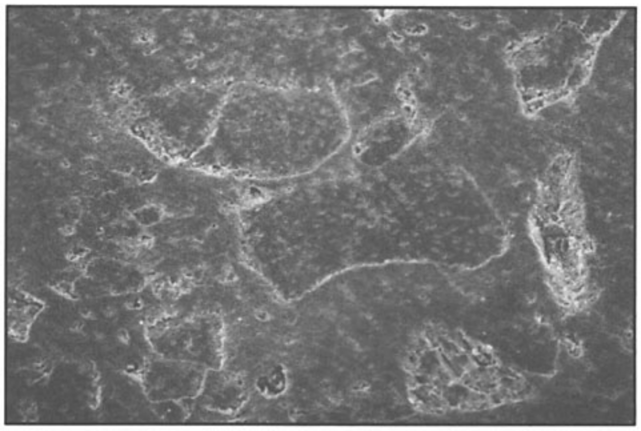
where

γ_{sv} = interfacial energy for solid/vapor

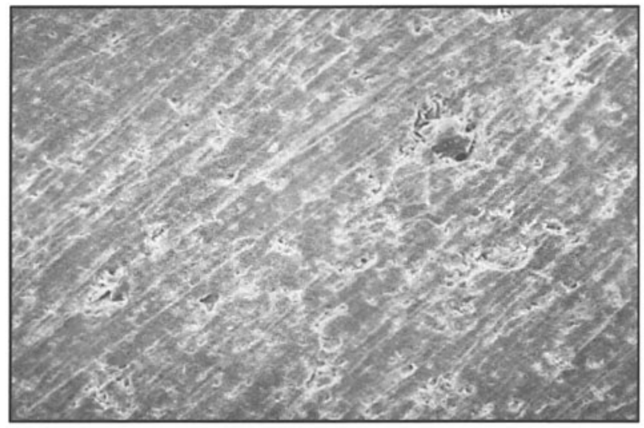
γ_{sl} = interfacial energy for solid/liquid

γ_{lv} = interfacial energy for liquid/vapor.

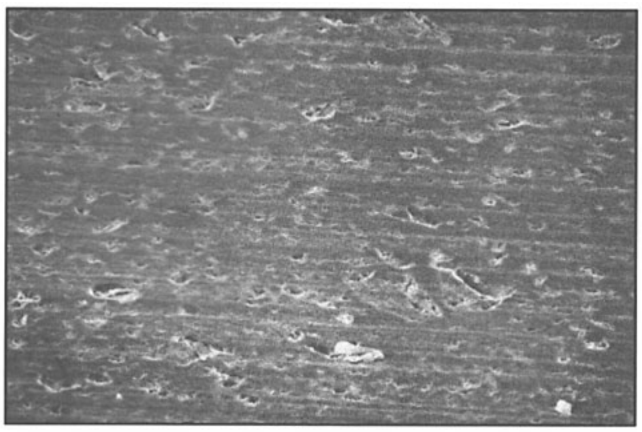
4. Compound 9038; surface finish = 51–71 μin. (Ra); magnification = 101X.



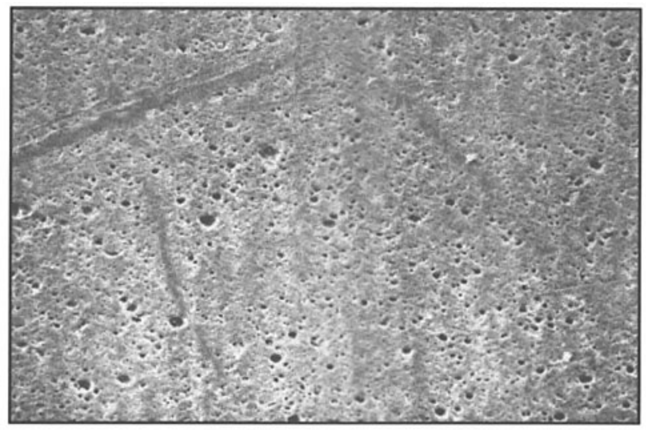
5. Compound 9614; surface finish = 48 μin. (Ra); magnification = 93.5X.



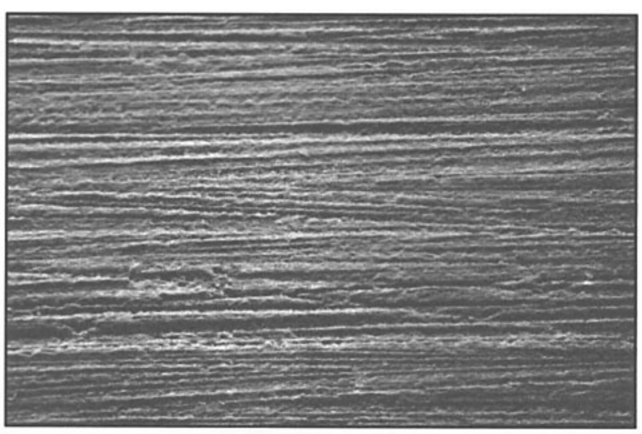
6. Compound 9707; surface finish = 38–46 μin. (Ra); magnification = 102X.



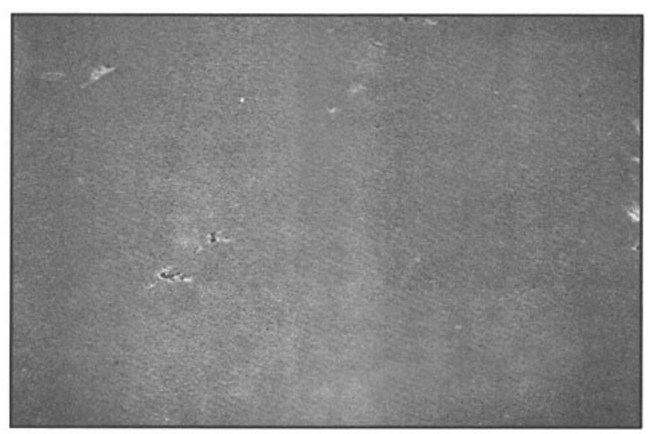
7. Compound 9796; surface finish = 36–46 μin. (Ra); magnification = 100X.



8. Compound 9808; surface finish = 63–68 μin. (Ra); magnification = 102X.



9. Granite; surface finish = 8–25 μin. (Ra); magnification = 99.5X.



The second configuration, also under nonreactive conditions, represents the phenomenon of nonwetting by a steady-state obtuse angle of $\theta > 90°$. This angle occurs when

$$\gamma_{sv} < \gamma_{sl} < \gamma_{lv}$$

Wetting can be defined as the reduction of γ_{sv} of the rigid substrate (roll cover) by the liquid (white water/shower water). It is important to realize that wetting is a thermodynamic process. A liquid will wet a solid when it allows the system to attain a lower energy. In the case of nonwetting, the surface energy of the rigid substrate is not reduced by the liquid, although an intimate interface is formed.

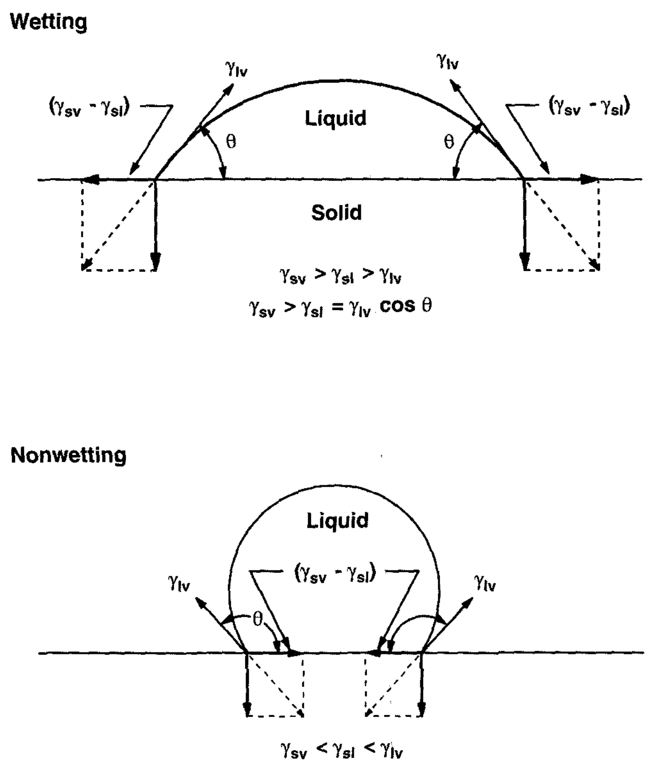
Thus the driving force for wetting of the rigid substrate is $\gamma_{sv} - \gamma_{sl}$, which acts on the periphery of the liquid drop, as seen in Fig. 10. γ_{lv} is the resisting force, with its lowest free-energy shape that of a sphere. The familiar Young–Dupre equation (*6*) represents a balance of these forces, yielding a steady-state contact angle:

$$\gamma_{sv} - \gamma_{sl} = \gamma_{lv} \cos\theta$$

To relate this to roll-cover/white-water interactions, we can consider the following scenarios. Surface contamination can lead to a nonwetting phenomenon, even when $\gamma_{sv} > \gamma_{lv}$. In this case, γ_{sl} must be greater than both γ_{sv} and γ_{lv}. Thus foreign particles (pitch, rosin deposits, etc.) can lead to nonwetting situations between the cover and white water. If $\theta < 90°$, an indication that wetting is occurring ($\gamma_{sv} > \gamma_{sl} > \gamma_{lv}$), then an aqueous film can form on a clean cover surface. However, if $\gamma_{lv} > \gamma_{sl} > \gamma_{sv}$, a true interface is also present, but the nonwetting liquid will not penetrate surface irregularities.

Table V shows the contact angles and surface energies associated with a given surface finish for the five cover formulations listed in Table III and for granite. All of the cover surfaces are wettable with water, with compound 9808 indicating the highest degree of wettability of the synthetic covers tested.

10. Sessile-drop configurations at wetting and nonwetting conditions



V. Surface finish, contact angle, and surface energy for five composite materials and granite

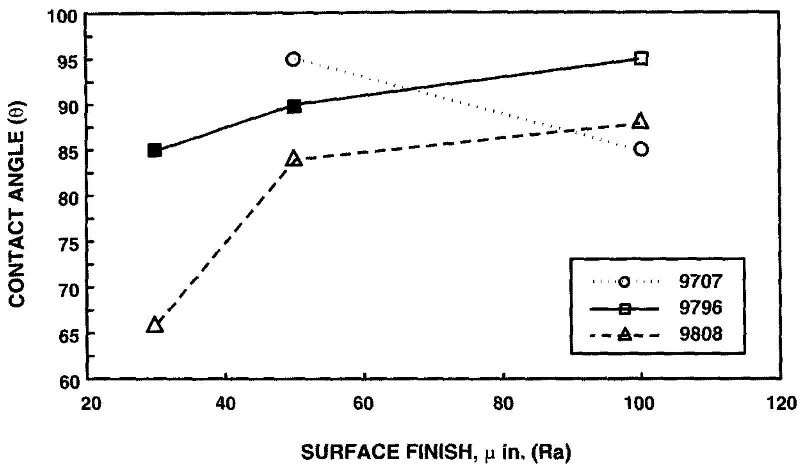
Type of cover	*Surface finish, µ in. (Ra)*	*Contact angle (water), θ*	*Surface tension (γ_{total}), dynes/cm*
Filled rubber (9038)	60	82–86	34
Filled rubber (9614)	60	87–90	35
Filled rubber (9707)	95	85–89	31
Filled thermoset (9796)	42	87–90	34
Filled thermoset (9808)	42	77–82	39
Granite*	50–100	77–79	47

*Suguri *et al.* (*7*)

The granite cover had the highest surface energy (*7*). Granite has a very high polar component of surface energy compared with the composite materials presented here. One would expect the contact angle for granite to be low, indicative of its wetting potential. Table V shows that the contact angle is indeed low, 77–79°. However, compound 9808 had a similar contact angle of 77–82° despite its lower surface energy.

It is a common practice to determine γ_{sv} experimentally by measuring the contact angle θ and using the equations given previously. However, such data must be carefully considered, since erroneous results can be produced by absorption of gases at the surfaces, migration of impurities to the surface and/or the interface, and interfacial chemical reactions. In addition, contact angle θ depends heavily on temperature, relative humidity, and

11. Contact angle as a function of surface finish for three composite cover materials



the surface finish of the substrate. Rougher surfaces can lead to a phenomenon called contact-angle hysteresis (*8*), in which the advancing contact angle is higher than the receding contact angle because of surface porosity and/or roughness. This phenomenon may explain the similarity of contact angles for compound 9808 and granite despite granite's higher surface energy.

The presence of a liquid film over the surface of a roll cover is thought to aid in the release of the paper web through a mechanism of nonintimate contact of the web to the cover surface. **Figure 11** shows that the wettability of the two thermoset composite surfaces is increased by lowering (smoothing) the surface finish. The opposite behavior is obtained for the filled rubber composite containing a low-energy (hydrophobic) component. The smoother finish leads to more intimate contact with the low-energy component, thus decreasing the wettability of the surface.

The degree of wettability and uniformity of the liquid/cover interface can be controlled by manipulating the additives present in a composite compound. This enables the roll-cover manufacturer to modify a cover formulation to fit a given set of application parameters.

Center press roll survey results

Our company initiated a worldwide survey of center press roll covers in June 1990, with an emphasis on high-speed machines. The survey was carried out in an effort to track the performance of various types of synthetic roll covers, in comparison with granite rolls. The objectives were to identify

- Safe cover materials
- Current operational performance
- Future development opportunities.

Responses were received from 31 manufacturers of newsprint, fine paper, supercalendered, lightweight coated, kraft, corrugating medium, and some specialty grades. Table IV summarizes the results for compounds 9707 and 9796 and for granite.

The survey demonstrated that thermoset composites are being used with relative success. Compound 9707 (used in more than 650 covers) has experienced only a handful of operating problems related to unacceptable release. However, the pitch- and rosin-laden furnishes typical of northeastern and southeastern North America have posed a problem for synthetic covers in the past. This is where the test for new cover materials will lie.

Summary

Web release from a center press roll is a critical performance characteristic. Granite rolls have been the traditional choice in these applications because of their excellent release characteristics. However, recent catastrophic failures of granite rolls suggest that the higher temperatures, loadings, and speeds of modern paper machines may be approaching the threshold of tolerance for operation of granite rolls.

Synthetic covers for center press rolls are widely used throughout the industry as an alternative to granite. The potential success of a synthetic release-roll cover in a given application is determined by its performance in four key areas.

- **Temperature stability.** As operating temperatures in the paper machine continue to increase, the roll's ability to maintain stable hardness and dynamic modulus at elevated temperature is of paramount importance.
- **Wear resistance.** Improving the wear resistance of a cover leads to more-uniform release of the paper sheet. This is a critical performance criterion and is an important factor in the success of granite roll covers.
- **Surface topography.** The uniformity and distribution of microvoids on the roll surface may have a greater effect on the wear resis-

tance of the cover surface than on wettability and release. Fillers play a critical role in maintaining surface topography.

- **Wettability.** The wettability of a cover surface has a pronounced effect on the interaction between a paper web and the cover surface. Granite's success as a release-roll cover is largely due to its excellent wettability. Composite covers containing hydrophilic materials provide the greatest wettability when they are ground to a smooth finish.

Manufacturers of synthetic roll covers have labored to produce materials with high temperature stability, low wear rates, and good wettability. The next challenge will be to formulate materials that can perform successfully in the pitch- and rosin-laden furnishes typical of northeastern and southeastern North America. The presence of stickies in furnishes containing recycled fibers will pose a further challenge. TJ

Literature cited

1. Vestola, J., Niskanen, J., and Vähäpesola, J., Pulp Paper Can. 91(6): 100(1990).
2. Eriksson, H. M., 2nd International PIRA Conference, PIRA, Leatherhead, UK, 1990.
3. Oliver, J. F., Tappi 65(3): 119(1982).
4. Oliver, J. F., CPPA Trans. Tech. Sect. 8(1): 301(1982).
5. Pikulik, I. I. and McDonald, J. D., 78th Annual Meeting Proceedings, CPPA Technical Section, Montreal, 1992, p. A15.
6. Young, T., Miscellaneous Works (G. Peacock, Ed.), Vol. I., Murray, London, 1855, p. 418.
7. Suguri, M., Yamada, K., and Nandate, M., Japan Pulp Paper Aug.: 77(1983).
8. Adamson, A. W., Physical Chemistry of Surfaces, 4th edn., Wiley Interscience, New York, 1982, p. 345.

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