UNDERSTANDING FRICTION

by

J. D. McDonald
Pulp and Paper Research Institute of Canada
Canada

ABSTRACT

Friction plays a critical role in many web handling and winding problems in the paper industry. Although these problems can often be reduced to simple mechanical models, the models require the coefficient of friction of the material as an input. However, coefficient of friction of paper can be an elusive measurement which depends on measurement conditions, handling and even on previous measurements on the same sample. This paper looks at how friction should be measured for different applications. Fundamental principles are used to explain the chemical nature of friction which is essential for understanding and controlling friction in the paper industry.

Introduction

Friction has important consequences for the production and conversion of paper and board. This review of friction examines web handling and winding problems, controlling factors and measurement challenges.

For many product specifications and web handling processes in the paper industry, higher frictional forces are better. Friction gives stability to paper rolls, and allows boxes and sacks of materials to be stacked. In web handling, friction maintains traction between a web and a roller to prevent wandering and misregistration [1]. Many converting operations brake or drive paper rolls by means of external belts (Figure 1) or core-mounted drive shafts (Figure 2). This requires sufficient interlayer frictional force to resist slippage between paper layers [2-4] which can be quantified as torque capacity [4] or frictional stress [5]. Surface winding of low friction paper can cause interlayer movement below the paper roll surface under the nip which can lead to defects such as crepe wrinkles (Figure 3) [5-10]. Lightly loaded nip feed processes such as copiers require traction to transport sheets. In web offset presses, multiple webs are pulled through a nip before the folding operation (Figure 4) [11]. Web tension of the outer webs

195

is generated by the frictional force of the roll whereas the tension of the interior webs is limited by the frictional forces transmitted from web to web (Figure 5). Insufficient interlayer friction leads to reduced tension of the interior webs and the possibility of misregistration or web breaks.

There are also problems associated with high friction. On printing presses where the paper rolls are braked by metal bands, high friction between the band and the paper can cause the outer layer of paper to stop but still allow the underlying paper roll to rotate [2,3]. This will create a bubble ahead of the contact point with the band and eventually cause a web break. A combination of high friction and interlayer pressure can cause paper rolls to vibrate and bounce on two-drum winders [12-14]. So in reality, friction between paper layers and between paper and other surfaces must be within a certain range as dictated by the mechanics of web handling and winding equipment.

Coefficient of Friction

When two bodies are in contact, their relative motion in the plane of contact is opposed by frictional force. Leonardo da Vinci was the first to state the laws of friction; the frictional force is independent of the area of the sliding surfaces and proportional to the load between them [15-17]. These observations were later verified by Columb, who also made the distinction between the force of static friction, that is the force required to start sliding, and kinetic friction, the force required to maintain sliding. Columb showed that kinetic friction is less than static friction, and approximately independent of speed of sliding [15].

Although the above laws are generally obeyed by a wide range of materials, there are exceptions such as compressible plastics and rubbers [17,18]. Because paper is also soft and compressible, its behaviour doesn't always follow the classical laws of friction.

The frictional force (F) between most surfaces is proportional to the normal force (N) that holds them together. The proportionality factor is called the coefficient of friction (μ).

$$F = \mu N \qquad \{1\}$$

This relationship is illustrated in Figure 6 for a block of material on a horizontal surface where the normal force is the weight of the block. This arrangement is a common way of measuring coefficient of friction.

The coefficient of friction between two surfaces of the same material will depend on several factors: surface strength, chemistry, and topography. When two surfaces are pressed together the superficial area of contact is determined by the dimensions of materials, but the actual area of contact, as determined by surface topography, is usually in the order of only several percent of the superficial area (Figure 7) [17]. With metals, plastic deformation occurs at these contact points and friction is related to the shear strength of the surface at these points. For paper, the surface strength

is related to the fibre structure as well as the distribution of additives, such as clay, which can reduce the surface strength [17].

Paper to Paper Coefficient of Friction

Paper to paper coefficient of friction can vary over a wide range because of differences in wood, pulping processes, papermaking and additives. This range is illustrated in a recent study [19], where a directory paper had the highest COF and a paper made from recycled fibre had the lowest. The kinetic COF differs from the static COF by a constant value (Figure 8).

Measurement Challenges

Measuring the coefficient of friction of paper can sometimes be as complicated as understanding quantum physics. The Heisenberg uncertainty principle, states that is is impossible to simultaneously measure the position and momentum of a small particle, such as an electron with infinite precision. The act of measurement can change the values. A similar effect occurs when measuring the COF of paper. For acidic paper, the COF often decreases with each slide [16,17,19-21]. However, with alkaline paper that contains additives such as precipitated calcium carbonate, the COF increases with each slide (Figure 9) [22]. Typically, the static coefficient is recorded after at least three slides and often as many as ten slides to account for this effect [23]. To accurately measure the friction of the first slide and minimize handling, equipment has been designed to automatically lower the sled into position to avoid rubbing prior to testing [24].

With acidic paper, the COF is probably controlled by fatty acids on the surface (Figure 10). Successive sliding combs and aligns the hydro-carbon chains which lowers the frictional force. With alkaline paper, small particles act as free bodies to lubricate the interface during the initial slides (Figure 11). In subsequent slides, these particles are broken down or lodged in the paper surface which increases the frictional force.

The Effect of Measurement Pressure and Speed

Most equipment for measuring static paper-to-paper coefficient of friction use speeds between 0.5 to 6 mm/s and blocks weighing 200 grams which exert pressures below 0.5 kPa [25,26]. For board and sack, pressures between 1.4 kPa and 6 kPa are specified to reflect the higher loadings between boxes and bags for products like cement or seed grains [27-30]. For nip-induced defects like crepe wrinkles which occur within paper reels and rolls during reeling and winding, the web speed and pressures are significantly higher. Are measurements at these lower speeds and pressures representative of those in a winder nip? In principle, this question could be addressed using a horizontal plane tester by increasing the weight of the sled. However, there is a practical limit to this approach because a one meter column of lead would be required to exert a pressure of 100 kPa. This would be cumbersome as well as presenting a serious challenge to the load cells and force actuators of conventional friction testers.

To address this question, we adapted an instrument that was originally designed to study the performance of lubricants for oil well pumps (Figure 12) [19]. A paper sample attached to the upper plate is stroked over a second sample attached to the lower

plate at a pressure determined by the spring setting. A tri-axial force sensor in the lower plate simultaneously measures the frictional and normal force. We found that static and kinetic paper-to-paper coefficient of friction is independent of the measurement pressure (Figure 13) and speed (Figure 14). This means that the results of standard laboratory tests can be used to predict performance in winding nips even though the conditions differ by several orders of magnitude.

Surface Roughness

The coefficient of friction between two surfaces of similar material is generally independent of surface smoothness [15-17,19,31,32]. Surface smoothness can be a factor for a hard surface in contact with a soft surface where gouging or ploughing by the harder material can increase coefficient of friction [17]. For a wide range of calendering conditions COF is lower for smoother paper surfaces (Figure 15) [19]. However, surface smoothness is usually a product specification for printability so that practical changes would have little or no influence on paper to paper coefficient of friction [16,17,19,31, 32]. In contrast, the chemical nature of the surface has a dominant effect [16,17,20,21,31-33].

Surface Chemistry

Most paper is composed primarily of wood fibres. Fillers such as clay can be added to increase opacity and fill surface voids to improve printability. Surface coatings such as starch can be applied to size the surface affecting water penetration. Clay coatings are applied to control surface properties for printing applications. All of these factors can have an effect on coefficient of friction.

The coefficient of friction of wood pulp is primarily controlled by the extractives which encompasses hundreds of different molecules. Each one of these molecules has a unique effect on COF depending on its chain length and particular functional groups. The COF of a pulp depends on the relative proportion of these components. For simplification, the extractives can be broadly divided into two classes: fatty and resin acids. Fatty acids generally lower COF and this effect increases with hydrocarbon chain length (Figure 16) [17,33,34]. Resin acids generally increase COF [16,17,32,33] as does moisture (Figure 17) [19,31,33,35]. The knowledge is exploited by ballet dancers who apply rosin (resin acids) or water to their shoes to increase friction on wooden dance floors [36]. For recycled fibres processed by flotation de-inking, fatty acid soaps are commonly used as ink collectors and carry-over of slippery material on the fibre surface can lower COF.

The relative proportion of fatty and resin acids depends on tree species, growing conditions, and pulping process. In extreme circumstances, mills will segregate wood species but generally they have limited control over harvesting so the COF of the fibre is usually a given in dealing with friction problems.

Additives which increase paper to paper coefficient of friction include synthetic sodium alumino silicate (SSAS) pigments [21], precipitated sodium silicate (PSS) [37,38] and calcined clay [37]. The effectiveness of these pigments appears to be related to their amorphous structure and increases with their porosity as measured by oil

198

absorption [21,37-39]. Materials such as talc or delaminated clay which have a platelet structure, reduce coefficient of friction [21,38]. A promising approach for mills producing flotation deinked pulp is to replace fatty acid soaps as a flotation collector with distilled tall oil soaps with higher resin acid contents [40].

Dynamic COF

The dynamic coefficient of friction between paper and a metal surface is important in many converting operations. The coefficient of friction depends on the roughness of the metal surface [17] as well as surface chemistry and operating conditions.

On many printing presses, braking of paper rolls and tension control is done with metallic bands in direct contact with the roll surface. The number of braking bands is dictated by the width of the paper roll. In a printing plant, a number of unwind stands feed webs to separate printing stations which are later collated into the complete newspaper. If there is a problem with one web, the operator initiates a red-button stop to brake each roll within a minimum number of revolutions. This reduces the chance of a sympathy breaks in adjacent webs which could damage the printing plates and minimizes waste paper. Two possible problems related to friction can occur during a red-button stop. If the friction between the band and the paper is too low, the roll will run-on after the rest of the press has stopped, breaking the web. If the band to paper COF is too high the top layer of paper will stop but the rest of the roll will continue to rotate. This causes the paper to bubble and eventually break ahead of its point of contact with the band. This condition is called run-ahead. The dynamic coefficient of friction between the band and paper is the key to understanding this problem.

The dynamic coefficient of friction between paper and a band was measured using a rig designed to simulate the braking mechanism on a commercial printing press as shown in Figures 1 and 18 [2,3].

The dynamic coefficient of friction was calculated from the band braking equation using the measured values of the band tensions, T_1, T_2 and the wrap angle, α.

$$\mu = \frac{1}{\alpha} \ln\left(\frac{T_2}{T_2}\right) \qquad \{2\}$$

Lowering the web speed from 900 m/min to 10 m/min caused the coefficient of friction to increase from 0.28 to 0.61, as shown in Figure 19. This phenomenon would exacerbate the problem of run-ahead as the paper roll decelerates after a red-button stop.

The friction between the band and the paper is controlled by the accumulation of material scoured from the paper onto the band. This layer is thin because, even under close examination, it is not visible. Increasing the relative speed between the paper and band increases the shear and the band temperature which could soften that layer and reduce the frictional force. Similarly, increasing the normal force brings this layer into more intimate contact with the paper which will increase the friction (Figure 19).

199

The dynamic COF using a clean band was 0.23 was well below that measured in the test rig (Figure 19). A contaminated band gave a COF on paper of 0.65 which was equal to the COF measured at the lowest speed and highest normal force on the test rig.

Chemical analysis identified the contaminants on the band as a mixture of resin and fatty acids. Resin acids have been previously recognized as increasing paper to paper COF [16,17,32,33]. To show that deposits on the band influence the COF between the band and the paper, three model compounds were applied to small pieces of band material. The dynamic COF was determined by dragging these treated blocks over paper samples on the TMI tester. Mineral oil gave the lowest metal to paper COF of 0.38 (Figure 20). With oleic acid the COF was 0.45 whereas with resin acid it increased to 0.63. These experiments with model compounds suggest that resin acids that accumulate on the band are the major factor in determining the dynamic COF between the band and the paper.

Summary

Coefficient of friction of paper is a difficult measurement because it is sensitive to handling and environmental conditions such as relative humidity. Because paper-to-paper COF is affected by previous movement, it is probably necessary to use instruments that mechanically bring two paper surfaces together. Laboratory measurements of COF can be used to predict paper performance at higher loadings and speeds, because the measured values are independent of these factors.

The dynamic coefficient of friction between a paper and metal surface depends on operating conditions such as applied pressure, speed, and the roughness of the metal surface. This measurement must be done using conditions that are representative of the process being studied.

The frictional characteristics of paper are primarily determined by the characteristics of natural wood extractives and chemical additives and these must be controlled for proper performance in web handling and winding.

REFERENCES

1. Spielbauer, T.M. and Walker, T.J., Theory and Application of draw control for elastic webs with nipped pull rollers. Proceedings of the Second International Conference on Web Handling. Web Handling Research Centre, Oklahoma State University (1993).
2. Hamel, J., Ménard, A., and McDonald, J.D. Les facteurs qui contrôlent le glissement à l'arrêt sur les presses d'imprimerie. Conférence Technologique Estival (1999).
3. Hamel, J., Ménard, A., and McDonald, J.D. The factors that control run-ahead on printing presses. Proceedings of the Fifth International Conference on Web Handling. Web Handling Research Centre, Oklahoma State University (1999).
4. Good, J.K., and Vaidyanathan, N., The importance of torque capacity in predicting crepe wrinkles and starring in wound rolls. Proceedings of the Third International Conference on Web Handling. Web Handling Research Centre, Oklahoma State University (1995).

5. McDonald, J.D. and Ménard, A., Layer-to-Layer slippage within paper rolls during winding. Proceedings of the Fourth International Conference on Web Handling. Web Handling Research Centre, Oklahoma State University (1997).

6. Lucas, R.G., Winder crepe wrinkles; their causes and cures. Paper Age 19(5):30 (1983).

7. Lemke, R.J., Uotinen, J., and Oinonen, H., Factors involved in winding large diameter newsprint rolls on a two-drum winder. Proceedings of the First International Conference on Winding Technology, Swedish Newsprint Centre, Stockholm, Sweden. p.79 (1987).

8. Schonmeier, H., Experience with modern single-drum winders for newsprint. Proceedings of the First International Conference on Winding Technology, Swedish Newsprint Centre, Stockholm, Sweden. p.93 (1987).

9. Daul, M. The influence of deinked fibre on winding of newsprint rolls. Proceedings, TAPPI Finishing and Converting Conference, TAPPI Press, Atlanta. p.53 (1992).

10. Lucas, R.G. and Williams, R.T., Winding problems associated with recycled fibres and additives in today's papers, Proceedings, TAPPI Finishing and Converting Conference, p.151, TAPPI Press, Atlanta, GA (1997).

11. Yuhara, T. and Kodaka, I., Influence of newsprint properties on printing press web tension - impact of tensile stiffness. International Paper Physics Conference, Niagara-on-the-Lake, Ont., p.99 (1995).

12. Daley, D.A., How paper rolls on a winder generate vibration and bouncing. Paper Trade J. 151(50):48 (1967).

13. Roisum, D.R., The mechanics of winding. TAPPI Press, Atlanta, GA., (1994) p. 157-164.

14. Olshansky, A., Roll Bouncing. Tappi J. 80(2):99 (1997).

15. Dowson, P., History of Tribology. Longman Group Inc., New York (1979), p.96-100, 213-222.

16. Back, E.L., The oxidative activation of paper surfaces and friction between papers. Das Papier 42(10A):V31 (1988).

17. Back, E.L., Paper-to-paper and paper-to-metal friction. International Paper Physics Conference, TAPPI Press, Atlanta, GA, p. 49 (1991).

18. Moore, D.F., The friction and lubrication of elastomers. Pergamon Press, Toronto (1972), p.5-7.

19. McDonald, J.D., Gratton, M.F., Sherson, G.E., Ko, P.L., and Ménard, A., Measuring paper friction: Testing conditions and papermaking factors. 1996 TAPPI Finishing and Converting Conference, TAPPI Press, Atlanta, GA. (1996).

20. Klementschitz, W., Haner, A., and Dreier, F., Studies dealing with the static coefficient of pulp and paper. Das Papier 26(11):733 (1972).

21. Haller, T.M., The importance of coefficient of friction to the newsprint industry. Preprints CPPA/TS Newsprint Conference:141 (1989).

22. Ko, P.L., and Amini, J., Friction characteristics between paper and a polished surface. Proceedings, 6th International Congress on Tribology. EUROTRIB '93 Budapest, Aug. 1993, Vol. 5, p.20.

23. Singleton, M.C. and Russell, J.A., Factors influencing paper friction: is the third test best? Appita J. 50(6): 481 (1997).

24. Johansson, A., Fellers, C., Gunderson, D., and Haugen, U., Paper friction - influence of measurement conditions. Tappi J. 81(5):175(1998).

25. TAPPI T549 pm-90, Coefficients of static and kinetic friction of uncoated writing and printing paper by use of the horizontal plane method. TAPPI Press, Atlanta.

26. TAPPI T548 pm-90 Coefficient of static friction of uncoated writing and printing paper by use of the inclined plane method. TAPPI Press, Atlanta.
27. TAPPI T815 om-85, Coefficient of static friction of corrugated and solid fibre-board (inclined plane method) TAPPI Press, Atlanta.
28. TAPPI T816 om-87, Coefficient of static friction of corrugated and solid fibre-board (horizontal plane method) TAPPI Press, Atlanta.
29. TAPPI T503 om-89, Coefficient of static friction of shipping sack papers (inclined plane method) TAPPI Press, Atlanta.
30. TAPPI T542 om-88, Coefficient of friction (angle of slide) of packaging papers (inclined plane method) TAPPI Press, Atlanta.
31. Inoue, M., Gurnagul, N. and Aroca, P., Static friction properties of linerboard. Tappi J. 73(12):81 (1990).
32. Gurnagul, N., Ouchi, M.D., Dunlop-Jones, N., Sparkes, D.G., and Wearing, J.T., Factors affecting the coefficient of friction of paper. J. Appl. Polymer Sci. 46(5):805 (1992).
33. Broughton, G. and Gregg, J.L., Some observations on the kinetic coefficient of friction of paper. Tappi 35(11):489 (1952).
34. Moore, D.F., Principles and applications of tribology, Pergamon Press, Toronto (1975), p. 138-143.
35. Fellers, C., Bäckstrom, M. and Htun, M., Paper-to-paper friction-paper structure and moisture. Nord. Pulp Pap. Res. J. 13(3):225(1998).
36. Laws, K., The physics of dance. Shriver Books, New York (1984), p.41-42.
37. Withiam, M.C., The effect of fillers on static friction properties. Tappi J. 74(4):249 (1991).
38. Negele, A.R., Performance of kaolin pigments in mechanical and recycled pulp-containing papers. Proceedings, TAPPI Papermakers Conference, TAPPI Press, Atlanta, :285 (1991).
39. Wason, S.K., Shastri, S., and Goulet, Y., PSS products for newsprint and groundwood papers. Pulp Paper Can. 94(8):T209 (1993).
40. Dorris, G.M., Dagenais, M., Douek, M., Boegh, K., and Allen, J., Use of distilled tall oil as a flotation collector in deinking mills. Pulp Pap. Can. 98(12):T469 (1997).
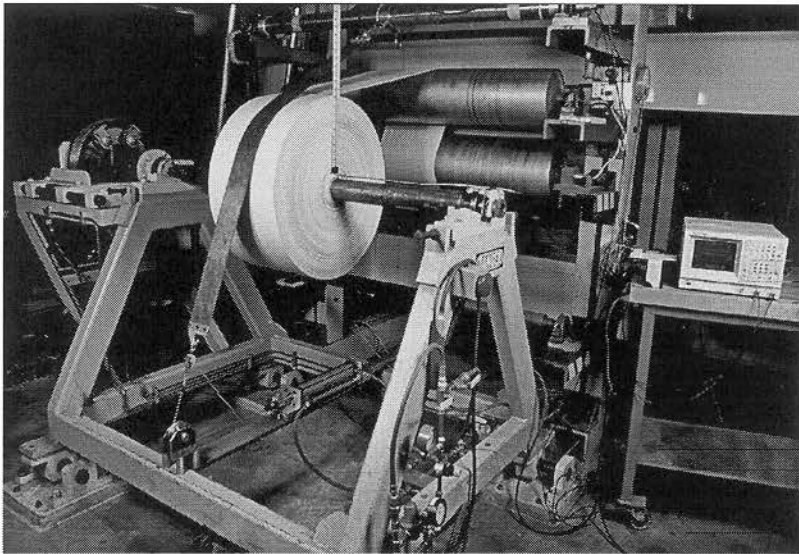
Figure 1. Unwind stand braked by a metallic band.
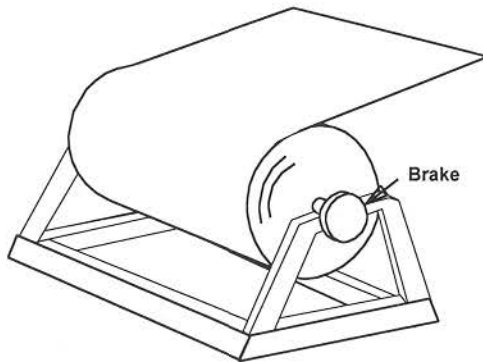
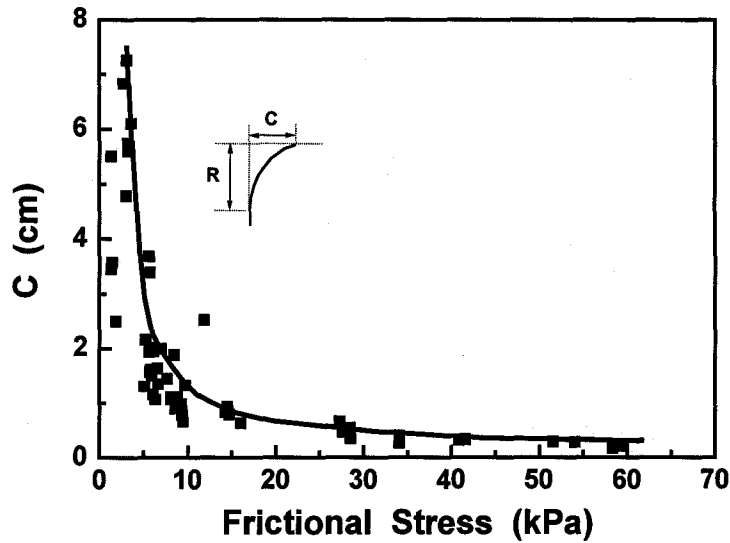**Figure 2.** Unwind stand braked through the core.

Figure 3. Relative movement of paper layers in a roll can be monitored with "J"-lines. "C" is the movement of the tip and "R" is the depth at which the movement starts. The size of the "J"-line is related to the frictional stress between paper layers (the product of coefficient of friction and interlayer stress) [5].
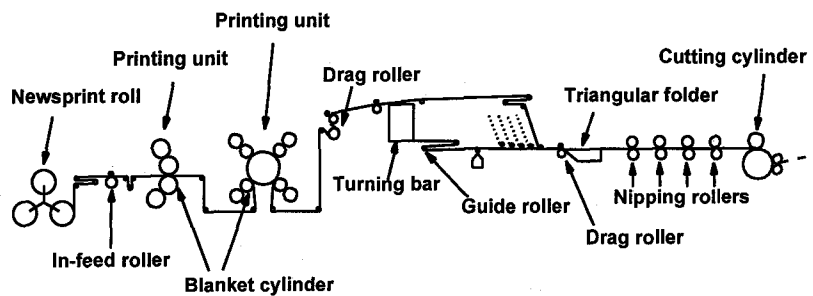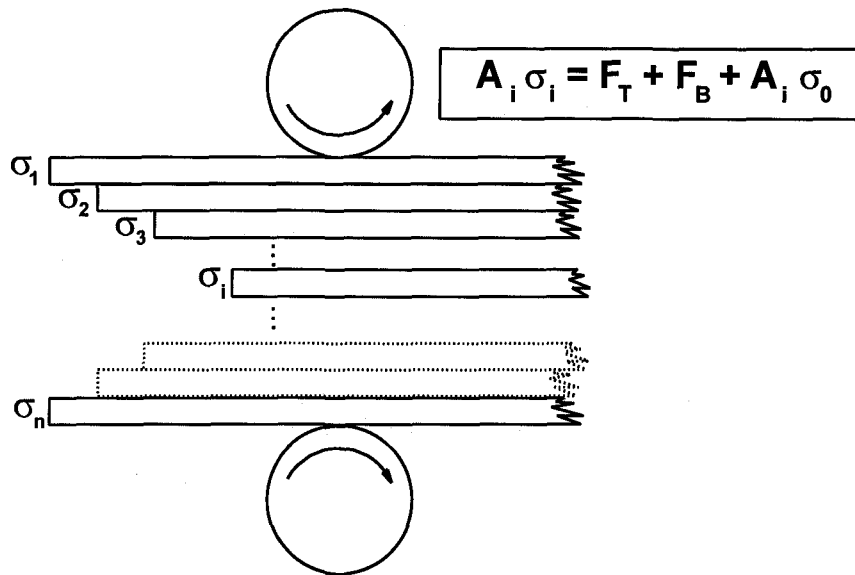

Figure 4. Web runs in a newsprint printing press.

$$A_i \sigma_i = F_T + F_B + A_i \sigma_0$$

Figure 5. The stress of an interior web in a multi-web nip is generated by the frictional forces of adjacent webs [11]. σ_i is the stress generated in the ith web by the nip. σ_0 is the stress of this web before the nip. A_i is the cross-sectional area of the ith web. F_T and F_B are the frictional forces exerted by the adjacent top and bottom webs, respectively.

$$\mu = \frac{F}{N}$$
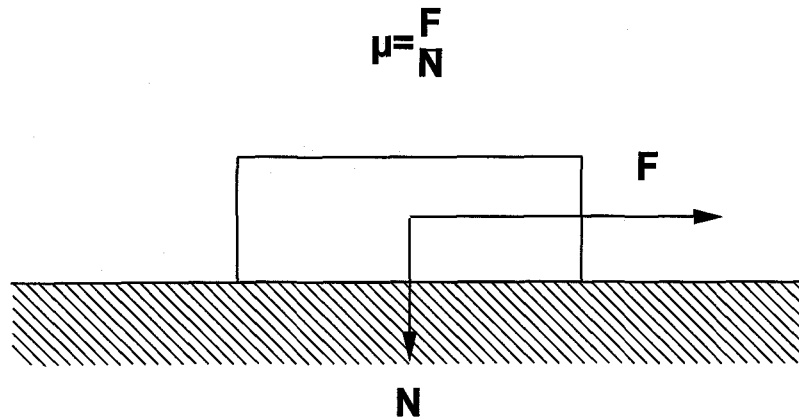
Figure 6. Horizontal plane method for measuring coefficient of friction.
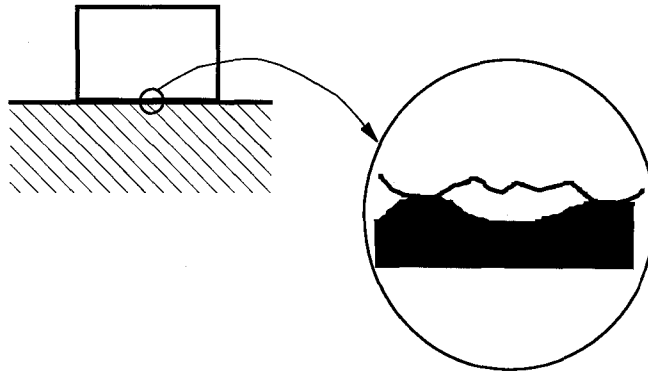
Figure 7. The actual contact area between two surfaces is small.
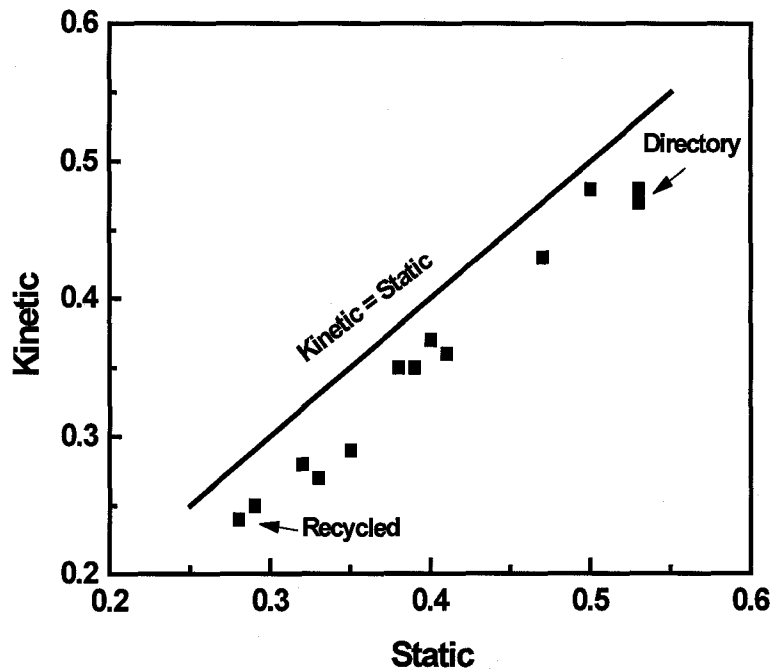
Figure 8. The static coefficient of paper is less than the kinetic coefficient of friction by a constant value [19]. Paper made from recycled fibres generally has low COF.
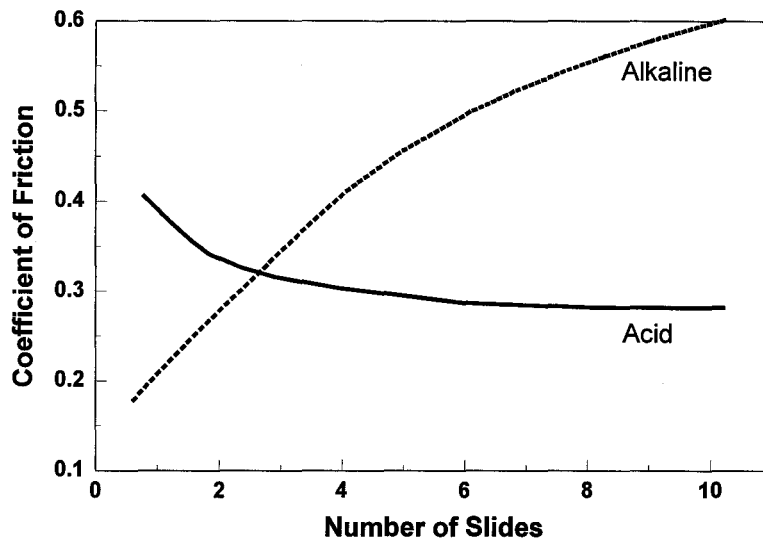
Figure 9. Coefficient of friction changes with number of slides.

Acid Paper

Hydro-carbon chains   Paper surfaces
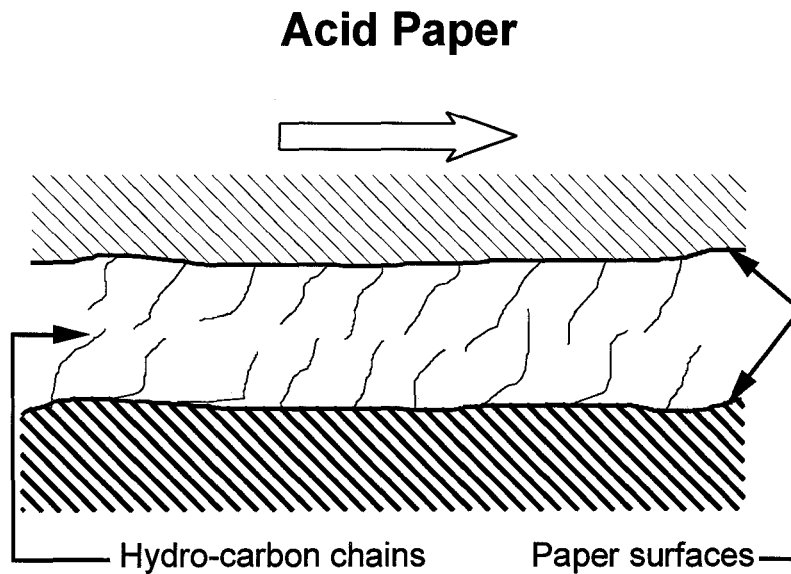
Figure 10. Hydro-carbon chains are probably aligned with sliding, lowering COF [33].

Alkaline Paper
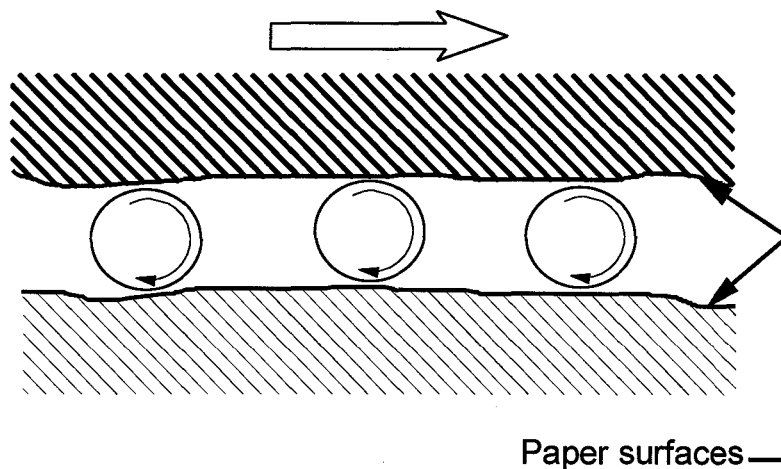
Figure 11. Free particles on the surface of alkaline paper provide lubrication [22].
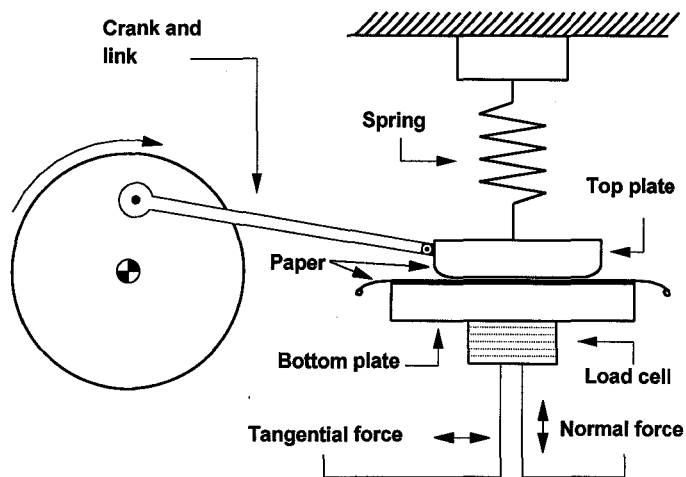
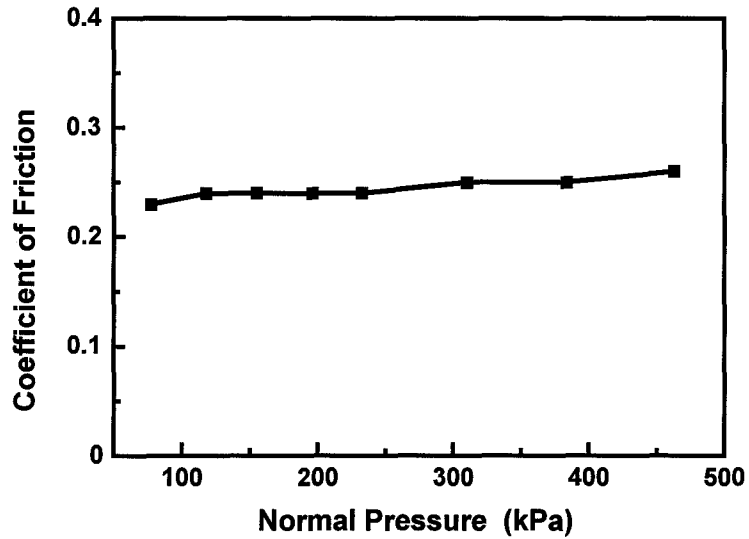**Figure 12.** Apparatus for measuring paper to paper coefficient of friction at high normal pressures and speeds [19].

Figure 13. Paper-to-paper coefficient of friction is independent of normal pressure [19].
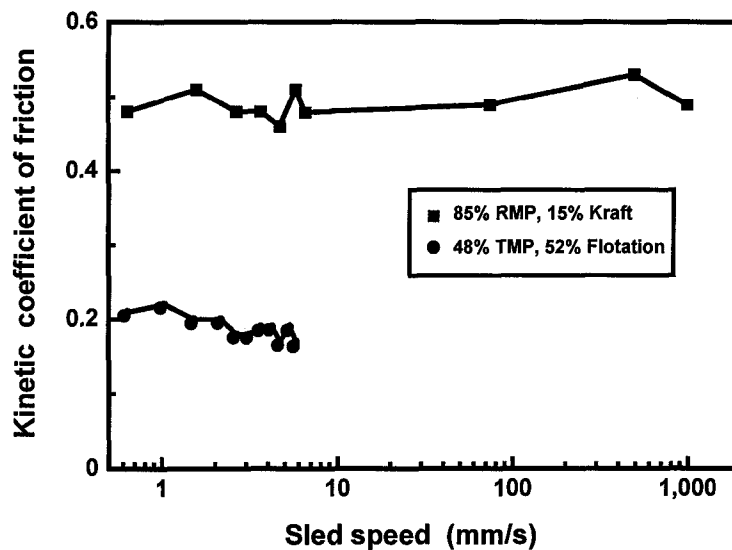

Figure 14. Paper-to-paper coefficient of friction is independent of measurement speed [19].
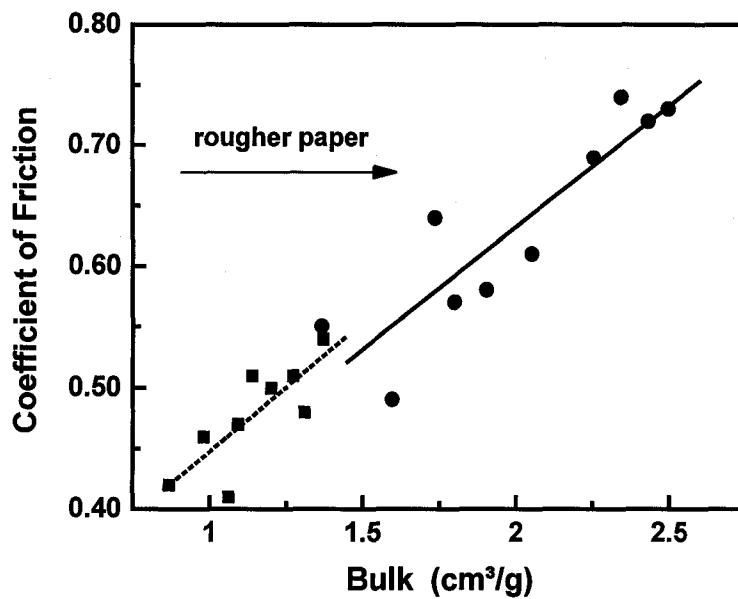
Figure 15. Rougher paper has a higher coefficient of friction but this cannot be exploited in commercial operation [19].
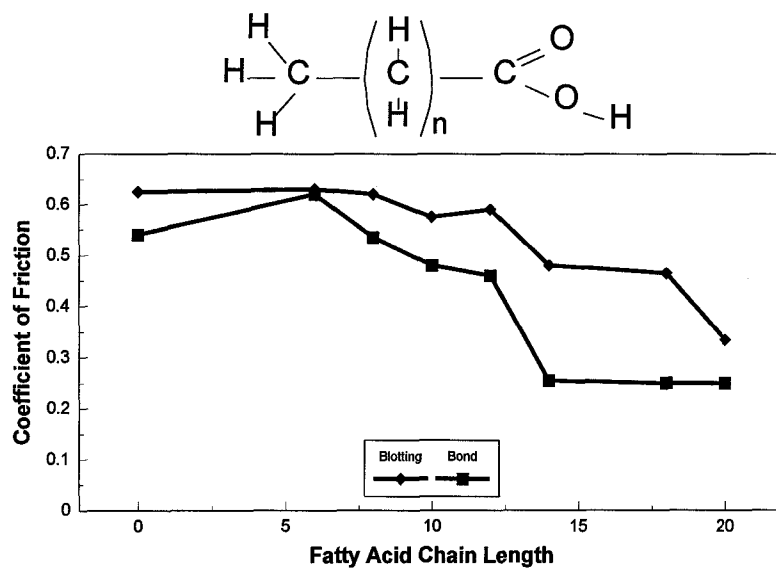

Figure 16. Hydro-carbons with higher chain lengths (n) on the surface of a material lower the coefficient of friction [33].
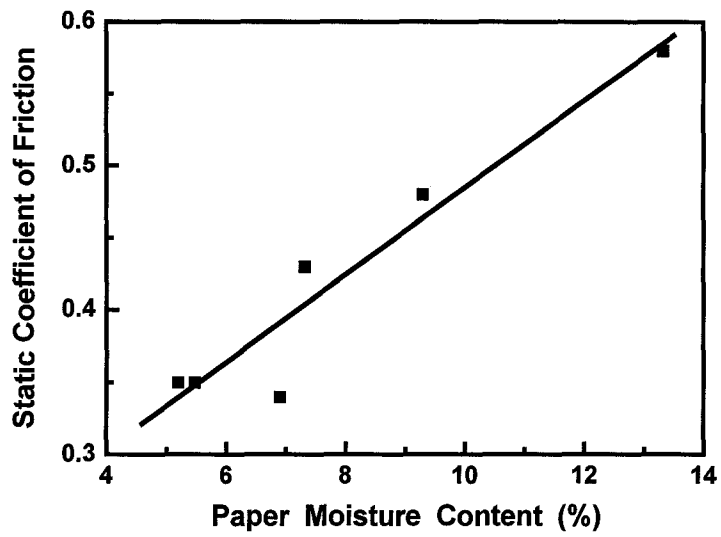
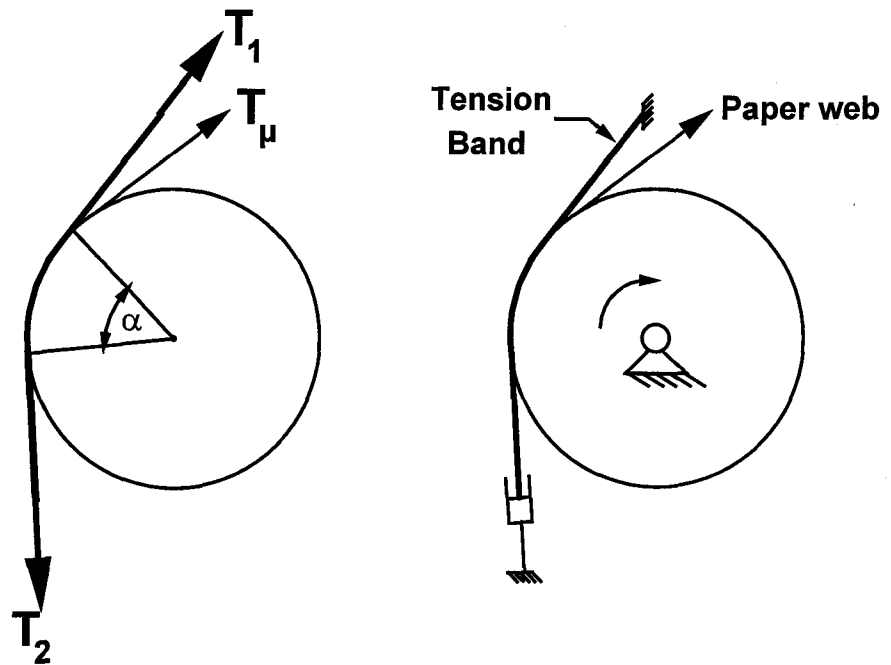**Figure 17.** COF increases with the moisture content of paper [19].

Figure 18. Force balance for a paper roll braked by a metallic band [2,3].

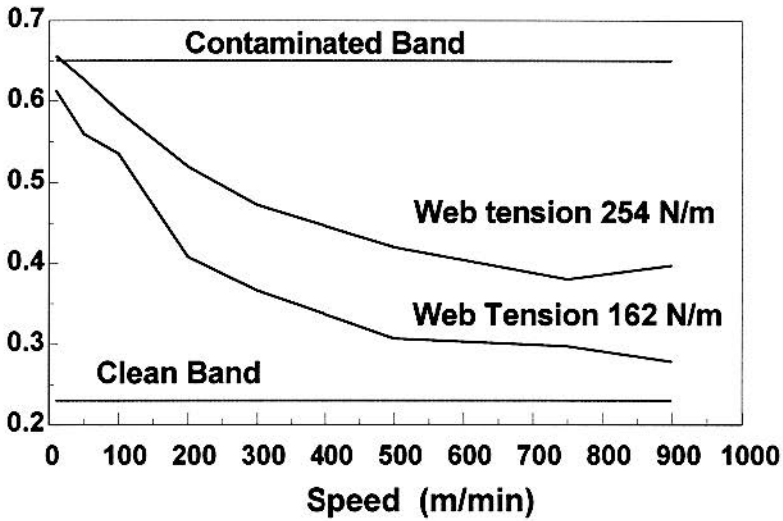## Paper to Band Dynamic Coefficient of Friction

Figure 19. The dynamic coefficient of friction between a metallic band and a paper surface decreases with increasing speed. Increasing the web tension, which requires a higher normal force to stop the roll, increases the COF [2,3].
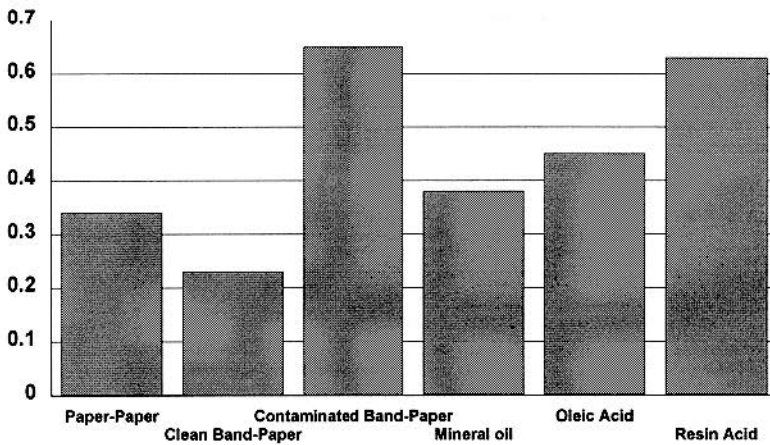
Dynamic Coefficient of Friction

Figure 20. The dynamic COF between a metallic band and a paper roll depends on the nature of material contaminating the band surface. Simulations with resin acids give the highest COF [2,3].

212

D. McDonald
Understanding Friction
6/8/99   Keynote - Session 2   8:30 - 9:20 a.m.

Comment - Steve Layne
In one of your slides you mentioned that the higher chain length fatty acids would lower the COF. Also you mentioned that after several subsequent slides that the higher chain lengths aligned to lower the COF.

Answer – D. McDonald, Paprican
The lower coefficient associated with fatty acids which have higher chain lengths is probably the result of more coverage of the surface. These experiments were done at a constant number of slides, not a single slide.

Question – David Pfeiffer, JDP Innovations Inc.
Is there a technique such as fluorescence that could be used to look at the surface of sheet of newsprint to find the distribution of fatty acids? My concept, as I have presented in previous meetings, about the J-line and crepe wrinkles was that there was intermittent motion among layers. In his paper Mr. Gueldenberg showed intermittent slippage between layers where certain areas held and others slipped relatively moving forward and backward in the nip. There must be an uneven distribution of these resin acids over the surface.

Answer – D. McDonald, Paprican
I am not aware of a technique that would allow you to easily look at the distribution on surface. When we extracted material off the metal band it was very difficult to pick out individual molecules. We could only look at families of molecules. You have to understand the complexity of it. I have of boiled it down to four classes of molecules but there are actually hundreds or thousands of different types of molecules so it's a very difficult problem in organic chemistry. My own feeling is that the distribution is uniform. I think it is friction with sliding, that is more related to the change in some papers small changes in initial movement cause some layers to be notably slippery.

Question – Jim Dobbs, 3M Company
In regard to your friction tester, most of us don't break our unwinds that way. Typically, there is single direction micro slip between web and roller. I just wondered if you are somewhat disturbed by the back and forth motion of your friction tester? Could you comment on that effect in terms of getting good values?

Answer – D. McDonald, Paprican
In that test we were just looking at a single, forward stroke.

Question – Jim Dobbs, 3M Company
Can you lift it and bring it back again?

Answer - D. McDonald, Paprican
No we couldn't because of the way it is loaded.

Comment - Jim Dobbs, 3M Company
But it would be better to go in one direction.

Answer - D. McDonald, Paprican
I may have confused you in this review because it includes a whole series of different experiments mostly done on lab instruments where you pull the block in one direction, and lift it into position for the next slide. The reciprocating instrument was used to look at loading pressure and speed. .

Comment – Jim Dobbs, 3M Company
Okay. That wasn't totally clear.

Question --Bob Lucas, Beloit Corporation
You had a slide that showed the effect of moisture content on the coefficient of friction, and it shows that with higher moisture content, friction is higher. I might expect that if you were testing a sample from a paper machine in operation I would expect that the higher moisture content would increase the plasticity in the machine direction and the result would be a lower coefficient. Could you comment?

Answer - D. McDonald, Paprican
On a relative scale the change in friction that you would get with a moisture change would be on an order of magnitude greater than that induced by surface modifications due to additional calendering.

Question - Dave Roisum, Finishing Technologies, Inc.
In some cases the coefficient of friction has been found to drop when we roughen the drums with traction coating. Can you comment on that? Particularly in grades like light weight coated.

Answer - D. McDonald, Paprican
I am not sure. That's a question for the Wayne Gretzy of Paper Surface Science.

Question:
In the classical sense of tribology, friction has several sources that include mechanical and chemical effects. Do you have any comments on the importance of the mechanical deformation of the surface asperities in the case of paper fibers? What kind of contribution do they have on friction of paper?

Answer - D. McDonald, Paprican
General experience is that the chemical nature of the surface dominates. I showed some examples where the mechanical nature of the surface can have an effect on the coefficient of friction. For example, the degree of calendering can change the COF. However, from a practical point of view you can't use it as a control tool. With some fillers, such as calcium carbonate, you can get free bodies that can lubricate the surface.

Question – Wolfermann, Technical University, Munich
Do you have any experience with the dynamic friction coefficient depending upon the pressure? Changing the pressure, may change the surface as well as the friction coefficient.

Answer – D. McDonald, Paprican

Changing the applied pressure does change the dynamic coefficient of friction. The data is shown in Figure 19. To maintain a force balance, increasing the web tension, increases loading pressure by that band which increases the dynamic coefficient of friction.