CONCERNING COEFFICIENT OF FRICTION

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FRICTION BEHAVIOR IS A RELEVANT ISSUE FOR PAPER GRADES FROM TISSUE TO LINERBOARD.

A COEFFICIENT OF FRICTION THAT IS TOO HIGH, TOO low, or simply inconsistent can be the source of serious (sometimes quite mysterious) problems of many sorts. A list of these problems could include such things as:

- Roll winding and rewind problems
- Crepe wrinkles within the roll
- Roll telescoping during transit
- Problems with web tracking and print registration
- No feed or multiple feed during sheet feeding
- Registration errors in die cutting or converting
- Corrugator runnability problems of several kinds
- Sliding on conveyer when product should not, and vice versa
- Stack and pallet instability, whether cartons, sheets, sacks, or printed materials.

On the more positive side, friction behavior can also be useful in differentiating a superior product from its competition. **Figure 1** shows the coefficient of friction for the first 30 sheets within reams of copier papers sold under six different brand names. Some are obviously more consistent than others. That is not an accident.

Friction behavior is a relevant issue for grades from tissue to linerboard. It may involve technical disciplines at several stages within the papermaking process. That being the case, a general understanding of friction behavior and issues can be a valuable asset for all.

COEFFICIENT OF FRICTION AND "SLIDE ANGLE"

A French scientist from the 1600s, Guillame Amontons, was the first to document the relationship that we call coefficient of friction. He observed that if one doubled the contact force between two objects, the force required to slide one with respect to the other also doubled. Within limits, there is a fixed relationship between contact force and sliding force. That relationship is called the coefficient of friction, COF. It is most generally represented by the Greek letter μ.

We differentiate between static and kinetic friction. "Static" refers to the force required to initiate sliding; "kinetic" refers to the force required to maintain sliding.

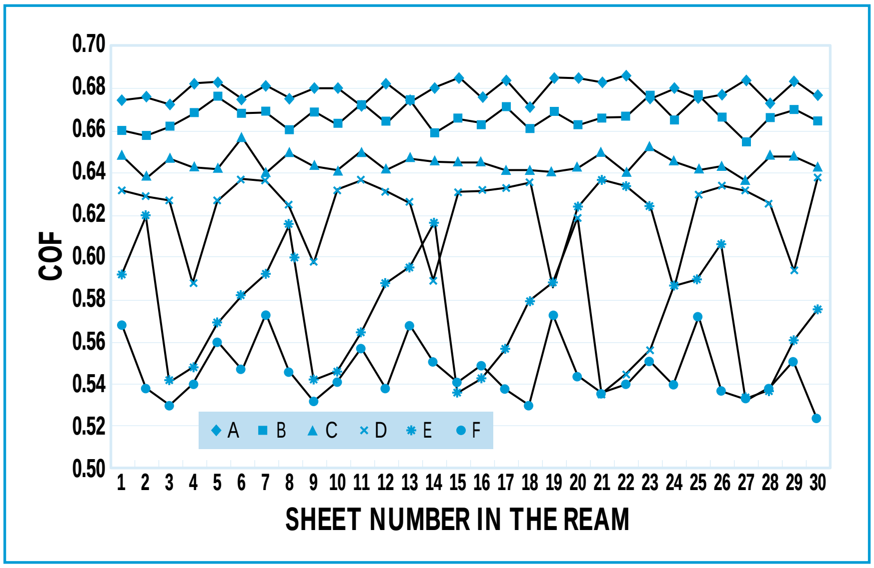
There is an alternative concept. Rather than measure contact force and friction force, one may place a sled on a flat surface, and then raise (tilt) that surface until the sled begins to slide. The sloped surface forms an angle with the horizontal that is referred to as the slide angle. The tangent of the slide angle is the coefficient of friction. (This concept is suitable for determining static friction only.)

Scientists as far back as DaVinci were interested in friction behavior and recorded their observations. We have come to refer to these as the laws of friction, but in fact they are not physical laws at all and are not strictly true. In reality, coefficient of friction can vary as a function of the normal force applied, temperature, humidity, speed of testing, and the material underlying the material being tested. The COF measured in a standard test is not necessarily that which will be experienced in actual application. If the conditions are different, friction will also be different. Standard tests provide an essential, consistent point of reference; they don't tell the whole story.

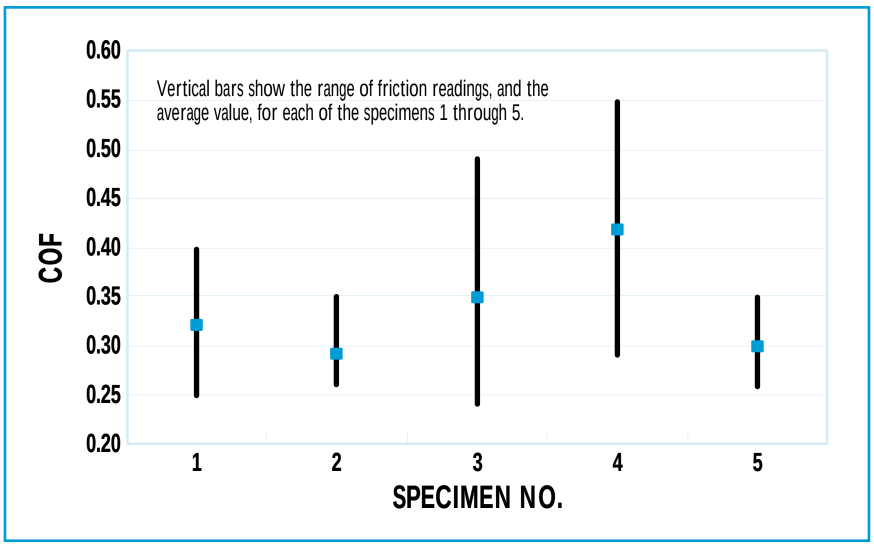
MEASUREMENT METHODS AND STANDARDS

More than one standard has been written for the inclined plane and horizontal plane methods of measurement. The various standards for each differ in amount of contact pressure, sliding distance, sliding speed, number of slides required, and backing material.

Unfortunately, tests conducted by conventional methods do not yield consistent results. A recent round robin conducted in Europe tells the story. When the same materials were evaluated by the TAPPI T 815 and T 816 methods at five different laboratories, the results varied significantly from lab to lab. The test report summarizes: "The differences between labs are very high, with a statistical range of ±50% of the mean round value (and) with a typical range of ±30%" *(1)*.



1. Static coefficient of friction for the first 30 sheets of paper in each of six reams of copier paper marked "A" through "F." Each data point is a single reading made with an ISO-based horizontal-plane instrument. Cyclical patterns occur because multiple rolls with different friction values are sheeted into the same ream.



2. Round robin results for five inclined-plane instruments and five specimen linerboards. Vertical bars show the range in results from minimum to maximum.

Results for five different materials, evaluated on five different inclined-plane instruments, are shown in **Fig. 2.** These results are not atypical. Tests run in different labs by different technicians often yield significantly different COF values. Research by Johansson, et al., at the Swedish Pulp and Paper Research Institute (STFI) *(2)*, reveals that there are in fact significant variables not controlled by the existing standards.

Based in part on the STFI research, an international working group has prepared an ISO standard for the measurement of coefficient of friction of paper. ISO 15359 sets procedures and requirements for:

- Contact-free handling and mounting of the test specimens
- Automatic placement of the sled
- A specified rest time
- A specified ramp time
- Backing materials
- Control of sled twist (yaw)
- Elimination of stick-slip in the sliding portion of the test
- Higher sliding speeds.

These changes remove the operator as a variable in the test and yield results that are markedly more consistent. An example of an ISO-based horizontal-plane, static-only instrument is shown in **Fig. 3.** The TAPPI Test Methods will eventually be harmonized to conform to the ISO requirements.

CONTROLLING COEFFICIENT OF FRICTION OF PAPER

A theory of friction

Thus far, we have talked about the meaning of coefficient of friction and how to measure it; we have not considered why it varies, or how to change it and control it. Our instincts about what makes friction "high" or "low" can be misleading. A rational model for friction behavior, such as the adhesion theory advanced by Bowden and Tabor *(3)*, can be helpful. This model portrays friction force as the product of area of contact times cohesive strength. Contact area is a smoothness and surface compliance issue. We are sometimes surprised when a smooth paper has higher COF than a rough paper, but the model illustrates why that can easily be the case. Cohesive strength is a surface chemistry issue. Anything that reduces cohesion at the surface reduces COF. The oils present on one's hand are sufficient to cause a marked reduction in COF.

Three situations representing different approaches

Friction problems arise in a variety of circumstances and from a variety of causes. In some instances, the solution is quite simple and straightforward. In others it can require a more sophisticated approach. Three cases will illustrate.

Case 1. The weather changes, and suddenly a paper that had run well won't run at all. This is not an uncommon nor surprising situation. Relative humidity in an uncontrolled environment can change (even during the course of a day) from less than 50% RH to more than 90% RH. Under these circumstances, COF for linerboard can increase 40-50%, and that for newsprint can more than double. Is it any wonder that friction problems can be cyclical or seasonal? The most direct solution is, of course, to control the environment.

Case 2. The paper (or board) has an inconsistent or low COF due to high levels of post-consumer recycled content or use of a particular filler or coating. Overall properties of the paper are good, but coefficient of friction must be raised and controlled to meet runnability or functional requirements.

The answer here is often an anti-skid agent applied late in the papermaking process (after the web is dried) or in converting processes. Anti-skids are of two general kinds: polymeric; and colloidal silica or alumina. These materials have been around for a long time and are widely used. Many suppliers of chemicals to the paper industry have a product of this type. Effectiveness generally increases with rate of application—but only up to a point. Along with the benefits there are some concerns: misting and dusting, cleanup, presence of VOCs, and perhaps health risks. The products do differ, so work with the suppliers to select the right product and to optimize its application.

Case 3. The paper is a highly engineered product in which a filler, coating, or size is used to achieve special properties. Friction behavior is designed into the paper along with the other properties. If there is a problem with friction in this instance, one must begin to take into serious account the cohesive properties of the material that exists at the very surface of the paper and the effect of materials within the paper that influence the surface material. It is a subject that requires very specialized knowledge, but it can be valuable for the rest of us to at least have a conceptual understanding of the mechanisms at work.

The literature tells us that clean paper fiber has a relatively high COF on the range of 0.600 to 0.700, and that "low friction" problems are caused by the presence of "fatty acid" compounds in the furnish that migrate to the surface of the sheet as drying takes place. These compounds have a low cohesive property and can greatly reduce the coefficient of friction.

One approach to dealing with this problem is the use of fillers that can "capture" the fatty acids and hold them within the sheet, preventing their collection at the surface. This approach has been shown to be effective in improving COF. Not all fillers behave in this way, however, and some actually reduce COF.

For a better understanding of this subject, see an article by M. C. Withiam in *Tappi Journal (4)* and one by Ernst Back in the proceedings of the 1991 TAPPI International Paper Physics Conference *(5)*.

3. A horizontal plane, static friction instrument, based on ISO 15359. Sled is automatically "placed" by cantilever arm. Moving table creates and measures COF, reported in display.

A RECOMMENDATION

There are several parts to this, but I call it one recommendation because it is actually a package. I believe this approach can be helpful in reducing the incidence of friction-related problems and eliminating the mystery surrounding them when they do occur. It can lead to a more consistent product and to better understanding between papermaker and converter. My suggestions are to:

- Be aware that COF is important to the runnability of the paper you work with and the performance of your product.
- Be aware that COF is sensitive to changes you cannot see or feel.
- Include COF as one of the paper properties routinely measured.
- Relate COF to the operating parameters of your equipment. Keep records so that you can compensate for changes in paper properties.
- Work out a reasonable specification for COF—and hold to it.

The tools are in place. I believe you will find the time and effort to be worthwhile. TJ

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