INFLUENCE OF COATING PROPERTIES ON PAPER-TO-PAPER FRICTION OF COATED PAPER

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ABSTRACT

Coated paper-to-coated paper friction properties were examined in relation to printing runnability troubles like erroneous double feeding of paper sheets. Higher calcium carbonate (PCC) ratio to clay in mixed pigment coatings resulted in higher static and kinetic COFs. Micro-roughness in the order of pigment particle size is considered to relate to it, as cube-shaped particles of PCC resist sliding. Calendering decreased COF at larger amounts of PCC, but did not change at all COF of the sole clay formulation. Addition of GCC decreased COF. The rate of decrease in kinetic COF with increasing the number of sliding for the GCC-rich formulation was higher than that for the PCC-rich formulation, presumably because protruding parts, characteristic of the GCC-rich formulation, in the surface was selectively flattened. Addition of SB-latex up to 14 pph decreased COF, but static COF had the highest value at 18 pph. An anti-slip property as a rubber of SB-latex developed only in the static mode. Among lubricants used, the wax type decreased COF the most remarkably with more effects on kinetic COF than on static COF.

INTRODUCTION

Paper-to-paper and paper-to-other material frictions are related to many sorts of issues regarding printing runnability, print quality and printing press design. High friction is desired in high-speed printing to maintain good register. Erroneous double or multiple feeding of sheets of paper is a serious trouble involved in copiers and personal printers as well as in commercial printing presses and industrial OCR. In every case, anyway, it is very important to keep paper friction properties constant and stable because modification of hardware require much more efforts to adjust the printing system.

As far as erroneous double feeding is concerned, there are many possible factors involved; coefficient of friction between rubber roll and paper and between paper sheets, attraction occurring between paper sheets due to static electricity and so on. On the other hand, demands for coated paper in market are growing with the aim of high print quality. As quantity of consumed coated paper increases, it has more occasions to be processed through a variety of sheet feeders. This study focuses on coefficient of friction (COF) between coated papers, so coated paper properties that are likely to influence the COF were chosen and examined.

As for uncoated paper, several properties influencing COF were reported. For pulping and bleaching, Kappa number did not affect friction properties despite differences in surface energy[1). For papermaking and paper properties, beating does not significantly affect friction, but the author demonstrated that surface rigidity enhanced by beating increased COF slightly[2]. Rough/rough surfaces showed a lower static COF than smooth/smooth surfaces for paperboard handsheets, as indicates that the interlocking of surface asperities was not a factor[3]. For fillers, common fillers such as hydrous kaolin and talc decreased kinetic COF; calcined kaolin and, in particular, synthetic precipitated silicas and silicates increased it. Filler size and shape were considered to be dominant factors[4]. For surface chemistry, wood extractives like long-chain saturated fatty acids, fatty alcohols and tristearin reduced COF most efficiently[5].

EXPERIMENTAL

Materials

Coating colors were prepared from following materials. Clay (UltraWhite-90, Engelhard, USA) has a mean diameter of ca. 1.5 μm. Precipitated calcium carbonate (PCC, Brilliant-15, Shiraishi Kogyo, Japan) has a mean diameter of ca.0.4 μm. Ground calcium carbonate (Softon-1500, Shiraishi Kogyo) has a mean diameter of ca. 1.5 μm with a broad distribution. Styrene-Butadiene (SB)-latex (LX407G, Nippon Zeon, Japan) has a mean diameter of 100 nm and a glass transition temperature of 15 °C. Starch (phosphoric ester type, P-140, Oji corn starch, Japan) as a co-binder, dispersant (polyacrylate T-40 Toagosei, Japan) and sodium hydroxide (special grade, Wako Pure Chemical Industries, Japan) were also used.

Lubricants used are three types of dispersions. Stearate A (Nopcote C-104-HS, San Nopco, Japan) is a calcium salt of higher fatty acid. Stearate B (SN-Cote 231) is also a calcium salt of fatty acid with a shorter hydrocarbon chain. The wax type (SN-Cote 950) is an polyolefin. They are not originally developed to reduce COF, but to improve releasing from rolls, wet ink acceptance, antidusting at supercalender rolls.

Coating colors and coated paper

Four series of coated paper was prepared. Table 1 shows the formulation of three series of pigment mixture of the coating color. The first series (#1-#5) contains different ratios of clay and PCC. Coat weight ranged from 10 to 13 g/m^2. The second series (#6-#9) contains different ratios of PCC and GCC at a constant level of clay. Coat weight ranged from 18 to 24 g/m^2. The third series (#10-#13) contains different contents of SB-latex. Coat weight ranged from 10 to 13 g/m^2. Table 2 shows that for different types of lubricants all at 2 pph. Every material but SB-latex was dispersed with a centrifugal disperser (two combined rotations on the container's and the disperser's axes, hybrid mixer HM-500, Keyence Corp., Japan) for 20 to 40 min in total at adequate intervals to prevent temperature rise. SB-latex, which tends to be cohered easily by hard dispersion, was added last and dispersed for 10 s.

All of the coating colors were applied to woodfree base paper of 63.7 g/m^2 basis weight with a wire bar #7 using a motor-driven draw-down coater (YOA-B, Yoshimitsu Seiki, Japan). Then, they were hot air-dried for 1 min. All of the coated paper, unless mentioned, were calendered with a laboratory calender (No.2232, KRK, Japan) equipped with a pair of a steel and a neoprene rubber rolls at a linear pressure of 14.7 kN/m and a speed of 2.5 m/min. Surface temperature of the steel roll was ca. 60 °C.

Measurement

Surface roughness was determined as a centerline average roughness calculated from surface profiles measured by a confocal laser scanning microscope (CLSM) (VF-7500, Keyence Corp., Japan) or by a stylus profilometer (SE-3, Kosaka laboratory, Japan). Also, Bekk smoothness was measured using Oken type tester (modified Bekk characterized by hydraulic pressure difference practically measured in place of time). Gloss was measured by a portable-type glossmeter (Multigloss-268, Minolta, Japan). Micrographs were taken with a scanning electron microscope (S-4000, Hitachi, Japan) and with the CLSM.

Friction tests were made with two types of apparatus. One was a friction sensitivity tester originally designed for fabric texture (KES-SE, KatoTech, Japan). The dimension of a test piece on the sled was 70 mm in length and 35 mm in width. That on the table was 40 mm in width. The sliding speed, the vertical pressure and the sliding distance were 10 mm/s, 1.98 kPa and 35 mm. The other apparatus was an automatic friction coefficient testing machine (Sagawa Manufacturing Inc., Japan). This machine is designed in conformity with ISO 15359. All of the testing conditions in measurements followed also the ISO standard. In results, the first and the third static COF and the third kinetic COF will be mainly shown. The sliding speed was 0.2 mm/s for the static COFs and 20 mm/s for the kinetic COF. **Figure 1** represents the sled and the table of this machine. A step motor drives the table accurately and precisely. Setting of a test piece onto the sled is automated and can be performed easily without any touch of the test piece. Every friction test was performed under the standard condition, 23 °C and 50 % r.h.

RESULTS AND DISCUSSION

Ratio of Clay, PCC and GCC

Figure 2 shows that static and kinetic COFs increased with increasing the amount of PCC, for both the calendered and the uncalendered samples. **Figure 3** shows roughness measured by the CLSM and 85 ° ISO gloss. Only from a standpoint of roughness, there seems to be a trend that rougher surfaces provided lower COF for the calendered samples. But, calendering did not only smoothened the surface, but made the surface structure closely packed. Note that high density and rigidity resulting from the packing might be a more dominant factor. Another possible factor is pigment particle shape. Cube-shaped particles of the rhombohedral PCC might have resisted sliding. Practically, larger oscillations, namely, more intensive stick-slick behavior was observed in the friction change during sliding, characteristically of PCC-rich samples. To paraphrase it, roughness in the particle size range what is called micro-roughness is closely related to COF. With regard to calendering effect, calendering decreased COF more remarkably at larger amounts of PCC, but no effect was observed with the sole clay formulation. Importance of microstructure was stated in the reference[6)]. In the reference, the use of clay particles with different average diameters had no marked effect on the friction properties; a great difference was however noted between papers coated with kaolin and with $CaCO_3$; and significant differences were also detected when using calcium carbonate particles of different shapes.

It concluded that it was the particle shape and its influence on the surface microstructure that was of importance.

Figure 4 shows a GCC effect on COF. The automatic friction coefficient testing machine was used to measure COF for only this series of coated paper. So, static COF was much lower than those shown for the other series of coated paper, because the sliding speed was as low as 0.2 mm/s for this series in spite of 10 mm/s for the rest. Addition of GCC decreased the third static COFs and the kinetic COFs, though it did not affect the first static COF significantly. The first to the third kinetic COFs indicate that kinetic COF decreased with increasing the number of sliding for the GCC-rich formulation, but, in contrast, it was unchanged or rather surprisingly increased for the PCC-rich formulation. The GCC contains large particles and one might predict these large particles would obstruct smooth sliding. **Figure 5**, in practice, shows that centerline average roughness increased and gloss decreased both with increasing the amount of GCC, but unexpectedly, GCC addition facilitated sliding. About roughness, there are some articles that stated it decreased COF[3)]; and there are others that stated it increased COF. With uncoated sandpaper-molded handsheets prepared so all of the properties other than roughness would be equal, roughness increased COF with the exception of the very rough sheets[2)]. More discussion must be made after serious consideration on contact area between two facing sheets of paper tested, plastic and elastic deformability of surfaces and adsorption of water molecules on surfaces and so on. For coated paper, plastic deformability of surfaces seems to be very important as micrographs of the surfaces imply.

Figure 6 is a scanning electron micrograph showing a surface of the coated paper (20 pph of GCC) after friction measurement. The test piece was set on the table and subjected to three times of sliding, one measurement sequence. Some scratches due to sliding are observed to run in the horizontal direction, namely, the sliding direction. The center of the surface indicated by an arrow seems to have been scarified probably by large particles on the counter test piece set on the sled. Scarification is likely to occur more often with coated surfaces with more GCC added. But, more commonly, scratched and deformed parts had flatter surfaces like an area in the lower right-hand corner, suggesting that it would permit smooth sliding afterwards. Practically, Bekk smoothness increased after friction measurement for all these coated paper samples.

Figure 7 shows surfaces of the coated paper (10 pph of GCC) after friction measurement. The test piece had been set on the sled. Image (A) was acquired with a conventional CCD camera. Considerable number of scratches due to abrasive sliding can be observed at the upper left near the center of the image and some abrasion also can be seen at the upper right. Image (B) captured by the CLSM shows a contour map of the identical location of the sample. In this image, whiter areas represent higher elevations. The two images confirmed that the location of scratches agreed well with that of zones at high elevations. Actual contact generating friction in sliding occurs with higher or protruding parts of each test piece. The rest of it that occupies most of the surface is not contacted or loosely contacted.

Content of SB-latex

SB-latex is a kind of rubber, so addition of SB-latex was likely to increase COF. **Figure 8**, however, shows that addition of SB-latex up to 14 pph decreased COF. The static COFs had the highest COF at 18 pph. The property as a rubber appeared only in the static mode. Regarding roughness as shown as Bekk smoothness, the third kinetic COF, in particular, correlated well with smoothness. This result reversed the relationship with the previous series of the GCC-containing coated paper. To discuss roughness effects on COF further will require more data and consideration.

Lubricant effects

Figure 9 shows lubricant effects on COF. The wax type reduced COF most of the three. When compared between static and kinetic COFs, the lubricants reduced kinetic COF more effectively. In particular, the wax type reduced it by 44 %. The effects of lubricants were well explained and discussed in the past research[5].

CONCLUSIONS

Coated paper-to-coated paper friction properties were examined. Higher PCC ratio to clay in mixed pigment coatings resulted in higher static and kinetic COFs. Micro-roughness in the order of pigment particle size is considered to relate to it, as cube-shaped particles of PCC resist sliding. Calendering decreased COF at larger amounts of PCC, but did not change at all COF of the sole clay formulation. Addition of GCC decreased COF. The rate of decrease in kinetic COF with increasing the number of sliding for the GCC-rich formulation was higher than that for the PCC-rich formulation, presumably because protruding parts; characteristic of the GCC-rich formulation, in the surface was selectively flattened. Addition of SB-latex up to 14 pph decreased COF, but static COF had the highest value at 18 pph. An anti-slip property as a rubber of SB-latex developed only in the static mode. Among lubricants used, the wax type decreased COF the most remarkably with more effects on kinetic COF than on static COF.

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Table 1 Coating color formulation of the series of pigment mixture

Ingredient	Added amount, pph												
<Color #>	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Clay	0	30	50	70	100	70	70	70	70	70	70	70	70
PCC	100	70	50	30	0	30	20	10	0	30	30	30	30
GCC	0	0	0	0	0	0	10	20	30	0	0	0	0
SB-latex	10	10	10	10	10	10	10	10	10	6	10	14	18
Starch	2	2	2	2	2	0	0	0	0	2	2	2	2
Dispersant	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	1	1	1
Sodium hydroxide	0.01	0.01	0.01	0.01	0.01	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.01
Solids, %	45	47.5	50	52.5	55	45	47.5	50	52.5	54.7	55	55	54.2

Table 2 Coating color formulation of the series of lubricants

Ingredient	Added amount, pph		
Clay	70	70	70
PCC	30	30	30
SB-latex	10	10	10
Starch	2	2	2
Lubricant			
- Wax type	2	0	0
- Calcium stearate A	0	2	0
- Calcium stearate B	0	0	2
Dispersant	0.1	0.1	0.1
Sodium hydroxide	0.01	0.01	0.01
Solids, %	55	55	55

Fig. 1 Sled and table of the automatic friction coefficient testing machine

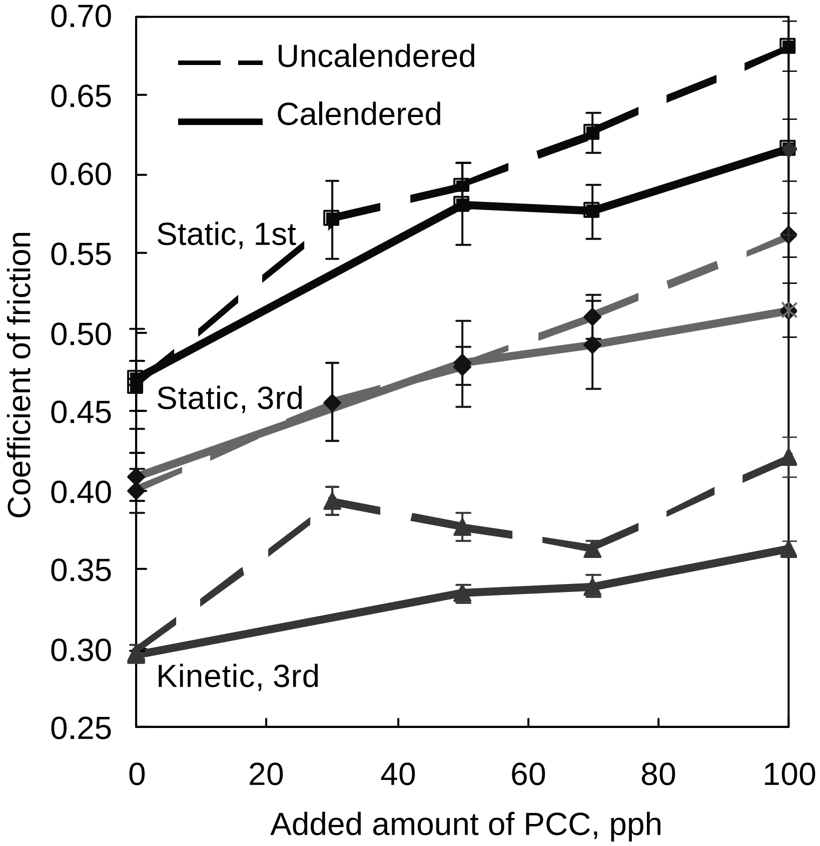


Fig. 2 Influence of PCC / Clay ratio on COF
(Bars indicate 95 % confidence level in every graph.)

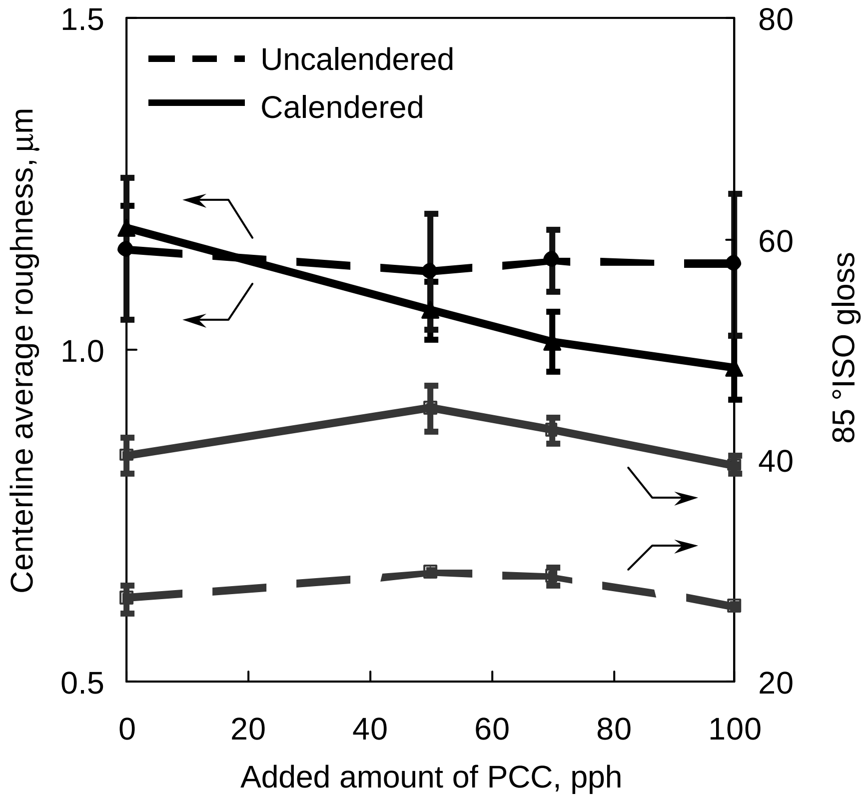


Fig. 3 Roughness and gloss of PCC/Clay series of coated paper

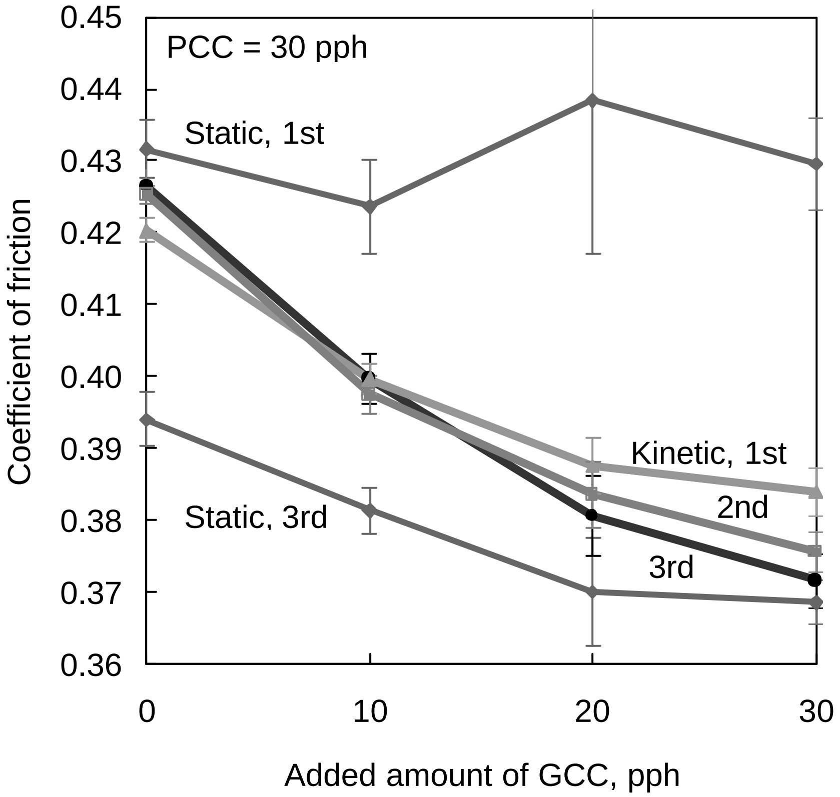


Fig. 4 Influence of GCC content on COF

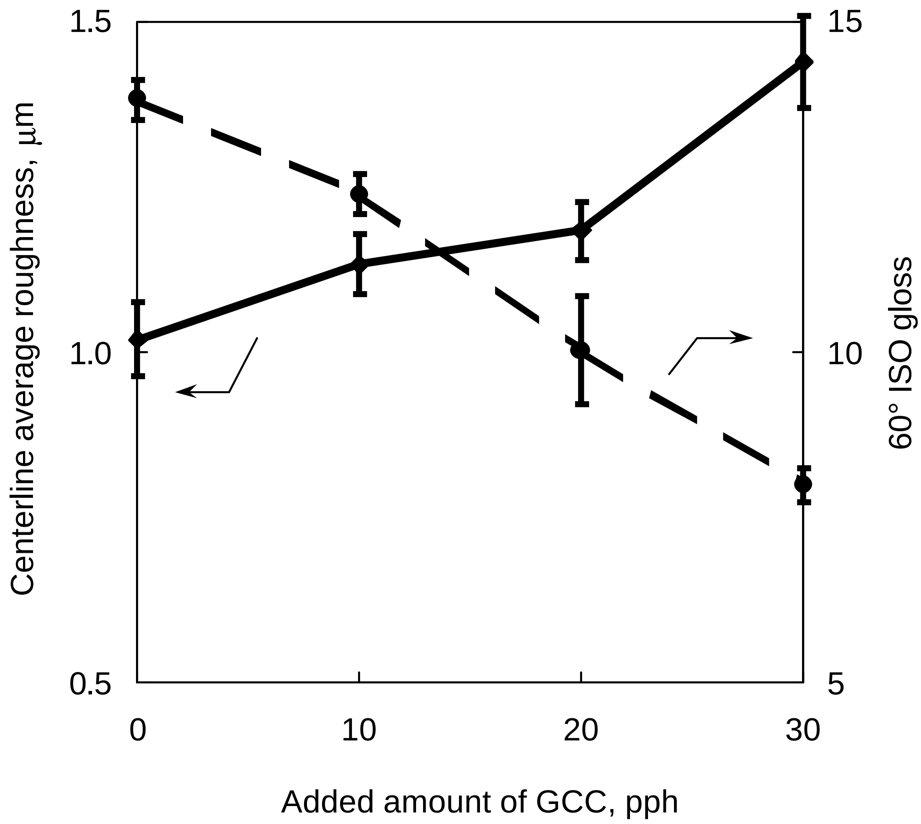


Fig. 5 Roughness and gloss of GCC containing coated paper

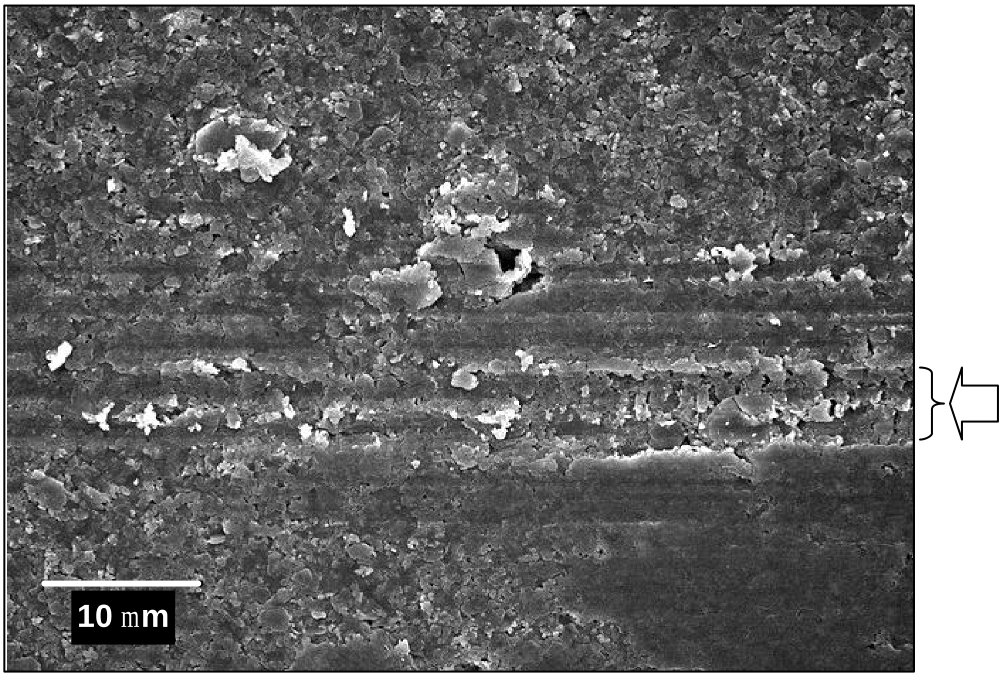
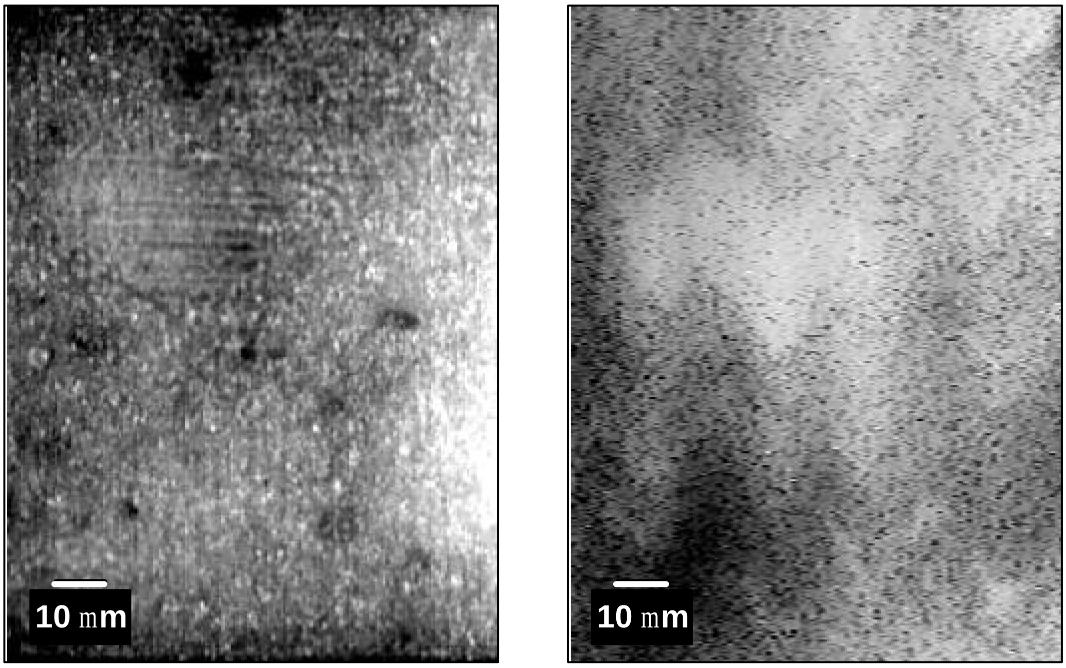


Fig. 6 Surface of on-table test piece of coated paper (20 pph of GCC) subjected to three times of sliding obtained by scanning electron microscopy.



(A) CCD-camera image (B) Profile image

Fig. 7 Surface of on-sled test piece of coated paper (10 pph of GCC) subjected to three times of sliding. Images (A) and (B) are of the identical location.

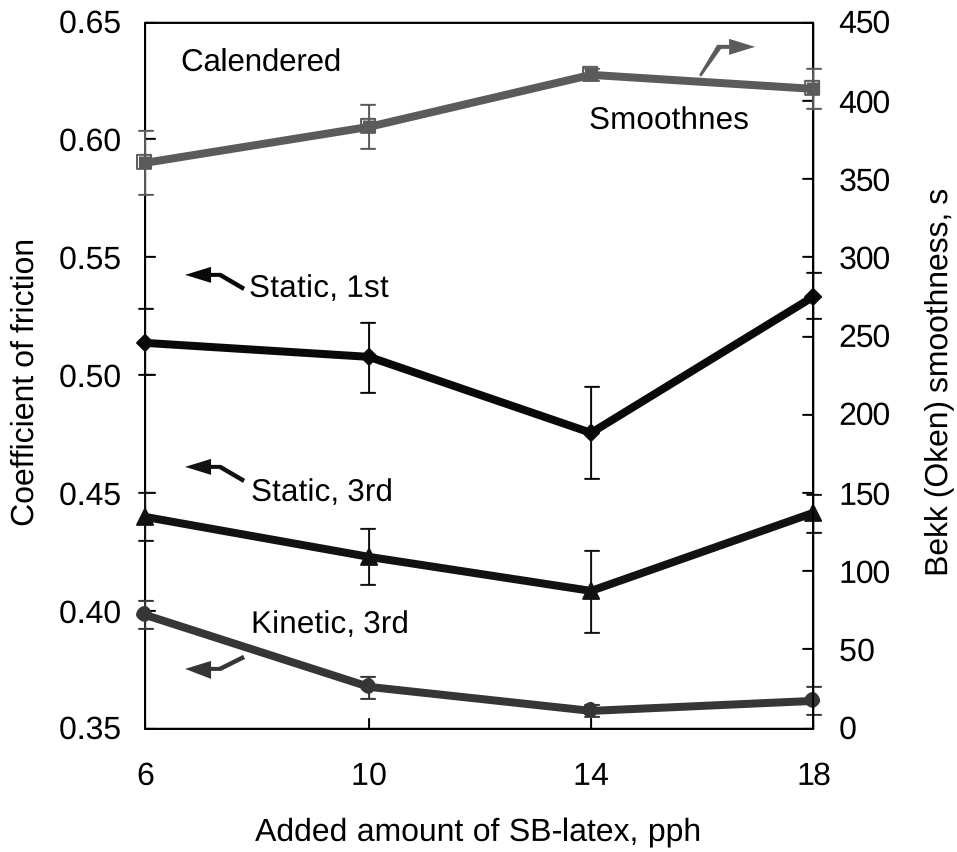


Fig. 8 Influence of SB-latex content on COF

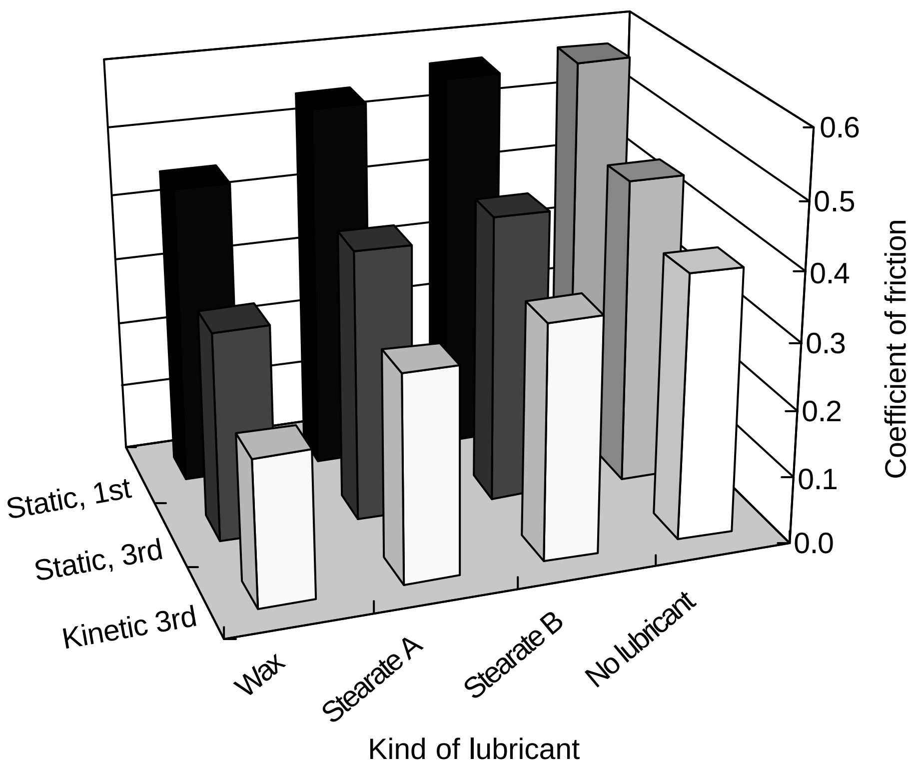


Fig. 9 Influence of lubricants on COF