Study on the Slide Angle, Gloss, and Rub Resistance of UV Non-Skid Coatings

Dimitri Ploumidis*

Keywords: Coating, ink, UV, rub, slip

Abstract

Coatings are used in order to enhance the visual appeal of a package, as well as to provide certain functional elements related to its performance throughout the processing line of the printer/converter and end user. This study examines the performance of UV coatings for packaging applications, as determined by the amount of friction, expressed as degrees of slide angle; durability, expressed as number of rubs; and gloss levels. These performance parameters are determined by the formulation of the coating, but they are also affected by a number of other variables. In this study, the examined variables are two substrates, different ink formulations, different amounts of radiant energy, two coating formulations, and the amount of time off the press. It was found that for UV non-skid coatings, both the substrate and the amount of radiant energy significantly affect the slide angle of the package. Additionally, there is a strong inverse relationship between the slide angle and rub resistance; however, the greater the number of variables involved in the relationship between slide angle and rub resistance, the weaker the correlation. No relationship between gloss levels and any of the other variables was found. Finally, the variability in slide angle testing and its correlation with rub resistance is being discussed.

---

*Pacific Southwest Container

Introduction

The application of UV coatings in single face laminated boxes serves multiple purposes. Their high-gloss appearance enhances the visual appeal of the product and they provide protection as they form a very resistant layer. In addition, UV non-skid coatings, by the frictionizing agents in their formulation (waxes and silicones), determine the slip properties of the product. Being able to specify such performance characteristics for each customer and application is a challenge, as it has to take into account all the structural elements of the package like substrates, inks and coatings, the light source, a variety of press variables, and environmental conditions that are often uncontrollable.

What is found to be even more challenging is that certain markets demand products that simultaneously satisfy the requirements for increased durability, gloss, and high slide angle. This requirement could be the most difficult to meet, as the increase in friction by waxes and silicones could potentially result in damage or decrease of gloss when the boxes rub against each other. Researching the relationship between these properties could be the most valuable aspect of this research. Additionally, the influence of different stocks and different amounts of radiant energy will be examined.

Literature Review

When UV inks and coatings are exposed to a UV light source, the photoinitiators absorb the light energy from certain wavelengths and form free radicals, which cause monomers and oligomers to polymerize instantaneously forming a film with high abrasion resistance, no smearing, and high gloss. If the amount or type of UV energy is not sufficient to penetrate the ink and coating film and cause polymerization, then a certain portion of the film will remain "uncured" and wet. This effect is more obvious with thick ink films and especially dark pigments that absorb the light and prevent its penetration to the bottom of the film (Rousu, Gustafsson, Preston, and Heard, 2005; Arceneaux, and Willard, 2007).

“Curing” can be a misleading term as it attempts to describe both the chemical reactions of the product and the physical characteristics related to its performance. For the purpose of discussion in this paper, “chemical cure” refers to the conversion of reactive groups to create a network of polymers. “Physical cure” refers to whether the performance of the product meets the requirements of the customer, abrasion and chemical resistance, surface energy, gloss, and friction. The controversy lies in that while the physical cure is either acceptable or not, chemical cure is achieved at various degrees: no ink or coating converts at 100% and some materials are formulated to perform with conversions as low as 70% or 80%. The lack of a “perfect” cure means that certain portions of the ink and coating remain wet and this might result in unacceptable performance. Assessing the degree of cure, however, is not always practical on a production environment, and there is uncertainty regarding what is acceptable or whether the product is sufficiently cured (Raymont, 2001).

Nevertheless, there are ways to measure the process and reduce the uncertainty, starting with monitoring the effectiveness of the UV system. Towards this end, there are two important variables, irradiance and radiant energy. Irradiance is the radiant power that arrives at the surface of the substrate and is relevant to a particular wavelength range. It is expressed in W/cm^2 and is essential to penetrate pigments, provide depth of cure, and allow adhesion to the substrate. Knowing the minimum irradiance and staying above that threshold is important to allow penetration of the cure through the coating and ink. The radiant energy density is irradiance over time and is expressed in mJ/cm^2. Radiant energy is most important for total and complete cure (Raymont, 2002), and exceeding the threshold is equally if not more critical for producing a conforming product.

Then, the performance characteristics of the product need to be assessed. Friction is measured by slide angle, or coefficient of friction (COF). The chemical resistance and degree of cure of the coatings and the inks are commonly assessed respectively through MEK (methyl ethyl ketone) and IPA (isopropanol) tests though other solvents can be specified. Potassium permanganate stain test can also be used to assess the chemical degree of cure. The visual appeal could best be characterized by gloss. The surface tension is measured by dyne solutions. Adhesion can be evaluated by tape tests. Abrasion and scuff resistance by rub tests. This study will focus on gloss, slide angle, and rub resistance. One limitation that is frequently mentioned in the literature on UV inks and coatings is the lack of accuracy in measuring the physical properties of the product. This difficulty is more pronounced in production environments, where such evaluations are referred to as "a bit more subjective" (Fox, 2010) or "empirical" (TAPPI 815, 2006).

The most challenging parameter is perhaps the measurement of slide angle, as described in TAPPI 815. The standard determines "*the coefficient of static friction of most packaging materials by measuring the angle at which one test surface begins to slide against the inclined surface as the incline is increased at a constant and prescribed rate. The test is frequently referred to as slide angle, as the coefficient of friction is numerically equivalent to the tangent of that angle.*" Testing according to T815 is empirical and subject to variation due to multiple conditions. The results might not even correlate between the laboratory and the field or between different phases of the product's life cycle. Indicative of the variation is that the reproducibility for uncoated surfaces is 15%. To decrease variability, the testing needs to be done by the same devices and under the same environmental conditions, by the same operator, on samples that have been identically treated. Even if all these conditions are met, the repeatability is 6%. For this study, the measurements were taken at the 3rd slide to decrease variability, as this is the recommendation when the coating contains frictionizing agents like waxes and silicones. Each slide angle value is the average of 5 measurements. For rub resistance we referred to TAPPI 830 (2004), ink rub test of container board that is used to differentiate between strong and weak ink films, their adhesion to container board, as well as to rank container board surface resistance to rubbing and scuffing. This test is also described as empirical.

Another critical parameter is the type and behavior of the inks. The black ink used in this test was straight UV and the rest of the inks were hybrid. Hybrid inks differ from straight UV inks by having a conventional component in addition to the monomers and oligomers (Rousu, Gustafsson, Preston, and Heard, 2005). With hybrid inks, UV coating can be applied inline without the decrease in gloss that is observed when conventional inks dry underneath the coating. Nevertheless, since there is a conventional component, a part of the hybrid ink may still be wet prior to the application of the coating and some decrease in gloss can be observed. Similarly, if the UV component is not fully cured prior to the application of the coating, then the same decrease in gloss would occur (Duncan and Battersby, 2007; Bean, 2009). This would be more likely on jobs with full coverage or heavy and dark ink films as they would be more difficult to fully penetrate. When this occurs, it can be hypothesized that the irradiance and radiant energy were not enough for complete cure and the wet component of the ink film followed the topography of the substrate's surface and dragged the UV coating with it. This resulted in the formation of an anomalous surface on the coating that scatters the reflected light decreasing the amount of gloss. The recommendation for the printer is to fully cure the ink prior to the application of the coating by use of interdeck lights or a pre-coating unit. One additional problem with hybrid inks is that they contain less UV-curable material and thus they require more UV energy to be fully cured resulting in loss of gloss and adhesion failures (Balmer, 2007). On the other hand, heavy cross-linking due to overexposure to UV radiant energy could cause higher rigidity or brittleness. This could result in a decrease of rub resistance.

The surface properties of the substrate can have a similar effect on gloss and rub resistance, as the ink will sink in varying degrees inside the substrate. The low absorption of paper coatings has been found to allow less penetration and therefore better overall rub resistance than other substrates (Rousu, Gustafsson, Preston, and Heard, 2005).

Two references were found that deal with the variables in question. One is a study by The Flint Group (2008) that states that the additives necessary to maximize rub resistance will negatively affect gloss readings as coat weights increase. Further, it is stated that the higher the rub resistance, the lower the slide angle. The other study, by BASF (Biehle, Bankowsky, Enenkel, and Menzel, 2001), deals with the relationship between radiant energy and scratch resistance. Under the assumption that the cross-linking density of the polymer at the surface of the coating determines the scratch resistance of UV coatings, it was found that reducing the speed, and thus increasing radiant energy, led to a significant improvement in scratch resistance. It was further observed that the increase in scratch resistance saturates at higher amounts of radiant energy.

Objective

A. Determine the effect of paper type on the slip properties of UV non-skid coated surfaces (Hypothesis A and B)

B. Determine the effect of radiant energy on the slip properties of UV non-skid coated surfaces (Hypothesis C)

C. Examine the relationship between degrees of slide angle and rub resistance (regression analysis)

D. Examine the relationship between degrees of slide angle and gloss (regression analysis)

We will also discuss standard TAPPI 815 and the effect of varying the amount of radiant energy on slide angle, rub resistance, and gloss.

Methodology

Two UV non-skid coatings were selected, Coating A and Coating B. Coating A has a stronger photoinitiator package with a broader spectrum than coating B and is expected to cure with less energy. The formulation of the coatings, apart from the difference in the photoinitiator package, is identical. The coatings were formulated to respond to middle UV range, UVB and UVC, and to a lesser degree outside their optimum range. The optimum energy level for curing Coating A is 240 mJ/cm^2 and for curing Coating B it is 350 mJ/cm^2, when using a laboratory unit set at 300 wpi and running at 100 fpm. In order to get this information, the coatings were applied with an 180Q anilox that laid between 2.0 and 2.5 lbs per ream on SBS stock. When sufficient cure was established the UV light source was measured with an IL0290 device.

All of the inks were hybrid with the exception of the black that was straight UV. The inks were cured at a laboratory unit set at 200 wpi running at an average speed of 76 fpm. Once cure was established with a thumb test, radiant energy and irradiance were measured with a Compact 390B and a Power Puck Radiometer. The optimum radiant energy measured with the Compact 390B unit was 91 mJ/cm^2 on average (range 58–135 mJ/cm^2). With the Power Puck, the radiant energy measured at UVA wavelengths was 60 mJ/cm^2 on average (range 50–83 mJ/cm^2) and the total radiant energy measured for all the spectrum ranges was 145 mJ/cm^2 (range 115–202 mJ/cm^2).

The UV lights at the press are capable of emitting 400 wpi and were set at 80% of their capacity (320 wpi). The resulting radiant energy, with the press running at 8,400 impressions per hour, was 126 mJ/cm^2 on average measured with the

Radcheck TR-202 unit, passing 4 strips through the press. As the Radcheck unit measures at UVA wavelengths, we can say that the necessary radiant energy for curing the inks was achieved.

One of the limitations of the study was that the radiometer used to measure the coatings reports at different wavelengths than the Radcheck device and therefore the values cannot be directly compared. Another limitation was that the radiant energy and irradiance needed to achieve optimum cure for the inks varies depending on ink film thickness, emulsification, and area coverage. Therefore, the optimum energy levels reported from the labs might not perfectly correlate with actual production.

The fountain solution used was STARFOUNT SF-5089.

The two stocks that were selected were Solid Bleached Sulfate (SBS) and Clay Natural Kraft (CNK). For this study, the main difference between them was that the top surface of CNK has a higher slide angle prior to any application of ink or coating.

The printing press was a 64-inch KBA Rapida with 6 printing units with UV interdeck lights, an online coating tower with a 10 BCM anilox roll, and 3 delivery UV lights. The UV lights carry standard medium pressure mercury bulbs and elliptical reflectors. The delivery section is also equipped with IR dryers. The coating unit was thoroughly cleaned before switching from one coating to the other. The coating weight was measured to be 2,939 lbs/3,000 sq. ft. with a 10 BCM anilox roll. The first test form was printed using two interdeck UV lights, one after the first black and one at the end of the process, and 3 UV delivery lights. The second test form was printed with an interdeck light after each of the two inks and three at the delivery.

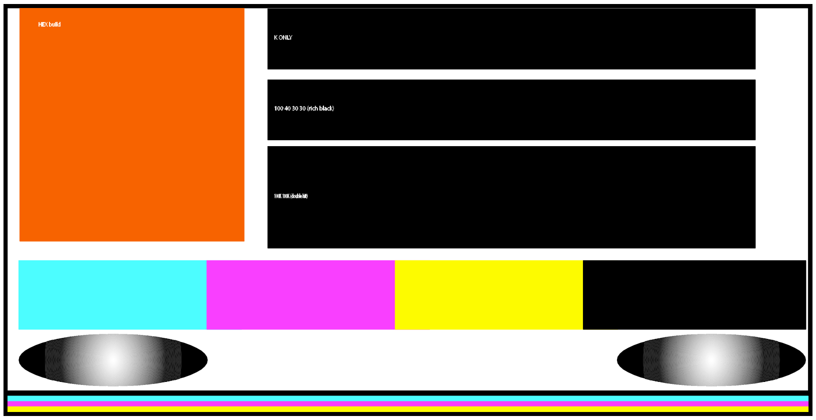
The reported radiant energy measurements of the press are combined of the output of all the lamps. This means that the inks towards the end of the press, as well as the coatings that were exposed only to the delivery lights, received less radiant energy.

Two test forms were developed so that the behavior of each coating over different ink formulations would be measured and evaluated. The layout of Form 1 was:

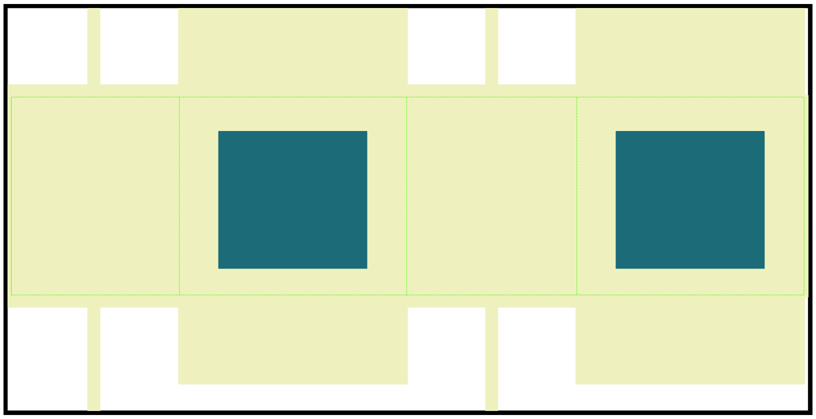
1) a single black area (K only)
2) a rich black area made with a 100K-40C-30M-30Y build (RICH K)
3) a double-hit black area (2K)
4) a build made with 68% process magenta, 80% process yellow, and 74% hexachrome orange (HEX)
5) an area without any ink (STOCK)

Form 2 was built with two special spot colors, a light cream and a dark blue.

Form 1



Form 2



The samples for each condition were gathered after the first 500 impressions, which were considered sufficient for the ink and water to reach equilibrium and the UV lights to warm up. The sequence of the test is shown in Table 1.

Table 1. *Press sequence of coatings and stocks during test.*

Test Form	Coating	Stock
TEST FORM 1	Coating A	SBS
TEST FORM 1	Coating A	CNK
TEST FORM 1	Coating B	CNK
TEST FORM 1	Coating B	SBS
TEST FORM 2	Coating B	SBS
TEST FORM 2	Coating B	CNK
TEST FORM 2	Coating A	CNK
TEST FORM 2	Coating A	SBS

Samples printed with Coating A were also passed through a laboratory curing unit a second time to determine if the additional amount of radiant energy had an effect on the degrees of slide angle. These results are shown in the Hypothesis C test.

Finally, we varied the UV light configuration and lamp output, measuring radiant energy and testing slide angle, rub resistance, and gloss in an effort to see the effect of radiant energy on the performance characteristics of the product. For this last test, we used Coating A on SBS stock and test Form 1, focusing on the double hit of black.

The slide angle tests were performed according to TAPPI 815 and the rub resistance tests according to TAPPI 830, using a 4-lb weight on a SUTHERLAND 2000 rub tester and rubbing two samples dry over their coated surfaces at 42 strokes per minute. Gloss was measured at a 60-degree angle. The tests, conducted by the same operator so that they are more repeatable, took place between 3 to 8 hours after the press, and again 4 days after they were printed. This study reports the results 4 days after production.

The pressroom and labs where the tests were conducted are only temperature controlled and humidity could vary. Throughout these tests, the humidity ranged from 40%–55% and temperature from 70^{o}–76^{o} degrees.

Test Results and Discussions

Null Hypothesis A: There is no difference in the degrees of slide angle of a single UV non-skid coating that is applied over two different unprinted substrates.

Table 2. *Coating B over unprinted stock.*

CNK	SBS
31	25
30	32
30	23
32	23
30	28
30	25
30	28
32	26
Average: 30.6	**Average: 26.2**

Since the p value < a (0.0021 < 0.05), we reject the null hypothesis that the variances are equal and run a two-sided t-test assuming unequal variances. The results where that the t Stat > t Crit (4.096 > 2.306) and the p value < a (0.003 < 0.05). Therefore, we reject the null hypothesis that the means are the same. We can say with 95% confidence that a UV non-skid coating when applied over two different unprinted substrates, results in different slide angles.

Null Hypothesis B: There is no difference in the degrees of slide angle of a single UV non-skid coating, when applied over two different printed substrates.

Table 3. *Coating A over printed stock.*

Area	CNK	SBS
K only	28	23
K only	33	25
K only	35	27
K only	40	23
HEX	30	30
HEX	34	27
HEX	33	31
HEX	35	30
2K	32	27
2K	27	21
Average	**32.7**	**26.5**

For the second hypothesis, we assume that the data are dependent and we therefore perform the t-test for paired data. The results of the test were that the t Stat> t Crit (4.68 > 2.2) and the p value = 0.00067 < a and therefore we reject the null hypothesis that the means are same. This means that at 95% confidence level, two stocks with UV non-skid coating applied over ink have significantly different degrees of slide angle.

Null Hypothesis C: The amount of radiant energy received by the coating has no effect on the degrees of slide angle of a single UV non-skid coating.

Table 4. *Amount of radiant energy.*

	One Pass	**Two Pass**
HEX SBS	48	30
K only SBS	34	23
RICH K SBS	39	27
2K SBS	27	21
SBS stock w/o ink	31	24
HEX CNK	44	35
K only CNK	36	40
RICH K CNK	38	35
2K CNK	32	27
CNK stock w/o ink	41	45
AVERAGE	**37.1**	**30.8**

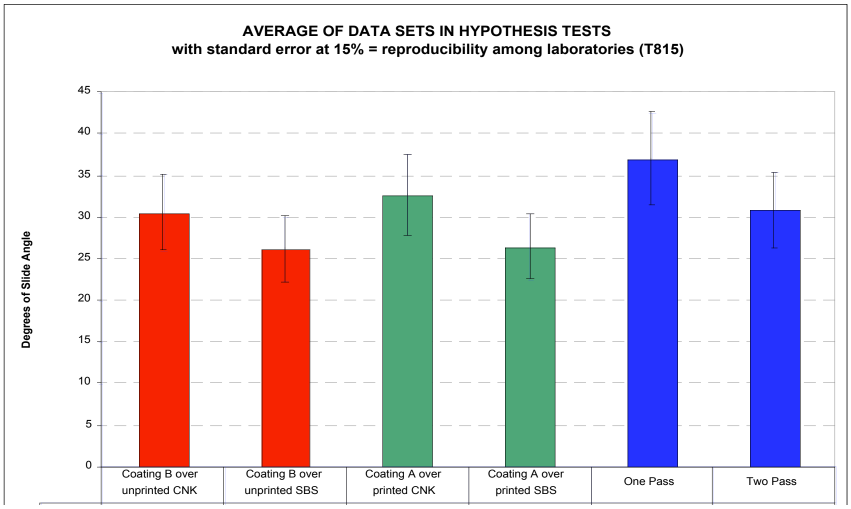
Our third hypothesis deals with dependent data sets and we performed the t-test for paired data. The test resulted in t Stat > t Crit (3.04 > 2.26) and p value 0.014 < 0.05. This means that at 95% confidence level we rejected the null hypothesis that the means are equal and conclude that there is significant difference on the degrees of slide angle when UV non-skid coatings are exposed to different amounts of radiant energy.

To further the discussion, we assumed that the data sets were independent. In this case, the p value > a (0.313 > 0.05), and we therefore had to accept the null hypothesis that the variances were equal. Proceeding with the t-test under that assumption, we found that t Stat < t Crit (1.99 < 2.1) and p = 0.062 > 0.05. We therefore accept, at a 95% confidence level, the null hypothesis that the means are the same.

The difference in the results between the paired t-test and the t-test assuming equal variances indicates that the amount of radiant energy is not the most important factor in determining the slide angle of a product. When different stocks and inks are included in the mix, then the effect of radiant energy is not statistically significant as the variability introduced by the other parameters obscures any differences in slide angle. When the variables are held constant, however, as is the case of the paired t-test, different amounts of radiant energy result in significantly different degrees of slide angle.

The last part of the hypothesis testing discusses TAPPI T815, according to which the reproducibility between labs is 15% and the repeatability 6%. It has to be noted that this applies specifically to “untreated, uncoated packaging papers,” and unfortunately there is no clause for coated stocks. If we assume that the 15% reproducibility can be applied as standard error to our results, then we conclude that there is no difference between any of the tested conditions. Alternatively, we could state that the test method is not accurate enough to discriminate between different degrees of slide angle or that we cannot compare results between any two labs (Figure 1). These limitations are known, however, as the standard (T815, 2006) *“describes the condition of that surface at the moment of test. This may or may not relate to the condition of that surface in use.”*

Figure 1. *Average of data sets in hypothesis tests.*



The tests were nevertheless performed in the same labs and by the same operator and we can assume that the applicable standard error would be the 6% repeatability. Calculating the standard error as the standard deviation of the data set over the square root of the number of samples (Table 5), we observe that the standard error for each of the data sets is not more than 7.8% of the variation, which approximates the 6% repeatability of T815. In this case, the difference between the averages of each data set can be considered to be significant.

Table 5. *Standard error calculations.*

	Standard Error	
	CNK	**SBS**
COATING B OVER UNPRINTED STOCK	0.99%	3.95%
COATING A OVER PRINTED STOCK	4.13%	3.45%
	One Pass	**Two Passes**
AMOUNT OF RADIANT ENERGY	5.47%	7.77%

We can state that CNK board has a higher slide angle than SBS board for any UV non-skid coating regardless of whether there is ink or not. Additionally, an additional exposure to an UV light source would individually affect each set of variables.

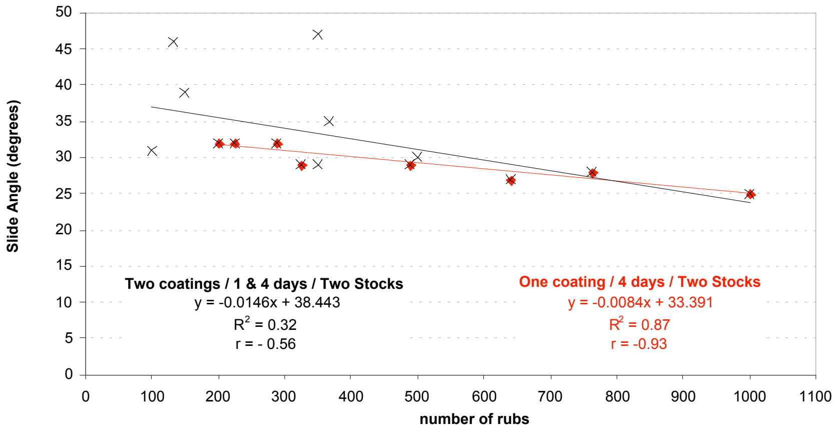
The next part focuses on the relationship between slide angle and rub resistance, and between slide angle and gloss. Table 6 shows the measurements conducted under each examined condition. The analysis focuses on the change in the strength of the correlation as more variables are added.

Table 6. *Rub resistance, slide angle, and gloss.*

coating / color / days off press / substrate	rub resistance	slide angle	gloss
coating A / k / 4 / sbs	1000	25.0	84.15
coating A / hex / 4 / sbs	325.0	29.0	89.65
coating A / blue / 4 / sbs	487.5	29.2	67.00
coating A / cream / 4 / sbs	762.5	28.3	95.00
coating A / 2k / 4 / sbs	640.0	27.0	77.85
coating A / k / 4 / cnk	200.0	32.0	77.35
coating A / hex / 4 / cnk	225.0	32.0	84.60
coating A / 2k / 4 / cnk	287.5	32.0	69.60
coating A / blue / 1 / sbs	350.0	28.7	64.80
coating A / cream / 1 / sbs	366.6	35.3	93.90
coating B / blue / 1 / sbs	150.0	39.3	72.70
coating B / cream / 1 / sbs	350.0	46.7	95.10
coating B / blue / 4 / sbs	100.0	31.3	70.00
coating B / cream / 4 / sbs	133.0	46.0	94.90
coating B / 2k / 4 / sbs	500.0	29.6	N/A

First, we will focus on the relationship between degrees of slide angle and rub resistance. Observing Figure 2 we can see that our ability to predict the relationship decreases as we include more variables. There is a strong inverse relationship between the degrees of slide angle and rub resistance when only one coating is involved, measured 4 days after the press and over both stocks. When we add a second coating and the measurements conducted within one day after the samples were printed and coated, then the relationship becomes statistically weak.

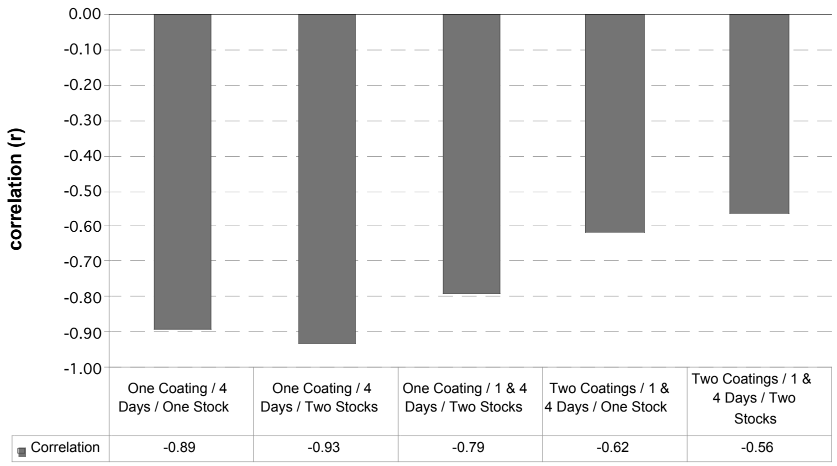
Figure 2. *Slide angle and rub resistance relationship.*



This indicates that if the same UV non-skid coating is used and the time between its production and measurement are the same, then we can predict its friction properties by measuring the rub resistance. The inverse relationship also indicates that at least with the coatings used in this study, it is improbable to satisfy high requirements for slide angle and rub resistance in the same time: the higher the rub resistance, the lower the slide angle.

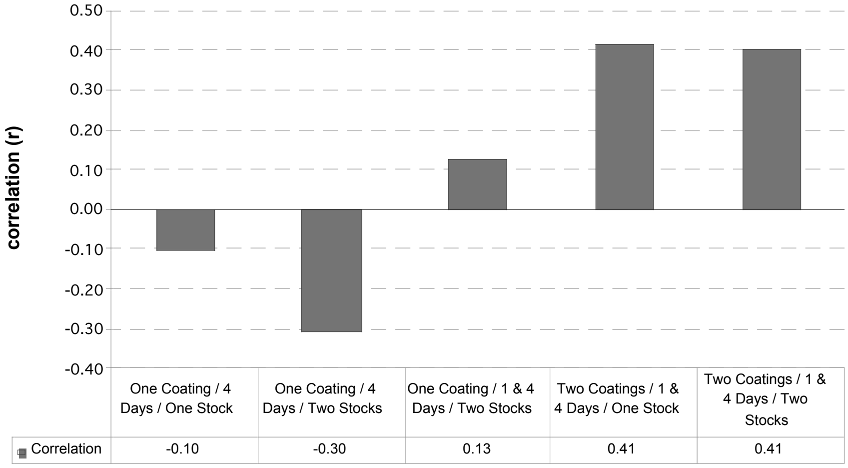
In Figure 3 we have a more analytical representation of the effect of adding more variables on the strength of the relationship between slide angle and rub resistance, which deteriorates to insignificance as shown by the decrease in the correlation value.

Figure 3. *Relationship between slide angle and rub resistance over different conditions.*



The next objective is to examine the relationship between gloss and slide angle (Figure 4), where we found that there was no condition where the relationship was strong.

Figure 4. *Relationship between slide angle and gloss over different conditions.*



Finally, we analyzed the effect of varying the amount of radiant energy on slide angle, rub resistance, and gloss. We printed two hits of black ink on SBS stock and applied Coating A. Then, we varied the number of interdeck and delivery lights as well as the UV power, keeping the press speed constant. The resulting measurements of radiant energy are shown in Table 7, together with the measurements of slide angle degrees, rub resistance, and gloss.

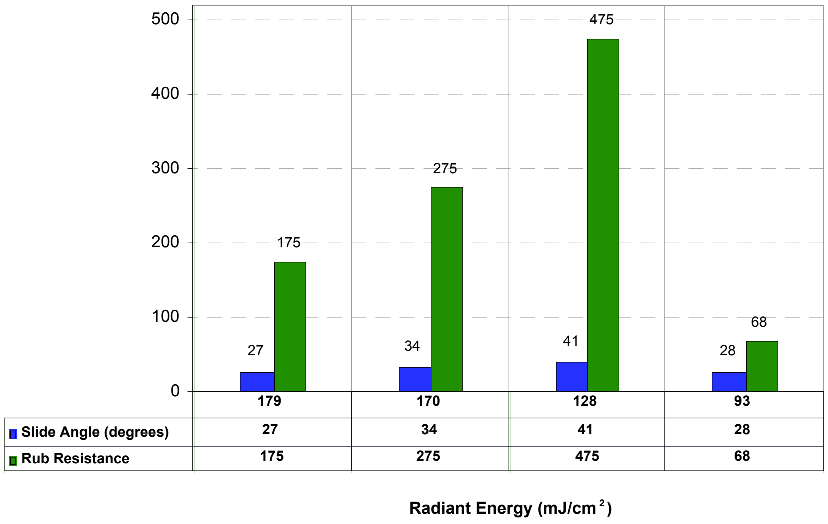
Table 7. *Relationship between radiant energy, slide angle, rub resistance, and gloss.*

Relationship between Radiant Energy, Slide Angle, Rub Resistance, and Gloss					
UV power (interdeck)	**UV power (delivery)**	**Radiant Energy (mJ/cm^2)**	**Slide Angle (degrees)**	**Rub Resistance**	**Gloss**
3 @ 320 wpi	3 @ 320 wpi	179	27	175	96
2 @ 320 wpi	3 @ 320 wpi	170	34	275	94
3 @ 240 wpi	3 @ 240 wpi	128	41	475	95
2 @ 240 wpi	3 @ 240 wpi	93	28	68	90

We can see that the relationship between radiant energy and either slide angle or rub resistance is not linear. When either too much or not enough radiant energy is emitted on the samples, then the relationship changes as degrees of slide angle and number of rubs prior to scuffing decrease. The effect on friction can be explained if we assume that more radiant energy results in a higher percentage of polymerization and therefore smoother ink and coating surfaces. The decrease in rubs as we increased radiant energy was due to "over-curing" of the ink or the coating, making it too brittle and decreasing its resistance to scuffing.

It has to be noted, that the results of the last test contradict the results of the previous testing. The correlation between slide angle and rub resistance is strong, but this time it is direct: the higher the slide angle (blue bars), the higher the rub resistance (green bars). Figure 6 graphically describes this relationship.

Figure 6. *The relationship between degrees of slide angle, rub resistance, and radiant energy.*



	179	170	128	93
🟦 **Slide Angle (degrees)**	**27**	**34**	**41**	**28**
🟩 **Rub Resistance**	**175**	**275**	**475**	**68**

Radiant Energy (mJ/cm^2)

An explanation to this contradiction is that in the first set of tests the radiant energy was being held within the range that was recommended by the ink supplier, where in the second test the radiant energy exceeded those guidelines. Assuming that the results of the second test (Figure 6) are valid, the operating window of the ink and coating combination was exceeded. It could be speculated that a total of 93 mJ/cm^2 results in “under-cure” and that more than 170 mJ/cm^2 results in “over-cure” and both are equally disruptive to the relationship between friction and durability. To determine the relationship of radiant energy precisely, we need to vary it along the range that is recommended for the given ink and coating.

The fact that we do not know the exact percentage of reaction displays either a limitation of this research or of the industry in general, allowing subjective and empirical estimations of performance. It leaves open room for speculation whether there was a difference in one of the press variables between the first and second tests that affected the results, or whether the repeatability and reproducibility of the measurement either of the UV light source, the rub resistance, or the slide angle are very low.

Summary

The results from the first two hypothesis tests was that different substrates affect the slip properties of boxes coated with UV non-skid coatings, regardless of whether there is ink or not printed on the substrate. The third hypothesis showed that the amount of radiant energy has an effect on the friction of the product. However, further analysis showed that radiant energy is not the most important factor, as the variability in the measured degrees of slide angle that is introduced by other parameters is greater than the variability introduced by variations in the amount of radiant energy.

Next, we discussed standard T815. Assuming that the 15% reproducibility is applied as a standard error on the results of this test, then there is no difference in the slip properties under any of the examined conditions. This would mean that no two labs could communicate with each other with reliable results, or that the testing method is inadequate for determining friction properties, or that there are indeed no differences in slip properties. The repeatability factor (6%), however, approximates the standard error calculated by these test results. In this case, we consider these tests repeatable and we can state that CNK board has higher slide angle than SBS board, and that a second pass from a UV light source individually affects each set of variables.

We determined that under controlled test conditions, there is a strong inverse relationship between the degrees of slide angle and rub resistance that would allow us to predict the friction properties of a product by measuring its rub resistance, or the opposite. The relationship, however, becomes weaker as we add more test conditions. The fact that the relationship is inverse means that at least with the tested coatings, it is improbable to satisfy high requirements for slide angle and rub resistance in the same time: the higher the rub resistance, the lower the slide angle. Gloss levels do not display any significant correlation with slide angle or rub resistance.

Finally, we saw that the relationship between radiant energy and either slide angle or rub resistance is not linear. It seems that there is an optimal range of radiant energy in which, if exceeded, the friction properties and durability of the product decrease. In that case, even if rub resistance and slide angle are still strongly related to each other, their relationship is no longer inverse but direct. At this point we enter the area of speculation, as we do not know the exact percentage of reaction in the ink and coating. We can speculate that we over-cure or under-cure the product, that the tests or testing methods of the performance characteristics of the product are not reliable, or that there is strong bias in the measurement of the UV light source.

Acknowledgments

I would like to thank the team members of Pacific Southwest Container for going through the extensive testing—press runs and numerous slide angle tests and rub tests—necessary for this study in their efforts to improve product performance. I would also like to thank the scientists of the ink and coating companies for offering their expertise and advise, both daily and during this study, and especially Joe Chiaramonte from C&A and Virginia Brown and Mike Sadjak from INX.

Literature Cited

Arceneaux, Jo An and Kurt Willard. 2007 "RadTech Printer's Guide: UV & EB Chemistry and Technology," accessed in 03-08-2010: http://www.radtech.org/print/guide.htm.

Balmer, Rod. 2007. "Assessing pros and cons of hybrid ink solutions," accessed in 03-08-2010: http://www.radtech.org/print/guide.htm.

Bean, Anthony. 2009 "RADTECH REPORT SEPTEMBER/OCTOBER 2009 Hybrid Sheetfed Lithographic Systems – State-of-the-Art", accessed in 03-08-2010: http://www.radtech.org/print/guide.htm.

Biehle, M, H. Bankowsky, P. Enenkel and K. Menzel. 2001. "Influence of different parameters on the scratch resistance of UV coatings," BASF AG, Germany, accessed in 03-08-10: www.radtech-europe.com/files_content/biehlerpaperoctober.pdf.

Duncan, Don and Graham Battersby. 2007. "RADTECH Printer's Guide: Advancements in UV-Hybrid inks," accessed in 03-08-2010: http://www.radtech.org/print/guide.htm.

Flint Group. 2008. "Folding Carton Surface Performance, Making a Problematical Prediction," accessed in 03-08-10: http://www.na.flintgrp.com/printers_resource/foldingcartonsurfaceperformance.html

Fox, David. 2010. "3 keys to UV," *American Printer,* January 01, 2010.

Raymont, Jim. 2001. "Life After the Honeymoon: Getting to Know, Understand, Respect and Live with Your UV System and Process," *SGIA Journal,* Third Quarter.

Raymont, Jim. 2002. “Radiometers – The best of intentions,” *SGIA Journal,* Third Quarter.

Dr. Rousu, Sanna, Jan Gustafsson, Dr. Janet Preston, and Dr. Peter Heard. 2005. “Interactions between UV curing, hybrid-UV and sheetfed offset inks and coated paper – commercial print trials,” *Taga Proceedings 2005*.

TAPPI 815. 2006. “Coefficient of static friction (slide angle) of packaging and packaging materials (including shipping sack papers, corrugated and solid fiberboard) (inclined plane method). (Proposed revision of T 815 om-01).”

TAPPI 830. 2004. “Ink rub test of container board,” (T 830 om-04).