Coating Space™
A 3-D View of Creping Cylinder Coatings

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ABSTRACT

Making quality tissue commonly relies on the development of an adhesive coating on the creping cylinder. The coating must afford a level of protection for the Yankee surface and be soft enough to allow uniform creping and prevent coating buildup during the creping process. These coating properties must be designed to fit the existing process in order to produce the desired sheet properties and support machine efficiency. This can be very difficult, as the basic needs of the creping process are interrelated. A unique and simple model to address the needs of the Yankee coating and design the appropriate coating package is called "Coating Space." In this model, coating properties are defined by using a three-dimensional domain defined by the axes of adhesion level, durability and hardness.

Successful movement within Coating Space is facilitated by a clear correlation between laboratory and manufacturing environments. Laboratory measurements such as peel adhesion force, glass transition temperature (T_g), modulus (G'), durability and moisture sensitivity are quantitative techniques that can be used to define the interrelationships between the different Coating Space axes. By understanding and utilizing Coating Space concepts, mill operations can easily manage the creping process for optimal performance. A review of technical considerations, relationships and case studies supports the validity of this model.

INTRODUCTION

Production of tissue to meet quality targets commonly relies upon optimization of the creping process. A key to superior performance is the development of a robust coating on the surface of the creping cylinder. This coating must facilitate protection of the cylinder's surface, provide appropriate levels of adhesion and yet be soft enough to be managed during the creping process. Since every product and process design is unique, real time customization of the coating system is critical. This is usually one of the most challenging aspects of tissue production, since many coating characteristics are interrelated, but such customization can have some of the greatest rewards in terms of productivity and product quality.

Those involved with the application, operation and design of creping cylinder coatings have struggled to find a common language to understand and communicate their needs, observations and learnings. This is particularly important when using different chemistries that are sprayed on the dryer surface for the purpose of enhancing the creping process. Physical and chemical properties of the neat products have limited utility since it is the dehydrated coating or film formed on the dryer that is really the material of interest, not the neat product. The coating on the creping cylinder can be a complex mixture resulting from the combination of at least two products (adhesive and release) and in fact could be the result of up to four or five additives, if co-adhesives and modifiers are employed. Additionally, furnish type, refining, wet end additives and water chemistry all influence the development and properties of the coating (Oliver 1980). Finally, mechanical and operational considerations such as cylinder surface temperature, creping cylinder metallugy, machine type and drying strategies can directly affect coating performance (Marzullo 1989).

With all of these factors in mind, it is no wonder that a common understanding of creping cylinder coatings is hard to achieve. The complex nature and impact of numerous factors makes choice and optimization of the coating and the creping process a formidable task. It has become critical to develop a model that can easily be used by the tissue maker to control and further optimize the process. The model has to be flexible enough to take into account variations normally encountered in day-to-day operations, while robust enough to facilitate process optimization and new product development. The model needs to include characteristics that the tissue maker tries to control in the process, and to clearly demonstrate the relationships between these characteristics. A model developed by Nalco that meets all of these needs is called *Coating Space*.

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DISCUSSION

Coating Space is a new conceptual tool for understanding coating properties and their interrelationships. The space, as shown in Figure 1, is the three-dimensional domain defined by the axes of durability, adhesion and softness. These axes represent characteristics of the coating film that develops on the surface of the creping cylinder. The concept recognizes the individual contributions of the adhesives, releases and modifiers and how these can affect the overall character of the coating. It also recognizes how mechanical and operational practices change the performance of the coating. It can be used as a predictive tool when coupled with new laboratory techniques for measuring film properties.

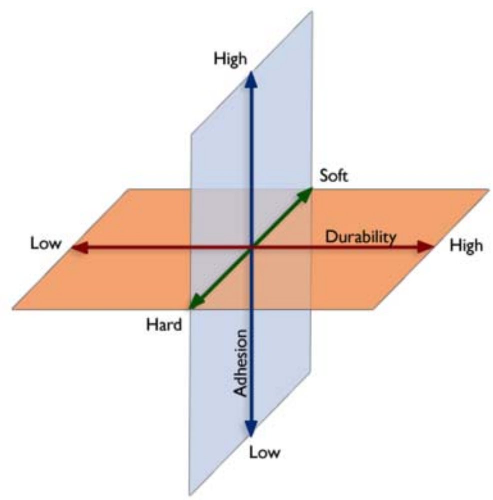

Figure 1 — *The axes of Durability, Adhesion and Softness of the coating film define the three-dimensional Coating Space.*

DETAILED DESCRIPTION OF COATING SPACE AND AXES

The *Coating Space* model is best understood, if we define the three axes in greater detail, and relate them to common commercial machine observations of coating behavior and machine runnability.

Adhesion – Adhesion is the degree to which the tissue is attached to the creping cylinder. There are two locations on the creping cylinder where adequate adhesion levels are critical.

1. Suction pressure roll (SPR) nip – (on conventional machines) the adhesion provided here is critical for providing uniform sheet transfer and facilitating efficient drying of the sheet. The adhesion at this point is sometimes referred to as "wet tack" adhesion.
2. Tip of the creping doctor blade – the level of adhesion provided at this point facilitates the transformation of the flat sheet into a three-dimensional tissue product with the desired sheet properties of bulk, absorbency and softness.

Common machine observations or behaviors associated with high and low adhesion levels at the creping blade are outlined in Table 1.

Table 1 — *Machine behavior associated with high and low adhesion levels.*

High adhesion	Low adhesion
Good sheet control	Sheet "flies"
More crepe bars per unit length	Coarse crepe bars
More coating on dryer	Shiny dryer
Higher pocket angles	Low pocket angles
More stretch	High caliper
Less strength	More strength

Coating Softness – Softness is a term related to the viscoelastic properties of the coating. A softer coating has a lower modulus, is more flexible and is less brittle. A soft coating re-wets more easily than a hard coating. Again, there are two locations where softness of the coating is critical for optimizing the creping process.

1. SPR nip – the coating must be soft enough at this point to facilitate intimate sheet contact and adhesion to the creping cylinder.
2. Tip of the creping doctor blade – For successful creping, the doctor blade tip must ride below the sheet/coating interface, but not ride on the creping cylinder's metal surface. If the coating is too hard, the doctor blade will ride on top of the coating next to the sheet and defects and breaks will occur. If the coating is too soft, the creping doctor blade will cut through the coating and ride on the metal surface of the creping cylinder. This is undesirable as damage of the creping cylinder can and usually does occur. Additionally, operational creping doctor blade life can be very short. Both of these conditions will adversely affect productivity.

Common machine observations or behaviors associated with hard and soft coatings at the creping blade are outlined in Table 2.

Table 2 — ***Observations associated with hard and soft coatings.***

Hard Coating	Soft Coating
Higher doctor blade loadings	Lower doctor blade loadings
Chattering potential	Good blade penetration
Potential for pin holes and breaks	Good runnability; soft tissue
Most coating remains, even after blade change	Easy coating recovery after blade change
Edge deposits	Fewer edge deposits
Thin coating layer	Thick coating layer

Durability – This coating property is normally localized to the SPR nip. A durable coating has sufficient integrity to resist the dynamic hydraulic pressure and movement at the SPR, yet still facilitates sheet transfer and avoids felt filling. If the coating is too moisture sensitive (not durable enough), it is probable that the coating will be washed off the creping cylinder surface. Typically, this condition can exist in the newer, faster Crescent former machine configurations, where sheet solids range from 8 to 15%, and felts are usually saturated coming into the SPR nip. Twin wire formers, suction breast roll formers and some older machine technologies tend to carry less water in the sheet, and the felt entering the suction pressure roll nip can accommodate a less durable coating.

Common machine observations or behaviors associated with high and low durability coatings are outlined in Table 3.

Table 3 — ***Observations associated with high and low durability coatings.***

High durability	Low durability
Low sensitivity to moisture	High sensitivity to moisture
Persistent coating layer on creping cylinder	Easily washed off
Can tolerate high moisture sheets	Best with low moisture sheets
Used with high basis weight products	Used with Low/medium basis weight products
CD profile issues can occur	Even CD profile

Interrelationships between Coating Properties – As with many papermaking variables, the three *Coating Space* axes of adhesion, softness and durability are interrelated.

- Higher adhesion coatings tend to be softer with lower durability.
- Lower adhesion coatings tend to be harder with higher durability.

By utilizing these basic relationships, it is possible to understand how a coating will react when changes are made in coating chemistries or conditions of use. It is very difficult to change only one characteristic of the coating at a time. Any change in one of the characteristics will likely affect the other two, causing a multi-directional shift within the *Coating Space.*

LABORATORY METHODS FOR DEFINING COATING PROPERTIES

The above discussion defined the properties of the *Coating Space* variables and related them to common machine observations and behaviors. For developing new coating additives, and implementing changes to existing coating programs, it is very useful to have techniques for quantifying these variables on a laboratory scale. Conducting initial evaluations in the laboratory is obviously more efficient and decreases the risk to customer assets and productivity vs. conducting all evaluations through the use of machine trials. On the other hand, all laboratory techniques have limitations, and at an appropriate point, the dynamic response that can only be attained from a commercial trial is necessary. Fortunately, laboratory methods are available to guide developmental and optimization efforts.

Adhesion Tests – Many methods are available for the quantification of adhesion. These may range from simple subjective tests of the "stickiness" of a coating film, to sophisticated peel adhesion tests where a paper or cloth sample is peeled from a coating under carefully controlled conditions (Furman 1990). Measurements can even be made of the deflection force on a creping blade that crepes a paper sample from a laboratory-scale creping cylinder (Ramasubramanian, Shmagin 2000).

An example of the type of information that can be obtained from peel adhesion measurements is provided in Figure 2. Here various release agents were evaluated to determine their effect on the adhesion provided by the coating film. A clear differentiation is evident in the level of adhesion reduction provided by the products. The tests were conducted by applying a wet film of the blended PAE adhesive and release to a metal panel. This film was heated to 100°C and a wet cotton strip was laminated to the film. After heating again to 100°C, the strip was peeled from the film at a constant angle and speed. The average force required to peel the strip was recorded.

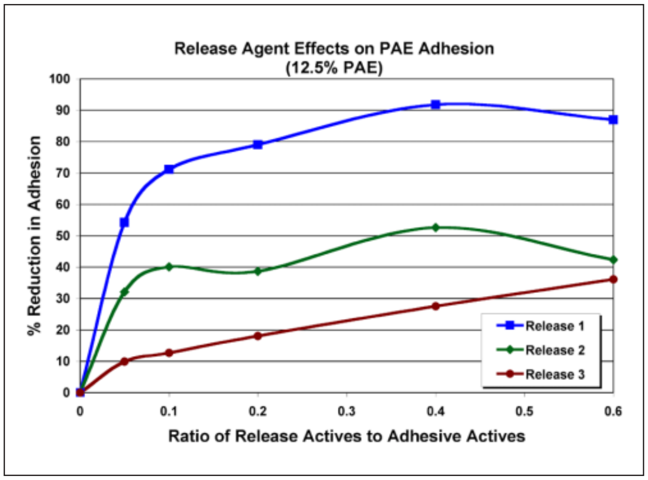

Figure 2 — *Peel adhesion measurements of the effect of release agents on a PAE adhesive.*

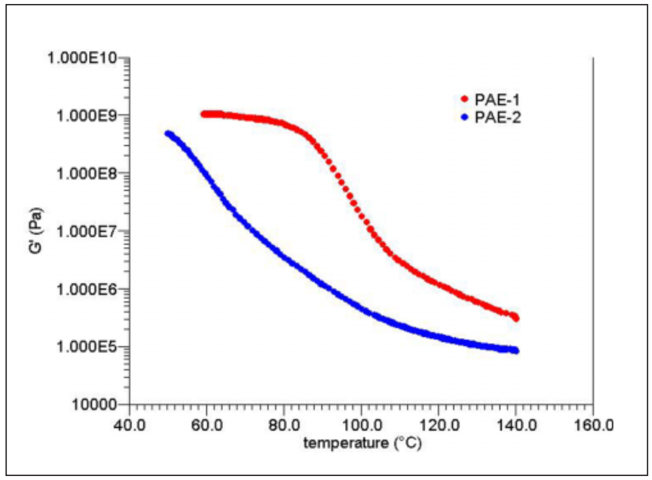

Figure 3 ***Shear storage modulus versus temperature for two modified PAE polymers.***

Film Softness Tests – Again a number of methods are available for quantifying the softness, flexibility and viscoelastic properties of coating films in the laboratory. Ranking scales can be devised to judge the relative softness/hardness and flexibility of the films. Various standardized (ASTM) hardness tests are also available such as indentation hardness testers (Knoop, Pfund, durometer), the pencil test and Sward-type hardness rocker (see References). Thermal mechanical analysis (TMA) instrumentation can also be used to monitor changes in film dimensions as a function of temperature or load applied to the sample.

The glass transition temperature (T_g) is the temperature at which polymers change from a brittle glassy state to a softer rubbery state. For polymers used as creping cylinder adhesives, it is desirable for the temperature of the coating to be above the polymer's T_g so that good contact between the sheet and the adhesive coating is obtained, thus resulting in good adhesion (Furman, Su 1992). Polymer T_g's are typically measured using differential scanning calorimetry (DSC).

Finally, modulus values of the films can be measured by means of dynamic mechanical analysis (DMA) or rheology instrumentation. The modulus is the slope of the stress-strain curve for the film. Films with lower modulus values will behave as softer materials (Furman, Su 1992). For creping cylinder coating films, a shear modulus measurement is most appropriate since the creping blade is shearing into the coating on the rotating creping cylinder (Ramasubramanian, Crews 1998). Figure 3 shows the shear storage modulus for two different PAE adhesives as a function of temperature. One can easily discern the softening of these polymers as the temperature is increased. The behavior is not only influenced by the molecular weight and the degree of crosslinking in the PAE resin, but also by the level of modifier that is used.

It is important to conduct these tests under carefully controlled conditions of temperature and humidity, or more correctly moisture content in the film. Equally important is the preparation of good quality and consistently uniform films.

Durability Tests – Durability is a somewhat more elusive quality to measure since it is defined relative to the conditions of use in the creping application. In our definition, durability relates to the integrity of the coating at the SPR. A durable coating resists the dynamic hydraulic forces and high moisture conditions present at the SPR nip. Again various ranking schemes can be devised to provide a relative number to laboratory coatings. These can be, for example, the resistance of the coating film to being washed off or dissolved from a surface, when subjected to removal forces in aqueous environments. Further quantification can be obtained by examining the degree of swelling (volume change) and the percentage of insoluble material when the films are immersed in water.

CHANGING COORDINATES WITHIN THE COATING SPACE

Changing coordinates within the *Coating Space* can be accomplished in a number of ways. These can include changes to the base creping adhesive, changes to the release agent, addition of, or changes to, the modifying agent(s), changes in the ratios and absolute add-on levels of the coating components, and finally changes to the mechanical and operational practices. Let's discuss each tactic in more detail in regards to the overall coating strategy.

Adhesive Selection – The selection of the correct adhesive platform is critical to establishing the proper initial reference coordinates within the *Coating Space*, from which other changes can be considered.

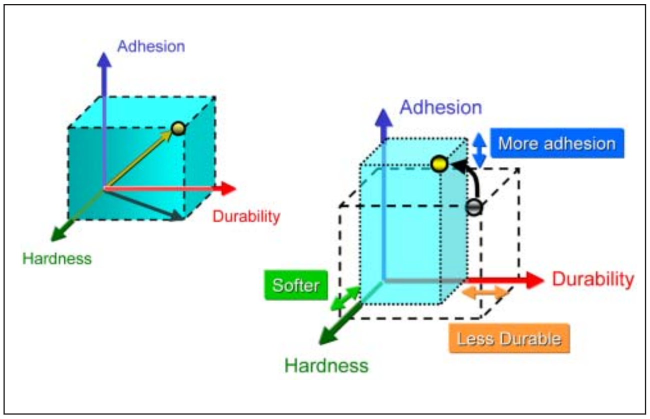

Figure 4 — *Changing adhesive platforms.*

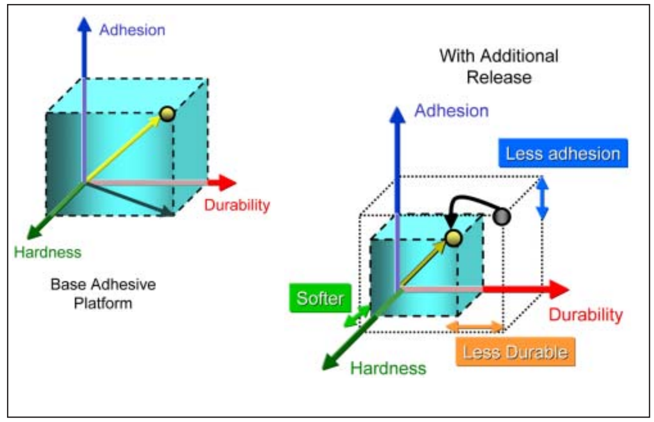

Figure 5 — *Release impact on adhesive platform.*

The tissue making process, and the properties desired in the tissue product, are used to define these initial coordinates. The creping adhesive forms the base for the Yankee coating and, therefore, its properties define the center of the three-dimensional space. Currently, it is possible to choose from many different types of polymeric adhesive products. Typical polymer types include poly(aminoamide)-epichlorohydrin (PAE), polyethyleneimine (PEI), polyvinylalcohol (PVOH) and modified polyacrylamide (MPAM). It is important to recognize that there are many variants within each class, since polymer composition and properties can easily be changed by monomer ratios and distribution, molecular weight, crosslinking level and charge type and density. Figure 4 provides an example of how *Coating Space* is used to define a change in the adhesive base platform. With an increase in adhesion, the coating will typically be less durable and softer in character.

Each adhesive platform, by itself, will have certain adhesive, hardness and durability coordinates within the *Coating Space*. In selecting the adhesive, it is critical to choose characteristics that will support desired product attributes and operational needs of the tissue making process. Polymer properties will also change on the creping cylinder surface with differences in temperature and moisture. Some of the polymers crosslink *in situ* on the creping cylinder surface and are impacted by basic chemical reaction kinetics. Some of the materials do not chemically react on the surface of the dryer, but merely form a film after evaporation of the water carrier. All known adhesive characteristics, laboratory evaluations, other machine chemical additives, machine conditions (such as moisture profiles), former type, press arrangements, creping conditions, application cost restrictions and desired tissue quality must be considered before choosing an adhesive platform.

Release Selection – The release agent is typically the primary material used to change the adhesive behavior of the sheet on the creping cylinder. In *Coating Space* terms, the release facilitates movement along the adhesion axis. As Figure 2 demonstrated previously, this movement is always in the direction of less adhesion. Figure 5 shows that adding additional release (or changing release types) can also result in less durable and softer coatings.

The selection of the release agent is based upon the adhesion level required and the product and process requirements.

One should keep in mind that other properties of the coating will change when different release formulations are used. Simple oil-based materials tend to interfere with the film forming process and often result in non-homogenous films with pockets of oil that have separated from the adhesive during the water evaporative phase of film formation. Highly engineered releases have the potential to be more stable within the film matrix, as the distribution of micron-sized oil particles is more uniform throughout the film. Release agents that are based on non-oil, or surfactant, chemistries can be more compatible, thus resulting in improved film uniformity. Due to the more homogeneous film, coating properties at the microscale are enhanced.

Care must be taken to match the properties of the release being used with the base adhesive material. If a release that is relatively weak is coupled with an adhesive that typically builds a hard coating, it is probable that the tip of the doctor blade will not penetrate the coating. This will result in numerous sheet breaks and a coating that will build unevenly and in an uncontrollable manner. If an aggressive release is paired with a soft and less durable adhesive material, it is likely that the resulting coating will be removed from the dryer due to a lack of hardness and durability. Changing the type and amount of release agent should be considered when there has been a significant process change. Changes in wet end chemistries, furnish, grade, product design and normal process variation may, and probably will, require changes in the release strategy.

Modifier Selection – A modifying agent, by definition, is any material that, when added to the creping adhesive, modifies a property of that adhesive. Modifiers are used as vehicles to move along the axes of adhesion, softness and durability within the *Coating Space*. Modifiers can be defined according to their function and in general fall into two broad categories, those that act to soften, or maintain the softness (Rose 2004), of the coating and those that act to increase the durability and hardness of the coating. In so acting, both categories affect the adhesion of the coating. More specifically, humectants and some surfactants help to soften the coating and can result in increased adhesion as the coating durability and hardness are reduced (Furman, Grigoriev, Su, Kaley 2004). Crosslinking agents tend to increase durability and hardness with a corresponding loss of adhesion as shown in Figure 6. Inorganic phosphate materials are often used as coating modifiers and can serve several functions. They tend to improve durability of the coating, while at the same time helping to improve film formation and protection of the creping cylinder.

Operational and Product Considerations – How the above materials are used to provide a coating program is dependent on the tissue making process and the desired product attributes, as well as the characteristics of the materials chosen. Each process will be different, but there are some general trends and guidelines that are observed and recommended.

- **Facial and Super Premium Bath Tissue** => Softer coatings are employed that utilize higher adhesive to release ratios in multi-component systems and favor higher coating add-on levels. Typically, these processes crepe with open pocket geometries and at lower creping moisture levels, <4%. A typical coating system is composed of a high adhesion base material, often combined with aggressive modification. Humectant-type modifiers are often used to help keep the coating soft and adhesive, while phosphate chemistries are used to help spread the coating and protect the dryer.
- **Premium Bath Tissue** => Again, higher add-on levels are employed, but with solids ratios that slightly favor releasing type materials. These operations will utilize creping pocket angles of 80 to 90 degrees with creping moistures often in the 4 to 5.5% range. Humectant, surfactant and phosphate modifiers are often employed.

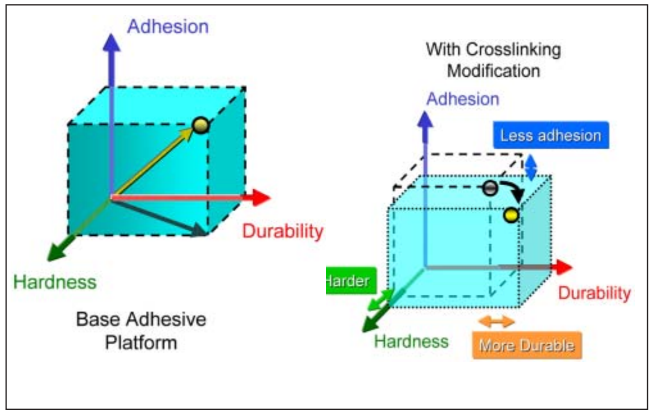

Figure 6 — ***Crosslinking impact on coating.***

- **Value Tissue** => These operations will utilize lower add-on levels of adhesive in conjunction with a high add-on of release agent. Creping pocket angles of 70 to 80 degrees are often observed. Creping moisture in the range from 4.5 to 6% is common. Base adhesive materials tend to be harder and more durable. Releases tend to be oil-based. Modification is usually with phosphate to help create a uniform coating and protect the dryer.
- **Towel and Napkin** => These operations also utilize low add-on levels of adhesive, since the presence of permanent wet strength in the system also contributes to coating. Typically, adhesive/release ratios significantly favor the release component. Pocket geometries are normally in the 70 to 80 degree range with creping moistures ranging from 4.5 to 6%. Phosphate materials are often used to help facilitate uniform coating development and creping cylinder protection.

CASE STUDIES

Following are two examples showing how coating space concepts can be used to optimize the creping process

CASE STUDY NUMBER 1

A tissue maker, utilizing a virgin fiber furnish wanted to increase reel bulk by increasing the adhesion of the sheet to the creping cylinder, but did not want to end up with a hard, unmanageable coating. The desire was to make the shift to improved quality, while hopefully maintaining or improving runnability.

Discussion – Bath tissue produced with this process consistently had lower than desired bulk. Process reliability was adversely affected when attempts were made to meet tensile specifications for this grade. To maintain productivity, operations elected to run on the high side of the strength targets. The root cause of the low bulk was determined to be related to the creping cylinder coating, both from the materials used and the operating strategy employed. The incumbent coating package resulted in a very hard coating. Edge deposits at the deckle edge of the sheet, along with sheet defects, resulted in numerous sheet breaks. Release usage was relatively high to maintain commercial productivity.

Utilizing *Coating Space* concepts, a plan was developed to change the incumbent platform adhesive from one that was harder and very durable to a system that was softer and had higher adhesive characteristics. Two release materials were chosen for evaluation: 1) a non-oil modifying release 2) a highly engineered oil-based release with extended modification. The objective was to develop a coating that would allow the tip of the doctor blade to ride under the sheet/coating interface, while still providing some protection to the surface of the creping cylinder. It was also believed that a softer coating system would help reduce edge deposits and improve overall runnability.

Outcome – As can be seen in Figure 7, bulk increased with the soft adhesive/non-oil system, while no improvement was observed with the soft adhesive/oil release system. Visually, the adhesive/non-oil coating was significantly more uniform with a small amount of dust being present.

The mill chose to continue with an extended evaluation of the soft adhesive/non-oil coating system and documented a significant improvement in process stability. Doctor blade life was improved 50 to 75% over the incumbent materials. Bulk has remained above historical levels, and the mill can now commercially run to the center of their tensile specifications. In general, the quality and runnability has improved. The operating window has been widened.

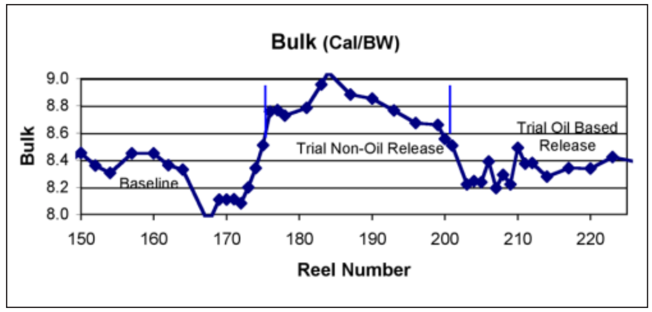

Figure 7 — *Bulk as measured by sheet caliper/basis weight for trial conditions in Case Study 1.*

CASE STUDY NUMBER 2

A tissue maker utilizing a recycled fiber furnish wanted to increase machine productivity by increasing stretch in the paper and reducing the number of blade changes per day. Improved softness of the creped sheet was also highly desired. Past attempts at creping aggressively to gain stretch had resulted in a hard, unmanageable coating. Pin holes, picks and breaks often limited attempts to improve quality properties of the sheet.

Discussion – The *Coating Space* model is most effectively utilized when the impacts from the entire process are defined and considered. In this case, a thorough audit of the machine was conducted including:

- Wet End – including furnish and chemistry
- Felt Survey – including permeability
- Creping Process – including geometry, creping moisture, general sheet adhesion
- Reel Sheet Characteristics – including quality characteristics, crepe structure, variation

Nalco and the customer were able to determine that a creping program utilizing a soft, high adhesion coating would likely lead to the desired improvements. The higher adhesion would allow the mill to crepe more aggressively and result in increased stretch, while reducing blade wear and still protecting the creping cylinder.

Further, it was determined that the release oil used in the incumbent process could not soften the hard, durable coating that resulted from use of a crosslinking PAE adhesive. Even aggressive, highly engineered modifying releases or surfactant modifiers could not effectively manage the characteristics of this coating. To be successful, the entire coating system had to be changed. The change was accomplished by first selecting a coating that was intrinsically softer and then matching it with an aggressive modifying release. It was important to start with a cylinder coating that was soft enough to allow creping doctor tip penetration for runnability, but hard enough to protect the dryer and have higher adhesion properties to mechanically work the sheet on the tip of the creping doctor.

Outcome – The metrics for evaluating success of the new coating system were defined by how much stretch was generated for each unit of crepe (MDS/%C), and by blade life. As can be seen in Figure 8 below, there was a documented 9.3 % improvement in the MDS/%C metric. It is expected that additional improvements can be made with continued optimization of the creping process.

Improving doctor blade life and reducing blade changes should result in increased machine productivity. A simple way to improve blade life is to reduce the wear rate of the doctor blade. This presents a more constant creping doctor tip geometry (kg/sqcm) to assure penetration and management of the creping

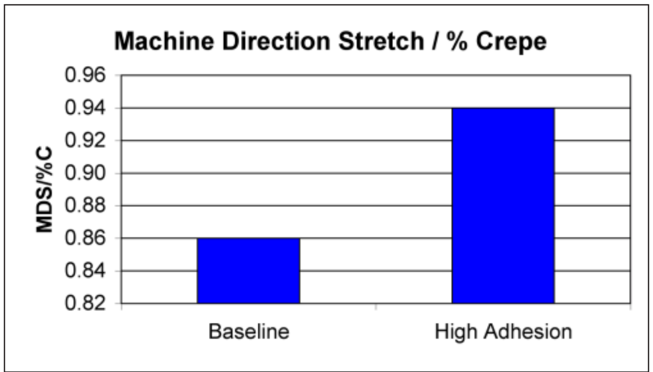

Figure 8 — ***Machine direction stretch/% crepe for Case Study 2.***

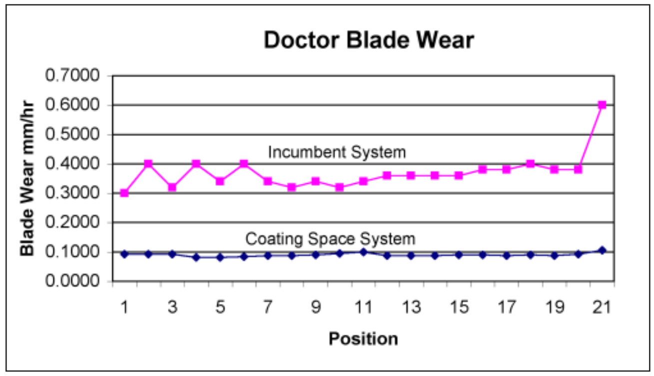

Figure 9 — ***Doctor blade wear from Case Study 2.***

cylinder coating. The graph in Figure 9 demonstrates the change that occurred by changing coating system characteristics. A 76% reduction in blade wear was observed, which resulted in an increase in blade life.

SUMMARY

- *By combining good basic knowledge of the tissue machine and sound technical concepts of the creping process, a coating system can be chosen leading to improvements in productivity and quality.*
- *Coating Space is a simple, but three-dimensionally dynamic, model that can help tissue makers develop creping cylinder coating characteristics to fully capture the potential of the creping transformation.*

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