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Optimizing bulk via the creping process

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INTRODUCTION

On a Light Dry Creped (LDC) tissue machine, many things play a role in the final bulk or caliper of the finished sheet. From the fiber preparation area through to winding we can identify the main process drivers as:

- Fiber type
- Refining strategy
- Forming wire design
- Forming section set up
- Suction pressure roll nip design
- Drying bias (hood vs Yankee)
- Creping process
- Winding process

This article will deal predominately with the creping process as it relates to optimizing bulk on bath and facial grades on LDC machines, and assertions made here within can be taken as assuming all other parameters being equal. The intention is to help clarify methods for increasing bulk generation via the creping process and dispel common misconceptions regarding generating bulk at the creping blade.

A paper machine operator will often seek to impact bulk via adjustments to the following creping parameters:

1. Crepe ratio
2. Creping pocket angle
3. Creping moisture

Unfortunately, a lack of understanding of the basic physical properties being impacted often leads to less than desired results. Let us examine in detail what is happening at the blade through adjustment of each of these parameters.

GENERATING BULK VIA THE CREPING PROCESS

With the modern equipment and high quality furnish available, it is possible to be able to start up a new tissue machine and be making saleable, high quality tissue within hours. Previous barriers to entry for manufacturers related to process patents, organizational knowledge, channel to market and access to high quality fiber no longer apply in most cases. It has become quite easy, relatively speaking, to make decent tissue at high speeds. What now contributes greatly to separating good from great in the tissue market is dependent on an organization's ability to leverage maximum value creation through the creping process.

The creping process, more than any other step in the tissue making chain, is what determines the final product's characteristics. It is the most efficient manner of debonding and bulking the sheet structure.

In light dry crepe, running the formed base sheet through the creping process results in the following property adjustments:

Total strength of the sheet	-40 to -80%
Bulk	+200 to 350%
Stretch	unlimited
Basis weight	+ 10 to 35%
Absorbency	+ 200%

Table 1.

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This is done in order to produce a rather nebulous characteristic that the end customer refers to as: softness. This stated "softness" is composed of the following main tactile sensory characteristics [1,2,3]:

- Bulk Softness: property measures include compression, tensile stiffness, elongation, bending stiffness, and sonic modulus.
- Surface Smoothness: property measures include texture and friction.

Beyond the improvement in perceived handfeel, bulk/caliper is important to the tissue manufacturer from a cost and marketing perspective. All things being equal, increased bulk can be considered a "banked currency" that manufacturers can spend or leverage in a variety of ways.

This is easy to understand in terms of the ranges quoted above for property adjustment via the creping process in Table 1. A manufacturer capable of generating 10% more bulk than its competitor through the creping process is provided with multiple potential ROI streams for that excellence. Some of the ways he has the potential to do this are as follows: Improve efficiency:

1. Reduce basis weight while maintaining bulk specification: Reduced fiber cost per case
2. Reduce crepe ratio while maintaining bulk specification: Increased production rates
3. Reduce sheet count while

maintaining roll size and density: Reduced fiber cost per case

4. Increase creping moisture while maintaining bulk: Reduced energy consumption
5. Substitute with lower quality fiber while maintaining bulk: Reduced fiber cost

Leverage marketing opportunities:

1. Promote the absorbency gain vs competition obtained via reduced sheet density
2. Wind larger roll size to benefit from the customer perception of value on the shelf

Design of the base sheet parameters and efficient execution of manufacturing is critical to separating the wheat from the chaff. Those who do so will enjoy better product quality and operational efficiency.

ADJUSTING THE CREPING FOR BULK CREPING MOISTURE:

The adjustment of the creping moisture to impact bulk is a commonly used method. The basic understood principle is that adhesion increases as creping moisture reduces. It is accepted that this increased adhesion will result in the generation of more bulk. Empirically, the premise often plays out this way, but more is at play here.

Some creping chemistries will indeed become harder, resulting in a greater adhesion of the sheet to the Yankee, as creping moisture is reduced. This in not, however, a universal fact and is highly dependent on where in the surface temperature spectrum you are beginning and what type of creping adhesive is being used. As an example, the graph above displays the tack curves of several commonly used creping adhesives vs creping moisture and temperature.

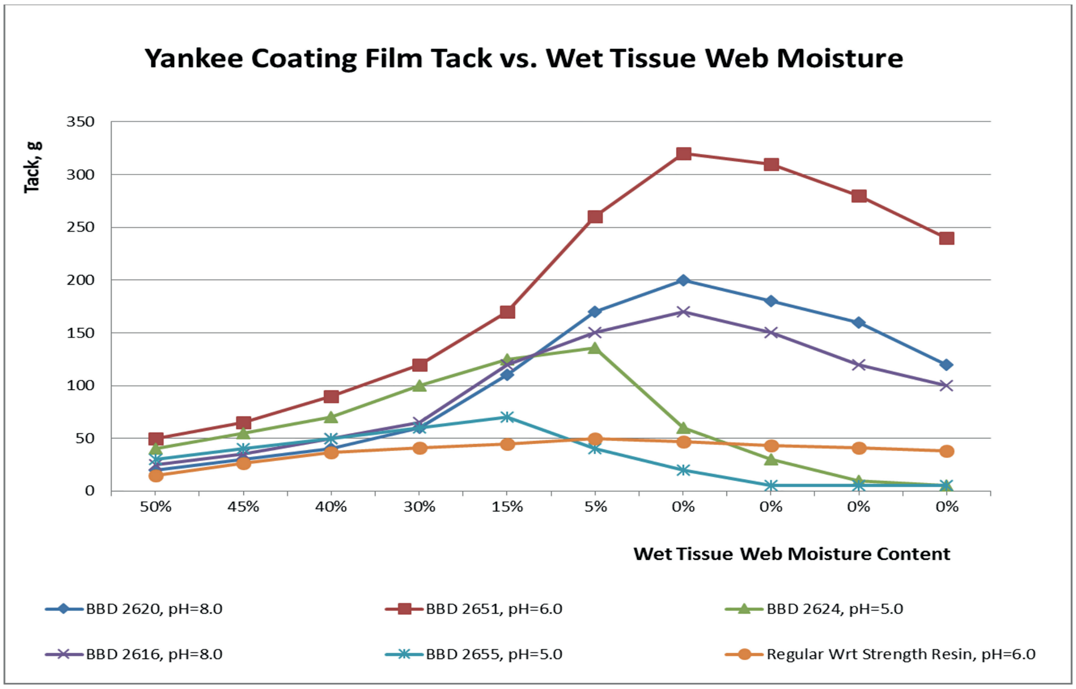

Figure 1. *Yankee coating film tack vs wet web moisture.*

As we can see, many common adhesives are losing tack as creping moisture is driven down due to the glass transition profile or reduced internal bond strength as water content is driven out of the polymer matrix.

Another basic premise driving an increase in bulk at lower creping moistures relates to the inherent properties of hydrogen bonding of cellulose fibers. The primary bonding mechanism between fibers in paper is due to hydrogen bonding. This hydrogen bonding potential is maximized via a small amount of bound water within the paper structure by several mechanisms including plasticizing of the fibers and bridging.

In order to maximize bulk generation, the correct adhesive package must be chosen for the intended creping moisture range.

As such, most cellulosic structures exhibit their maximum strength properties somewhere between 6 and 10% moisture. As the paper is dried below this level, the sheet becomes more brittle and strength properties are reduced. The result is that as we reduce creping moisture, we are bringing a weaker sheet to the face of the blade, which will result in more sheet explosion at similar speeds and adhesion levels.

In order to maximize bulk generation, the correct adhesive package must be chosen for the intended creping moisture range. This is particularly true at the extremes of the LDC creping moisture range, below 3% or above 6%. Signs that your adhesive package is unsuited to your conditions would be:

- Unstable sheet handling
- Breaks, pick-outs
- Reducing moisture results in lower, not higher bulk

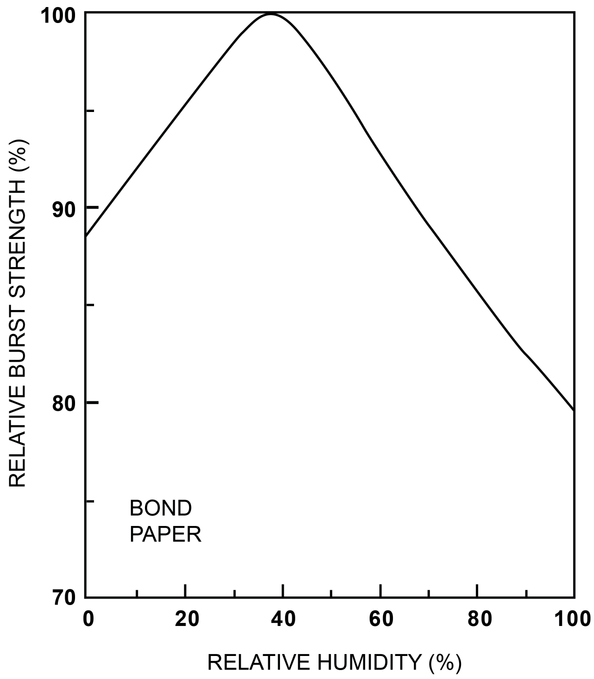

Figure 2. *Burst strength of paper vs ambient relative humidity.*

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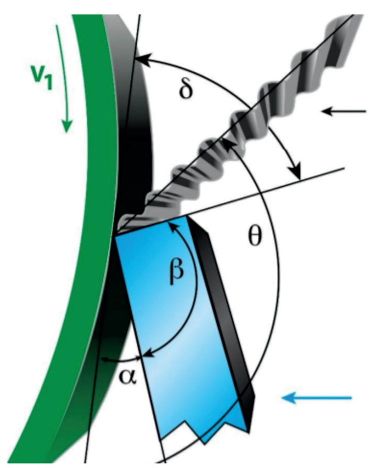
Lab selection of the proper adhesive for a given creping moisture can only be achieved via testing of the adhesive films at the operating temperatures for that creping moisture. This is accomplished via heated platins on tack tester units and creping sled apparatus.

CREPING POCKET ANGLE

The creping pocket angle is defined as the angle between the creping blade shelf and the tangent to the Yankee surface at the point of contact of the blade. This angle is the result of the application angle, blade bevel, and deflection of the blade. Figure 3 shows the relationship of angles for a theoretical, non-flexing blade.

Tissue makers generally adjust the angle by switching out blades of varying bevel angles in order to achieve the desired creping pocket angle. This is done because opening and closing the pocket impacts the ratio of micro crepe to macro crepe. Typical LDC creping pocket angles range from as closed as 74 degrees for some towel, napkin and commercial bath to as open as 100 degrees for high quality facial.



α = sliding wear angle (blade holder angle – deflection angle)

ß = blade bevel angle (90˚ here)

ď = pocket angle

ϴ = blade to sheet angle

Figure 3. *Creping geometry (4).*

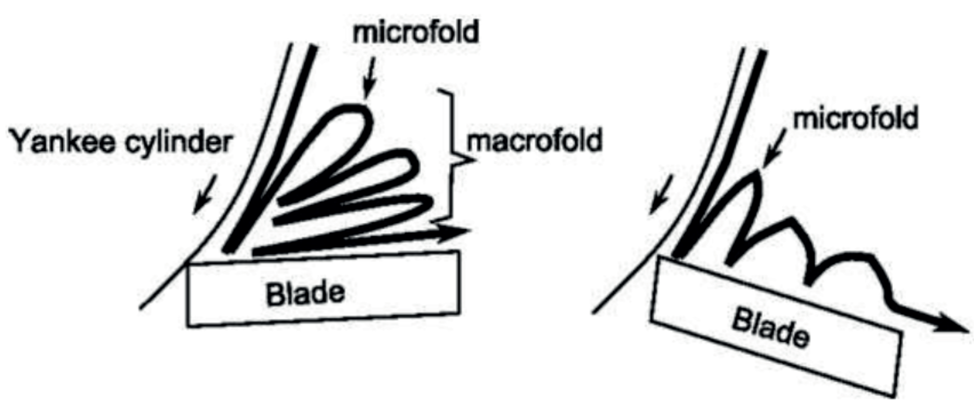


Figure 4. *Creping process and the formation of micro-folds and macro-folds as a function of the creping pocket angle. Left: small angle. Right: large angle [6].*

The prevalent description in the industry for micro and macro crepe formation is summarized by Raunio and Ritala [6].

However, this theoretical model only considers geometric or shaped bulk [7]. This process is related to column failure mechanics, whereby the increasingly uniform adhesion results in explosive de-densification as explained by Dr. Wes McConnell:

As Crepe Frequency increases, the dimensions of the sheet also need to be incorporated on a microscopic level. Figure 5 shows the relationship between the Crepe Frequency and the ratio of Crepe Length (1/CF) to sheet thickness (80 microns).

At low crepe counts, the crepe length is much larger than the sheet thickness and the sheet can bend or buckle as shown. However, as the crepe count approaches 30 crepes/cm, the ratio of crepe length to sheet thickness approaches 5:1. At this point the sheet cannot easily buckle. Instead, the sheet must expand or explode in the z-direction leading to de-densification of the sheet. De-densification is accompanied by increased bulk, tensile breakdown, increased stretch/crepe, softness and void volume. In stratified sheets we can often see sheet delamination [7].

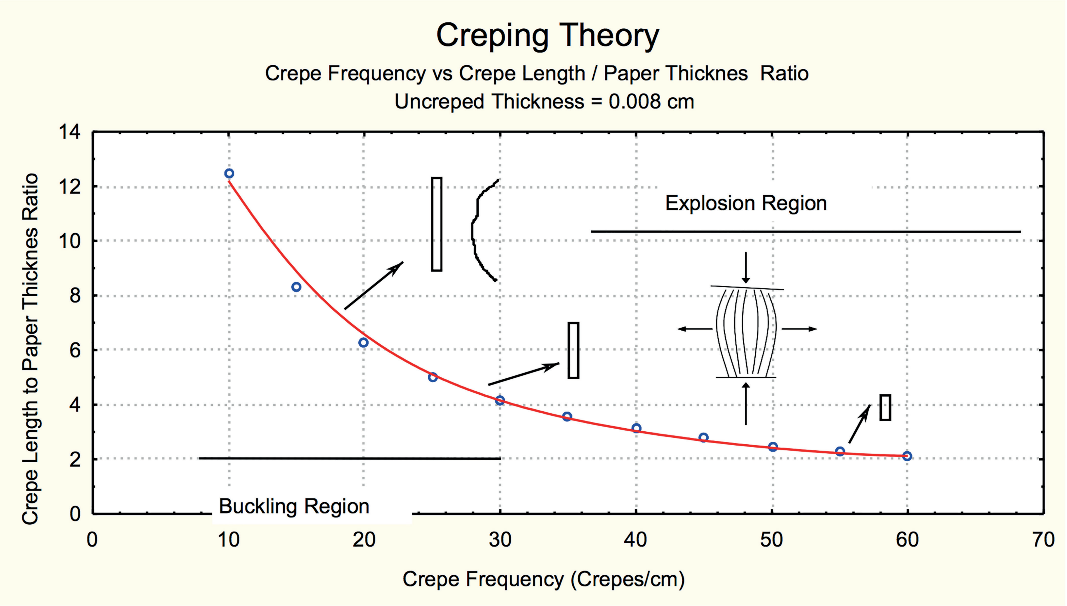


Figure 5. *Crepe frequency vs crepe length.*

This change in the way the crepe structure is created changes the base sheet characteristics as follows:

Tensile breakdown: Generally, closing the pocket angle increases tensile breakdown. This can be easily rationalized with the understanding that a more open pocket presents a blade shelf to the incoming sheet which is angled away, allowing the sheet to exit the creping pocket more quickly and efficiently. In this manner, less of the kinetic energy is transferred into the fiber web. It is here that two competing theories collide: higher energy creping in the closed pocket should produce a more exploded sheet structure which has higher bulk and greater clothlike softness, but this is not what occurs. Although measured tensile will drop, the stiffness, sheet density and surface smoothness will move in softness-reducing directions. This is attributed to a combination of the larger macrofold production due to the buildup of the sheet within the creping pocket.

opening the [creping] pocket promotes a finer crepe structure by allowing the sheet to clear the shelf more quickly.

Crepe structure: as mentioned above, opening the pocket promotes a finer crepe structure by allowing the sheet to clear the shelf more quickly. The caveat with promoting a more open pocket for the benefits associated with the finer crepe are that the impact on tensile breakdown, sheet handling and bulk targets must be dealt with. Creping with a more open pocket necessitates a greater level and a higher uniformity of adhesion of the sheet to the Yankee coating.

In general, it can be assumed that:

- More closed pocket angle → lower crepe counts, lower tensile, higher stiffness, lower smoothness, higher reel bulk, higher base sheet density, greater loss of bulk through winding and converting.
- More open pocket angle → higher crepe counts, higher tensile, lower stiffness, higher smoothness, lower reel bulk, lower base sheet density, lower loss of bulk through winding and converting.

In order to maximize bulk generation, the papermaker must maximize sheet explosion via adhesion uniformity. Lack of adhesion uniformity between the sheet and the Yankee will result in coarser crepe, forcing an opening of the pocket to meet surface smoothness requirements and a potential step change loss in bulk. A good explanation of the mechanism and importance of uniform adhesion can be obtained via *Better Bond, Softer Tissue. Tissue World Magazine, Feb.-Mar. 2003. John Stitt.*

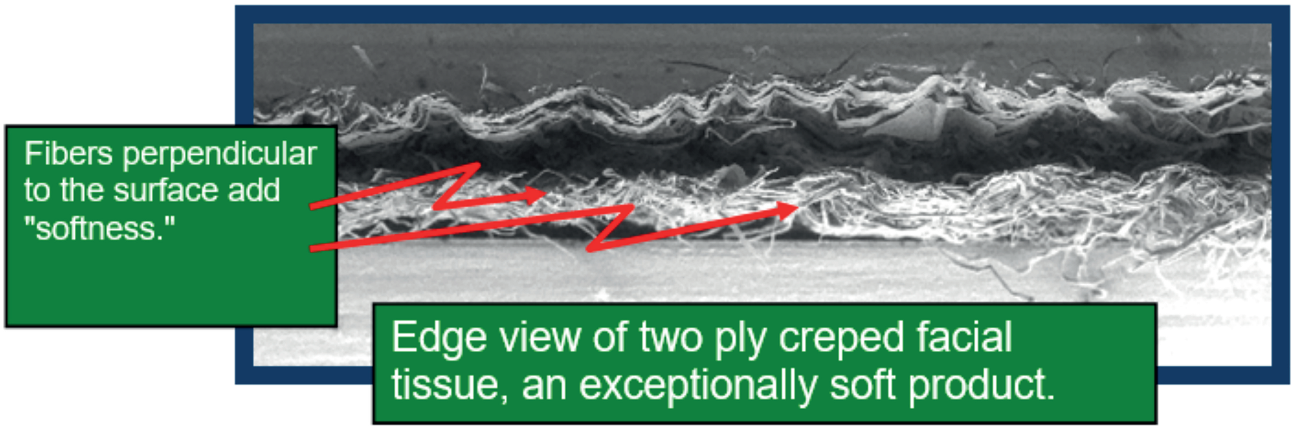


Figure 6. *Picture of base sheet delamination via optimized creping.*

CREPE RATIO

Stretch is an important property of the tissue base sheet and finished product. It plays a role for efficient converting, dispensing and perceived handfeel. Base sheet elongation is comprised of two components:

- Mechanical stretch: imparted via the crepe ratio (reducing the speed of the reel with respect to the Yankee)
- Internal stretch: Disruption of fiber-to-fiber bonds to allow for slippage between fibers which results in % elongation of the sample in excess of the mechanical stretch imparted to the sheet via the crepe ratio.

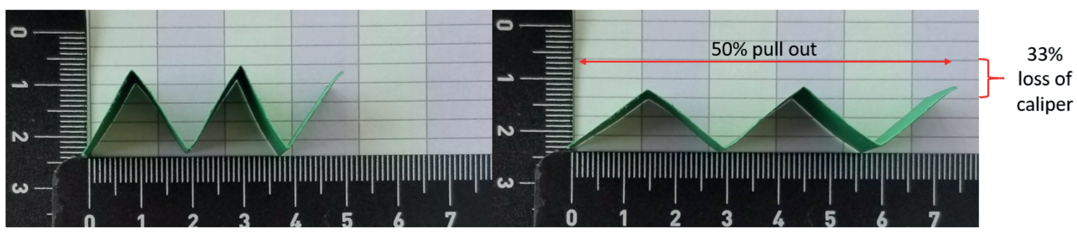


Figure 7. *Representation of bulk loss due to mechanical stretch added via crepe ratio.*

Internal stretch is an excellent predictor of both bulk to basis weight efficiency as well as perceived softness. In order to create internal stretch, the sheet must be adhered to the Yankee via the adhesive coating in a highly uniform manner [5].

While crepe ratio can impart mechanical stretch, internal stretch is imparted via high energy creping. The resulting sheet explosion produces disruption of the sheet structure and de-densification of the fiber matrix. This allows for fiber slippage within the matrix. In this way, internal stretch becomes a good indicator of high sheet disruption, which is necessary for resilient bulk generation.

Conversely, crepe ratio stretch, beyond a certain point, not only reduces production rates, but it results in ever diminishing returns with respect to bulk generation. The bulk created in this manner on the tissue machine is rapidly lost via any pulling through a winder or converting line. We can represent this with an uncreped sheet of paper to represent mechanically induced folds.

Conversely, if we take the extreme opposite case of a cotton ball, where its structure is nothing more than fiber entanglement, we can see that individual fiber slippage within the structure results in much less caliper loss during pull out. This action also provides for increased internal stretch, allowing the tissue maker to achieve stretch values in excess of the crepe ratio being employed. We can see that creating bulk that will best endure through the converting process requires an exploded, delaminate structure.

Ultimately, tissue makers would like to produce tissue at the lowest possible crepe ratio in order to maximize efficiency. Creping pocket angle selection along with the adhesive package optimization are the biggest drivers of what final crepe ratio will

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be necessary in order to meet the required stretch and bulk targets. Maximizing the uniformity of the sheet adhesion to the Yankee, in order to create internal stretch via an exploded and delaminated base sheet, will allow for lower crepe ratios to be employed.

COMMON MISCONCEPTIONS

When trying to optimize the creping process for increased bulk to basis weight, there are several common misconceptions that plague a large portion of tissue makers:

Blade pressure

Many tissue makers misunderstand the purpose of blade pressure with respect to managing sheet quality. It should go without saying that blade pressure is irrelevant to the sheet itself. Blade pressure is dependent mostly on the Yankee coating adhesive package properties that are being used on the individual machine. On modern high-speed tissue machines, blade pressure is predicated on the pressure required for the blade to penetrate the organic coating, getting under the sheet, but not passing all the way through to the surface of the Yankee.

Yankee coating

A Yankee coating adhesive package that is optimized and works great at 5% creping moisture is unlikely to function well at the sort of increased surface temperatures that will result if the tissue maker pursues creping moistures of 3.0% or lower to increase bulk. As explained above, different Yankee coating adhesives develop different film properties at different temperatures. The transition to the lower moisture creping should include a plan for ensuring the correct adhesive has been specified for the purpose.

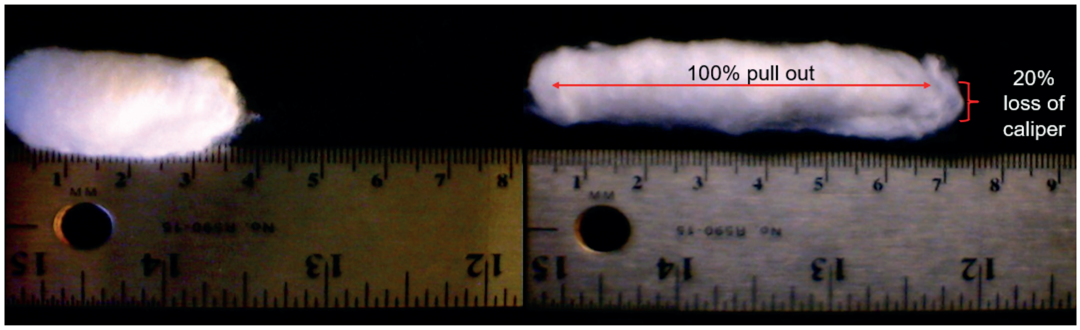

Figure 8. *Cotton ball representation of an exploded, delaminated base sheet.*

creping mechanics can be optimized to provide the specifications in the most cost-effective manner.

SUMMARY

Adjustment of the creping process in order to maximize bulk to basis weight presents tissue makers with an excellent opportunity for improved quality and process efficiency. When a clear understanding of the desired end-product goals has been established between marketing, production and the creping package supplier, creping mechanics can be optimized to provide the specifications in the most cost-effective manner.

As creping is the main driver of bulk generation, the setup of the three main levers of the creping process, namely the geometry, creping moisture and crepe ratio, must be undertaken to achieve the product specifications by extracting maximum value from the creping process. This is generally well understood by tissue manufacturers, but results are often not achieved as expected due to not having the correct Yankee coating adhesive package in place for the new operating conditions desired. Modern laboratory film and materials testing capabilities now allow for much better prediction of the type of chemistry required at nonstandard creping moistures.

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