IDENTIFYING THE RIGHT PRESSURE SENSITIVE ADHESIVES FOR FILMIC APPLICATIONS

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Abstract
With the continuing transformations within the paper industry resulting in supply shortages, and an increased focus on sustainability, many companies are responding by utilizing filmic substrates for label and tape applications. However filmic substrates have a more diverse range of end uses and performance requirements than paper, requiring careful selection of a filmic adhesive. In this presentation we will evaluate the range of PSA performance criteria needed for filmic adhesive selection, such as: coating method, clarity, water and blush resistance, plasticizer migration, converting characteristics, regulatory trends, and recycling standards.

1. Introduction

In recent years, various supply chain disruptions have impacted paper stock availability and pricing, particularly in the US and Europe [1] [2] [3] [4] [5]. Shortages, strikes, and volatility have forced adhesive customers to consider alternative pressure sensitive constructions to fulfill orders, maintain inventories, and control cost. Additionally, an increasing industry focus on sustainability is driving interest in filmic constructions that are recycling compatible and lower carbon footprint. [6] Demand for filmic face stocks has been steadily growing over the last decade and is forecasted to continue [7] [8]. With this increasing focus on filmic constructions, it is important to understand the unique criteria necessary for the proper selection of filmic adhesives. The paper will provide a brief overview of key selection criteria for the roll label, graphics, protective film, and specialty tape market segments. It is not intended to be a comprehensive evaluation of all factors that may influence filmic adhesive selection.

2. Methods

All adhesive testing data reported here was conducted according to the PSTC-101 test method. Unless otherwise specified, adhesives were coated using a custom-built doctor blade coating table operating at 12 inch/min draw down speed, dried for 4 minutes at 115°C in a convection oven, and hand laminated to commercial grade 50 lb SCK release liner. Dry coat weights were 18-21 g/m^2, unless otherwise noted. Commercial filmic face stocks were used in all testing and were corona treated at the manufacture. Coating was done as directly onto filmic face stocks (i.e. “direct coated”), except for PVC, which was coated by applying adhesive to the release liner, and then laminating to PVC films after drying (i.e. “transfer coated”). Laminated strips were aged overnight under a 15 lb weight in controlled temperature and humidity (CTH, i.e. 72°F and 50% relative humidity). Sheets were then cut into strips and applied to test panels for aging and or adhesive testing.

Test panels were obtained from Cheminstruments and annealed prior to first use according to manufacturer instructions. Panels were cleaned prior to each use by immersion for 24 hrs at room temperature in a bath of 25% Chem Tech Magic 1050, followed by wiping with a Kimwipe soaked in acetone or IPA. Cleaned panels were allowed to dry and equilibrate to CTH conditions prior to applying adhesive strips. All adhesive testing was conducted at CTH conditions, unless otherwise noted.

Peel test specimens were prepared by rolling down 1 inch x 5 inch strips on stainless steel (SS) panels using a single forward and single reverse pass with a Cheminstruments roll down machine configured with 5 lb rubber rollers at 12 inch/min roll down speed. Peel tests were conducted at 180 degrees geometry using a Cheminstruments SP-2100 peel tester at 12 inch/min peel rate. Average force values were recorded for each specimen, and five replicate specimens were averaged together to obtain the reported value. Error bars represent ± 1 standard deviation of 5 replicates, unless otherwise stated. Backing tape was not used to mitigate face stock stretching.

Loop tack tests were conducted with a Cheminstruments loop tack machine operating at 12 inch/min speed, using a 1 inch wide test strip and a 1 inch wide SS panel to achieve a 1 square inch contact area. Loop tack replicates were conducted using fresh test strips and fresh locations on a cleaned SS panel. Maximum force values were recorded for each specimen, and five replicate specimens were averaged together to obtain the reported value. Error bars represent ± 1 standard deviation of 5 replicates, unless otherwise stated.

Static shear tests were conducted using a 1 inch x 1 inch x 1 kg geometry in a Cheminstruments static shear testing station with each specimen set to a 178° hanging angle with a 30 minute dwell time on panel at CTH before hanging. Backing tape was not used to mitigate face stock stretching, unless otherwise noted. Time to failure for each specimen was recorded, and replicate specimens were averaged together to obtain the reported value. All replicates were tested simultaneously to ensure consistent experimental conditions. Error bars represent ± 1 standard deviation of 5 replicates, unless otherwise noted.

3. Discussion

For this discussion, we will consider the market segments of roll label, graphics, protective films, and specialty tapes. Roll label refers to label stock that is prepared on wide format rolls of filmic face stock, typically found in applications such as durable drum labels, prime labels, or variable information labels. The graphics segment refers to applications such as point of sale graphics, wall coverings, vehicle wraps, and decals. Protective films are a specialized segment specifically referring to removable films used to protect metal, glass, or plastic surfaces from scratches, corrosion, and damage during transport and installation. Protective films must be cleanly removable within a defined time window after applying, and may include applications such as screen protectors, stainless steel appliance films, protective window films, etc. Specialty tapes represent high performance filmic tapes such as high temperature tapes, wire wraps, and automotive assembly tapes. Each of these market segments differs in adhesive selection criteria in terms of materials used, coating methods, and application requirements.

A wide range of filmic materials are available for use in pressure sensitive applications. Graphics typically utilize PVC films due to superior ink receptivity, printability and flexibility. PET films are also common for graphic applications when weathering, high clarity, or durability are important. For roll label, filmic face stocks are traditionally used when superior durability, printing resolution, or optical clarity are required. BOPP, PET, PE, and PP are the most common face stocks in the filmic roll label market [6]. Filmic face stock selection for the specialty tape market is more diversified, due to niche performance requirements. For general purpose tapes, face stocks may already be films (carton sealing tape) or paper (masking tapes), but economics are the key driver in their selection. For masking tapes specifically, the low cost paper face stocks require saturants to boost strength, and coatings to achieve desired moisture resistance, and release / unwind requirements. Specialty tapes, however, are usually filmic, foam, or foil based structures due to their performance requirements. For example, PVC is a

common face stock for electrical tapes, PET and foil constructions are common for HVAC applications, and polyimide is common for high temperature tapes. Each of these markets present unique challenges for choosing filmic adhesives, which will be discussed in the following sections.

3.1 Coating Method

Adhesive selection for filmic structures should consider the coating method for the intended market segment. As summarized in **Table 1**, A wide range of adhesive coating methods are active in North America. For roll label, high speed (> 500 FPM), wide format (> 40 inch), and low coat weight (12-22 g/m^2 dry) are preferred. Coating methods such as curtain, slot die, and reverse gravure are common in North America. For graphics and protective films, adhesive coating quality is more important than maximizing line speed, so coating methods such as gravure, Meijer rod, and slot die are more common. For specialty tapes, higher coat weights (>50 g/m^2) are usually required to achieve performance requirements, so slower line speeds are acceptable.

Table 1: Market Segment Comparison

	Roll Label	**Graphics**	**Protective Film**	**Specialty Tape**
Key Requirements	Speed, Uniformity	Quality, Appearance	Removability, Appearance	Performance, High Coat Weight
Face stocks	PET, PP	PET, PVC	PVC, PP, LDPE	PET, PVC, PP, PI, Foil
Coating Methods	Slot Die, Gravure, Roll, Rod, Curtain	Slot Die, Gravure, Roll	Slot Die, Gravure, Roll, Rod	Slot Die, Roll, Rod
Converting	Rotary Die, Slitting, Matrix Stripping	Rotary Die, Matrix Stripping	Slitting	Slitting, Water Jet

For the roll label, graphics, and protective film segments, uniformity and smoothness of the adhesive layer are critical for both clear and opaque face stocks. Films used for roll label and graphics are smooth and flexible, with relatively low adhesive coat weights compared to specialty tapes, so imperfections in the adhesive coating, such as orange peel, haze, or grit, will be readily visible in the final constructions. Conversely, for specialty tapes, adhesive appearance requirements are less critical.

For hot melt adhesives, compatibility of the film construction with the temperature of the molten adhesive is an additional consideration. Films that are direct coated cannot be extensible at the adhesive melt temperature. If extensible films are required, the adhesive should be transfer coated from a dimensionally stable release liner or direct coated onto the non-extensible film in the construction. In some cases, extensibility issues in direct coating operations can be mitigated by increasing the gauge thickness of the extensible film, but this approach is not considered a best practice, because thicker gauge films may still become extensible during periods of line stoppages or insufficient line speed. Chilled backing rollers also may be helpful at mitigating extensibility by maintaining cooler web temperatures, but testing must be done to ensure adhesive anchorage is not adversely affected, and

chilling temperatures must be uniform along the chilled roller axis. The same considerations of temperature compatibility apply to coatings on the filmic webs (e.g. primers, barrier coatings, etc.).

Similarly, solvent based adhesives require solvent compatibility with the filmic face stock in direct coating operations. Films that swell or weaken in the presence of adhesive solvents will lead to challenges maintaining uniform web tension, film strength, and coat weight control.

As with all adhesives, specific ranges of solids, rheology, and surface tension are required for each coating method to achieve acceptable runnability. For water-based adhesives, foam mitigation and foam dissipation are particularly important, especially for high shear coating methods (e.g. reverse roll). Foam mitigation is usually addressed through formulation, like all constructions, but closer attention to wettability is required for films.

Wettability is most important for direct coating operations, where the liquid adhesive is applied directly to a filmic face stock. Corona treatment is recommended for PP, PE, PET and other low surface energy films to promote adhesive wetting and adhesive anchorage. Ideally, corona treatment should be conducted immediately prior to coating, with a target surface energy range of approximately 35-45 dyne/cm. However, corona treatment alone does not guarantee appropriate wetting, because the adhesive rheology and dynamic surface tension also play a governing role.

Measuring and predicting wettability in production environments remains an area of active research. Although the fundamentals of wetting are well understood, lab experiments and coating trials are still required to ensure adequate wetting behavior in production. Typically, adhesives are formulated and coated using a lab scale draw down machine onto filmic face stocks of uniform and known surface energy. The wet and dry coated films are then qualitative assessed for appearance as a gross indicator of what the wettability may be in production. Poorly wetting adhesives exhibit significant edge crawl and dewets within a few seconds of coating, and in extreme cases, may yield a discontinuous coating.

Wetting behavior in the lab does not always correlate with wetting behavior in production. This can be demonstrated by considering the Capillary Number. Capillary number (**Equation *1***) is a dimensionless number defined as the ratio of viscous forces to surface tension forces in a liquid medium. When Ca << 1, surface tension forces dominate, and a liquid coating will tend to form droplets to minimize surface area (i.e. dewetting). When Ca >> 1, viscous forces dominate, effectively preventing dewetting.

$$Ca = \frac{\mu V}{\sigma}$$

μ dynamic viscosity
V web velocity
σ dynamic surface tension

Equation 1

When calculating Ca, it is important to utilize viscosity and surface tension values at the same shear rate and surface age as the process under consideration (see **Figure 1**). For nearly all production coating operations (curtain, slot die, roll, gravure), viscosity values at mid- to high-shear conditions should be used, whereas lab coating conditions (doctor blade, Meijer rod) are often best represented by low shear viscosities (i.e. Brookfield viscosity). Similarly, surface tension should represent dynamic surface tension values (measured on a bubble tensiometer) obtained at the same liquid surface age as the process under consideration. Static surface tension (e.g. sessile drop, Du Noüy ring, and contact angle) methods are not appropriate, because static surface tension represents the liquid adhesive after surfactants and additives have fully diffused to liquid interfaces, and coating operations usually do not achieve this

equilibrium state in practice. The time scale relevant for dewetting is the time between when the adhesive is applied and when the adhesive achieves a nonflowing state, either by drying (SB and WB adhesives) or by cooling (HM adhesives). In production, this time scale is typically less than 1 second.

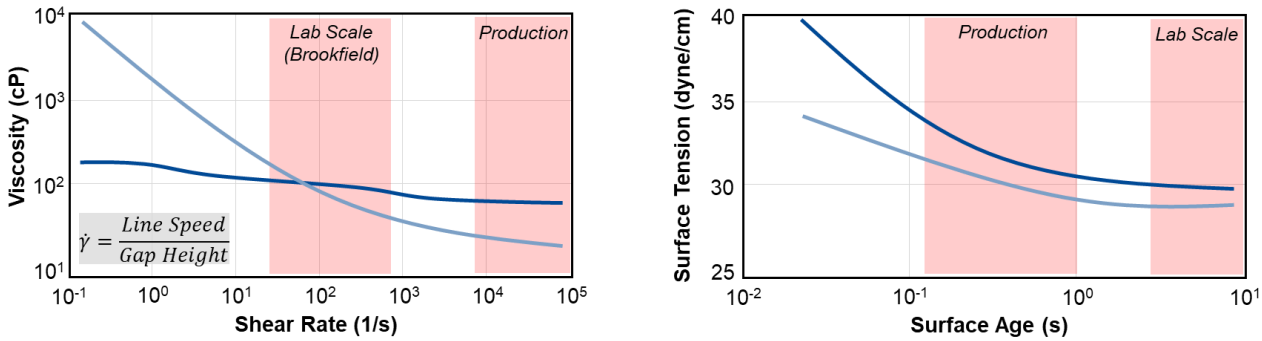

Figure 1: Comparison of lab and production scale conditions for viscosity and surface tension. Production windows represent typical operating conditions for most PSA coating operations.

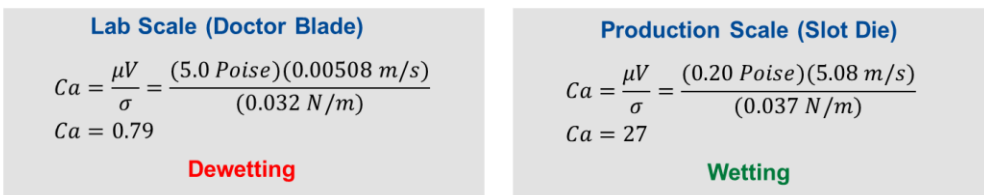

Figure 2: Example calculation demonstrating how lab and production scale conditions can yield different wetting results.

As can be seen in the example calculation in **Figure 2**, an adhesive may exhibit Ca << 1 at lab scale, but Ca >> 1 in production primarily due to the higher shear rates present in a production coating operation. In the example, higher shear rates yield a lower viscosity fluid. This explains why lab scale coatings do not correlate to production scale wetting.

When formulating to improve wettability, it is often easier to increase viscosity than to reduce surface tension. During the coating operation, minor dewetting can usually be addressed by increasing line speed or adjusting corona treatment levels.

It should be noted that dynamic surface tension and rheology are also temperature dependent. When formulating water-based adhesives, it is good practice to confirm the absence of strong temperature-viscosity dependencies due to hydrogen boding, particularly when using associative rheology modifiers. When using hot melt adhesives, the use of chilling rollers or strong air currents across the web can impact rheology and thus wetting.

3.2 Plasticizer Resistance

PVC may be "monomeric", "polymeric" or "a monomeric/polymeric blend", and it may be formed by calendaring or casting. Monomeric PVC is formulated using small molecule plasticizers, which tend to migrate easily into adhesive layers, so monomeric PVC requires adhesives with the highest plasticizer resistance possible. Polymeric PVC is formulated using larger molecule plasticizers which exhibit lower migration tendency, so polymeric PVC can be used with adhesives offering lower plasticizer resistance. Cast PVC is almost always polymeric, whereas calendared can be either, or a blend of both.

In addition to plasticizer migration, adhesive selection for PVC constructions should also consider dimensional stability (shrinkage). Cast PVC generally exhibits greater dimensional stability, compared to calendared PVC. When using calendared PVC, adhesives must also have high shear strength to counteract shrinkage in the final application. This can be a difficult technical requirement in the case of monomeric calendared PVC, as the adhesive will be required to maintain high shear performance throughout the lifetime of the construction, despite significant levels of migratory plasticizers diffusing into the adhesive. Heat, and sometimes humidity, tend to accelerate plasticizer migration, further challenging the adhesive performance. Plasticizer resistance is also important to maintain adhesive performance during prolonged periods of warehousing finished vinyl constructions.

There is currently no standard test method to evaluation plasticizer resistance. The industry norm is to quantify plasticizer resistance experimentally by measuring the reductions in peel and static shear performance as a function of heat aging conditions using representative sample constructions. Aging conditions, coat weights, PVC type, and targeted performance vary by application and customer. Typical testing conditions used by BASF to evaluate plasticizer resistance are shown in **Figure 3** and **Figure 4**, along with representative data for commercial acrylic emulsion adhesives.

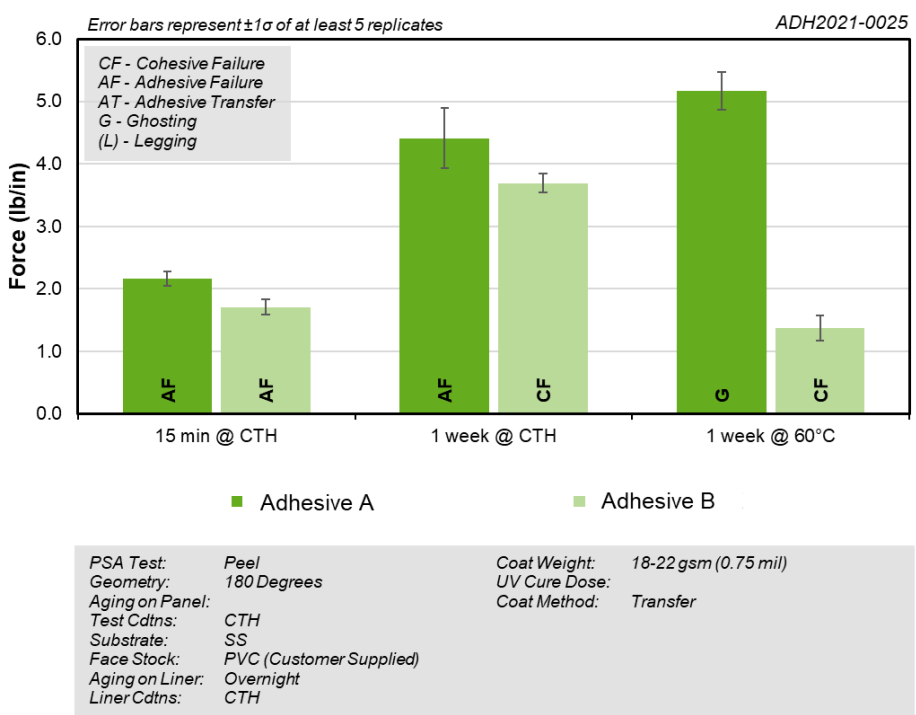

Figure 3: Example of typical plasticizer resistance data for two emulsion acrylic adhesives after aging on panel. Adhesive A is a commercial filmic adhesive exhibiting good plasticizer resistance, and

Adhesive B is a commercial filmic adhesive not designed for plasticizer resistance. Target criteria is less than 20% loss of peel relative to 1 week at CTH. (CTH = 72°F, 50% RH.)

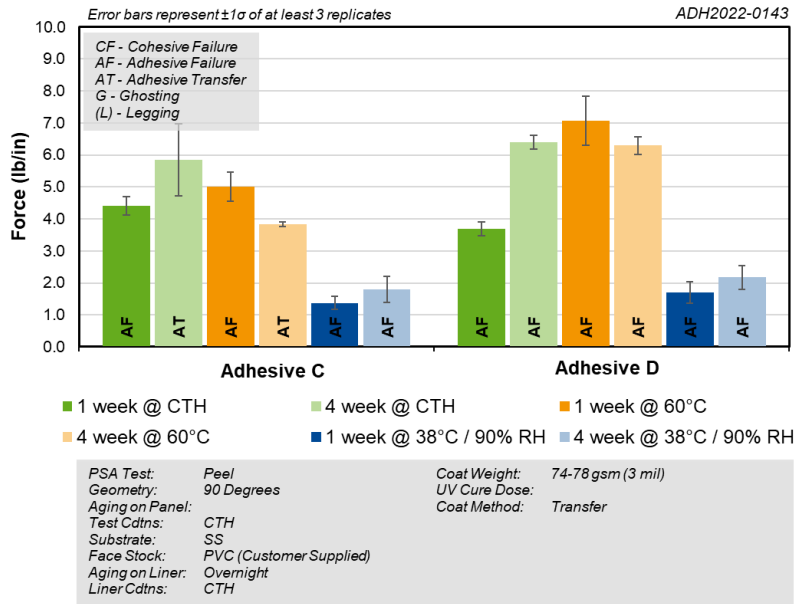

Figure 4: Example of an alternative plasticizer resistance evaluation. Adhesive C is a commercial emulsion acrylic adhesive not designed for plasticizer resistance, but still exhibiting excellent performance in a plasticized construction. Adhesive D is a commercial emulsion acrylic adhesive specifically designed for plasticizer resistance. Target criteria is less than 20% loss of peel performance between 1 week and 4 week aging at a given aging condition, and no change in failure mode.

Aging may be conducted with the PVC strip applied to a release liner or to a SS panel. Aging on release liner is used to simulate plasticizer migration during warehousing of the finished construction (i.e. "shelf stability") before reaching a customer. Aging on panel is used to simulate plasticizer migration in the final application after reaching a customer. Results from aging on liner will usually differ from those obtained by aging on panel. This is due to the different surface energy of SS compared to the liner. Polar migratory components in the adhesive will tend to diffuse toward a high surface energy interface (i.e. SS), or away from a nonpolar interface (i.e. liner), which leads to compositional gradients in the adhesive coating which then affect diffusion rates of plasticizers from the PVC.

As with all adhesive application testing, but especially with plasticizer migration studies, it is important to include control samples, age samples simultaneously, and utilize statistics to evaluate results. This is because plasticizer migration is a dynamic phenomenon that may be difficult to reproduce from day to day or batch to batch.

3.3 Clarity and Blush Resistance

Blush resistance, also known as "water whitening resistance" (WWR), is the degree to which an adhesive will retain optical clarity in the presence of moisture. Adhesives that are not blush resistant will transition from an optically clear appearance to an opaque white appearance, making them unsuitable for "clear on clear" applications, in which the end user must see through the adhesive layer.

One example of a WWR application is a clear filmic label on a shampoo bottle. The shampoo product can be seen by looking through the filmic label and the optically clear bottle. This application would require WWR due the humid environment that the bottle will be located in. Another example is a clear filmic label on a glass drink bottle, which may be immersed in a cooler filled with ice water.

Water whitening is caused by swelling of the adhesive microstructure as water ingress occurs. When water-based adhesives are coated and dried, the dispersed polymer particles concentrate and coalesce into a close packed hexagonal array, resembling a honeycomb. The grain boundaries between these polymer domains are rich in water-soluble additives used in the dispersion, such as salts and ionic surfactants. As water ingress occurs, these grain boundaries swell, increasing the spacing between the hydrophobic polymer domains. When the spacing between polymer domains increases to approximately 300 nm, scattering of white light begins to occur, and the adhesive appearance transitions from clear to white. For an adhesive that is directly exposed to water, the whitening process can occur within minutes or even seconds. Although the whitening process is usually reversible upon drying, nearly all WWR applications require no change in optical clarity, so reversibility is not considered.

Solvent borne (and hot melt) adhesives typically exhibit excellent WWR performance, since their microstructure does not contain grain boundaries or water-soluble additives. Solvent borne adhesives dry into films that have featureless microstructures without grain boundaries, since the polymeric chains remain entangled throughout the drying process.

There are no standardized test methods available for measuring water whitening resistance. The most common approach used by the PSA industry is to coat and dry an adhesive onto a clear film (usually corona treated PET) at a target coat weight, and then immerse the test strip in water. Multiple strips are prepared in replicate and immersed for different durations. At each immersion time, strips are photographed (without removing from the water bath) and assigned a relative blush ranking. Ideally, relative rankings are assigned while using a positive control (optically clear reference sample) and a negative control (fully whitened “worst-case” sample) to minimize observer bias. In practice, control samples are not always used. Although immersion times are not standardized, samples with exposed adhesive will usually exhibit water whitening within 1 hour of immersion or less. In some cases, samples may be laminated to another film prior to immersion, such that only the adhesive near the edges of the construction is exposed. In this case, immersion times may extend up to several days.

In recent years a number of more objective and quantitative methods have begun to appear, in which the same coating and immersion procedures are utilized, but the evaluation is done by either: (1) quantifying optical density, or by (2) quantifying contrast of a periodic pattern placed behind the test strip. Optica density measurements require a spectrophotometer with an integrating sphere, a haze meter, or a laser, which are not always available. Spectrophotometric techniques are highly accurate and suitable for measuring real-time blush development, but they are susceptible to spatial gradients in the sample, because they measure a spatially localized point.

Optical contrast methods typically utilize an image of the sample and obtain contrast values using image analysis software. Optical contrast techniques utilize a larger sample area, making them more robust to coating defects, and very suitable for statistical analysis. However, there are many definitions of optical contrast, and many are affected by average image brightness as well as nonuniform lighting conditions (e.g. glare).

An example of a relative ranking method is shown in **Figure 5**. The sample shown in the upper image exhibits poor WWR, whereas the sample in the lower image exhibits excellent WWR. Relative ranking as a function of time is provided in the table below the images, representing WWR performance on a scale of one to five, where 1 is good WWR, and 5 is poor WWR.

An example of an image contrast method is shown in **Figure 5**. The test strips are immersed in water on a checkerboard background and then photographed at various durations. The photographs at each time interval are converted to an 8-bit grayscale image, and then each strip is analyzed to determine average pixel intensity values the checkerboard squares. The average pixel values of white and black squares are measured, both for squares covered by a sample strip, and for squares not covered by a sample strip. The equation shown in **Figure 5** is then used to calculate a definition of optical contrast that is independent of average image intensity. In this definition, contrast values can range from 0 (completely opaque) to 1 (perfectly transparent), and samples with the smallest drop in contrast vs. time represent the best WWR.

	Immersion Time (min)									
Adhesive	0.17	0.50	1	3	5	10	20	30	40	50
E	1	1	2	2	3	3	4	3	4	4
A	1	1	1	1	1	1	1	1	1	1

Rating from 1-5 (1 = no blush, 5 = full white) *ADH2019-0040*

Figure 5: Example of a relative ranking method for water whitening using commercial emulsion acrylic adhesives.

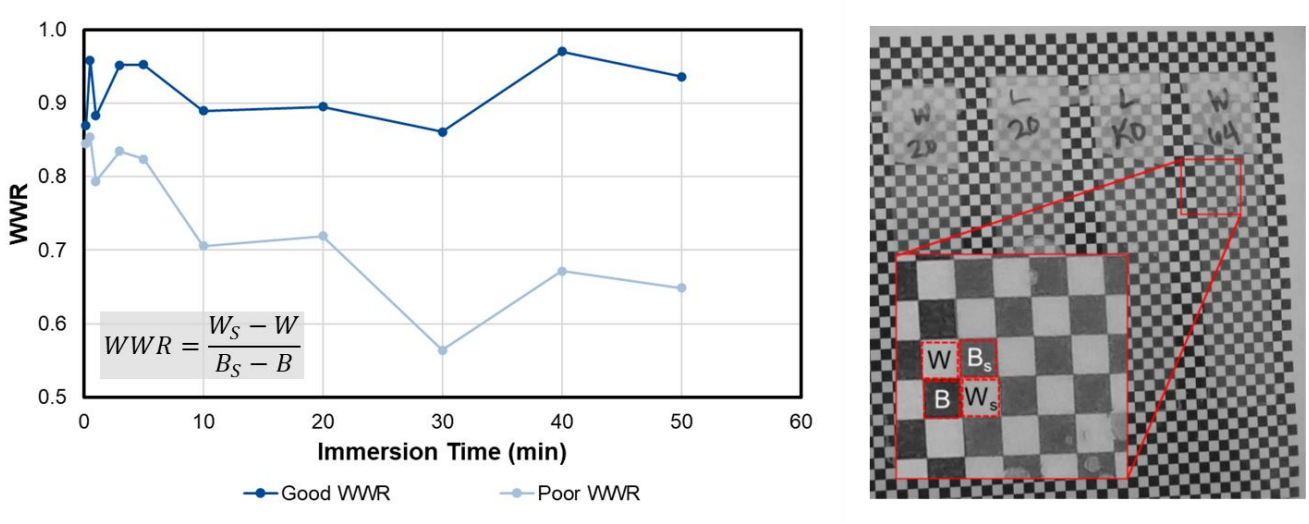

Figure 6: Example of an image contrast method evaluation of water whitening resistance (WWR) using 8-bit grayscale photographs of test strips overlaid on a checkerboard background. W_S is the average pixel value of a white square on the sample strip, B_S is the average pixel value of a black square on the sample strip, W is the average pixel value of a white square on the background pattern, and B is the average pixel value of a black square on the background pattern.

Some evaluations of blush resistance also include some basic measure of tack or adhesion after removing test strips from water immersion and allowing them to dry at controlled temperature and humidity conditions for a predefined period (e.g. 15 minutes). Tack may be measured by touch (with a gloved finger) or a tack probe to assign a rating. Adhesive removability can be measured by gently rubbing the adhesive (with a gloved finger) and rating how easily the adhesive rubs off the test strip. All of these techniques are highly subjective and intended as a gross indicator of PSA performance loss due to the water immersion process. More exact measurements of peel, tack and shear may also be done after immersion by applying the coated strips to panels and testing at controlled temperature and humidity. It is important to note that blush resistance does not correlate with PSA performance after immersion. Adhesives with excellent WWR may exhibit significant drops in peel and tack performance in the presence of moisture or water immersion, and vice versa.

In some cases, edge adhesion is specifically measured. For edge adhesion evaluation, the entire water whitening study is conducted on test strips of adhesive coated film that are applied to a substrate, so water ingress is restricted to only the edges of the test strips. The substrate may be plastic, metal, or even another film. The test strips are then ranked according to the degree of edge delamination after immersion in water. Due to the use of a laminated structure in this method, immersion times of 72 hours or longer may be needed to obtain meaningful results. Immersions may be done in ice water, hot water, or room temperature water, and are selected based on the end use application. Some end use applications where cold or warm water immersion conditions may be relevant include beverage labels and sterilization labels.

3.4 Converting Characteristics

Converting characteristics are another important consideration when selecting filmic adhesives. Filmic constructions are frequently more sensitive to common converting challenges than other constructions,

particularly with thin gauge films (< 1.5 mil). Slitting operations are common in all market segments, so adhesive buildup on slitting knives is almost always a concern. Water jet cutting has appeared in recent years as a viable alternative to knife slitting of filmic and foam constructions and is specifically intended to avoid the adhesive buildup issue. This can be helpful when slitting to narrow widths (~1/4 inch) such as is common with specialty tapes. However, water jet cutting requires adhesives with excellent moisture resistance to avoid edge delamination and, in the case of clear filmic structures, also may require water whitening.

Rotary die cutting and matrix stripping is common in roll label and graphics, and to a smaller extent in some specialty tapes. Although adhesive buildup is still a concern with die cutting, minimizing legging is also critical for this operation. For both knife slitting and rotary die cutting, converting issues tend to be more common with softer adhesives (T_g less than approximately -30°C), especially in warm environments (i.e. hot summer day). Chilled rollers are a common industrial practice to improve converting performance of soft adhesives, but chilled rollers cannot always compensate for adhesives with poor converting behavior. Additionally, since films are generally tougher and more flexible than paper, filmic structures may require higher die pressures to get clean cuts. Higher die pressures will exhibit higher strain on the adhesive, which may induce ooze, legging, and other viscoelastic phenomena.

Peel strength of the adhesive should be considered when predicting converting performance. If adhesion force is too high, softer films, such as PVC, may be susceptible to stretching or distortion during weeding or matrix stripping, or web breaks will be common. For roll label, high speed automated applicator equipment, such as is used for bottle labels, requires a well-defined release force from the liner to ensure consistent and reliable operation.

There are several approaches to measuring and predicting converting performance for an adhesive, all of which are only rough indicators. To estimate the relative level of adhesive buildup on knives, rollers, and rotary die cutters, one industry norm is to examine static shear performance at controlled temperature and humidity conditions in accordance with PSTC-101 test methods. Static shear values form lab samples that are less than approximately 1000 min using a 1 inch x 1 inch x 1 kg test geometry should be cause for concern. For evaluating release force, the recommended approach is to use a release force tester operating at the same line speed and environmental conditions (temperature and humidity) as the production operation. For meaningful results, it is also important to utilize the exact same construction that will be used in production in these tests.

Dynamic mechanical thermal analysis (DMTA) is another approach that can be used to predict converting characteristics. DMTA is a rheological method in which a dried adhesive is placed in a cone and plate fixture at known temperature and subject to an oscillatory rotational strain of 1% or less. Either the temperature or the frequency of the strain is then varied while measuring the applied torque. The relation of torque to strain is directly related to the elastic modulus (G*) of the adhesive. Plots of the storage (G') and loss (G") components of the elastic modulus are constructed vs. temperature or frequency. These plots provide insight into the adhesive viscoelastic character at different temperatures and time scales.

When studying converting performance, it is useful to construct a plot of storage modulus (G') vs. frequency (**Figure 7**) at the temperature that the web will be during the converting operation (typically around 25°C). The plot is then examined in the range of time scales typical of the converting operation (typically 10^2 – 10^3 Hz, see **Appendix A**) and compared against a control. Higher G' values in this

region are preferrable, as this indicates a stiffer adhesive at the temperature and time scale of a converting operation. This method reliably predicts the adhesive character in the absence of high strain deformations, such as legging.

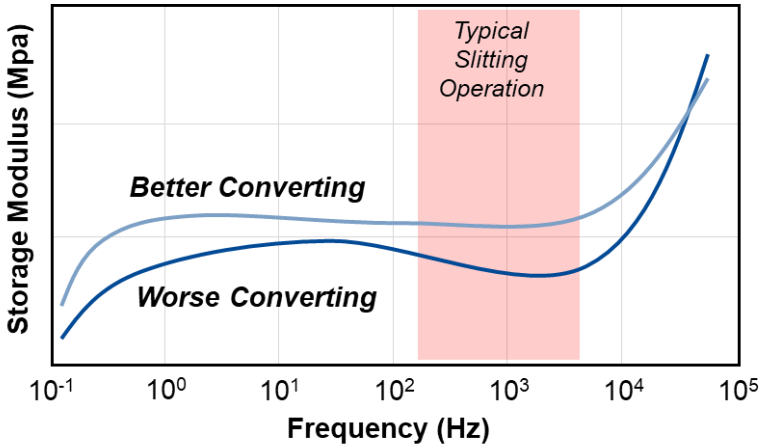

Figure 7: Depiction of DMA frequency sweep comparing adhesives of differing convertibility.

None of the above methods will correlate perfectly to adhesive behavior in a production environment. Release testing is an approximation of production conditions. Static shear correlating with slitting is only an empirical heuristic, and DMTA only evaluates low strain behavior in the absence of face stock and liner interfaces. Converting operations depend strongly on the thickness of face stock, liner, adhesives, and other coatings, as well as line speed, temperature, humidity, laminating nip pressure, adhesive residual moisture, web tension, and condition of the knives or die cutters.

3.5 Regulatory and Sustainability Trends

Regulatory and sustainability trends are playing an increasing role in filmic adhesives selection. As of January 4, 2021, APEO-based surfactants are no longer permitted for sale and import in the EU. Although no regulatory driver currently exists in the US, similar legislation has been expected for some time, and some adhesive suppliers have begun to proactively phase out APEO-based adhesives. Supply chain disruptions in North America over the past five years have also accelerated the industry transition to APEO-free adhesives due to increased awareness and concern for supply security. As a result, APEO-free adhesives represent a more secure long-term sourcing option as suppliers continue to transition to APEO-free portfolios.

Sustainability is another key driver for filmic adhesive selection. Various carbon balanced, low carbon footprint, and/or life cycle analysis approaches are being utilized by adhesives suppliers. These calculations provide good guidance for products offered by a single supplier but are challenged by a lack of consistency in their approach across suppliers. As a result, assessments cannot currently be compared across suppliers, but this landscape is continuing to evolve with calls for the establishment of industry standard approaches.

One sustainability topic that does have industry consensus is recycling of filmic labels for PET containers. The Association of Plastics Recyclers (APR) has established best practices and standardized test methods, such as Method PET-P-00, for defining requirements of a recycling compatible filmic label. Such tests evaluate: (1) the ability of a filmic label to remove cleanly from a PET substrate in

caustic water conditions, (2) the adhesive to separate easily from the recycling process, and (3) the quality of the resulting recycled PET substrate. This test has been widely adopted in the filmic adhesives label segment (known informally as “APR wash-off”), and several label and adhesives suppliers have developed abbreviated internal screening methods to predict recycling performance. Roll label products can also be certified to the APR standard by third party testing labs. It should be noted that the results of the APR wash-off tests are strongly dependent on the choice of PET substrate, adhesive formulation, and filmic face stock, so an “APR certified” label or adhesive may not be suitable for recycling on constructions other than the ones for which it was tested.

4. Conclusion

Selection of filmic adhesives requires additional considerations that are less relevant for other constructions. Market dynamics are increasingly favoring filmic constructions across all market segments considered here. Wettability, plasticizer resistance, and water whitening resistance are important considerations for filmic adhesive selection that usually are not a concern for paper constructions. Due to the lack of industry testing standards for these properties, various industry norms are used, with varying levels of subjectivity and applicability, which must be understood for proper adhesive selection. Similarly, converting performance can be more challenging with filmic constructions, and the suitability of several testing approaches to predict converting behavior have been discussed. Lastly, sustainability, and in particular, recyclability, is an increasingly important factor to consider in filmic adhesive selection, especially for the roll label segment.

5. Literature Cited

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6. Appendix A

The geometry shown in **Figure 8** can be used for calculating the appropriate time scale to use in DMA when predicting adhesive converting performance. In typical knife slitting operations, the male knife roller, which is sharpened and performs the slicing action, is a smaller diameter than the female knife. For a male knife roller radius, ***R***, a cutting depth of ***T***, and a line speed of ***v***, the time scale for slitting, ***t***, is given by **Equation 2**. The inverse of the ***t*** corresponds to the frequency of interest in a plot of G' vs. frequency.

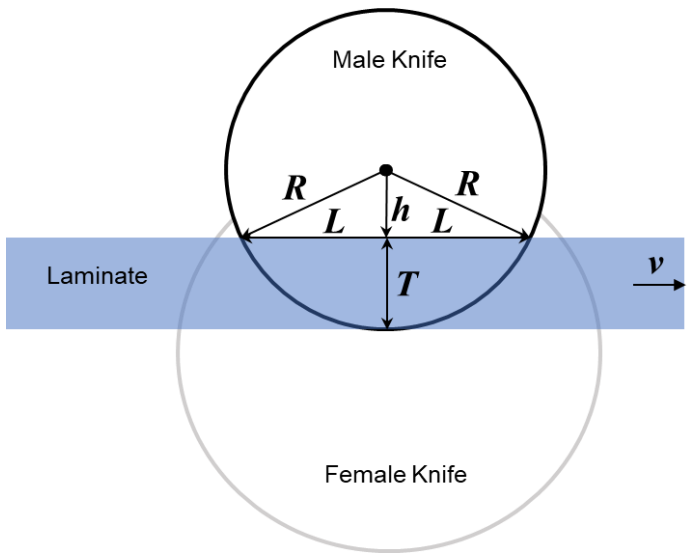

Figure 8: Geometric diagram of a slitting knife arrangement as viewed in the cross-web direction.

$$t = \frac{2\sqrt{R^2 - (R - T)^2}}{v}$$ **Equation 2**

Most slitting operations will operate with male knife diameters in the range of 4 to 10 inches, cutting depths of 4 to 7 mils, and line speeds in the range of 500 to 3000 fpm. For these conditions, the frequency of interest spans approximately 1.9 x 10^2 to 2.4 x 10^3 Hz. A similar geometric construct can be applied to rotary die cutting.

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