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The Effect of Pressure-Sensitive Adhesive Properties on
Screenability

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THE EFFECT OF PRESSURE-SENSITIVE ADHESIVE PROPERTIES ON SCREENABILITY

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ABSTRACT

Pressure-sensitive adhesives (PSAs) are the major source of stickies in paper recycling. It is desirable that the PSA not break down into very small pieces during repulping so that it can be screened out. However, it is not clear in the literature what mechanical properties of PSAs are required to make PSAs screenable. In this study, the screenability of a range of PSAs was evaluated. The hydrophobicity, peel, shear, tack and viscoelastic properties, tensile strength, and contact angle of these PSAs were measured. High tack and peel strength generally increase the screenability of PSAs. The dynamic property of the PSAs also has an effect on screenability. A PSA with a higher stretch index has higher screenability. It is also necessary for a screenable PSA to have a certain degree of hydrophobicity. The optimized PSA properties for a screenable PSA in laboratory repulping settings are reported.

1. INTRODUCTION

In recent years, global interest has increased in the recycling of waste paper to supplement the use of virgin fiber as a way to protect the environment. Statistics show that major countries are increasing their use of recycled paper. For example, in 1991 to 1996, the USA increased its recovered paper utilization rate from 31% to 39%, Germany went from 50% to 60%, the UK went from 60% to 70%, France increased from 46% to 49%, and China went from 32% to 35% [1]. The increased use of recycled fiber has been accompanied by an increasing level of contaminants such as stickies. Stickies are hydrophobic, tacky, polymeric materials that are introduced into the papermaking system from a mixture of recycled-fiber sources. Stickies can break down and then reaggregate and appear at seemingly any place in the mill. When subjected to a number of factors including changes in pH, temperature, concentration, charge, and shear forces, stickies can deposit [2]. Stickies deposits can lead to decreased runnability, decreased productivity, and increased machine downtime. It has been estimated that stickies cost the paper industry between \$600 and \$700 million a year in the USA due to the cost of control methods and lost production attributed to stickies [2]. As a result, four of the seven recycling mills opened in the USA between 1994 and 1997 have closed, citing stickies as the main reason for the closure [3].

Stickies are mainly generated from pressure-sensitive adhesive products such as postage stamps, self-sealing envelopes, labels, etc. The first step to control stickies would be to prevent them from entering the mill in the first place. However, this is not an easy task. Problems of stickies can be prevented by careful inspection of the waste paper entering the mill. Many recycling mills employ people to remove some of the waste paper that has visible stickies contaminants, to avoid process problems [4]. Contaminated waste paper that is removed is sent

to the landfill, unused, at the expense of the mill. Screening and cleaning currently remove the majority of stickies. Macrostickies are effectively screened out with fine screens; however, as the slots in screens are made smaller, fiber loss occurs. Although microstickies can be partly removed by flotation and washing, many of them will still be left in the pulp furnish, which may create problems later in the papermaking process. It would be desirable to produce pressure-sensitive adhesives that can be totally screened out during the screening process. There are many studies ongoing in this area, but there is no fundamental understanding about the relationship between PSA properties and screenability. Obviously, this understanding is important because it will give PSA producers improved insight into the design of new screenable pressure-sensitive adhesives.

2. EXPERIMENTAL

2.1. Materials

Polyacrylate-base pressure-sensitive adhesives: XPD 1811, XPD 1822, XPD 1814, XPD 1988, 26146, 26222, 26171, 26207 were from BF Goodrich. 2077, 2232, 2233, 2431, 3 120, 5 014, 6072, 6210, 6240, 9110 were from Dyna-Tech Adhesives Inc. Tackifier Snowtack 780G and 755A were from EKA Chemicals.

2.2. Pulping and Screening

Office white copy paper containing 0.3% of PSA was repulped with a lab LAMORT pulper. Pulping conditions are shown in Table 1. The final pulp freeness was 250 mL. The pulp was screened on a Sommerville vibrating screen with a slot size of 0.2 mm without pressure.

Table 1. Pulping conditions for screenability tests.

Time	Temperature	pH	Consistency
20 min	50°C	10.5	10%

2.3. Image Analysis

Handsheets for Image Analysis were made according to the standard Buchner funnel methods (PAPTAC Standard C.4U). VWR 415 filter paper with pore size of 25 μm was used for filtration. The pad weight was 1.2 g. The pad was pressed according to the standard TAPPI method T205 om-88, air dried, and then dyed. The dyed pad was analyzed with Image Analysis. Screenability was calculated according to: $\text{Screenability} = (A_0 - A_s) \times 100\% / A_0$, where A_0 is the stickies area of unscreened pulp and A_s is the stickies area of screened pulp.

2.4. Surface Chemistry and Mechanical Properties of PSA

The contact angle of PSA was measured by FTA200 with PSA coated on a polyester film. The tensile strength and mechanical property of PSA were measured by Instron. The PSA sample for measurement was 0.025 mm thick, 15 mm wide, and 5 mm long. Tensile strength is the maximum torsion force in stretching the PSA film. The stretch index was a measure of the elongation level of the film until a break occurs.

3. RESULTS AND DISCUSSION

The function of PSAs is to ensure instantaneous adhesion upon application of light pressure. PSAs must possess viscous properties in order to flow and to be able to dissipate energy during the adhesive bonding process. They must also be elastic and be able to store bond rupture energy in order to provide good peel and shear performance. The end-use properties, which are essential in characterizing the nature of PSAs, include tack, peel adhesion, and shear. Tack measures the adhesive's ability to adhere quickly, peel adhesion measures its ability to resist removal through peeling, and shear measures its ability to hold in position when shear force is applied. These PSA end-use properties depend on the nature and composition of the PSA polymer. When papers containing PSAs are repulped in water, the PSA will interact with itself, fibers, water, and other materials during the repulping process. It may break or reaggregate under shear. For PSAs to be screenable, they must form large particles that do not pass the cleaning screen. The PSA end-use properties and other physical properties should determine the PSA behavior in repulping, and hence the screenability.

3.1. The Effect of Loop Tack on PSA Screenability

Figure 1 shows the effect of PSA tack on screenability. It can be seen that with increased tack, the screenability of the PSA increases.

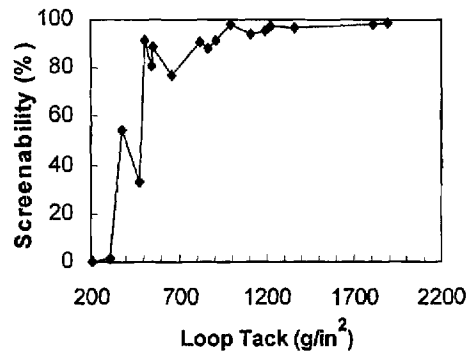


Figure 1. The Relationship between Loop Tack and Screenability.

Tack is defined as the force required for separating an adherent and an adhesive at the interface shortly after they have been brought rapidly into contact under a light pressure of short duration [5]. It represents the adhesive's ability to adhere quickly. Tack is measured in two steps: the contact step and the separation step [6]. During the first step, contact is made at the geometrical surface points, which increase to a larger area through wetting out, viscous flow, and elastic deformation. In the second step, debonding creates two new surfaces. During debonding, high tack means that the adhesive absorbs a high deformation of energy, which dissipates on the breaking of the bond. Thus PSAs with high tack generally have low bonding viscosity, high debonding viscosity, and high elasticity. During repulping, the PSA is subject to intermittent shear force. A PSA with higher tack would be able to absorb sudden shear force better, and thus would not be easy to break. Also, a PSA with high tack has high fluidity and bonding ability on light pressure. Because normally PSAs are hydrophobic, they tend to agglomerate with each other. PSAs with higher tack should adhere to each other more easily to form large particles during repulping.

3.2. The Effect of PSA Peel Strength on Screenability

Figure 2 shows the relationship between peel adhesion and screenability.

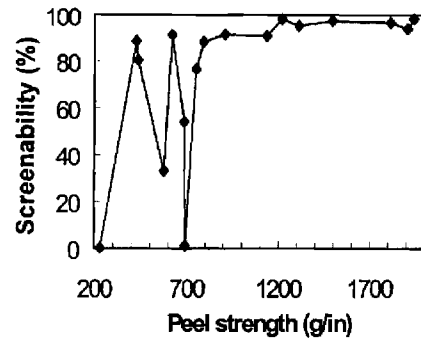


Figure 2. The Relationship between Peel Adhesion and Screenability.

Peel adhesion is the force required to remove a PSA-coated film from a specific test surface under standard conditions (specific angle and rate). It gives a measure of adhesive or cohesive strength, depending on the mode of failure [7]. Similar to tack, the measurement of peel adhesion involves a bonding step and a debonding or peeling step. The efficiency of the bonding process is related to the adhesive's ability to exhibit viscous flow. In order to achieve peel adhesion, the bonding stage involves some dwell time. Thus, the flow properties during the bonding step are less critical for peel than for tack. The debonding process involves a rapid deformation of the adhesive mass. Thus, the higher the peel strength, the higher the PSA's ability to resist bond deformation at high strain rates. Thus, PSAs with higher peel strength, on one hand, can form large particles with each other during repulping because of their better viscous flow. Furthermore, higher peel strength has greater ability to resist bond deformation at high shear. As a result, better screenability may be obtained for the PSAs with higher peel strength. In general, the results shown in Figure 2 support the above discussion. However, because the data are scattered, more studies are needed for a concrete conclusion.

3.3. The Effect of PSA Shear Strength on Screenability

Figure 3 shows the effect of shear strength on screenability. Obviously, no firm conclusion can be drawn from the results for a preferred shear strength range.

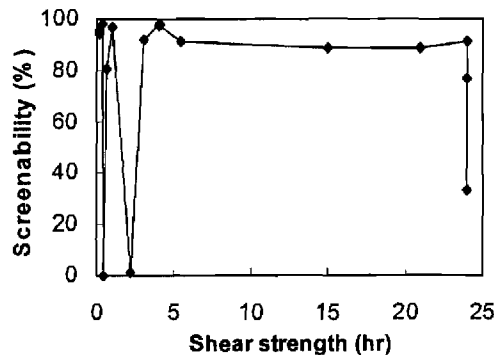


Figure 3. The Relationship between Shear Strength and Screenability

Shear resistance is measured as a force to pull the PSA material parallel to the surface to which it was affixed with a definite pressure [8]. It measures the cohesion strength of the PSA. PSAs

with higher shear strength have higher internal structural resistance; thus, they should be more difficult to break during repulping. On the other hand, PSAs are normally coated on paper as a very thin layer (~ 25 μm); the shear force in repulping is much bigger than the force needed to break the thin film. This may explain why shear strength does not have a determining role in PSA screenability.

3.4. The Effect of PSA Tensile Strength on Screenability

The effect of PSA tensile strength on screenability is shown in Figure 4.

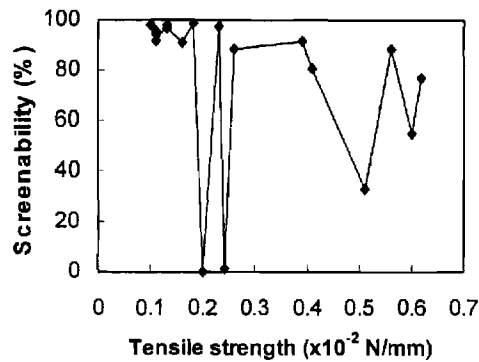


Figure 4. The Relationship between Tensile Strength and Screenability.

It is obvious that tensile strength also does not have a determining effect. Tensile strength is a measure of the PSA internal structural resistance to outside force similar to shear strength. It can be imagined that any PSA film will not break down if it has very high tensile strength. However, the “PSAs” that have very high tensile strength will not be considered real PSAs because they have no tack and peel adhesion. For PSAs coated on paper, tensile strength is so small that it cannot play a significant role in preventing the PSAs from breaking into very small particles, which could pass through the screen.

3.5. The Effect of PSA Dynamic Mechanical Properties on Screenability

We only measured the stretch index (elongation) of the PSA. The stretch index is measure by stretching a certain length (5 mm) of PSA film under a constant rate until it breaks. The stretch

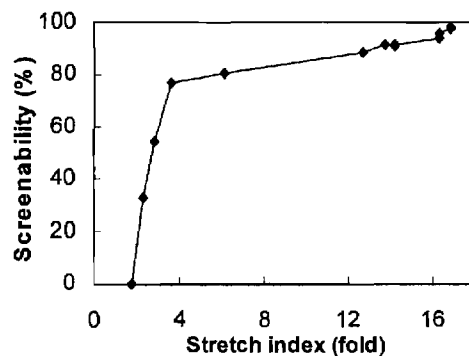


Figure 5. The Relationship between Distortion Properties and Screenability.

length divided by the original length gives the stretch index. The stretch index reflects the amplitude of deformation. Thus, a PSA with a higher stretch index generally is more difficult to break under stress because it can stretch under sudden high shear. PSAs have elasticity and also tend to agglomerate together. After the stretch, the PSA may either recover itself or flap over to form PSA particles again. Figure 5 shows that a PSA with a higher stretch index generally has better screenability.

3.6. The Effect of PSA Hydrophobicity on Screenability

PSAs with higher contact angles are more hydrophobic. From Figure 6, it can be found

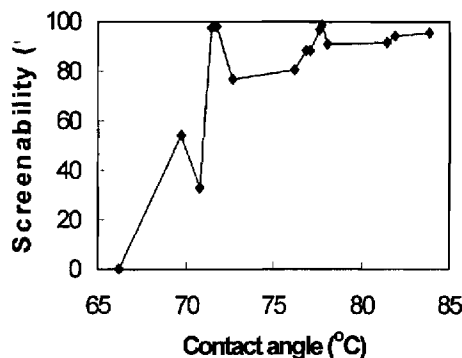


Figure 6. The Relationship between Contact Angle and Screenability.

that screenability increased as the contact angle increased. The reason for that may be that PSAs with high contact angles have a greater tendency to aggregate during repulping because of their high hydrophobicity. However, we are cautious on making this simple conclusion because of the limited data available at this time.

3.7. The Effect of Tackifier on PSA Properties and Screenability

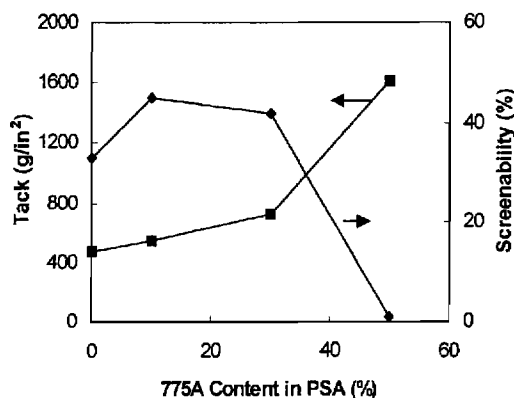


Figure 7. The Effect of Tackifier 775A on PSA Screenability.

From the above results, it seems the tackier the PSA, the higher is the PSA screenability. Thus, we intended to formulate PSAs with higher tack and to find the screenability of these newly formulated PSAs. Tackifier Snowtack 780G and 755A from EKA Chemicals were used to formulate different PSAs. Figure 7 shows that with increased tackifier 775A content, the tack of

the PSA increased; the screenability first improved slightly and then changed to almost unscreenable. Further study indicated that the tackifier 775A used in this study is slightly water soluble under pH 10.5. Therefore, we believe that some tackifiers were dissolved in the pulping water during the repulping process, resulting in the breakup of PSA film and the poor screenability.

We further used a water-insoluble tackifier, Snowtack 780G, to formulate PSA. Figure 8 shows that with increased tackifier content, the tack of the PSA increases and so does the PSA screenability. PSA XPD 1814 was also formulated with 50% of tackifier 780G. It was found that the loop tack of the PSA increased from 550 (g/in^2) to 1920 (g/in^2), and the screenability of the PSA increased from 88.7% to 98.3%.

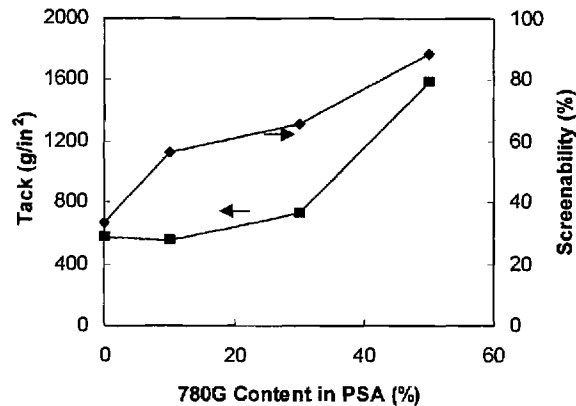


Figure 8. The Effect of Tackifier 780G on PSA Screenability.

The results indicate that PSA screenability can be improved by increasing its tack. But other factors, such as the hydrophobicity of the PSA materials under pulping conditions, should be considered. Higher hydrophobicity would be favorable for PSAs to agglomerate with each other to form large particles.

4. CONCLUSIONS

Increased tack generally increases the screenability. The reason for this is that tacky polymer particles adhere together more easily than nontacky particles. Because they strongly stick together, large particles can be obtained during the repulping process. Also, higher tack means the adhesive has higher ability in adsorbing energy in deformation. Therefore, the screenability was improved. Increased peel strength increases the screenability as well. Peel strength reflects the ability of PSAs to stick to other substrates under certain force. PSAs with higher peel strength would be able to form large particles with each other during repulping because of their better viscous flow. They also have higher ability to resist bond deformation at high shear. A PSA with a lower contact angle has higher hydrophilicity and has stronger interaction with water, fibers, and other hydrophilic materials. Thus it may be easier for the PSA to disperse into small particles or to be partially dissolved in water during repulping. A PSA with a hydrophilic surface is difficult to agglomerate to form large particles as well. A PSA with a higher stretch index generally has better screenability because this kind of PSA can absorb more energy during repulping and thus does not easily break down into small particles. Both tensile and shear strength, which are the measure of the PSA internal resistance to force, have marginal effect on the screenability. Although higher tensile and shear strength imply the PSA could tolerate higher force in breaking, other factors, such as tack, elongation, and hydrophobicity, are also very

important. It should be noted that no vacuum was applied during the screening in our study. If vacuum is applied, the polymer with high tack may distort easily and “swim” through the screen, which will reduce the screenability, while PSAs with high shear and tensile strength may be less likely to deform.

Generally, no single property is enough to determine the PSA screenability. It would be ideal for the PSA to have high tack, peel and shear strength, and reasonable hydrophobicity and elongation ability.

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