PSA properties and screenability in paper recycling

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ABSTRACT: Pressure-sensitive adhesives (PSA) are the major source of stickies in paper recycling. It is preferable for screening purposes if PSAs do not break down into very small pieces during repulping. However, it is not clear in the relevant literature what properties of PSAs are required to make them screenable. Properties of PSAs measured in this study were the hydrophobicity, peel, shear, tack, elongation property, and tensile strength. The relationships between these properties and screenability were evaluated. Increased tack and peel strength were found to increase the screenability of PSAs. It was also found that a PSA with a higher elongation property has higher screenability. The optimized PSA properties are reported for a screenable PSA in laboratory repulping settings.

Application: A fundamental understanding about the relationships between PSA properties and screenability can give PSA producers better insight into the design of new screenable PSAs.

Contaminants such as stickies in a paper machine will be significantly increased by increased use of recycled fibers. Deposits of stickies can lead to decreased runnability, decreased productivity, and increased machine downtime [1]. It has been estimated that stickies cost the paper industry between $600 million and $700 million a year in the United States as a result of lost production and the costs of control methods [2]. In fact, four of the seven recycling mills that opened in the United States between 1994 and 1997 closed, citing stickies as the main reason for closing [3].

Stickies are mainly generated from pressure-sensitive adhesives used in postage stamps, self-sealing envelopes, labels, etc. The best way to control stickies would be to prevent them from entering the mill, but this task is not easy [4]. Screening and cleaning currently remove most of the stickies. Macrostickies are effectively screened out with fine screens, but fiber losses occur as the slots in screens are made smaller. Although microstickies can be partially 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.

Producing screenable PSAs has been considered as a possible solution to the stickies problem in paper recycling. For PSAs to be screenable, they must form large particles that do not pass the cleaning screen. As a step on the way to producing PSAs that could be eliminated during the screening process, we explored the fundamental relationships between PSA properties and screenability.

BACKGROUND

In the development of environmentally benign PSAs, several approaches have been explored. One approach is to design water-soluble PSAs that could be dissolved in the recycling process and not become stickies [5]. Unfortunately, water-soluble PSAs usually present a problem in terms of poor moisture resistance and lack of adhesion. Furthermore, the dissolved adhesive would build up in the closed-loop water stream and cause further problems, such as water treatment and wet-end chemistry control.

A second strategy is to develop PSAs with higher density that could be easily separated by forward cleaners or PSAs with low density that could be removed by reverse cleaners and flotation units [6, 7]. However, the efficiency of removing stickies cannot be significantly improved by increasing or decreasing PSA density because stickies contain not only PSA but also fillers, fibers, and other elements. The final density of stickies strongly depends on the densities and fractions of these materials.

Finally, it would be desirable to produce pressure-sensitive adhesives that are strong enough to be broken up into relatively large particles during pulp action. These particles could then be totally screened out during the screening process [7, 8].

Comparing PSA screenability based on the chemical composition [7], Donnermeyer found that screening efficiencies in excess of 90% were obtained for the acrylic and rubber-based PSAs. The dispersible PSAs formed small particles during pulping that were only partially removed by screening. Solutia has developed a novel technology in the acrylic emulsion polymerization process that produces a new screenable/floatable adhesive with unique performance properties [9].

Unfortunately, there is no fundamental understanding about the relationships between PSA properties and screenability. This understanding is important because it will give PSA producers better insight into the design of new screenable PSAs.

EXPERIMENTAL

Materials

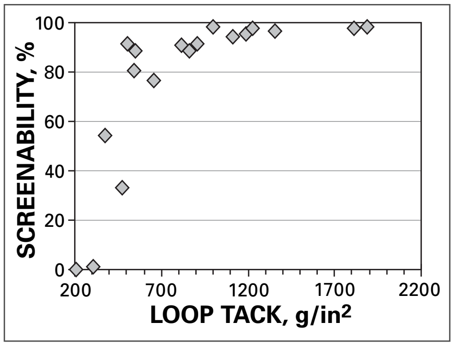
We used a total of 18 commercially produced PSAs from two different manufacturers. We also used two commercially produced tackfiers.

Preparation of post-consumer PSA tape for pulping

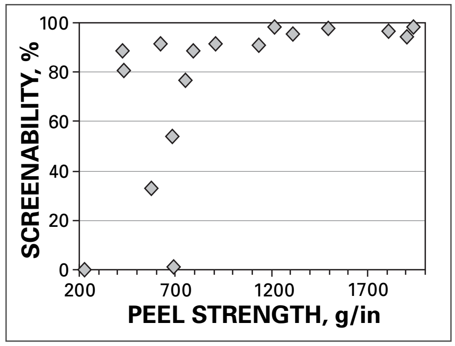
The emulsion adhesive was coated on a xerographic copy paper with a ChemInstruments Coater. The coating was dried at 90°C for 5 min. The cured adhesive paper was covered with a silicone release paper and pressed in a ChemInstruments Laboratory Laminator. The thickness of the PSA film was controlled at 0.025 mm. The silicone release paper was peeled from the PSA tape, and the tape was adhered to a piece of the copy paper to simulate post-consumer PSA tape.

Pulping and screening

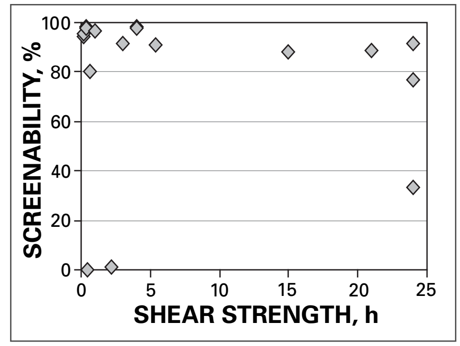
Office white copy paper mixed with post-consumer PSA tapes containing 0.3% of PSA was repulped with a lab LAMORT pulper. The pulp was cooked at 50°C for 20 min at pH 10.5 and 10% consistency.



1. The screenability of PSA increases as loop tack increases.



2. Peel adhesive strength greater than 1000 in/g tends to give better screenability.



3. Shear strength does not have a dominante effect on screenability.

The final pulp freeness was 250 mL CSF. The pulp was screened without pressure on a Sommerville vibrating screen with a slot size of 0.2 mm.

Handsheet preparation and image analysis

Handsheets for image analysis were made according to the Buchner funnel methods (PAPTAC C.4U). VWR 415 filter paper with a pore size of 25 μm was used for filtration. The pad weight was 1.2 g. The pad was pressed according to TAPPI T 205 om-88. The pad was air dried and dyed with Morplus Blue 1003. The dyed pad was analyzed by image analysis.

Evaluation method for screenablity

We evaluated the PSA screenability by comparing the stickies areas in handsheets prepared from the screened pulp with those in handsheets made from the unscreened pulp. The screenability was calculated by Eq. 1:

$$S = 100\% \times (A_0 - A_s)/A_0 \qquad (1)$$

where

S = screenability
A_0 = stickies area of unscreened pulp
A_s = stickies area of screened pulp.

Preparation of PSA tape

The emulsion adhesive was coated on both a silicone release paper and a polyester film. After the curing process, the adhesive silicone paper and polyester film were covered with silicone release paper and were pressed in the laminator. The thickness of the PSA film was controlled at 0.025 mm.

We used the PSA tape with two layers of silicone release papers to measure the PSA tensile strength and elongation. We used the PSA tape with one layer of polyester and one layer of silicone release paper to measure the PSA adhesiveness and hydrophobicity.

Adhesive, surface, physical, and mechanical dynamic properties

PSA tapes were conditioned at 25°C and 50% RH over 12 h before measurements were made. Loop tack was measured with a ChemInstruments loop tack tester according to TLMI Loop Tack Test Method [10]. Peel adhesion was measured with an Instron Model 1122 according to PSTC-1 [11]. Shear strength was determined by a ChemInstruments 8 Bank Oven Shear HT-8 according to PSTC-7 [12]. The contact angle of PSA was measured by an FTA200 with PSA coated on a polyester film.

The tensile strength and elongation properties of PSA were measured with an Instron Model 1122. The PSA sample for measurement was 0.025 mm thick, 15 mm wide, and 5 mm long. Tensile strength is the maximum tensile force in stretching the PSA film. The elongation property was a measure of the elongation level of the film, at the point a break occurs. The elongation index was calculated according to the Eq. 2:

$$\varepsilon = (L - L_O)/L_O \qquad (2)$$

where

ε = elongation index (dimensionless)
L_0 = original sample length, 5 mm
L = rupturing length of the PSA sample.

RESULTS AND DISCUSSION

PSA properties and screenability

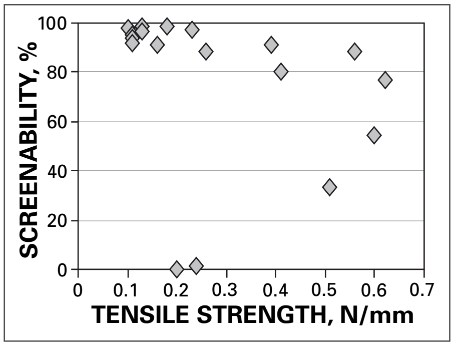
One important function of a PSA is to ensure instantaneous adhesion when light pressure is applied. PSAs must be able to flow and dissipate energy during the adhesive bonding process. They must also be elastic and must be able to store bond rupture energy to provide good peel and shear performance. The adhesive 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 adhesive 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 down or reagglomerate under shear. For PSAs to be screenable, they must form large particles that do not pass the cleaning screen. The PSA adhesive properties and other properties should determine the PSA behavior in repulping and hence the screenability.

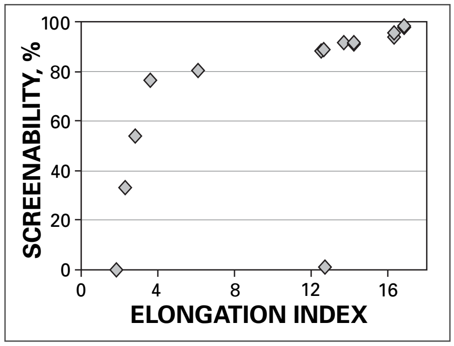
Loop tack. As **Fig. 1** shows, the screenability of the PSA increases with increased tack. Tack is defined as the force required to separate an adherent and an adhesive shortly after they have been brought rapidly into contact under a light pressure of short duration [13]. Tack represents the adhesive's ability to adhere quickly and is measured in two steps: the contact step and the separation step [10].

During the first step, contact is made at the surface points, which is an area that increases through wetting out, viscous flow, and elastic deformation. In the second step, debonding creates two new surfaces. During debonding, a condition of 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.

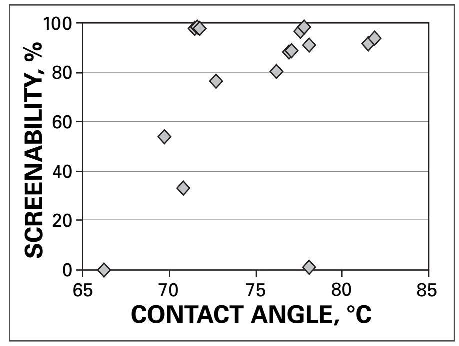
During repulping, the PSA is subject to intermittent shear force. A PSA with higher tack would be able to absorb



4. Tensile strength does not have a dominant effect on screenability.



5. A high elongation property coincides with good screenability.



6. A high contact angle leads to good screenability.

sudden shear force better and would not be easy to break. Also, a PSA with high tack has high fluidity and high bonding ability on light pressure. Because PSAs are normally hydrophobic, they tend to agglomerate. PSAs with higher tack should adhere to each other more easily to form large particles during repulping.

Peel strength. **Figure 2** shows 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. Similar to the measurement of tack, the measurement of peel adhesion involves a bonding step and a debonding or peeling step. To achieve peel adhesion, the bonding stage involves some dwell time.

Peel strength reflects the ability of PSAs to stick to other substrates under a force that tends to separate them. Thus, a PSA with a high peel strength does not separate as easily from a paper substrate as does a PSA with a low peel strength. During repulping, PSAs with high peel strength can form large particles with each other. As a result, better screenability may be obtained for the PSAs with higher peel strength. In general, the results shown in Fig. 2 bear out these observations, showing that a PSA with a high peel adhesion (over 1000 in./g) has good screenability.

Shear strength. Shear strength is PSA's ability to hold its position when shear force is applied [15]. As **Fig. 3** shows, our results are somewhat inconclusive in terms of the effect of shear strength on screenability. The data appear to be scattered, and more extensive testing would be needed to draw conclusions over a preferred range of shear strength.

Shear resistance is measured as a force that pulls the PSA material parallel to the surface to which it was affixed [15]. It measures the cohesion strength of the PSA. PSAs with high shear strength have high internal structural resistance and should be more difficult to break apart during repulping. However, PSAs are normally coated on paper as a very thin layer (about 25 µm). Since the force needed to break this thin film is less than the shear force experienced in repulping, shear strength does not have a dominant role in PSA screenability.

Tensile strength. As **Fig. 4** shows, tensile strength also does not have a dominant effect on PSA screenability. Tensile strength is a measure of the internal structural resistance of the PSA to outside force, which is 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 polymers that have very high tensile strength will not be considered PSAs because they have no tack and peel adhesion. For the thin film of PSAs coated on paper, the tensile strength is so small that it cannot play a significant role in preventing the PSAs from breaking into very small particles.

Elongation. We measured the elongation property by stretching a certain length (5 mm) of PSA film under a constant rate until it broke. The elongation index reflects the amplitude of deformation of a polymer film after it was stretched. It may be difficult to break a PSA with a high elongation index because it can stretch under sudden high shear. PSAs have elasticity and tend to agglomerate. After the stretch, the PSA may either recover itself or flap over to form PSA particles again. As the results in **Fig. 5** indicate, a PSA with a high elongation index (over 13) generally has good screenability (with the exception of one sample).

Hydrophobicity. PSAs with high contact angles are more hydrophobic and should have a greater tendency to aggregate during repulping. The data in **Fig. 6** support this assumption in general, with the exception of several samples. However, we are cautious in making this simple conclusion because of the limited data available and the narrow range of contact angles (from 66° to 84°) for our samples.

Improving screenable PSAs by adding tackifier

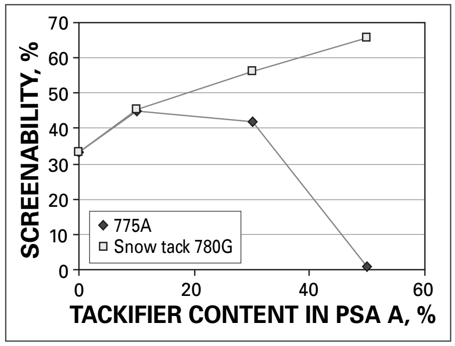
As these results indicate, the higher the tack, the peel strength, and the elongation index of a PSA, the higher is its screenability. Thus, we proposed to improve tack and peel strength and elongation index to formulate screenable PSAs. We also proposed to validate these relationships between PSA properties and screenability. We used the tackifiers Snowtack 780G and 755A from EKA Chemicals to formulate different PSAs with the commercial PSAs A and B.

Table I shows the effect of tackifier on the PSA properties. Loop tack and peel adhesion increased with the increased tackifier content in the PSA. Shear strength and tensile strength decreased as the tackifier content increased in the PSA. At a high tackifier content, the elongation index could also be improved.

Loop tack and peel adhesion could be improved significantly by adding tackifier to commercial PSAs. However, **Fig. 7** shows that with increased Tackifier 775A content, the screenability first improved slightly and then changed to almost zero (or unscreenable.) As the turbidity experimental results in **Table II** indicate, Tackifier 775A is slightly water soluble at pH 10.5, and Tackifier 780 is water-insoluble at pH 10.5. Therefore, we believe that some tackifiers were dissolved in the

PSA	Tackifier content, %	Loop tack, g/in.²	Peel adhesion, g/in.	Shear strength, h	Contact angle, °	Tensile strength, N/mm²	Elongation index	Screenability, %
A	—	475	575	24	70.8	0.51	2.3	33.1
775A	10	540	740	10	77.1	0.29	2.3	44.9
775A	30	720	1010	6	74.2	0.18	2.3	41.8
775A	50	1610	1950	5	67.8	0.17	7.9	0.8
780G	10	550	750	10	77.0	0.29	2.3	45.2
780G	30	730	1050	6	72.5	0.18	2.3	56.2
780G	50	1580	1880	5	71.1	0.17	6.1	65.5
B	—	550	425	21	77.1	0.56	12.7	88.7
780G	50	1620	1920	5	73.6	0.32	>16.8	98.3

I. Effects of tackifier on the properties of commercial PSAs A and B.



7. Screenability fell to zero with water-soluble tackfier (775A) but steadily improved with water-insoluble tackifier (780G).

pH	775A	780G
7	723	795
10.5	280	792

II. Turbidity of tackifiers.

pulping slurry during the repulping process, resulting in the breakup of PSA film and poor screenability.

As Table I shows for Snowtack 780G, PSA B, the loop tack and peel adhesion increase and so does the screenability with increased tackifier content (Fig. 7). PSA B was also formulated with 50% of Tackifier 780G. As shown in the table, the loop tack increased from 550 (g/in.²) to 1620 (g/in.²), the peel adhesion increased from 425 (g/in) to 1920 (g/in.), and the elongation index increased from 12.7 to over 16.8. As a result, the screenability of the PSA increased from 88.7% to 98.3%.

The results indicate that PSA screenability can be improved by increasing its tack, peel adhesion, and elongation property.

CONCLUSIONS

Increased tack generally increases PSA screenability. Because PSAs with high tack can adhere strongly to each other, large particles can be obtained during the repulping process. Higher tack also means the adhesive has greater ability to adsorb energy in deformation. PSAs with high peel strength can form large particles with each other when protected by waste paper from the water shear force. As a result, the PSAs with high peel strength are easier to screen.

A PSA with higher elongation property generally has better screenability. Such a PSA can absorb more energy during repulping and thus does not easily break down into small particles.

Both tensile strength and shear strength, which are the measures of the PSA internal resistance to force, have marginal effects on the screenability. No vacuum was applied during the screening in our study. If vacuum is applied, the polymer with high deformation ability may distort easily and swim through the screen, which will reduce the screenability; whereas PSAs with high shear and tensile strength may be less likely to deform.

A PSA with a high contact angle should tend to aggregate during repulping because of its high hydrophobicity. The study on contact angle supported this assumption in general except for a few samples. However, we are cautious in making this conclusion because of the limited data available and the narrow range of contact angles (from 66° to 84°) observed in this study.

Generally, no single property is enough to determine the PSA screenability. It would be ideal for the PSA to have high tack, high peel adhesion, and good elongation ability. **TJ**

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INSIGHTS FROM THE AUTHORS

Stickies are generated mainly from PSAs. Producing screenable PSAs has been considered as a solution to the stickies problem in the paper recycling industry. For PSAs to be screenable, they must form large particles that do not pass the cleaning screen.

The PSA adhesive properties and other properties should determine the PSA behavior in repulping and hence the screenability. An understanding about the relationship between PSA properties and screenability will give PSA producers better insight into the design of new screenable PSAs. However, there is no fundamental understanding to be had from published research regarding the relationships between PSA properties and screenability.

To study the relationship between PSAs properties and screenability, it is important to measure accurately the various properties of PSAs. In this study, lots of experimental instruments were used. Generally, no single property is enough to determine the PSA screenability. It would be ideal for the PSA to have high tack, high peel adhesion, and better elongation ability. Interestingly, both tensile and shear strength have only marginal effects on the screenability.

Future studies should confirm the relationships between PSA properties. More PSAs, such as rubber-based PSAs, need to be studied. We also need to synthesize environmentally benign PSAs that have the desired properties.

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