Print-Applied, UV-Curable Pressure-Sensitive Adhesives for Industrial Graphics Requiring High Temperature and Chemical Resistance

By Jeffrey Warmkessel

The use of printable pressure-sensitive adhesives (PSAs) has been increasing in industrial graphic applications. These applications include durable labels, nameplates, membrane switches and graphic overlays. Flatbed screen printing is already commonly used to produce graphic overlays and circuits. Printable adhesives can easily be used with screen printing equipment and technology that is already in place in most industrial graphic manufacturing operations.

Advantages of printable PSAs compared to the use of transfer tapes include:

- Waste reduction by printing adhesive only where it is needed compared to die cutting and disposal of transfer tape sections in areas where the adhesive is not desired.
- Design advantages, such as complex geometric shapes and moisture/gas flow channels, can be accomplished easily by screenprinting compared to the challenge of using transfer tapes.
- Elimination of adhesive buildup on cutting dies by printing the adhesive away from the cut line.
- Reduced time and cost of screen preparation relative to the production of a cutting die for new designs.
- Potential reduction of lamination steps used in the assembly membrane switches.
- Improved bonding to digital inks compared to transfer tapes.

Printable PSA Technology

A PSA is a viscoelastic material relying on applied pressure to bond two surfaces together. A printable PSA needs to have the proper rheology and viscosity to be applied by its intended method of application, such as screenprinting, flexography, rotogravure, etc. Printing a high-performance adhesive is often achieved by diluting it in solvent or water. While these products have desirable adhesion performance, their printing and curing can be challenging, especially when screen printing. The evaporation of solvent or water from the adhesive

Table 1

UV exposure and irradiance of 600W H bulb at 35 ft/min

Wavelength	Exposure mJ/cm²	Irradiance mW/cm²
UV-A	481	1,942
UV-B	427	1,753
UV-C	85	359
UV-V	510	2,090

while on the screen can cause a number of issues in making reproducible, quality prints. Long ovens with appropriate air flow are required to remove the solvent or water after the printing step. These disadvantages of printing and curing are addressed by using a one-component, 100% reactive UV-curable adhesive. A 100% reactive adhesive does not clog the screen or change in print thickness due to evaporation. The products discussed in this paper have been designed to be cured with UV lamps commonly used in the industry for UV-curable inks.

UV-Curable PSAs

Printable UV PSAs are liquid syrups that are screen printable and develop the desired viscoelastic properties upon UV exposure. The liquid syrups may be comprised of oligomers, monomers, photoinitiators and processing additives that UV cure by free radical or cationic polymerization. The goal is to optimize the compositions in order to deliver cured adhesive performance properties comparable to transfer tapes that are currently being used in industrial graphics applications.

A series of three printable UV-curable PSAs (A, B and C) were developed to cover the adhesive needs of most industrial graphic applications. The characteristics of the cured adhesives are summarized below. A commercial industrial transfer tape is included for comparison.

A = printable UV PSA with high cohesive strength and heat resistance

B = printable UV PSA with good tack, peel, and cohesive strength

C = printable UV PSA with excellent quick tack and peel

D = commercial transfer tape

Selection of the proper printable UV PSA depends upon the application's assembly and final use requirements.

Experimental

The three UV PSAs were screen printed at 2 mils (50 micrometers) adhesive thickness, followed by UV curing and testing along with the commercial transfer tape (also 2 mils). The flatbed press used was a two-post semiautomatic with a 74 mesh, 120 micrometers thread diameter polyester screen at 28 Newton tension force. The flood bar pressure into the screen was minimal and the flood speed was slow. A 60 durometer, round edge squeegee at an angle of 15° was used to print the adhesive. The squeegee speed was slow and the pressure into the screen was light (just enough to transfer the adhesive to facestock over a 1/8" off-contact setting). The slow speeds and low pressure minimized bubbles being incorporated into the adhesive puddle on the screen, which translated into fewer bubbles resulting in the adhesive prints.

The adhesives were cured with a 600 W/in Fusion®[1] H bulb at 100% power on a lab conveyor unit. The **A** and **B** adhesives require a minimum UV dose of 450 mJ/cm² of UV-A. This correlates to a conveyor speed of 35 ft/min and was used to produce the samples for adhesive property measurements. An EIT UV Powermap®[2] was used to record the UV energy delivered to the adhesive (Table 1). All samples were cured in one pass under the UV lamp.

The "C" adhesive can be cured over a range of UV exposures to tailor its performance for the application. If high tack is the primary requirement, a line speed of 45 ft/min or 337 mJ/cm² UV-A can be used, see Table 2. Subjecting

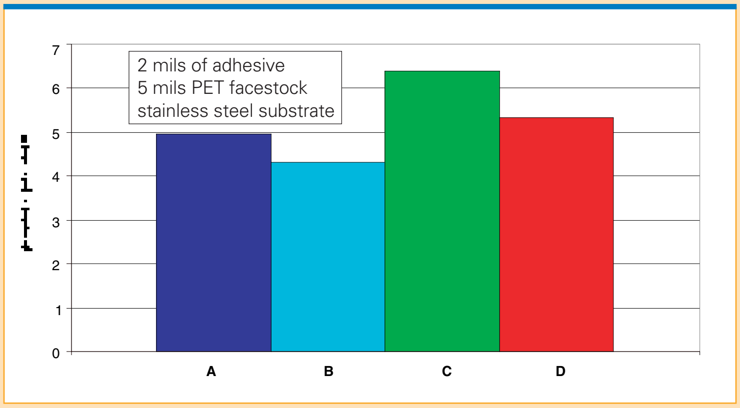
Table 2

UV exposure and irradiance of 600W H bulb at 45 ft/min

Wavelength	Exposure mJ/cm²	Irradiance mW/cm²
UV-A	337	1,937
UV-B	298	1,722
UV-C	59	352
UV-V	356	2,074

Figure 1

90-degree peel resistance at 24 hours



the adhesive to more UV energy, such as curing at 35 ft/min, will reduce its quick tack, but peels will increase and some cohesive strength gained.

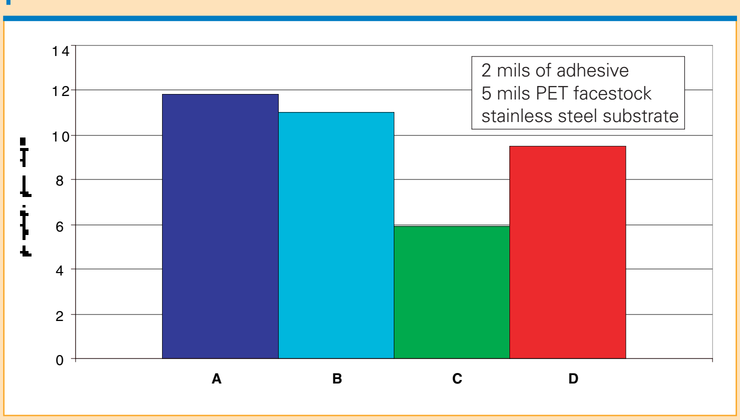
While the results in this paper are for adhesive films cured with a Fusion® H bulb, it has been shown that a common electrode-type, medium-pressure mercury lamp will produce similar results. Lamp input power settings of 200 W/in or 300 W/in will typically deliver sufficient irradiance (>500 mW/cm^2) to cure the adhesives.

Samples for testing were prepared using DuPont Melinex®[3] ST505 heat-treated polyester, as the substrate for adhesive application. 403 Stainless steel was used as the adhesion test substrate to bond the cure adhesive specimens. The stainless steel test plates were prepared by cleaning with acetone to remove residual adhesive. This was followed by sonication (30 minutes), rinsing with deionized water and a final wipe with acetone. Stainless steel plates are stored in a constant temperature and humidity room (75°F, 50% RH) overnight before using.

Adhesion tests of the printable UV PSAs and transfer tape were conducted following Pressure Sensitive Tape Council test methods.[4] All adhesive samples were at 2 mils thick. Peel tests were conducted at 90 degrees with a pull rate of 12 inches/min on an Instron®[5] 4411 testing device with a 100-pound load cell. Static shear testing was started after a 24-hour dwell to allow the adhesive to wet out the stainless steel surface. The adhesive area was 1” X 1” with a load of one kilogram. The shear plates are at a 2-degree positive angle to eliminate peel forces. The shear adhesion failure temperature (SAFT) uses cold-rolled steel plates that are degreased and allowed to sit overnight in the constant temperature humidity room before use. The SAFT procedure involves setting up a shear sample (1” X 1” adhesive area) with a 1-kilogram load in an oven. Starting at room temperature, the oven temperature was increased at 5°F per minute. The temperature when the sample failed was recorded. Chemical resistance involved soaking peel samples in the desired media for the specified time. The samples were removed, wiped dry and allowed to equilibrate in the constant temperature humidity room for 24 hours before peel testing.

Figure 2

Heat-aged (105°C for 10 days) 90-degree peel resistance

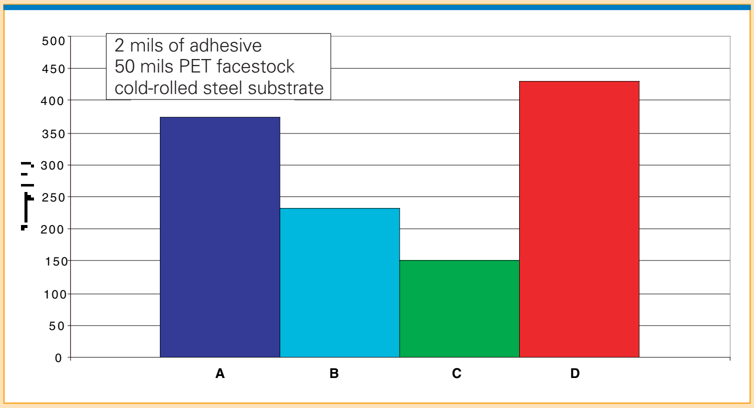


Results and Discussion

The room temperature peel adhesion was tested 24 hours after bonding. The 90-degree peel forces for the four adhesives are shown in Figure 1. Printable adhesive **C** was found to have the highest peel resistance (6.4 pounds per linear inch, pli). The transfer tape **D** and printable adhesive **A** had very similar peel resistance (5.3 pli and 5.0 pli, respectively). While printable adhesive B has higher tack than printable **A**, it

FIGURE 3

Shear adhesion failure temperature



has the lowest peel resistance (4.3 pli) of the tested samples. It should be noted that **A**, **B** and **D** exhibited an adhesive failure with clean removal from the stainless steel. Adhesive **C** exhibited cohesive failure leaving residue on both the polyester film and the stainless steel panel. All UV PSAs in this group were cured at 35 ft/min.

Peel samples on stainless steel were aged in an oven at 105°C for 10 days. After oven exposure, the samples were allowed to equilibrate at room temperature for 24 hours before conducting peel tests. Printable adhesives **A** and **B** gave the same result within experimental error (11.8 pli and 11.0 pli, respectively). Both **A** and **B** exhibited cohesive failure modes during the peel test. The transfer tape **D** produced peel strength of 9.5 pli. During the peel test of transfer tape **D**, it was observed that the samples had a "zipper" effect, which is evidence that the adhesive hardened during conditioning.

Shear adhesion failure temperature (SAFT) can be regarded as a test of the adhesive short-term temperature resistance. Samples were subjected to increasing temperature. The temperature where the sample failed under a 1-kilogram load was recorded. The results are shown in Figure 3. The transfer tape **D** had the highest SAFT of 430°F. Printable adhesive **A** produced a SAFT of 375°F. The other printable adhesives, **B** and **C**, had lower SAFTs of 233°F and 150°F, respectively. This is likely due to differences in crosslink density and molecular weight of the adhesive's polymer chains relative to the transfer tape and printable adhesive **A**.

Static shear testing was performed at room temperature (75°F) and elevated temperature (158°F) using a one kilogram load. The results are shown in Figure 4. Printable adhesives **A** and **B** matched transfer tape **D** with all samples reaching >10,000 minutes. Extended testing of **A** and **D** have now passed shear tests of more than 21,000 minutes (350 hours). Printable adhesive **C**, which is known for high tack and peel, has low shear resistance (1,860 minutes at room temperature and 60 minutes at 158°F).

Chemical resistance was measured for printable adhesive **A**, **C** and transfer tape **D**. Common ingredients, such as gasoline, methylethylketone (MEK), weak acid (vinegar), weak base (diethanolamine), 10W30 motor oil, deionized water and 5% salt water, were used. Peel samples were constructed on stainless steel and immersed in glass jars containing the chemical test substance. One-hour immersion was used with the gasoline and MEK. Four-hour immersion was used with the weak acid and base. Three-day immersion was used with the oil, deionized water and salt water. The results are summarized in Figure 5. All adhesives had good peel retention upon measurement after a 24-hour recovery. Immersion in weak acid, weak base, oil, deionized water and salt water had very little effect on the adhesive bond strength, especially for adhesives **C** and **D**. The largest peel

FIGURE 4

Static shears at room temperature (75°F) and elevated temperature (158°F)

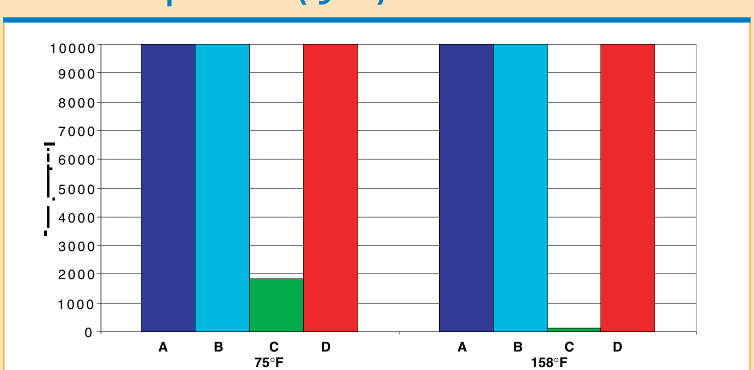
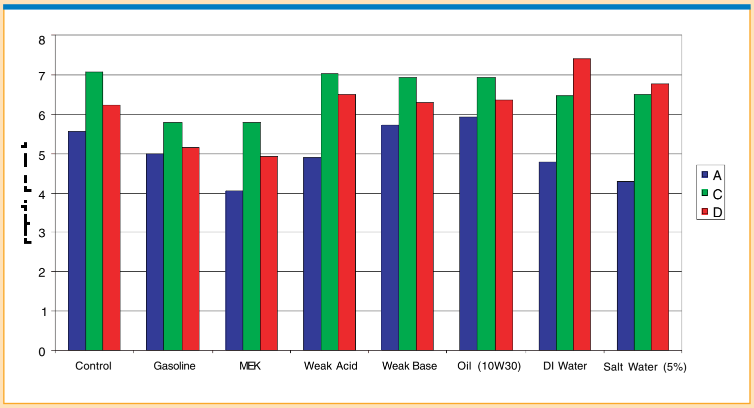


Figure 5

90-degree peel resistance of samples immersed in various agents



resistance decrease for the adhesives were immersion in gasoline and MEK where the values were more than 1 lb/in lower than the control samples.

In addition to the performance properties reported above, the **A** adhesive was found to have very good bonding to digital inks (HP Indigo) relative to the transfer tape **D**. This advantage is significant as industrial graphics applications increase the use of digital printing technology.

Conclusions

This testing shows that the performance properties of printable UV PSAs compares favorably with a commercial transfer tape. This series of printable UV PSA products was designed to meet the needs of industrial graphics and label manufacturers. Printable adhesive **A**, having similar performance to the transfer tape, is recommended for membrane switch and overlay applications where high temperature resistance is required. Printable adhesive **C**, having high quick stick and peel resistance, is designed for high-performing label applications. End-use application testing has begun to confirm the desired performance.

It is expected that use of printable UV-curable pressure sensitive adhesives will increase as manufacturers of industrial graphics and labels take advantage of process improvements and cost savings enabled by this technology.

Acknowledgements

The author gratefully acknowledges Renae Reeves for his efforts in conducting the adhesive testing.

References

1. Fusion UV Systems is a registered trademark of Fusion UV Systems Inc.
2. UV Powermap is a registered trademark of EIT Inc.
3. Melinex is a registered trademark of E.I. du Pont de Nemours and Company.
4. Test Methods for Pressure Sensitive Adhesive Tapes; Pressure Sensitive Tape Council, 14th ed., 2004.
5. Instron is a registered trademark of Instron Company.

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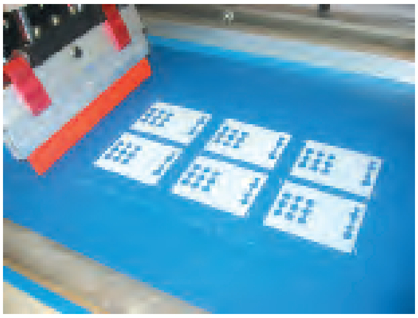
Membrane switch components

Membrane switch in user interface of microwave



Screen used for printing adhesive layer of membrane switch