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Novel Methods of Bonding Solar Cells

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ABSTRACT

Messy liquid adhesives, short work times, long cure times, difficult clean-up of stray adhesive — all of these are associated with liquid adhesives for bonding solar cells. Current adhesion methods have been in place since the ’70s: mix a two-part liquid silicone adhesive, coat a portion of adhesive onto a section of substrate, place the cells in a vacuum bag and wait for the adhesive to cure. Alternatively, one can use a fairly complicated robotic procedure to apply adhesive then fix a cell down and, again, wait for the adhesive to cure.

Some difficulties that need to be overcome include balancing the amount adhesive to spread out with the available worktime in order to get all the cells onto the substrate with good adhesion; controlling the bondline; ensuring that the adhesive cures correctly after application; and, finally, if there is any re-work, removing the part from the adhesive without damaging everything around it.

Key Words

Silicone, film adhesive, pressure sensitive adhesive, bonding, solar cells

(1) PRESSURE SENSITIVE ADHESIVE (PSA) FILM

A good solution for these problems may be a space-grade pressure sensitive adhesive (PSA) film or, if a cured adhesive in necessary, a curable film adhesive. Materials that can be handled as semi-cured films offer quick adhesion with no mess and can be die-cut to specific shapes prior to application.

These are some of the reasons that PSAs may be a better choice. Silicone PSAs are made by partially crosslinking a silicone polymer with a silicone resin, forming a loosely knit elastomer. These PSAs work by hydrogen bonding to surfaces — intermolecular forces that are fairly weak as individuals but, in large quantities, can offer excellent adhesion. The hydrogen bonding adhesion is typically lower at initial contact but, as the PSA wets onto the substrate, it improves significantly. The initial adhesion is called tack and is measured with a quick touch of a probe, after which the force to remove the probe is measured.[1] The wetted-out adhesion is typically measured by a peel or lap shear test, usually after 24 hours.[2]

Controlled Volatility (CV) PSAs, suitable for use in space environments, can be made by removing most of the low molecular weight species of a typical silicone PSA. The volatility can be lowered to surpass the ASTM E595 Controlled Volatility testing specification of 1.0% Total Mass Loss (TML) and 0.1% Controlled Volatility Condensable Material (CVCM). The PSA is initially in solvent and can be coated onto substrates or coated directly onto a release liner to make a free film. Silicone PSAs can be supplied at thickness from 1 mil to 10 mil in sheet or roll form, and the films can be die-cut to shape and applied like an ordinary tape. These PSAs have bond strengths ranging from 0.1 psi to 2 psi, tested using a 180^o peel test.[2]

For peel testing, a PSA film is bonded to a clean aluminum substrate. A 5-lb. weight is rolled over the PSA sample. The sample has a rest period of 24 hours prior to testing.

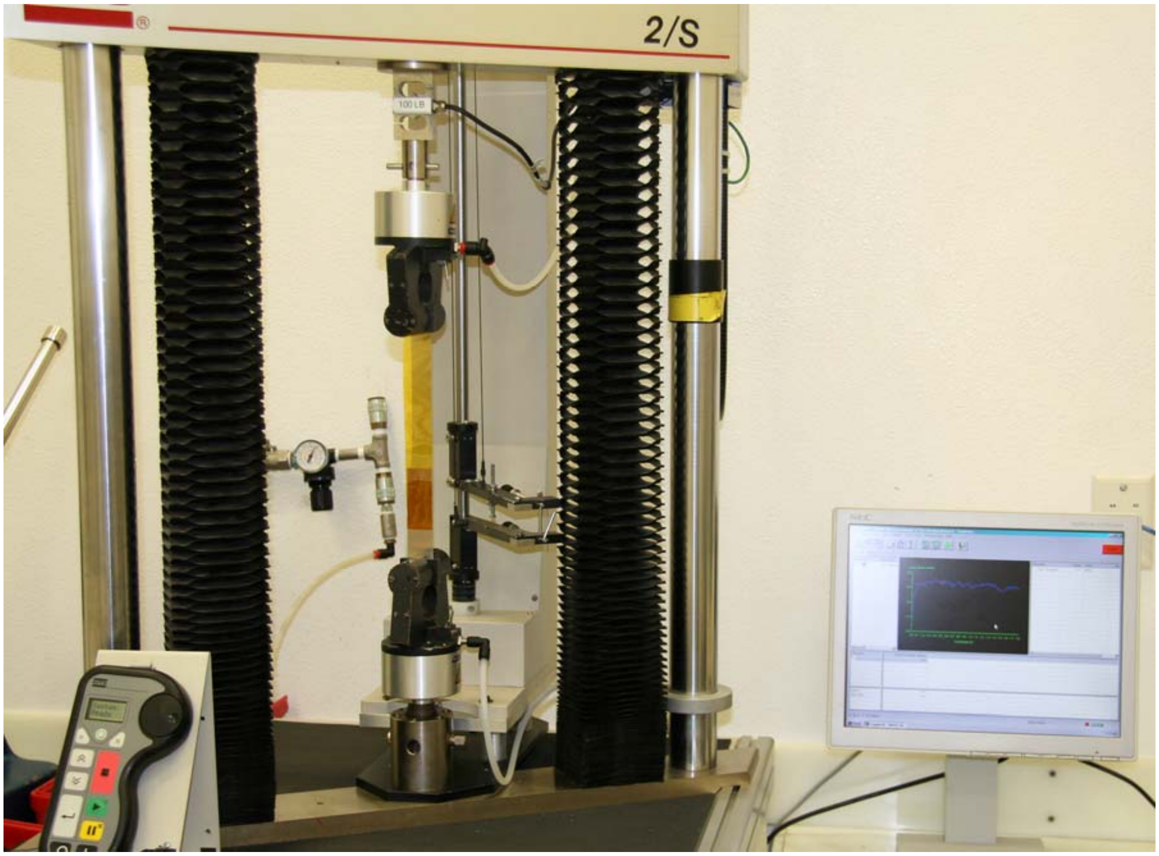

Figure 1: A peel test of PSA coated onto Kapton then peeled off of an untreated aluminum panel.

Adhesion can develop in minutes; but, typically, adhesion improves over time, as the adhesive wets over the surface. Adhesion can be adjusted from low tack/ low adhesion for something that needs to bond somewhat yet later be easily removed to a higher tack/ good adhesion of approximately 2 lbs. per square inch for more permanent bonds.

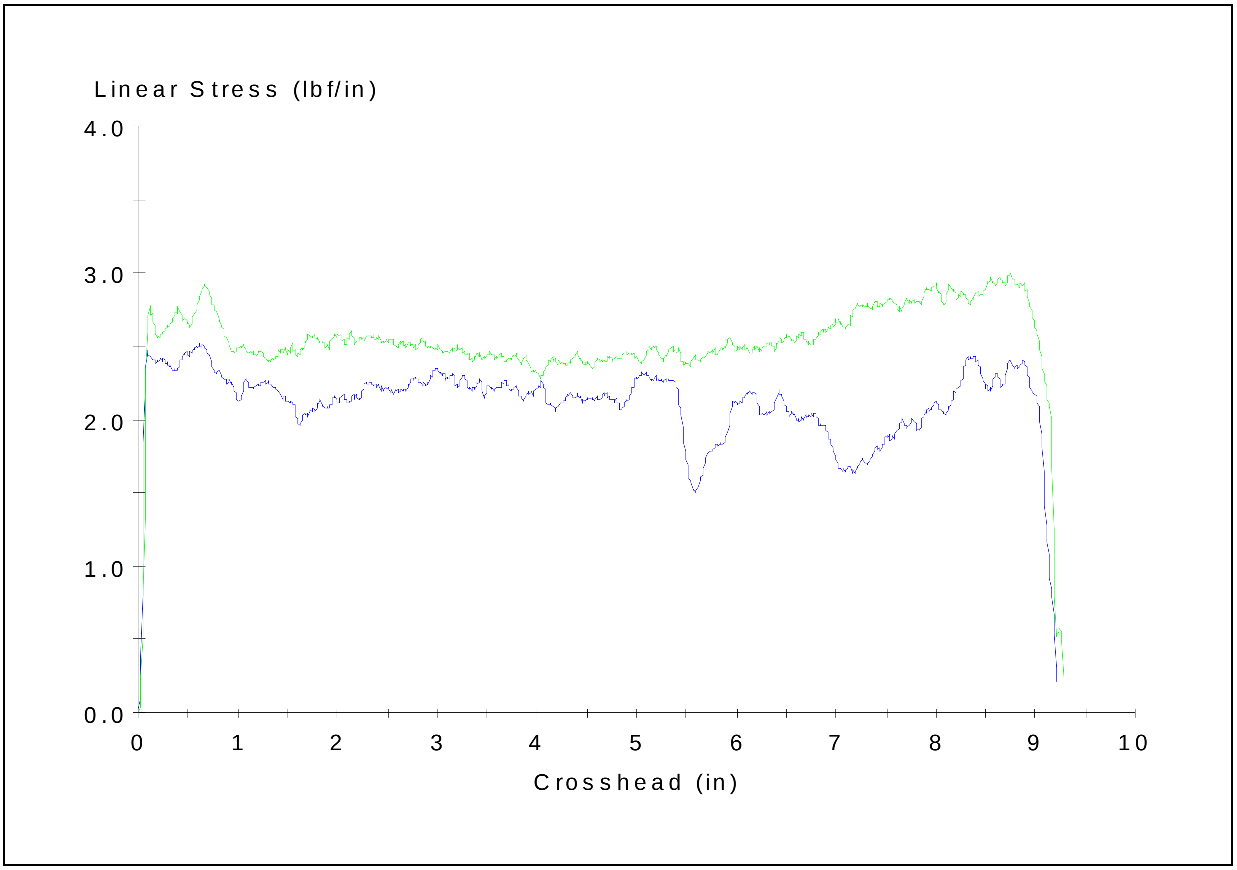

Figure 2: Graph of a peel test of a CV PSA.

One of the problems with ordinary PSAs is their resistance to temperature. At high temperatures, PSAs essentially melt or soften, and the adhesive strength fails. A solution to this problem is to partially crosslink the PSA so it has high-temperature adhesion. A relatively simple test to measure adhesion at temperature is a static shear test.[3]

For the static shear test, a sample is prepared by bonding one square inch of adhesive to an aluminum panel. The sample has a rest period of 24 hours. The panel is then fixed in an oven, and a 50g weight is hung on the panel, while the oven is heated to 175^{o}C. The PSA is required to remain bonded to the aluminum panel for 24 hours without failing.


Figure 3: Static Shear test; PSA coated onto Kapton and bonded to aluminum panels.

As a cover glass adhesive, the PSA offers good light transmittance from 375 nm to 1,100 nm. The PSA itself is very clear, wets out on practically any surface and offers good optical coupling between substrates. The refractive index of the PSA is 1.41.

Figure 4 is a UV/Vis of the transmittance of light through the PSA.[4] The PSA was sandwiched between two glass microscope slides, and a glass microscope slide was used as a blank.

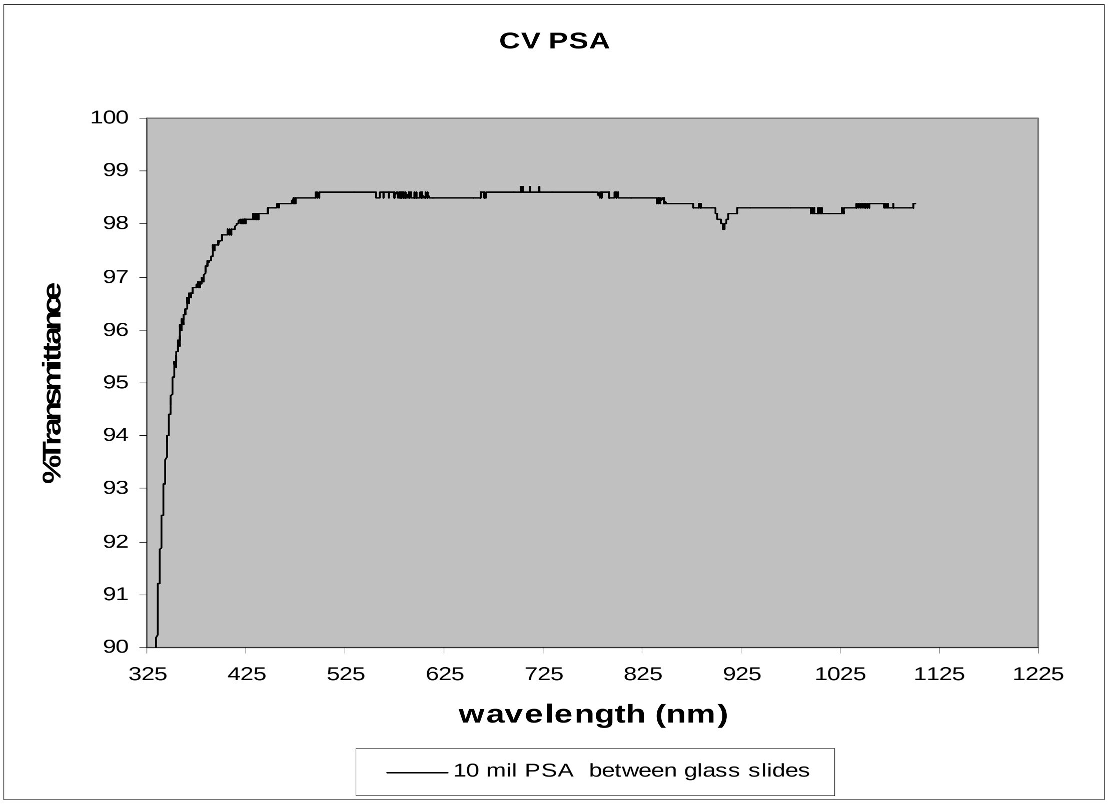

Figure 4: UV/vis spectrophotograph of PSAs

The PSA films can be die-cut to form shapes and sheets of PSA can be cut to multiple shapes. These films can then be transferred to large areas and are then ready for the next substrate to be applied, like cover glasses.

Some of the disadvantages of PSAs include the difficulty of handling such relatively thin films. Because they easily tear, films — especially the thinner films — should be transferred from a release liner to a substrate and not handled as film. In addition, as the films are sticky, they are difficult to keep from adhering to themselves.

Also, the transfer from release liner to substrate is critical so no bubbles or flaws are introduced. Bonding two flat, rigid pieces can present some difficulties. While flexible pieces can be rolled down onto the PSA, minimizing bubble entrapment, rigid pieces almost always capture a bubble and must be vacuum-bagged for a time to remove the air bubbles. This sometimes introduces a wrinkle in the PSA film. Fortunately, all of these problems have been solved in production, for example, by automakers sandwiching a plastic liner between sheets of windshield glass.

PSAs are silicones so the Coefficient of Thermal Expansion (CTE) is relatively high at approximately 300 ppm/C but the modulus of the PSA film is quite low so the films have some “give” between substrates of different CTE during thermal cycling, not unlike the typical liquid silicone adhesives currently in use.

(2) TWO-PART CURABLE FILM ADHESIVE

Two-part curable films are different than PSAs. PSAs are pre-cured and offer moderate adhesion without any further cure. A two-part system is similar to the current liquid silicone adhesives, except that Part A is a semi-solid film and Part B is a liquid activator similar to a primer.

Part A, the film adhesive, can be made in thicknesses ranging from 1 mil to 30 mils and is curable. These films can be filled with thermally conductive fillers, electrically dissipative fillers or both. These films are applied to a catalyzed substrate, and the two parts are joined. In 24 hours or less, the parts are bonded with a cured film.

The films come on release liners and can be handled as free film, transferring from the release liner to a substrate then bonding to a catalyzed substrate. If uncatalyzed, they have practically unlimited shelf life and will cure after catalyzation at room temperature in 24 hours or can be heat-accelerated. The film is a firm, uncured silicone that can be handled, die-cut or pressed onto substrates and still maintain its dimensions. When cured, it is a fully cured silicone elastomer with adhesion properties similar to liquid adhesives.

The film adhesives are tested for lap shear strength[5,] meaning the adhesive is cured between two untreated aluminum panels and the panels are then pulled apart on a tensile tested to measure the force required to pull the two panels apart.

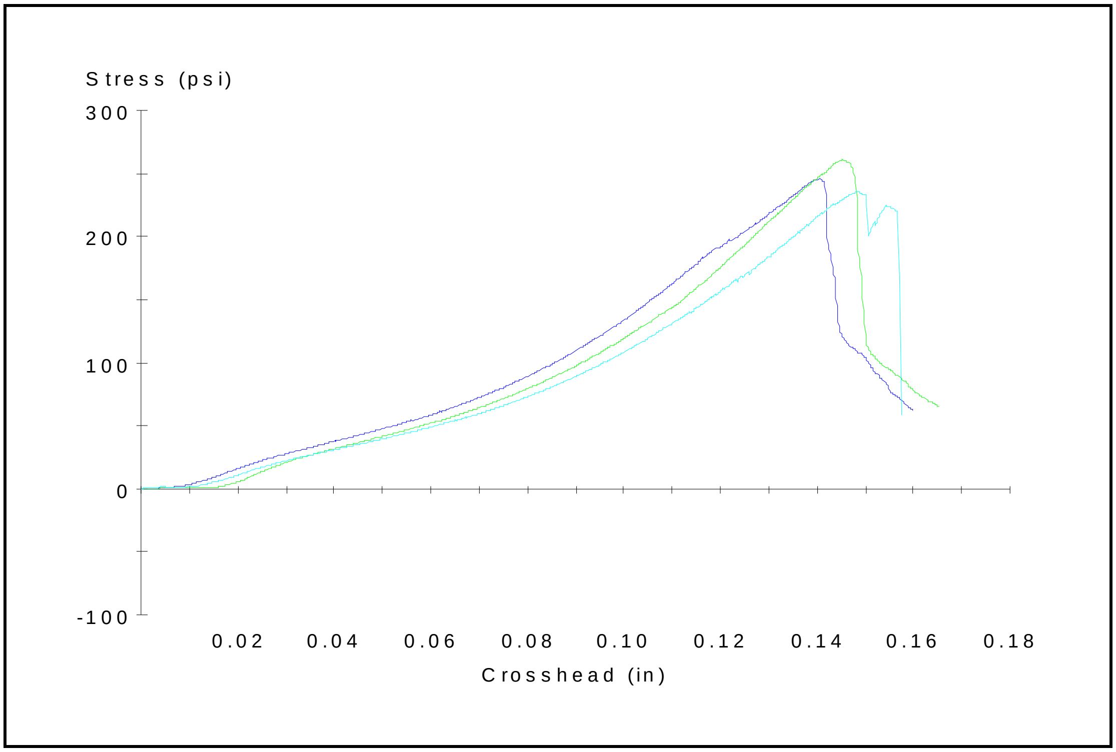

Figure 5: Graph of a lap shear test of unfilled film adhesive. Crosshead moves at 0.1in/min

Fillers can be added to the Part A films for different properties such as thermal conductivity. They can be filled with non-electrically conducting ceramic fillers like aluminum oxide or zinc oxide and have a thermal conductivity of up to 1 W/mK. These films are white and have good handling characteristics.

In addition, carbon black can be added to the silicone films to offer electrical conductivity. The electrically dissipative films can have resistivities from 10^8 ohm-cm to 250 ohm-cm.[6] Films can be developed with other fillers to tailor properties as desired.

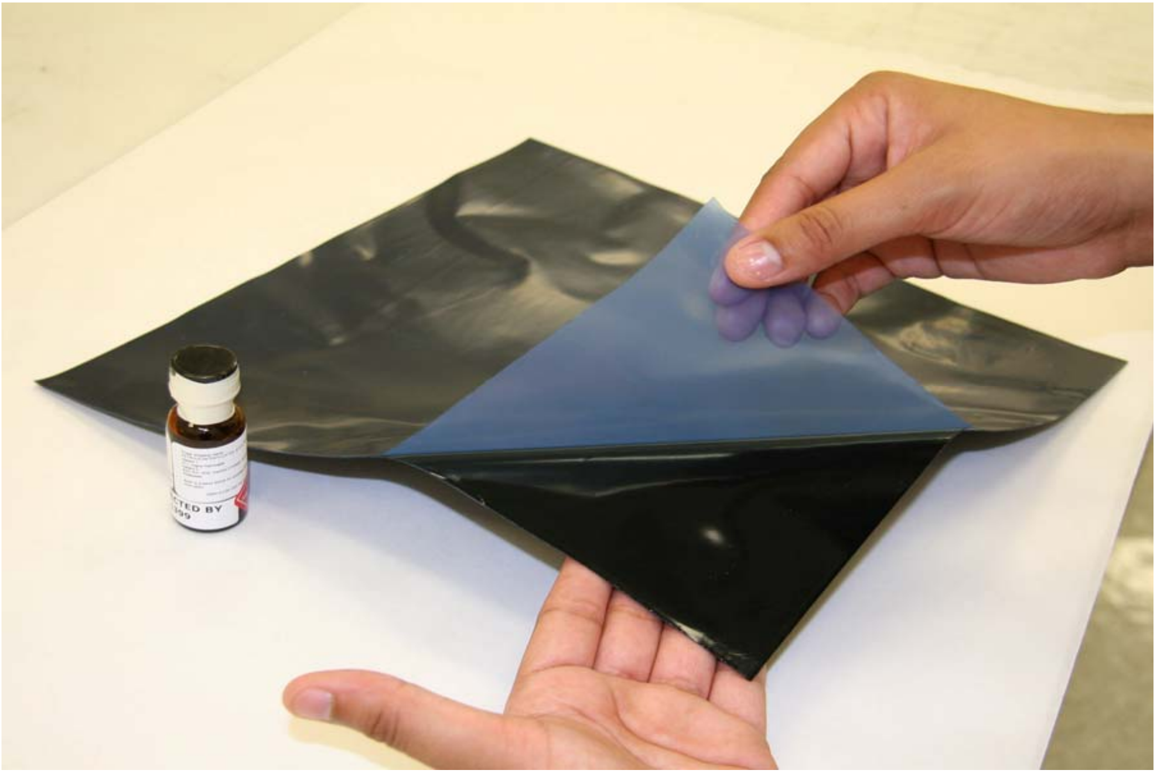

Figure 6: 12 mil thick Part A film adhesive and Part B liquid activator

In summary, new options are available as adhesives for spacecraft: silicone PSAs and two-part curable films. These films offer manufacturers increased flexibility and improved turnover rates with faster cure and ease of handling.

PSAs offer short cure times, pre-cut peel-and-stick operations that can move products through lines quicker with little to no wait time cure. The PSA bonds quickly enough to be handled immediately. Film adhesives offer permanent adhesion to a variety of substrates in a pre-formed, controlled thickness format. Both materials provide additional options and improvements in the manufacture of solar arrays.

References:

1) Nusil Test Method TM122 PSA Blunt Probe Tack Test, based on ASTM D2979
2) Nusil Test Method TM163 180^0 Peel Strength of PSA Sheeting, based on ASTM D903
3) Nusil Test Method TM152 PSA Static Shear Test
4) Nusil Test Method TM100 UV/visible Spectrophotometry, based on ASTM E275
5) Nusil Test Method TM010 Lap Shear Strength of a Cured Silicone, based on ASTM D1002
6) Nusil Test Method TM040 Volume Resistivity of a Cured Silicone, based on ASTM D257 and D4496