PSA TO STRUCTURAL ADHESIVE TAPES FOR AUTOMOBILE LIGHT-WEIGHTING SOLUTIONS

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To meet the ever stringent fuel efficiency standards, automobile manufacturers are continuing to look for ways to reduce vehicle weight. Aluminum and composites are increasingly becoming materials of choice for auto parts because of their lightweight and strength. These new materials bring new bonding challenges. Liquid adhesives are difficult to use, while structural adhesive tapes requires controlled storage. Two stage Pressure Sensitive Adhesive (PSA) to Structural Adhesive Tapes offer unique solutions to meet these challenges. These tapes provide tackiness for bonding, and provide high strength after final curing. The tapes are easy to use and store. Examples will be given on how to use the two stage adhesive tapes to bond composite to composite, metal and plastics. The performance of the two stage adhesive tapes can be designed to meet A stage and B stage performance requirements. A specific example will be given on how a two stage adhesive was designed, tested and validated for composite lamination application. This technology opens up new opportunities for PSA tape manufacturers to pursue a new and growing market space.

Introduction

With the increasing global concern on climate change and energy security, automobile manufacturers are facing increasing pressure to improve fuel efficiency on their fleet. For example, the U.S. government has set a goal to double the fuel economy to 54.5 miles per gallon by 2025. To achieve such fuel economy, an obvious solution is to reduce the overall weight of the vehicle while not sacrificing safety and other performance criteria. Automobile manufacturers are turning to aluminum and composite materials as building platform for the vehicles. Both aluminum and composite materials are more expensive than steel, therefore the automobile industry are also looking at areas where they can use adhesives instead of rivets and bolts to reduce costs. Furthermore, the bonding of dissimilar materials of steel, aluminum and composites requires materials with high modulus and wide service temperature range. The differences in coefficient of thermal expansion (CTE) reduce the effectiveness of traditional joining methods such as rivets and welds. The use of structural adhesives together with rivets and welds improves the bonding performance of the different materials.

Epoxy and polyurethane structural adhesives with 100% solids are now used in automobile manufacturing. Epoxy adhesives provide high strength but low flexibility, while polyurethane adhesives provide more flexibility with moderate strength. The main issue with liquid adhesives is the control of bond-line. The liquid adhesives can be one part or two part system. The one part adhesive generally has short shelf life and needs to be stored with refrigeration. The two part adhesives need be mixed prior to applying, and also have a working time before they start to harden. A structural adhesive tape can overcome most of these issues. Tape adhesives provide well defined bond-line, and do not require mixing. The majority of current structural adhesive tapes on the market, however, need to be refrigerated during shipping and storage, which creates logistic issues and increases cost.

Background

We developed a new type of tape: Pressure Sensitive Adhesive (PSA) to Structural Tape, to address the above issues with liquid adhesives and structural adhesive tapes. This type of tape is pressure sensitive when applied. Under external trigger such as heat or UV the adhesive becomes structural. These tapes are room temperature stable and do not need cold storage. The performance of pressure sensitive stage (A stage) and structural stage (B stage) can be tuned to give different performance of peel, tack and shear. These PSA to structural tapes could be used in assembly of automobile parts for light weight solutions.

Discussion

Characteristics and performance of of PSA to structural adhesive tapes

A simple illustration of concept of PSA to structural technology is shown in Figure 1.

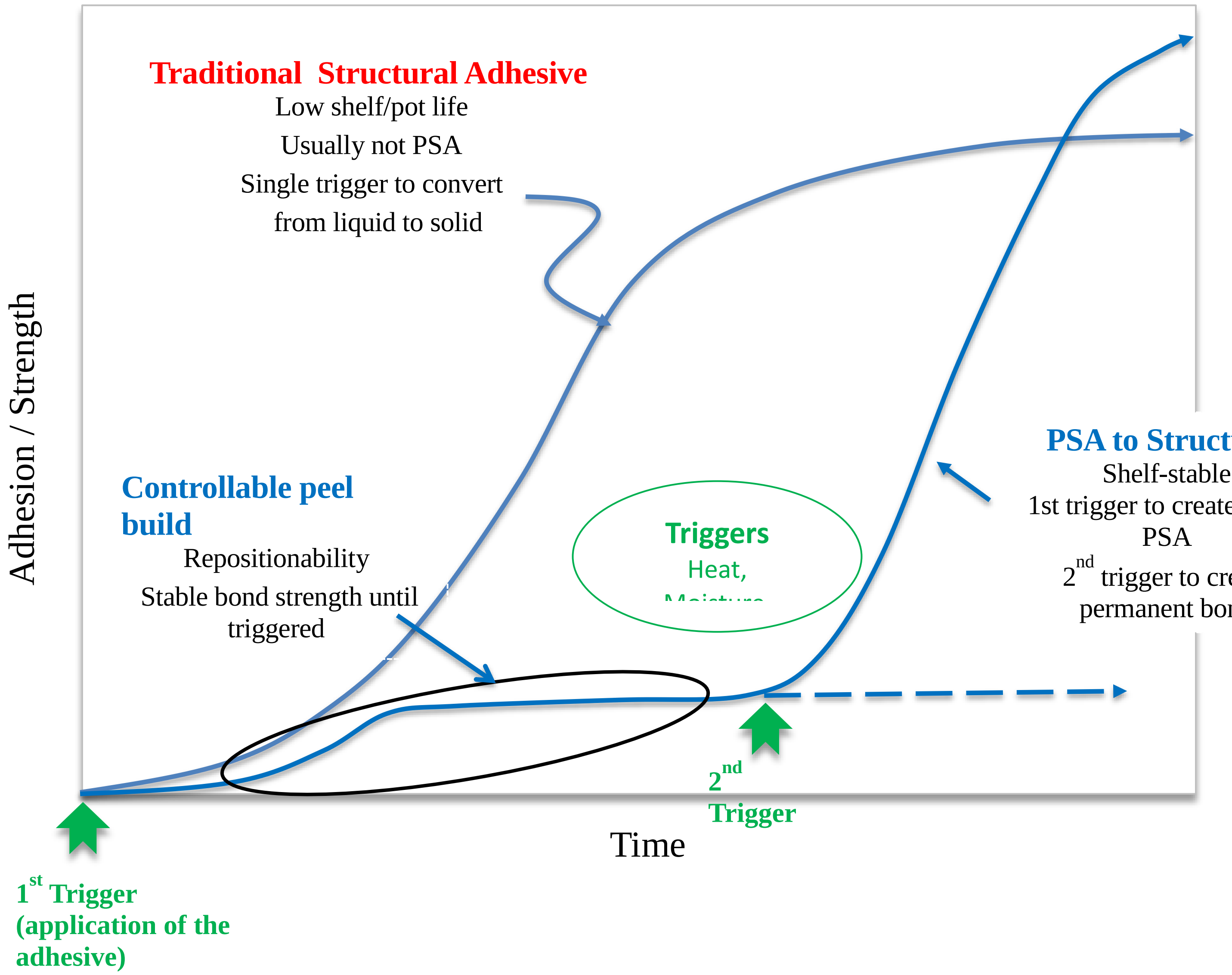

Figure 1. PSA to structural technology

Traditional structural adhesives, as shown in the red line of Figure 1, start to cure once material is bonded. This gives limited working time and repositionability during bonding. In PSA to structural technology, during the assembly stage the adhesive is pressure sensitive, which provides enough tackiness to hold the materials together, but without curing. Such characteristic provides users much more flexibility in assembly. Once the user is ready to finally bond the materials together, external trigger, such as heat or UV is applied to achieve the structural performance.

Current PSA to structural adhesives are solvent based adhesives, with about 48% solids, and a viscosity range of 3,000-8,000cps. The adhesives consist of base PSA polymer and other structural additives. They can be coated on typical solvent coating assets in PSA tape manufacturing.

The typical DMA scan of the PSA to structural adhesive is shown in Figure 2.

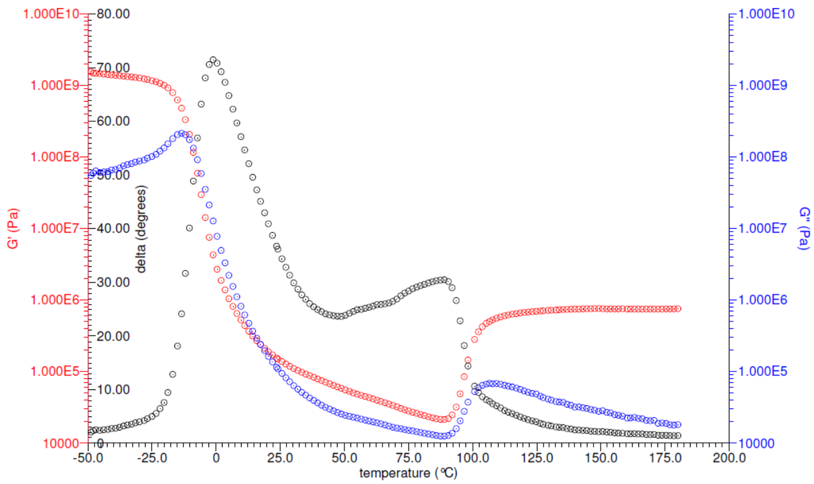

Figure 2. DMA scan of PSA to structural adhesive

At A stage, the adhesive has a glass transition temperature (Tg) at -2^{o}C. When the adhesive is heated to 95^{o}C, B stage curing starts and both storage (G') and loss (G'') modulus increase. As the adhesive becomes fully cured the storage modulus remains constant, while loss modulus starts to decrease, which indicates formation of a structural adhesive.

Just like typical pressure sensitive adhesives, the PSA to structural adhesives can be formulated to have different performance in peel and tack at A stage for different application needs. The performance range of A stage adhesive is shown in Figure 3 below.

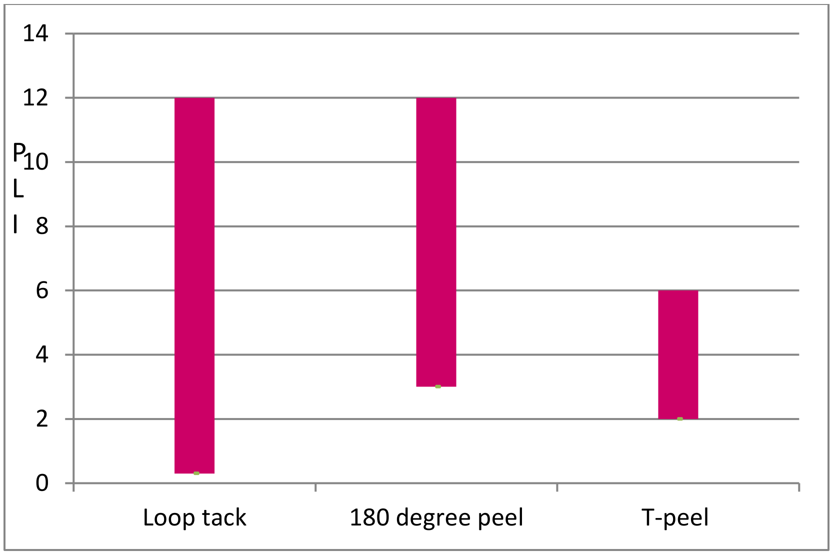

Figure 3. Performance range of PSA to structural adhesives at A stage. 180 degree peels and loop tack were tested on stainless steel panels. T-peels were tested with 2mil stainless steel foil/2mil stainless steel foil.

The low tack PSA to structural adhesives are useful for applications where repositionability is desired. The high tack adhesives are useful for difficult to bond surfaces, such as low surface energy surfaces, fibers, etc.

The performance of B stage adhesive can also be tailored to meet specific requirements. The T-peels can range from 4 to 10 PLI (stainless steel foil/stainless steel foil), while lap shear can range from 400 to 2,000psi (stainless steel/stainless steel). A lap shear in the range of 1,000 to 2,000psi is sufficient for most automobile applications. Therefore the PSA to structural adhesive tapes provide new efficient solution for structural bonding in automobiles.

The PSA to structural adhesive also have good high temperature performance. A typical thermogrammetric analysis (TGA) graph is shown in Figure 4.

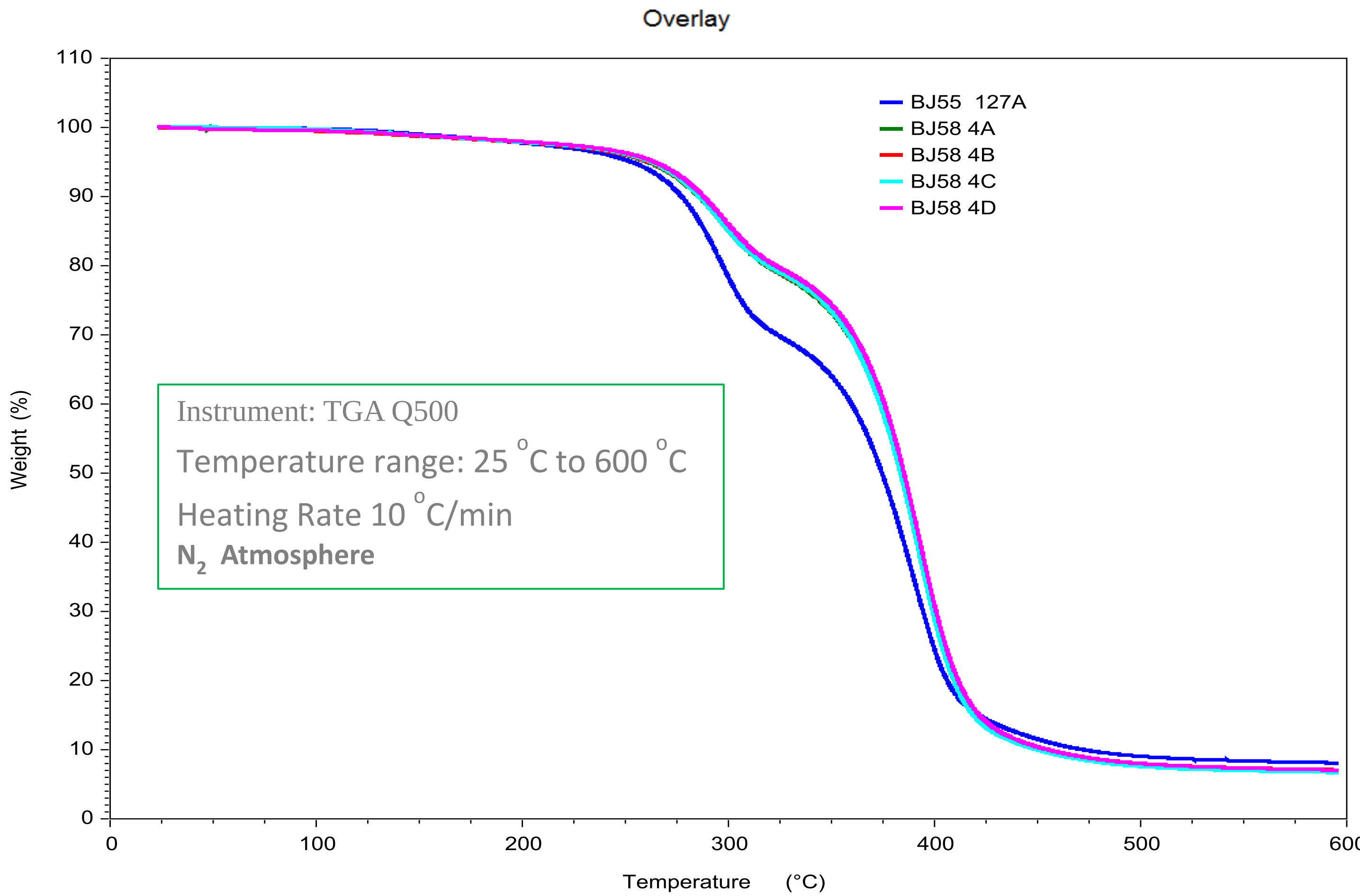

Figure 4. Thermogrammetric analysis of PSA to structural adhesives

It can be seen the adhesives are stable until 240ºC. Such high temperature stability makes the PSA to structural adhesive suitable for automobile applications.

In contrast to most current structural adhesive tapes, the PSA to structural adhesive tapes have excellent room temperature stability. The lap shear performance of a PSA to structural adhesive tape was tracked over a period of 12 months. The lap shear maintained at 700psi without noticeable change. No cold storage is needed to PSA to structural adhesive tapes.

Use of PSA to structural adhesive tape for composite lamination and automobile part assembly

Carbon fiber reinforced polymer composite (CFRP), a material well known for its strength and lightweight, are widely used in aerospace industry. It is also finding inroads in automobile industry. [2] The high end automobile market already uses carbon fiber composites. McLarens and Ferraris are the early adopters of CFRPs. CFRPs are gradually entering the medium to mass market. Recently, BMW is using CFRPs for roof elements, supporting roof pillars, and door frames in their new 7 series, i3 and i7 electric cars. With continued research to decrease cost of

CFRPs, we can see CFRPs will find more and more applications in automobiles.[2] Using PSA to structural adhesive tapes to provide bonding solutions of CFRPs offers a new and growing opportunity for PSA tape manufacturers.

CFRPs are often made by lay-ups of prepregs. The scheme is shown below.

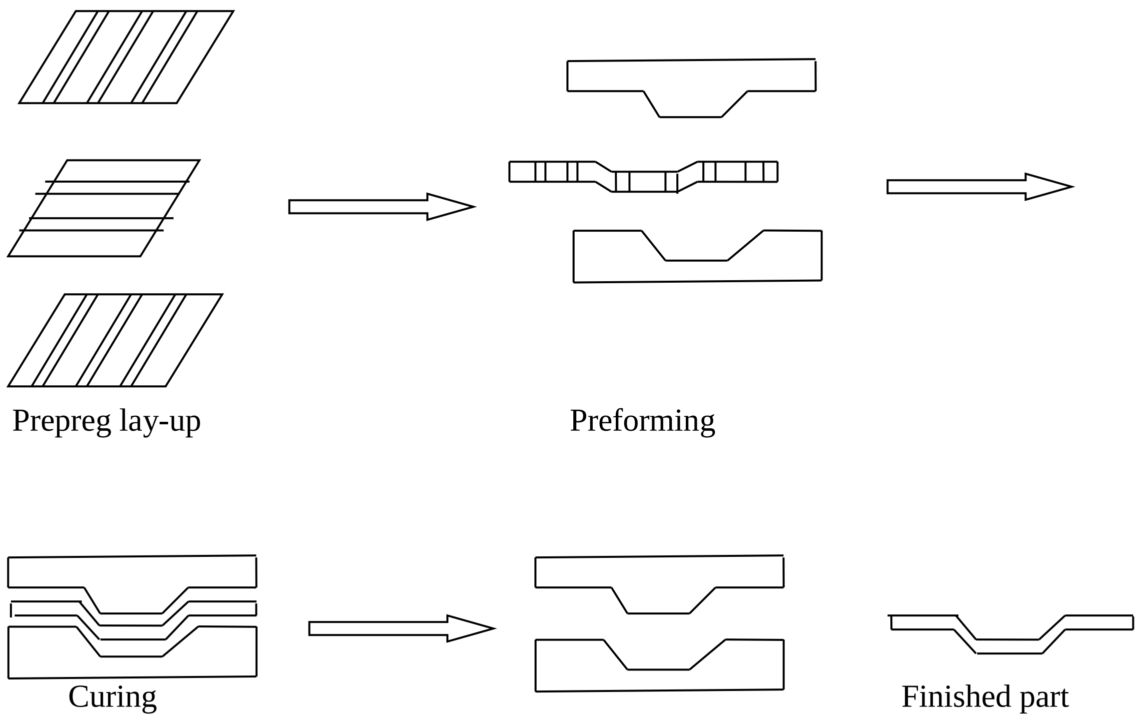

Figure 5. Composite lamination process

In the lay-up step, prepregs are arranged in layers so that fibers oriented in all directions. Then the prepregs are placed in a mold and heated for curing. In the next step the mold is removed and finished part is obtained. Current commercially available prepreg materials often show significant variations in tack strength, from point to point within a sheet and from sheet to sheet. Such inconsistencies can lead to void formation in the final composites laminate.[3] The PSA to structural adhesives provides consistent tack control of the prepregs. The adhesives and prepregs can be co-cured without adversely affecting performance of the composite materials. In addition, the PSA to structural tape can also be used to bond the prepreg with other substrates, such as metal and plastics, and cured together.

To prepare lap shear samples for testing of bonding of composites with composites, composite laminates were prepared with four layers of prepregs with 0^{o}, 90^{o}, $+45^{o}$,-45^{o} ply. Two strips, each one inch wide and three inch long were prepared. The adhesive (1mil thick, one inch long, one inch wide) was applied on one end of one test strip. The other test strip was placed on top so the two strips have one square inch area overlap. The test strip was immediately cured, with temperature gradually raising to 135^oC at 2^oC/min, then cured at 135^oC for 1hr. Two adhesive formula were tested. These adhesives were designed in such way that there are high percentage of curatives, and therefore gives high strength after curing. The base polymer was also designed in a way that a high strength backbone was incorporated in the polymer structure. The lap shear strength of composite to composite joint is given in Figure 6.

Adhesive type	None	Adhesive 1	Adhesive 2
Lap shear (psi)	1,700	1,864	>1,950*

*Lap shear test strip breaks at 1,950psi.

Figure 6. Lap shear strength of composite to composite bonding

It can be seen that with two stage adhesive, there is no decrease in lap shear performance of composite laminates.

The PSA to structural adhesive can also be used to bond composite with metals commonly used in automobile manufacturing, such as steel and aluminum. The lap shear strength of prepregs bonded with metals and then co-cured with Adhesive 2 are shown in Figure 7. Adhesive thickness was 1mil in these tests. Stainless steel was 316 stainless steel, 12mil thick. Titanium was high strength grade 5 titanium, 16mil thick. Aluminum was high strength 2024 aluminum, 20mil thick. The metals were tested as they are without treatment.

Metal	Stainless steel	Titanium	Aluminum
Lap shear (psi)	1,454	1,175	1,050

Figure 7. Lap shear strength of composite to metal bonding

It can be seen that the two stage adhesives provide excellent bonding between composites and metal. The bonding strength could possibly be further increased with treatment of metal with primer, sanding, etc.

PSA to structural adhesives can also provide excellent bonding strength between composite and plastics, such ABS. Because ABS has a glass transition temperature of 105^oC, a PSA to structural adhesive with low curing temperature (around 80^oC) was developed. When this adhesive was applied to bond ABS with composite material, the bond has excellent strength. During lab shear test the ABS panel breaks while the composite/ABS joint remains intact.

The PSA to structural adhesive tapes have good environmental resistance. Lap shear samples from Adhesive 2 of stainless steel/stainless steel, composite/composite, composite/stainless steel were placed in a 60^oC oven at 95% humidity and aged for 30 days. The lap shear were retested and results are shown in Figure 8.

Joint	Stainless steel/stainless steel	Composite/composite	Composite/stainless steel
Lap shear before aging (psi)	1,180	>1,950	1,454
Lap shear after aging (psi)	1,472	2,226	1,694

Figure 8. Lap shear of joints after aging

We can see that the PSA to structural adhesive does not show decrease in performance under such aging conditions.

Conclusions

PSA to structural adhesive tapes provide new solutions for automobile light-weighting challenges. The PSA to structural adhesives facilitates prepreg lay-up to manufacture composite parts without sacrificing performance. PSA to structural adhesive tapes have excellent room temperature storage stability. The adhesives also offer excellent bonding strength for composite/metal and composite/plastics when the prepregs and adhesives are co-cured. PSA to structural adhesive tapes overcame many issues with traditional liquid adhesives and structural adhesive tapes and could see many applications for future automobile manufacturing.

References

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