LOW-SHRINKAGE ACTIVE ALIGNMENT ADHESIVES WITH HIGH DIMENSIONAL STABILITY FOR AUTOMOTIVE HIGH-RESOLUTION CAMERA MODULE ASSEMBLY

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ABSTRACT

Active alignment, a state-of-the-art assembly method used to manufacture high-quality camera modules, is the foundation for the safety-critical functionality of advanced driver assistance systems (ADAS) used in today's automobiles. ADAS technology is expected to play an ever-increasing role in the future, enabling next-generation autonomous vehicles. The camera modules inside ADAS perform a vital function, helping ensure the safety of drivers, passengers and pedestrians. They must operate with high resolution and perform with superior reliability in harsh environments for the life span of the vehicle. The adhesives used to assemble these camera modules must meet strict industry requirements for low and consistent shrinkage, high dimensional stability and high adhesion strength. This paper introduces two new dual-cure automotive-grade adhesives. Both represent the next generation of highly reliable and dimensionally stable ADAS camera module adhesives. Finally, a brief outlook is given on what innovations can be expected in the future that will further improve the performance and efficiency of these adhesives.

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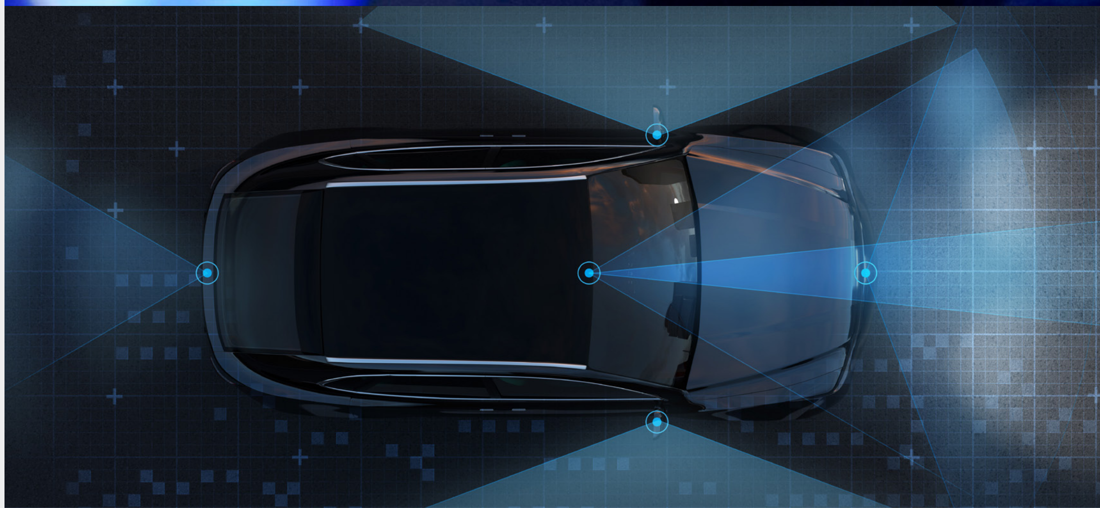

INTRODUCTION

Advanced driver assistance systems (ADAS) consist of multiple cameras, radar, ultrasonic, and light detection and ranging (LiDAR) sensors, all sending data to a central processing unit that provides feedback to the driver and vehicle control systems. Warning signals alert the driver to potential hazards and provide critical information to vehicle control systems designed to automatically assist with braking and steering for collision avoidance.

Advanced driver assistance systems have spurred the need for high-resolution camera designs. ADAS camera modules perform vital safety functions, providing a 360° camera view around the vehicle to assist both driver and vehicle awareness of the driving environment, ensuring the safety of drivers, passengers and pedestrians. ADAS cameras must provide high-resolution images and perform with superior reliability in harsh environments for the life span of the vehicle.

Today's high-quality ADAS camera modules make use of the active alignment assembly process to achieve superior camera focus and produce high-resolution images. The active alignment process precisely positions the camera's optical components to the image sensor (Figure 1) while an adhesive is used to fix the components in place. Compared to a threaded lens barrel, which can only be adjusted in the Z-direction, the active alignment workflow allows for six degrees of freedom in the alignment process, with an accuracy of 100 nanometers[1].

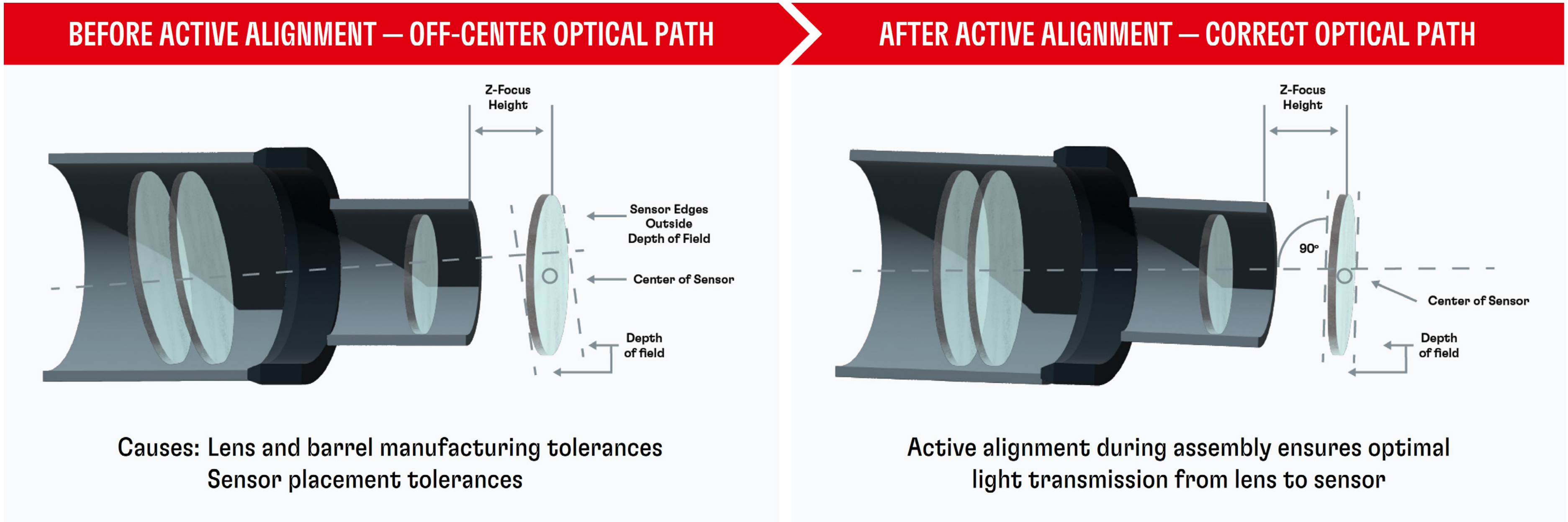

Figure 1. Optical path adjustment during active alignment.

ADAS cameras can only tolerate miniscule changes in the positions of its optical components, and the adhesive used plays a major role in meeting these precise positioning requirements. The adhesive must bond to a variety of substrates, cure quickly to high bond strength, and must exhibit low and consistent shrinkage during the curing process. While optical alignment workflows have the potential to precompensate for movements due to adhesive shrinkage, variations in shrinkage are problematic. It is therefore important for the adhesive to display consistent shrinkage that remains low, stable and predictable, ensuring a truly reliable camera module that will perform dependably in harsh conditions for the life span of the vehicle.

Environmental responsibility and workplace safety are other factors to consider when selecting a suitable adhesive for ADAS camera module assembly. The adhesive must be free of toxic chemicals and not contain any substances which are listed as substances of very high concern (SVHC) in the European Union's REACH regulation.

CAMERA ASSEMBLY PROCESS

The camera assembly process typically consists of five steps (Figure 2) and begins with the dispensing of the adhesive bead, followed by placing and positioning the optical components. In the third step, the optical components are precisely aligned for best focus. Their positions are fixed in the fourth step with a short UV cure (only a few seconds) before the camera module undergoes a post-cure to achieve the final bond strength of the adhesive. Post-curing can be achieved by exposure to either heat or moisture, depending on the curing mechanism of the adhesive's chemical formulation. The entire curing process occurs in two subsequent steps. Therefore, camera module adhesives are referred to as dual-cure adhesives.

Figure 2. Typical active alignment steps in ADAS camera module assembly.

ADHESIVE PERFORMANCE

Henkel provides an extensive portfolio of camera module assembly adhesives[2] formulated to meet a variety of customer needs. For example, the following dual-cure adhesives have a proven track record of outstanding success in camera module assembly.

- LOCTITE® 3217 is formulated for UV and thermal cure
- LOCTITE® ECCOBOND UV 9052 is formulated for UV and moisture cure

Henkel continues to develop new adhesives for camera module assembly, specifically designed to meet next generation requirements of the automotive industry. With increasing emphasis on environmental responsibility, the latest developments include LOCTITE® 3296 and LOCTITE® ABLESTIK NCA 3218. Neither of these adhesives contains substances identified as SVHCs, nor do they use any toxic ingredients, making them fully EU REACH-compliant. These adhesives are also free of antimony, which is still used in many other adhesives as a photoinitiator and has recently been identified as dangerous due to its potential health hazards[3].

LOCTITE® 3296 and LOCTITE® ABLESTIK NCA 3218, both dual-cure adhesives (UV and thermal), exhibit different adhesive performance characteristics to meet a variety of assembly requirements. For example:

- LOCTITE® 3296 provides a very high cure depth after only a few seconds of exposure to UV light and is designed to bond particularly well to aluminum and FR4
- LOCTITE® ABLESTIK NCA 3218 is designed for use in assembly processes that require low post-cure temperatures and is especially favorable for assembling components made of plastic. Additionally, it provides an exceptionally high glass transition temperature (Tg)
- LOCTITE® ABLESTIK NCA 3218 is intentionally colored gray, requires a slightly longer UV cure and yields a lower cure depth than LOCTITE® 3296, but allows for efficient light blocking from outside to enhance camera performance

ADHESIVE PERFORMANCE – CONTINUED

Key features of these advanced adhesive formulations are summarized in Tables 1 and 2. Both products are formulated to first cure when exposed to UV light, followed by a secondary thermal cure.

Table 1. Key features of next-generation camera module adhesive LOCTITE® 3296.

Property	LOCTITE® 3296*
Cure type	UV + thermal
Chemistry	Epoxy cationic
Appearance	Opaque
SVHC-free	Yes
Non-toxic	Yes
REACH-compliant	Yes
Antimony-free	Yes
Outgassing test	Passed
Shelf life at -20 °C	6 months
Viscosity @ 23 °C 15/s	32 Pa·s
Tg by DMA (tan delta)	192 °C
E' modulus at 25 °C by DMA	9.4 GPa
CTE 1 (average between 25 °C to 125 °C)	25 ppm/K
Cure depth‡	4.3 mm
Water absorption after 1,000 hrs. immersion at RT	<0.6 wt %
Shore D hardness	94
Volume shrinkage	1.0 %
Dimensional stability (bond line thickness change of 650 µm bond line)	
1,000 hrs. 85 °C / 85 % rel. H	+0.3 %
1,000 hrs. heat storage 125 °C	-0.7 %
1,000 cycles heat shock -40 °C to 125 °C	-0.4 %
Adhesion strength (die shear strength) on plasma-treated aluminum to aluminum	7.7 MPa
UV and thermal post-cure 1,000 hrs. 85 °C / 85 % rel. H	10.8 MPa
1,000 hrs. heat storage 125 °C	10.4 MPa
1,000 cycles heat shock -40 °C to 125 °C	9.8 MPa

* After UV cure for 3 seconds at 1,000 mW/cm² and 365 nm and following thermal post-cure for 30 minutes at 120 °C.

‡ After UV cure for 3 seconds at 1,000 mW/cm² and 365 nm.

Since the dimensional change of the adhesive over the lifetime of the camera module should be as low as possible, it is important to predict how much this change will be. Therefore, LOCTITE® 3296 was dispensed on an aluminum substrate by means of a machine-controlled time-pressure dispenser and fully cured to obtain a glue bead of 650 µm thickness. The thickness of the glue bead was then measured with a profilometer by scanning its profile with a stylus to obtain its initial thickness. Afterward, the specimens were exposed to test conditions common in the testing of camera module adhesives, which include a heat shock test at -40 °C and 125 °C (dwell time of 30 minutes at each temperature), a heat storage test at 125 °C, and a high humidity test at 85 °C with 85 % relative humidity. The thickness was measured at 500 hours and 1,000 hours. The measured change of the bond line thickness is depicted in Figure 3.

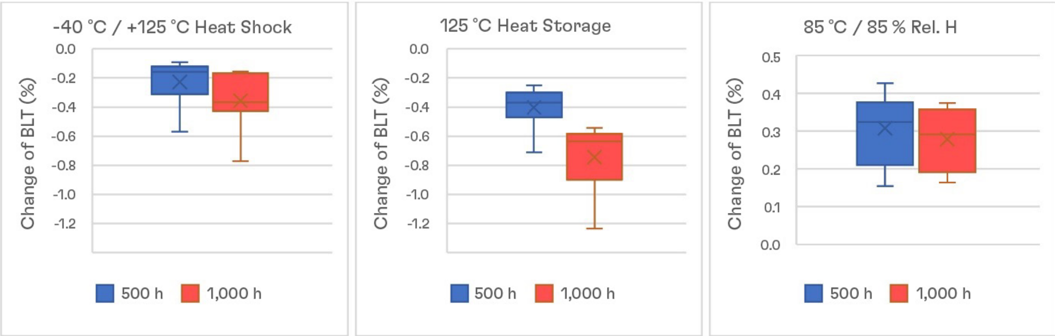

Figure 3. Change of bond line thickness (BLT) of LOCTITE® 3296 in percent of a cured glue bead of height of 650 µm after exposure to heat shock -40 °C / +125 °C (dwell time 30 minutes at each temperature), 125 °C heat storage and 85 °C / 85 % relative humidity testing after 500 and 1,000 hours.

Since UV curing of LOCTITE® 3296 only takes a few seconds to achieve its maximum cure depth, for camera module assemblies that require a broader glue bead, it is important that the UV light cures the entire glue bead over its full width without leaving uncured material that could subsequently contaminate optical components during the secondary thermal cure.

The cure depth is therefore another essential property of a camera module adhesive which can be easily determined. Figure 4 shows the cure depth of LOCTITE® 3296 for different cure times at 1,000 mW/cm² with a 365 nm UV LED.

ADHESIVE PERFORMANCE – CONTINUED

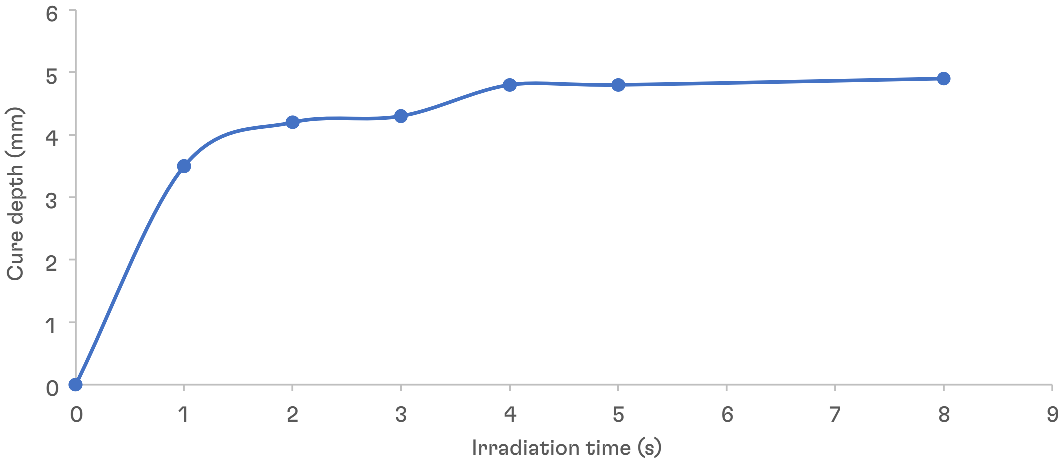

Figure 4. Cure depth of LOCTITE® 3296 after curing with 1,000 mW/cm² at 365 nm for different durations.

High dimensional stability after cure and obtaining a deep cure are essential prerequisites for next-generation camera adhesives. In combination with low and consistent shrinkage, the dimensional change during cure can be accounted for precisely and consistently during the assembly process using a constant precompensation value. The volume shrinkage of the adhesive was determined volumetrically by density measurements with a helium pycnometer after UV and thermal cure. Density measurements were taken on several batches, several times on the same batch, and on the same test specimen of a batch to allow for an estimation of batch-to-batch variation, the reproducibility and the repeatability of the test method. Volume shrinkage results are illustrated in Figure 5.

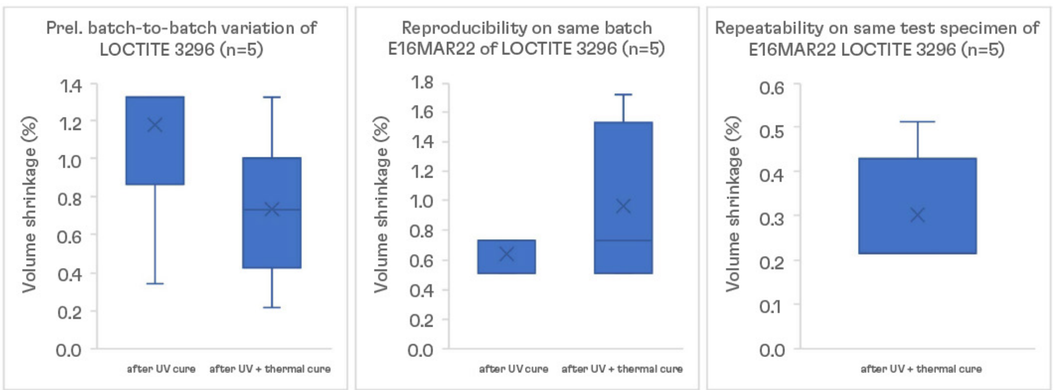

Figure 5. From the left to the right: Volume shrinkage of LOCTITE® 3296 after UV cure (3 seconds at 1,000 mW/cm² at 365 nm) and UV + thermal cure (3 seconds at 1,000 mW/cm² at 365 nm followed by 30 minutes at 120 °C) for n = 9 batches, n = 5 specimens of the same batch (E16MAR22) and volume shrinkage after UV + thermal cure for n = 5 measurements of one specimen of batch E16MAR22.

Table 2. Key features of next-generation camera module adhesive LOCTITE® ABLESTIK NCA 3218.

Property	LOCTITE® ABLESTIK NCA 3218*
Cure type	UV + thermal
Chemistry	Epoxy cationic
Appearance	Gray
SVHC-free	Yes
Non-toxic	Yes
REACH-compliant	Yes
Antimony-free	Yes
Shelf life at -20 °C	6 months
Viscosity @ 25 °C CP51, 5 rpm	27 Pa·s
Tg by DMA (tan delta)	215 °C
E' modulus at 25 °C by DMA	9.0 GPa
CTE 1 (average between 25 °C to 125 °C)	25 ppm/K
Cure depth‡	1.9 mm
Water absorption after 240 hrs. at 85 °C / 85 % rel. H	0.8 wt %
Shore D hardness	94
Volume shrinkage	1.4 %
Dimensional stability (bond line thickness change of 100 µm bond line)	
2,000 hrs. 85 °C / 85 % rel. H	0.10 %
2,000 cycles heat shock -40 °C to 125 °C	0.10 %
Adhesion strength (die shear strength) on plasma-treated FR4 to FR4 and polyphenylene sulfide (PPS) to PPS after	
UV and thermal post-cure	19.7 MPa on FR4, 25.6 MPa on PPS
2,000 hrs. 85 °C / 85 % rel. H	19.6 MPa on FR4, 22.4 MPa on PPS
2,000 cycles heat shock -40 °C to 125 °C	19.9 MPa on FR4, 31.5 MPa on PPS

* After UV cure for 3 seconds at 1,000 mW/cm² and 365 nm and following thermal post-cure for 30 minutes at 120 °C.

‡ After UV cure for 3 seconds at 1,000 mW/cm² and 365 nm.

ADHESIVE PERFORMANCE – CONTINUED

The cure depth of LOCTITE® ABLESTIK NCA 3218 for different UV irradiation times is shown in Figure 6. Higher cure depths can be obtained by curing the adhesive with a higher irradiance. The maximum cure depth is obtained after a similar curing time compared to LOCTITE® 3296. Although the cure depth is lower, LOCTITE® ABLESTIK NCA 3218 is still considered to provide a high cure depth given that it has a transmittance of only 11 % at 625 nm for a 1 mm thick glue bead. The lower transmittance provides excellent blocking of unwanted light from the outside which could interfere with the image sensor.

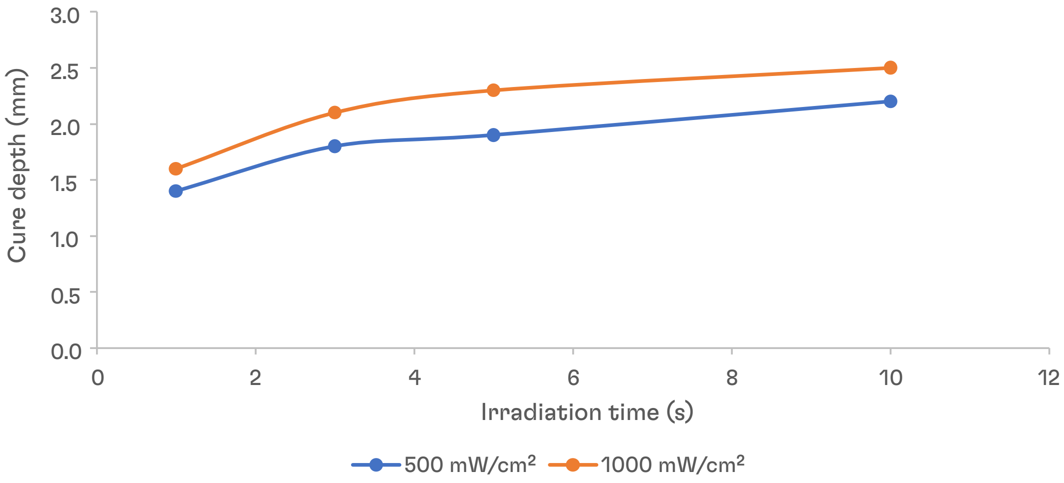

Figure 6. Cure Depth of LOCTITE® ABLESTIK NCA 3218 after curing with 500 mW/cm^2 and 1,000 mW/cm^2 respectively at 365 nm for different durations.

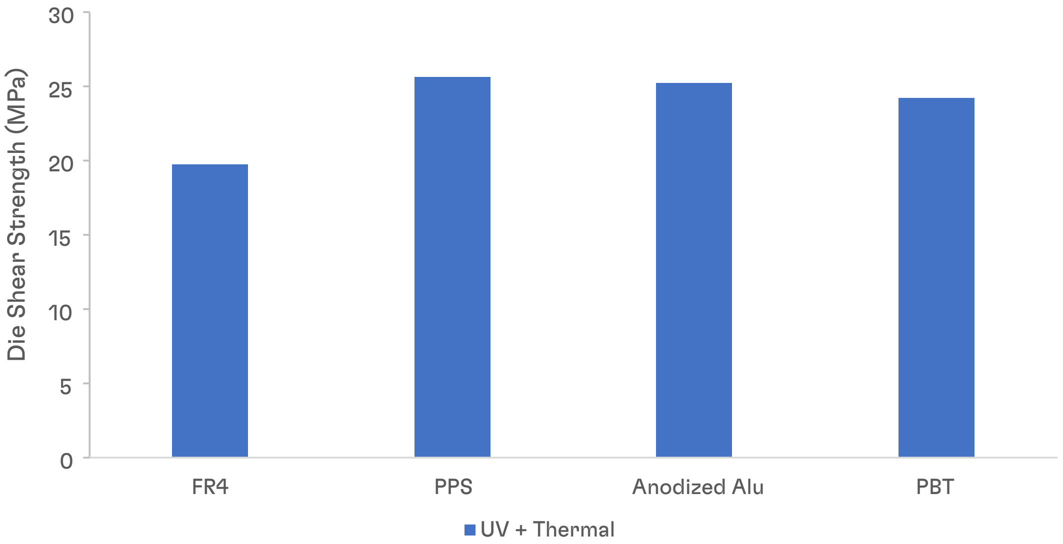

Figure 7. Die Shear Strength of LOCTITE® ABLESTIK NCA 3218 after UV cure for 5 seconds at 500 mW/cm^2 and 365 nm and following thermal post-cure for 60 minutes at 100 °C on various substrates.

Die Shear Strength (DSS) measurements were performed on a DAGE 4000 die shear tester with 300 µm/s shear speed. Plasma-treated dies (3 x 3 mm) of different materials were bonded with a 100 µm target bond line thickness to a plasma-treated substrate of the same material. The DSS after UV curing and full cure is depicted in Figure 7.

INNOVATIVE CHEMISTRY

LOCTITE® 3296 and LOCTITE® ABLESTIK NCA 3218 represent the next generation of camera module adhesives. By leveraging the advantages of purely cationic epoxy adhesives, both products provide a high Tg in combination with low and consistent shrinkage as well as high cure depths, and thus are superior compared to conventional adhesives employing free-radical curing mechanisms like acrylates. The typical differences of both chemistries are summarized in Table 3.

Table 3. Differences between cationic and free-radical curing systems for dual-cure camera module adhesives.

Property	Cationic	Free-radical*
Tg	High	Medium
Shrinkage	Very low	Medium to high
Cure depth	High	Low
Surface condition after UV cure	Non-tacky, no oxygen inhibition	Tacky due to osygen inhibition

* Free-radical or hybrid system.

SUMMARY

These new adhesives are both antimony-free, SVHC-free and EU REACH-compliant. They exhibit a low CTE over a broad temperature range, giving them excellent dimensional stability under harsh environmental conditions. Their superior dimensional stability enables camera sensors to make reliable, precise measurements. They cure very quickly within a few seconds of UV irradiation and do not suffer from oxygen inhibition like their free-radical counterparts. Their viscosity profile allows for easy dispensing with very good adhesion to various substrates, including plastics, making them an ideal choice for any high-quality camera module used in ADAS applications.

COMING SOON: A REVOLUTION IN CAMERA ASSEMBLY

While the next-generation dual-cure adhesives presented here offer excellent options for producing high-quality camera modules, we continue to push the boundaries of adhesive performance. Our latest breakthrough innovation, coming soon, will revolutionize the camera assembly process. This innovative one-step UV-cure camera module assembly adhesive will help our customers increase the output of their camera assembly lines, streamline the overall assembly process, significantly reduce the amount of manufacturing energy needed, and reduce the overall CO_2 footprint.

Our one-step UV-cure camera module assembly adhesive will provide all the advantages of LOCTITE® 3296, LOCTITE® ABLESTIK NCA 3218 and others while adding exceptionally high cure depth and a very high degree of conversion after UV cure. When incorporated into a compatible camera design, this adhesive will make it possible to omit the post-curing step for the very first time – while maintaining high glass transition temperatures and achieving final high adhesion strength after a single UV cure. Customers that partner with Henkel throughout their camera design process will be in the strongest position to integrate the latest adhesive technology innovations into their products and production processes going forward.

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