NOVEL LED-CURE FLEXIBLE BONDERS FOR MEDICAL DEVICE ASSEMBLY

ABSTRACT

As part of a light-cure adhesive innovation program, Henkel has developed two new LED-curable adhesives, LOCTITE® AA 3951™ and LOCTITE AA 3953.™ These new adhesives cure rapidly, with a combination of high flexibility and high strengths on many diverse plastic substrates. This paper details that combination of new properties, while maintaining all other product attributes associated with light-curing acrylic (LCA) adhesives.

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BACKGROUND

UV and visible light-curing of acrylate adhesives is a technology that continues to grow due to its favorable medical device applicability. Rapid curing, broad substrate adhesion, flexibility, and fluorescent detectability make light-cure acrylics the first consideration for many high-speed automated bonding operations.

Due to advances in curing technology, light-cure acrylates are being cured by LED systems instead of traditional bulb-based systems with increasing frequency. This trend will continue in the medical device market due to the several advantages of LED over mercury arc and metal halide UV lamps. LEDs are 60–80% more energy-efficient than conventional UV lamps. They are lower in cost and provide increased longevity with more consistent output. In addition, they do not contain mercury or produce ozone. Innovation in LED systems continues to lower the cost and increase the output of film and adhesive curing systems year by year. LEDs are expected to become the new trend for curing, so it is no surprise that the adhesives exhibited in this project were designed to be fully compatible with the most common LEDs on the market. Since LED technology is a recent development, many of the previous generation products do not have the same compatibility.

One of the major challenges with new substrates being introduced into the medical device market is the increased use of extremely soft and low surface energy thermoplastic elastomers (TPEs). Typical light-curing adhesives have shown poor performance on many of these substrates for two reasons: lack of adhesion and flexibility. Lack of adhesion inherently causes issues with bonding; however, a low tensile modulus and a high elongation allow adhesives to stretch in the bond-line and decentralize the peel forces. Peel is the most aggressive type of force for any adhesive and is common in flexible bonding applications. In an example case of the combination of a rigid and a flexible material, the adhesive has to “moderate” the different material behaviors under load. For such applications, a high elongation before break is a very beneficial property for an adhesive, and generally correlates to higher assembly strength.

Additionally, many of these TPEs are being chosen for tubing assemblies which require a low-viscosity adhesive to wick into tight diametrical gaps. The issues presented to adhesive formulators is that adhesion and low viscosity often need to be sacrificed to achieve flexibility. However, the new light-curing adhesive products presented in this paper have achieved a high degree of flexibility without sacrificing the other two properties.

DISCUSSION

Henkel has developed two new, LED-cure flexible LCA bonders. To fill several market needs, multiple viscosities were required for different gaps in flexible junctions. LOCTITE® AA 3951™ and LOCTITE AA 3953™ are 150 and 450 cPs, respectively. In addition to the high strength and flexibility in these low-viscosity products, each of these products are clear, fluorescent, and present good depth of cure.

HIGH ELONGATION & LOW VISCOSITY

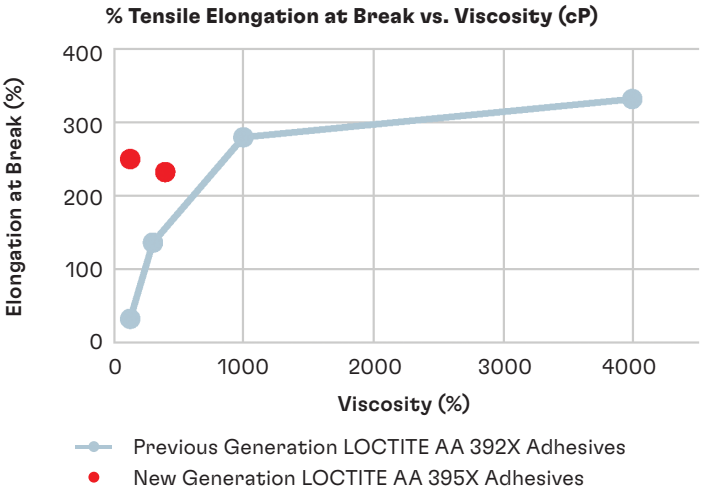


FIGURE 1. Comparison of elongation vs. viscosity for new and previous generation light-cure grades.

One unique characteristic of these new LCA adhesives is high elongation in combination with low viscosity. Previous grades have shown a dependency of flexibility on the viscosity, as illustrated in ***Figure 1.*** For higher viscous grades, a higher degree of flexibility was achieved. Looking at this the other way around, for low-viscosity acrylics, only a certain elongation was possible to achieve. The new performance combinations of LOCTITE AA 3951 and LOCTITE AA 3953 allow the use of highly flexible acrylics in applications requiring low viscosity, e.g., in small parts or narrow gap designs. This gap design is common in applications where solvent welding is being replaced.

FLUORESCENCE

Fluorescence offers users—particularly with automated lines—the opportunity to quickly and easily confirm if the product has been applied correctly to the mating parts. Colorless products without fluorescence do not have the required contrast to be detected on a high-speed production camera. Using a medium standard on the SICK camera, the following results were obtained.

This increased fluorescence performance, displayed in ***Figure 2,*** aids in the detection, allowing for the use of less-expensive detectors or enabling the detection of very small product quantities present in exceedingly narrow bond gaps.

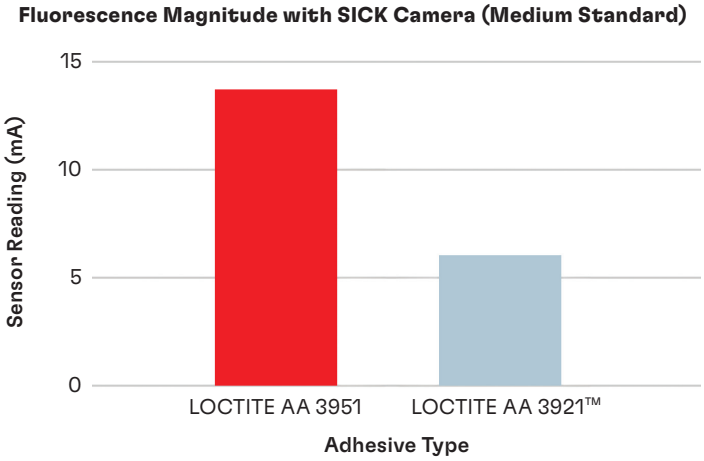


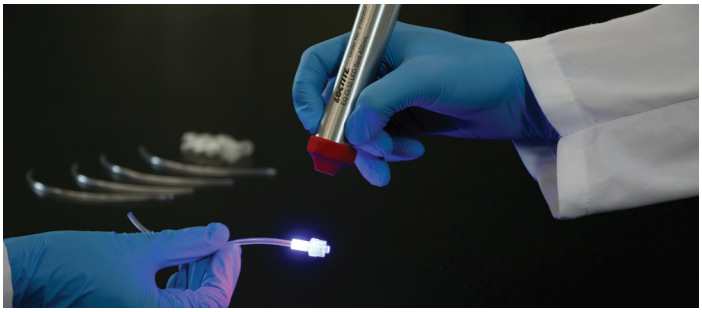
FIGURE 2. UV Fluorescence, SICK camera, medium standard. (LOCTITE AA 3921 is an earlier generation LCA.)

FIXTURE TIME

Fixture time is a commonly used indicator of the cure speed of light-cure products. The test entails bonding thin glass slides at different cure intervals until the bond is strong enough to break the glass when pull testing. Excellent fixture times on glass slides were achieved at less than 1 second cure at 405nm and extremely low light intensity ***(Table 1).*** LED 405nm compatibility is fundamental for new generation products as visible LEDs are now the choice of curing equipment due to efficiency, penetration, and speed. LOCTITE AA 3951 maintains a high speed even while fluorescing at a magnitude two or more times the previous generation. Increased fluorescence is a challenge for cure speed because fluorophores absorb the same wavelengths of light as the photoinitiators and are known to reduce cure speed.

Fixture Time (sec)—LED Flood, Cured at 10 mW/cm² at 405nm	
LOCTITE AA 3921	**LOCTITE AA 3951**
< 1 Second	< 1 Second

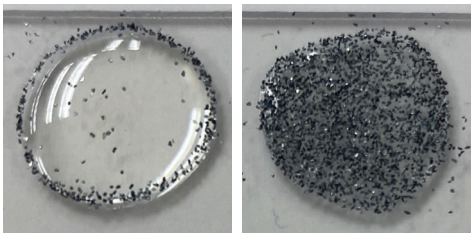
TABLE 1. Fixture time on glass slides.



SURFACE CURE

For light-cure acrylics, the surface cure is affected by oxygen inhibition. Full spectrum bulbs, which were traditionally used (prior to LED), emit visible light (400nm–420nm), UVA (315nm–400nm), UVB (280nm–315nm), and, most importantly, UVC (100nm–280nm). Visible and UVA light penetrate well into the adhesive and through the transparent substrates and provide cure through a bond gap. The UVC wavelength has low penetration and is primarily absorbed at the adhesive surface. This creates a high concentration of free radicals to overcome oxygen scavenging in the air-exposed surface layer. With LEDs, this wavelength combination is no longer possible, as LEDs emit one wavelength only. Therefore, when curing with LED, the surface cure must be fulfilled by the UVA (365nm) or visible light (405nm) wavelength only. ***Figure 3*** shows how LED surface tack was improved versus previous generations. At 100mW/cm² for 10 seconds, the silicon carbide powder cannot be brushed off the cured drop of LOCTITE® AA 3921™ due to its thicker uncured surface layer. In contrast, the new flexible bonder retains much less silicon carbide. At 500mW/cm² for 20 seconds, LOCTITE AA 3951™ no longer retains the silicon carbide, while the older generation still displays signs of a tacky surface.

405nm LED at 100mW/cm² for 10 seconds



405nm LED at 500mW/cm² for 20 seconds

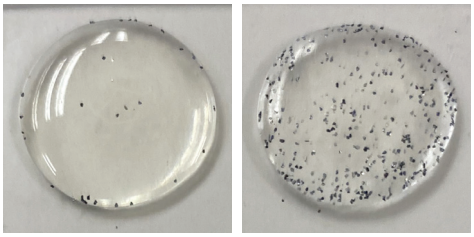


FIGURE 3. Surface tack testing using 80 grit silicon carbide powder, LOCTITE AA 3951 (Left), earlier generation light-cure acrylic (Right).

ADHESION STRENGTH

These new entrants to the LCA market consistently offer improved results across a variety of plastics, when compared to previous generation adhesives. ***Figure 4*** shows increased adhesion performance on ABS, PC, PET, and TPU.

It is worth noting that the new adhesive was able to reach substrate failure of the TPU ***(see Figure 5)***, while the previous generation grade did not.

Lap Shear Strengths on Various Substrates (N/mm²)

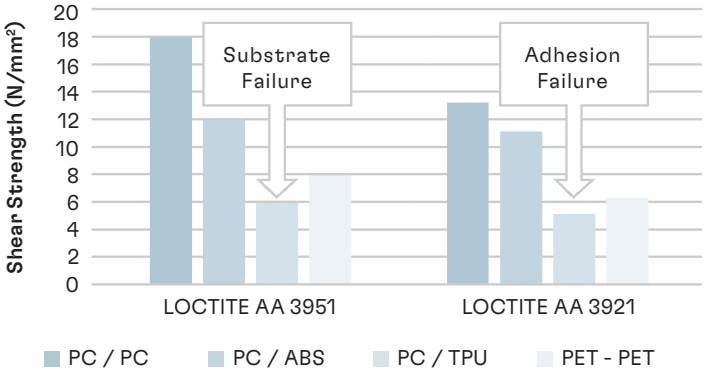


FIGURE 4. Adhesive shear strength on various substrates.

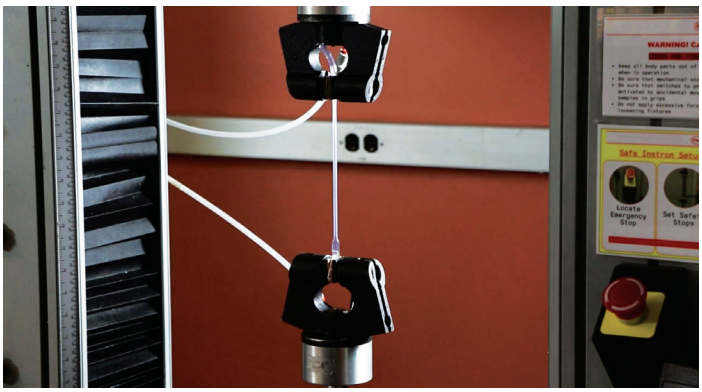
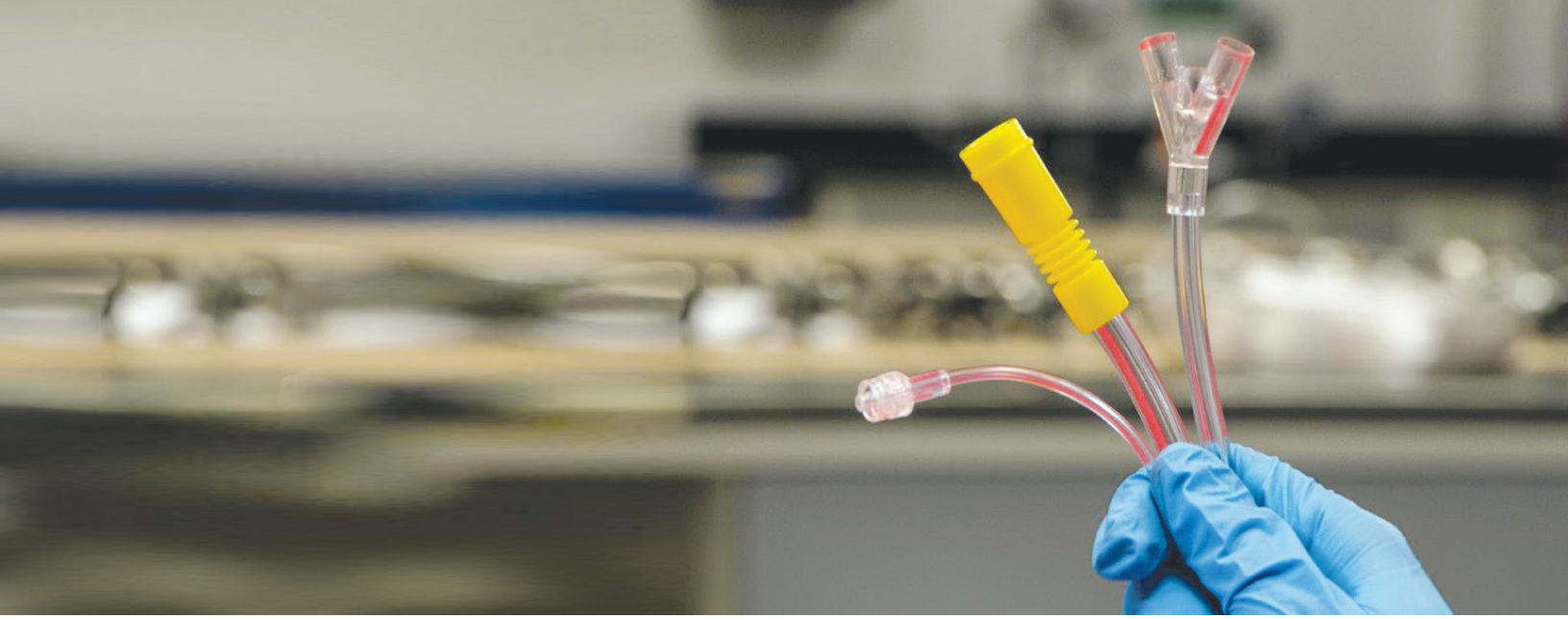


FIGURE 5. Shear adhesion test using LOCTITE AA 3951 resulting in substrate failure of the TPU.

REGULATORY IMPROVEMENT

As these newly developed LED-curable flexible bonders were developed primarily for the medical device market, ISO 10993 testing was performed to confirm that the adhesives met commonly acceptable biocompatibility standards. Additionally, LOCTITE AA 3951 and LOCTITE AA 3953™ were formulated with current health hazard designations in mind, replacing select traditional ingredients that were recently reclassified. This is a benefit to the safety of the designed medical device and its market approval, as well as a benefit to adhesive users who may have moderate to significant exposure times when operating or maintaining fully automated production lines.



CONCLUSIONS

The timely arrival of this adhesive product line is a great opportunity to ensure Henkel's position as the leading supplier in the light-cure adhesives market, especially at a time when the market is rapidly commercializing highly elastic TPE blends which may include TPU, TPO, SEBS, PEBA, polyesters, or combinations thereof. The high elongation and low viscosity of LOCTITE® AA 3951™ and LOCTITE AA 3953™ allow tight-fitting flexible parts to be bonded with ease. Visible LED compatibility ensures that users will obtain fast cure times, with good surface cure, using state-of-the-art curing systems designed for high-speed automated lines. All these attributes tie together to create a high-value package that is desirable to manufacturers in medical, electronics, aerospace, consumer goods, and beyond.

APPENDIX

ABS: Acrylonitrile butadiene styrene plastic.

Adhesive Failure: A term used to describe an adhesive bond failure in which the interface between the adhesive and the substrates delaminates.

Fluorescence: A property of a material that characterizes absorption of light in one spectrum and emission in a different spectrum. The wavelength of light absorbed and emitted is determined by the energy of the photons as it correlates to the difference in energy levels between the excited state and the ground state.

LED: Light-emitting diode.

LCA: Light-curing acrylic adhesive.

Oxygen Inhibition: A phenomena of radical cure polymer chemistries in which oxygen in the atmosphere diffuses into a curing resin and scavenges free radicals needed to cross-link the polymer. This leads to a layer of uncured material that is less than 0.1-mm thick on the surface of any resin exposed to the atmosphere.

PC: Polycarbonate plastic.

PEBA: Polyether block amide. A type of thermoplastic elastomer.

PET: Polyethylene terephthalate plastic.

SEBS: Styrene ethylene butadiene styrene.

Substrate Failure: A term used to describe an adhesive bond failure in which the substrates bonded fail internally prior to the interface between the adhesive and the substrates.

Tensile Elongation: A material property that describes the average amount of deformation that a material can undergo prior to failure.

Tensile Modulus: A material property that describes the rigidity of a material. It is determined by the stress strain curve during tensile testing and is often considered the slope of this curve. Different calculation techniques are required to obtain this number as not all stress strain curves are linear.

TPE: Thermoplastic elastomer. A plastic with elastic properties that can be melted for processing.

TPO: Thermoplastic olefin. A type of thermoplastic elastomer that usually has a very low surface energy.

TPU: Thermoplastic urethane. A type of thermoplastic elastomer.

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