

New Developments in Next-Generation Acrylic Adhesive Technology

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ABSTRACT

Acrylic adhesives offer the advantages of increased cost efficiencies, better aesthetics and improved impact resistance. They are ideal for applications in several manufacturing and fabricating segments including commercial vehicles, wind and energy equipment, and industrial products. Recently, new acrylic technology has been developed that offers superior lap shear strength, high elongation and high bake resistance combined with excellent failure mode across difficult-to-bond metal substrates.

INTRODUCTION

Acrylic structural adhesives are two-component systems (adhesive plus accelerator) that deliver bond strengths that can approach or exceed the strength of the substrate. Significant commercial use of acrylic adhesives began in the 1960s. “First-Generation” systems were brittle and generally utilized for plastic bonding.¹ They typically featured poly(methyl methacrylate) dissolved in methyl methacrylate (“syrup”) and an accelerator “lacquer” used at a high mix ratio.

“Second-Generation” acrylic structural adhesives have delivered effective bonding performance in a variety of commercial applications over the last 30 or more years. These systems were tougher, and offered improved low-temperature performance and improved bonding to bare metals. They featured butadiene rubber tougheners, metal adhesion promoters, and 1:1 and 4:1 mix ratios with formulated accelerators.

“Next-Generation” acrylic adhesives have evolved in recent years to offer increased performance for more demanding applications. Key features of the “Next-Generation” adhesives include advanced terpolymer and core-shell rubber tougheners, blends of polymerizable monomers, and a 10:1 mix ratio. Enhanced performance characteristics include:

- High lap-shear strength – targeting structural bonding applications
- Improved peel strength – better performance for applications with mixed-mode stresses
- Outstanding failure mode across a wider variety of substrates – more robust performance increasing utility for multiple applications
- High impact-resistance – suited for rugged applications where impacts may/will occur
- Improved fatigue resistance – holds up better under cyclic stresses or vibrations
- Excellent low-temperature performance – important for use in challenging climates
- Resistance to e-coat and paint bakes – bonding parts will not shift/separate during bake
- REACH-friendly formulation (Europe) – elimination of toxic components allows for global use

IMPROVED PERFORMANCE

It is instructive to compare a “Next-Generation” acrylic adhesive, such as LORD 852/25GB, to some of the most commercially successful examples of a “Second-Generation” acrylic adhesive. One important difference in physical properties is a significant increase in elongation (100-percent vs. 35-percent) for the “Next-Generation” adhesive while maintaining the same high tensile strength (both at around 18 MPa). This increase in elongation without loss of tensile strength is a key to many of the elements in improved performance for “Next-Generation” acrylic adhesives.

Another element of improved performance for the “Next-Generation” acrylics, one that is most visible to fabricators, is the excellent failure mode and robust performance across various, difficult to bond metal substrates. Figure 1 and Figure 2 show comparisons of the lap shear and T-peel bonding performance for “Second-Generation” acrylic adhesive and LORD 852/25GB. Lap shear strength is primarily a reflection of the tensile strength of the adhesive, whereas good peel performance requires more toughness and elongation. Thus the bonding results show equivalent lap shear strengths, while the more flexible “Next-Generation” adhesive demonstrates a clear improvement in the T-peel strength. A significant improvement in failure mode with the “Next-Generation” adhesive should also be noted.

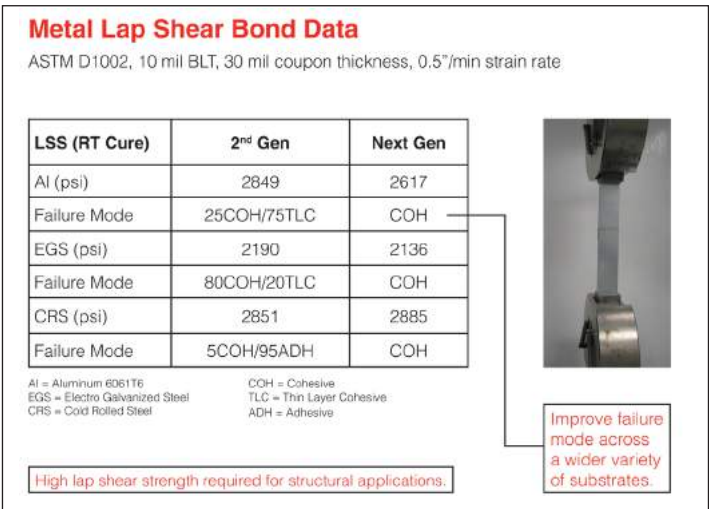


Figure 1: Metal Lap Shear Bond Data

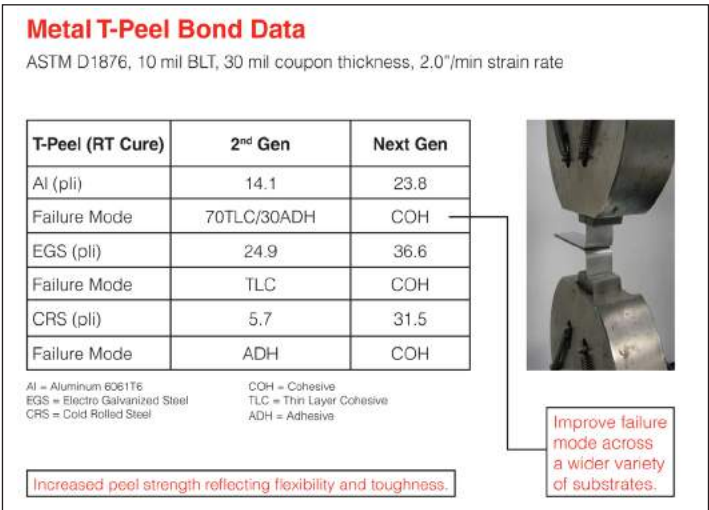


Figure 2: Metal T-Peel Bond Data

GOOD FAILURE MODE

Of course, physical properties of an adhesive are incidental if there is inadequate adhesion to the substrate. For fabricators, confidence in adhesion is greatly enhanced by seeing good cohesive failure when bonded parts are separated, especially if there is an even distribution of adhesive between the two surfaces. Being able to achieve this good adhesion on multiple substrates with a single adhesive is also of great value, reducing complexity in assembly and reducing the risk of mistakes if forced to use multiple adhesives.

Figure 3 shows a comparison of the failure mode between different metal substrates bonded with “Second-Generation” acrylic adhesive and LORD 852/25GB, with the samples pulled in T-peel. The consistent, uniform failure mode of the Next-Generation adhesive, when added to the impressive bond strength data, creates greater confidence in the robust performance of this adhesive.

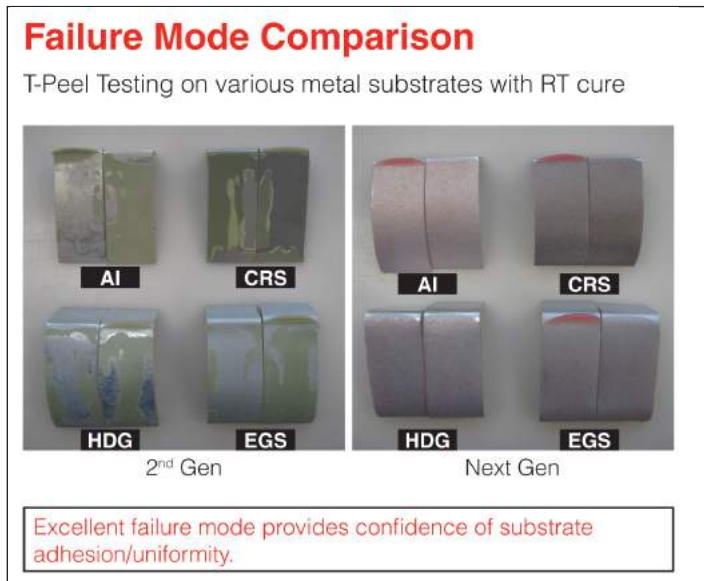


Figure 3: Failure Mode Comparison

BONDING ADVANTAGES

Acrylic adhesives offer distinct advantages over metal joining techniques such as riveting or welding, most particularly in durability, fatigue resistance, distribution of stress, aesthetics, corrosion resistance, and process simplicity/cost. As a replacement for riveting/welding, acrylic adhesives are used successfully in bonding applications in the automotive, truck/trailer and enclosure industries. Acrylic adhesives are also ideal for joining applications where mechanical fastening may not be feasible or practical, such plastic and composite bonding for recreational/marine vehicles, signs and facades. Figure 4 and Figure 5 depict common examples of bonding applications for acrylic adhesives.

Bonding Applications for Acrylic Adhesives

Replacement for welding and riveting

- Automotive
- Truck/Trailer
- Enclosures



Figure 4: Next-Generation acrylic adhesives are an ideal replacement for welding and riveting joining methods in automotive, truck/trailer and enclosure applications.

Bonding Applications for Acrylic Adhesives

Joining where mechanical fastening may not be possible or practical

- Rec/Marine
- Signs
- Facades



Figure 5: Next-Generation acrylic adhesives are useful in joining applications, such as recreational/marine, signs and facades, where mechanical fastening may not be possible or practical.

APPLICATION: UTILITY TRUCK BED ASSEMBLY

In this application, for the commercial vehicle market, the manufacturer specifically redesigned the truck bed to accommodate adhesives as an assembly mechanism, gaining advantages in processing time, aesthetics and cost. A more flexible acrylic adhesive provided the impact resistance needed for the demanding performance requirements of the dump-bed design. (See Figure 6.)

Welding is used to assemble the current dump-bed design. However, welding is an expensive and time-consuming process, especially with non-ferrous or coated metals, whereas adhesives can provide a much easier assembly method, requiring significantly less training and simpler equipment to perform. Furthermore, adhesives are more aesthetically pleasing since they eliminate the unsightly weld deformations in the truck bed. Adhesives allow the flat panels to maintain a pristine, smooth cosmetic appearance with no weld marks.

The truck manufacturer wanted the option of using one of three metal substrates - aluminum, galvanized steel, or Aluzinc®, an aluminum-zinc-alloy-coated steel, for fabrication of the dump beds. Aluminum was chosen as a panel for its lightweight and corrosion resistant properties, but aluminum is also more difficult to weld. Galvanized steel can be more difficult to bond than aluminum, and many acrylic adhesives do not adhere or cure well on this coated metal. Aluzinc® is even more challenging to bond, as the coating tends to cause variable bond performance even with the best of adhesives.

Furthermore, the manufacturer was looking for one adhesive that could be used for bonding all three metal substrates, avoiding the complication of managing multiple adhesives in their assembly process. It was important that the adhesive did not release or delaminate even under extreme use conditions, including indentation and deformation of the dump-bed. Any adhesive used also had to be able to handle a high-temperature paint-bake process, which would be performed after assembly.

The LORD 852/25GB “Next-Generation” acrylic was able to deliver excellent bond performance, with cohesive failure mode, on all three metal substrates for the dump-bed application. The room-temperature-cured adhesive also demonstrated the ability to withstand the paint bake temperatures of 180 to 200 degrees C, without degrading the bond performance of the assembly.

Several tests were performed to prove the efficacy of the acrylic adhesive for the truck assembly process:

- **Impact Resistance Testing** – This test demonstrated that sharp impacts hard enough to cause deformation of the substrate did not cause brittle delamination of the adhesive, and that the subsequent failure mode in tear-down was 100-percent cohesive. This result helped to build confidence that the frame could withstand the impact from heavy objects thrown into the truck without having the frame separate from the bed. (See Figure 7.)

Application: Utility Truck Bed Assembly

- Aluminum, Galvanized, and Aluzinc metal bonding
- Replace welding with adhesives – new design
- **Key Performance Needs:**
 - Excellent impact resistance, bake resistance and good failure mode.



Figure 6: The new design for this utility truck bed required a change in the assembly method from welding to adhesives.

Impact Resistance

- 2 mm thick aluminum substrate with 1 kg·m Gardner impacts



Impact from objects that dent dump bed must not delaminate the adhesive.

Figure 7: Impact Resistance Test

Bake Resistance – Metal Lap Shear Testing

ASTM D1002, 10 mil BLT, 30 mil coupon thickness, 0.5"/min strain rate

LSS (Next Gen)	Room Temp	180°C/40min Bake
Al (psi)	2617	2667
Failure Mode	COH	95COH/5TLC
EGS (psi)	2136	2033
Failure Mode	COH	COH
CRS (psi)	2885	3004
Failure Mode	COH	COH

Al = Aluminum 6061T6
EGS = Electro Galvanized Steel
CRS = Cold Rolled Steel

COH = Cohesive
TLC = Thin Layer Cohesive

Demonstrating excellent bake resistance, previously a challenge for 10:1 acrylic systems, was an important achievement.



Bond strength and failure mode maintained across variety of substrates.

Figure 8: Bake Resistance – Metal Lap Shear Testing

Environmental Resistance – Metal Lap Shear Testing

ASTM D1002, 10 mil BLT, 30 mil coupon thickness, 0.5"/min strain rate

LSS (Next Gen)	Aluminum	EGS	CRS
RT (psi)	2880	2115	2975
Failure Mode	COH	COH	COH
180°F (82°C)	1089	1090	1320
Failure Mode	COH	COH	COH
-30°F (-34°C)	3380	2627	4236
Failure Mode	TLC	TLC	TLC
14 Days 95°F/95%RH	2752	2016	2826
Failure Mode	COH	COH	COH

Al = Aluminum 6061T6
EGS = Electro Galvanized Steel
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Adhesive bond performance must often remain robust under challenging environments.

Figure 9: Environmental Resistance – Metal Lap Shear Testing

- **Bake Resistance Testing** – This test demonstrated that the lap shear strength and the failure mode were not altered during the baking process (180 degrees C/40 minute paint bake). This was a significant achievement, since bake resistance had previously been a significant challenge for 10:1 acrylic adhesive systems. (See Figure 8.)
- **Environmental Resistance** – This test demonstrated that the adhesive bond performance remained robust under challenging environmental conditions. Since vehicles must operate in all types of weather conditions – from warm and humid to freezing temperatures – the adhesive performance must be designed to match. The LORD 852/25GB adhesive was able to retain excellent bond strength on various metal substrates when exposed to environmental extremes. (See Figure 9.)

APPLICATION: WIND TOWER ASSEMBLY

For this application, the LORD 852/25GB “Next-Generation” acrylic adhesive was qualified for use in building wind towers. Due to its excellent failure mode on tough-to-bond substrates, the adhesive proved to be ideal even for the hybrid bonding – aluminum to hot-dipped galvanized metal – needed to manufacture wind tower shrouds. Figure 10 depicts the wind tower assembly application.

Application: Wind Tower Assembly

- Galvanized steel and aluminum bonding
- Large parts with variable bondline thickness
- Key Performance Needs:
 - Good failure mode and fatigue resistance



Figure 10: The wind tower assembly design required an adhesive that could provide good failure mode and fatigue resistance.

The application involved very large parts, bringing the additional challenge of variable bond-line thickness across the length of the assembly. Another key adhesive attribute required by this manufacturer was high fatigue and environmental resistance, allowing the wind tower shrouds to operate long-term under extreme conditions of vibration, heat and cold, and environmental exposure.

High elongation and high strength were other important properties that the adhesive had to exhibit. For the hybrid bonding, the adhesive had to handle a high coefficient-of-thermal- expansion (CTE) mismatch between the different metals. Steel and aluminum expand at different rates as temperatures change, and this “mismatched” expansion can put extreme stress on bonded parts. An adhesive must be both strong and flexible enough to tolerate the stresses that are created by a CTE mismatch.

Compared to “Second-Generation” acrylic adhesives, the “Next-Generation” acrylic adhesive offered higher fatigue resistance, allowing it to withstand the expected conditions during the wind tower's operation. The acrylic's high elongation, high strength and excellent adhesion across different metal substrates made it an ideal choice for this challenging application.

Several tests were performed to prove the efficacy of the LORD 852/25GB “Next-Generation” acrylic adhesive:

- Failure Mode Robustness Test – This test proved that the acrylic adhesive offered robust performance across a variety of substrates. It showed that the “Next-Generation” adhesive offer improved functioning compared to “Second-Generation” adhesives in bonding difficult-to-bond substrates. (See Figure 11.)
- Fatigue Resistance Test – In this test, the “Next-Generation” adhesive demonstrated improved fatigue resistance compared to previous generation technology. (See Figure 12.)

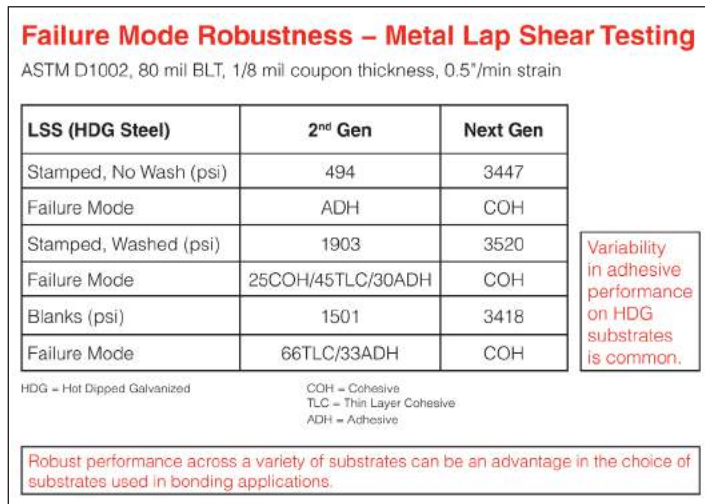


Figure 11: Failure Mode Robustness – Metal Lap Shear Testing

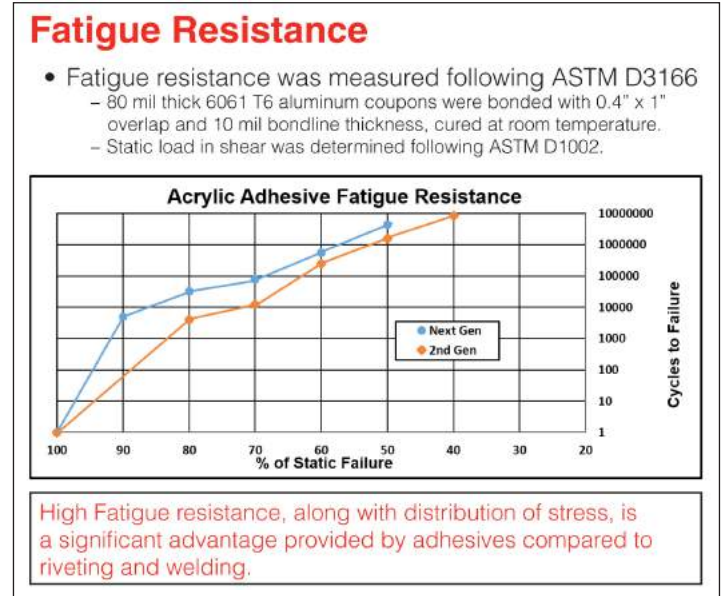


Figure 12: Fatigue Resistance vs. Bond Line Thickness

APPLICATION: ELEVATOR ASSEMBLY

In another application example, a manufacturer of industrial elevators was looking for an adhesive that offered not only excellent bonding performance, but could also support global manufacturing efforts. (See Figure 13.)

The elevator assembly parts were comprised of galvanized steel and 304 stainless steel. For this application, the customer required an adhesive that could provide excellent adhesion to these difficult-to-bond substrates without surface modification, including cohesive failure at high temperature. The “Next-Generation” acrylic was able to provide this superior performance.

Excellent high-temperature adhesive performance was important to the manufacture due to a concern that bonded parts might slide or separate as they were racked and conveyed through the paint-bake step of the automated production process. For this application, it was demonstrated that the LORD 852/25GB “Next-Generation” acrylic adhesive could deliver on the requirement of greater than 80 percent cohesive failure on the unprepared 304 stainless steel even when pulled in lap shear at 170 degrees C, providing the high-temperature strength required. (See Figure 14.)

Application: Elevator Assembly

- Galvanized steel and 304 stainless steel bonding
- Require good shelf life to support global manufacturing
- Key Performance Needs:
 - Bake resistance and good failure mode at 170°C



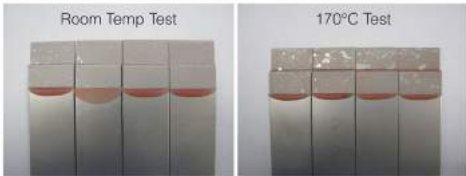
Figure 13: An adhesive that supports global manufacturing was a key requirement for the elevator assembly manufacturer.

Hot Strength – Lap Shear Testing on 304 Stainless Steel

ASTM D1002, 10 mil BLT, 30 mil coupon thickness, 0.5"/min strain rate

Test Temp	RT	170°C
LSS (psi)	2610	293
Failure Mode	95COH/5ADH	87COH/13ADH

COH = Cohesive
ADH = Adhesive



Customers want assurance that an adhesive will not fail during racking and movement through paint/e-coat bake processes.

Figure 14: Hot Strength - Lap Shear Testing on 304 Stainless Steel

Furthermore, this manufacturer needed an adhesive that provided good shelf life and met compliance regulations to support global manufacturing. The competitive adhesive had a shelf life that was so limited it caused shipping and storage problems for use in any location outside of its origin. To minimize production complexity, the manufacturer desired use of a single adhesive globally.

The LORD 852/25GB “Next-Generation” acrylic adhesive had the shipping and storage stability, and met the compliance regulations, needed to support the customer’s worldwide manufacturing efforts. It was developed to meet the increasingly strict requirements of global environmental regulations, eliminating components that would conflict with REACH requirements, for example. The adhesive could be shipped to various locations throughout the world and still be usable once stocked in local manufacturing facilities.

Acrylic adhesives can offer distinct advantages over other fastening methods, such as riveting and welding, including improved cosmetic appearance and distribution of stress for increased impact and fatigue resistance. “Second-Generation” acrylics have delivered effective bonding performance in a variety of commercial applications over the last 30 years. “Next-Generation” adhesives have evolved to offer improved performance for more demanding applications. Improved elongation, impact resistance and fatigue resistance, plus excellent high- and low- temperature performance and more robust bonding to a wider variety of substrates makes “Next-Generation” acrylics an even more attractive assembly choice for all fabricators.

REFERENCES

¹ “Handbook of Adhesive Technology,” 2nd Ed., 2003, Chapter 38

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