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OEM Body Shop ADHESIVE & SEALANT Selection Guide

Applications, Products, Joint Design Considerations, Testing & Specifications

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The Adhesive & Sealant Council

About the Guide

SCOPE AND PURPOSE

This guide educates the reader about typical applications of adhesives and sealants in automotive and heavy truck OEM body shops. This is the point in the manufacturing process where a series of stamped or molded panels are brought together to form the automobile body or truck cab, which is referred to in the industry as a body-in-white (BIW). It does not include adhesives and sealants that are used in downstream operations, such as OEM paint, assembly, and repair. The guide discusses the type and function of adhesives and sealants in several applications in bodies and cabs of light vehicles and heavy trucks. This guide also discusses common test methods and considerations for the selection of adhesives and sealants.

Published: October 2017

Cover photos source: Dow Automotive, BMW, Volkswagen

DISCLAIMER

The guide is intended to be an informative resource for a wide variety of adhesive bonding applications in automotive and heavy truck OEM body shops. It is not intended to be a guideline for best practices or a manual for design, engineering, or manufacturing. The content reflects contributions from the member companies of the **Adhesive and Sealant Council** that are public at the time of publication, and does not discuss applications of adhesives and sealants that are under development. For more detailed information, contact your adhesive or sealant supplier, or identify a supplier by using the ASC Vendor Select Tool.

The ASC Vendor Select Tool is a quick and efficient way for a user to find an adhesive or sealant chemistry that is used in a market segment for finished goods. The tool is located on **www.adhesives.org**, and can also be used to find typical raw material types or equipment. The Vendor Select Tool direct link to manufacturer's websites can be viewed using this link or by selecting on the desired sub-segment of passenger cars and trucks or trucks and buses

Additional resources for individuals seeking information on adhesives and sealant in automotive and heavy trucks:

- **Cars, Trucks, and Buses Industry Page on Adhesives.org**

ASC Whitepapers & Presentations:

- **Adhesives & Sealants as an Enabling Technology for Lightweight, Safe, and High Performing Steel Vehicles**
- **Adhesives & Joining Methods in Land Transportation**
- **Adhesive Opportunities & Outlook in Light Vehicles**
- **Adhesive Opportunities & Outlook in Heavy Duty Trucks & Buses**

ASC Growth Task Force

ASC would like to thank the following ASC member companies that have contributed time, figures, information, charts, pictures, and content for this guide.

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Contents

Introduction

Adhesives and sealants make significant contributions to the performance and durability of light vehicles and heavy trucks, and have been an integral part of the original equipment manufacturing (OEM) process for many years. Recent increases in consumer and regulatory demands for improvements to vehicle comfort, performance, safety, and fuel economy have resulted in an increase of the use of adhesives and sealants in cars and trucks.

The OEM body shop is the point in the manufacturing process where a series of stamped or molded panels are brought together to form the automobile body or truck cab, which is referred to in the industry as a body-in-white (BIW). Selection and of adhesives and sealants for use at automobile and truck original equipment manufacturers focuses on three primary factors, which are the:

1) Substrates to be joined
2) Service requirements of the joint
3) Process conditions and constraints for application and curing

Substrate materials and service conditions vary for each application of adhesive and sealant in a car or truck. Therefore, this guide is organized into sections that provide information on the primary applications of adhesives and sealants in OEM body shops. These applications are structural bonding, hem flange bonding, anti-flutter, expandable reinforcement, and body sealing. This guide discusses general practices of the industry, and it is important to note that testing an adhesive or sealant to determine appropriateness for an application is always recommended during the selection process.

The guide includes summaries of the adhesive and sealant chemistries used in OEM body shops, including a comparison of the relative properties and a discussion of the curing mechanisms. The cross-reference table on page 8 matches adhesive and sealant families to their common areas of use and allows the user to quickly navigate to sections of the guide of greatest interest.

Adhesives and Sealants Typically Used in Auto & Truck OEM Body Shop Applications

		Structural Bonding			Hem Flange	Anti-flutter	Expandable sealing & reinforcement	Body Sealing
ASC Designation	Chemistry	Steel - Steel	Mixed Metal	Composite				
Reactive Adhesives	Acrylic			●	●			
	Epoxy	●	●	●	●		●	
	Polyurethane (2c)		●	●	●			
Reactive Sealants	Polyurethane (1c)		●	●				
	Rubber based (SBR, butyl)					●	●	●
	EVA						●	

Although many of the service demands differ by application, there are some common service conditions and process constraints that apply to every application of adhesives and sealants in the OEM body shop. These include the need to demonstrate performance over a long period of time and a wide range of environmental conditions, as well as the ability to bond to and cure within the e-coat curing cycle of approximately 30 minutes at 180°C / 360°F without degrading. OEMs often test heat resistance of adhesives and sealants from a range of 140°C to 205°C (285°F to 400°F) to protect for process variation.

Passenger cars are tested for a lifetime of 10-12 years under severe operating conditions, but can last much longer in normal operating environments. As such, the adhesives and sealants used to build them must demonstrate the ability to perform well in the many conditions to which a vehicle might be exposed over that time. These conditions include years of exposure to extreme temperature, humidity, and road salt. Performance of adhesives and sealants must be acceptable and consistent over wide range of operating temperatures. The industry normally conducts tests at -40°C, 23°C, and 80°C (-40°F, 72°F,180°F) to evaluate suitability for body applications.

Aside from extreme conditions in the field, adhesives and sealants applied in the OEM body shop must tolerate the subsequent pretreatment and paint operations. This includes surface preparation, application, and curing of "e-coat," which is an electrophoretically applied paint. E-coat surface preparation can include degreasing, rinsing, and application of pretreatments, which, as with the the e-coat itself, are usually applied by fully immersing the BIW in a liquid bath. The e-coat is then cured in an oven for approximately 30 minutes at 180°C/ 360°F. E-coat is followed by a multi-step paint process, which includes multiple curing cycles at temperatures slightly below those of the e-coat oven.

Adhesive washout not only limits effectiveness of the adhesive, but can cause surface imperfections in the paint, which are difficult and time consuming to correct. As a result, washout resistance is critical for adhesives and sealants applied in the OEM body shop. The BIW may be rotated as it is submerged in the coating baths in order to avoid entrapment of air and assure coating of the inner surfaces of rails and pillars. Because of this, the uncured adhesives and sealants are normally high viscosity liquids or solids that are designed to stay in place as liquids wash over them in various orientations.

Figure 1: Car entering an automotive pre-treatment bath prior to ecoat. Car bodies are fully immersed in several wash, treatment, and rinsing baths before the adhesives and sealants applied in the body shop are cured in the e-coat oven. Source: Henkel

Once the e-coat is applied, it is cured in a high temperature oven before moving on to subsequent paint operations, which can include multiple heat curing steps. Although e-coat is cured at the highest baking temperature of any step, any adhesives and sealants applied prior to e-coat operations must not degrade, soften, or flow out of position during at any point of the process. As a result, all adhesives and sealants applied in the weld shop are thermosets.

Adhesives used for structural bonding of the BIW must be strong, durable, and temperature resistant. They must be easy to dispense and adhere to oily metals, since the body panels have mill oils and stamping fluids on them, which will not be cleaned until the paint pretreatment process. Single component adhesives are often used in these applications because they are easier and less complicated to handle and dispense when compared to two component adhesives. Single component adhesives do not require the metering and mixing systems required of two component systems to ensure they will work properly. Epoxy adhesives are typically selected for structural bonding of the BIW because of their ability to meet automotive service requirements, process efficiency in the OEM body shop, and not degrade upon exposure to e-coat curing for 30 minutes.

In some instances, it is desired or necessary to use adhesives that cure before or without the heat of the e-coat oven. In these cases, two component or moisture curing adhesives are used.

Two component adhesives are sometimes used sub-assemblies manufactured at a supplier and shipped to the OEM body shop because they build strength quickly. The green strength of the adhesive prevents the parts from shifting during shipping to the OEM facility which improves the dimensional stability of the component and helps suppliers and OEMs meet demanding manufacturing tolerances.

Some multi-material assembly operations, such as attachment of a composite roof to a metal-bodied vehicle, may occur after the paint process. Therefore, an adhesive that cures at ambient temperature would be selected for this application.

Light vehicle OEMs select two component adhesives for many of the same reasons as heavy truck OEMs. Additional detail can be found on page 27 of this guide.

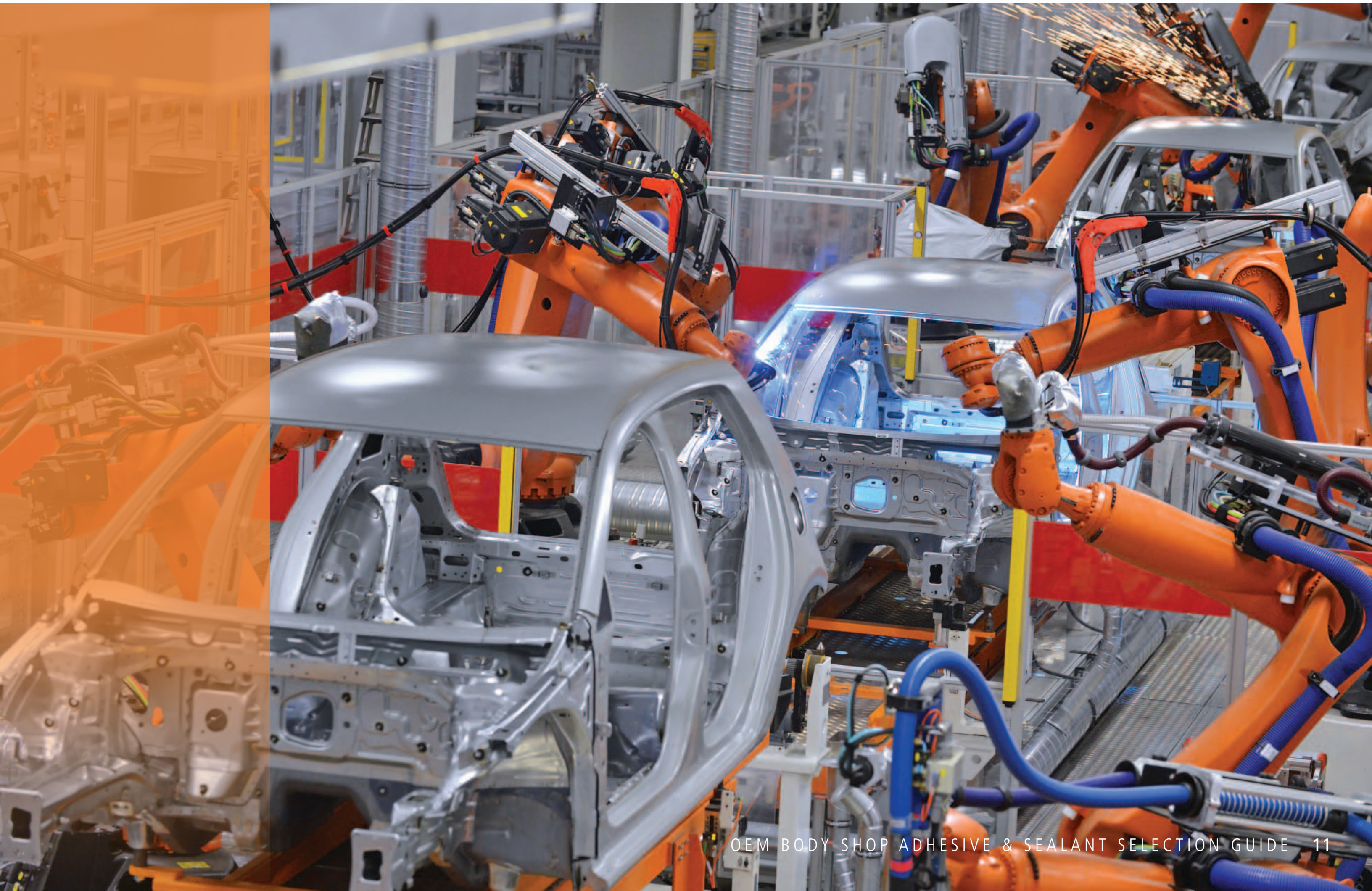
Structural Bonding of Light Vehicle and Heavy Truck Bodies and Cabs

LIGHT VEHICLE ARCHITECTURE

Construction of most passenger cars is fundamentally different than that of pickups and heavy-duty trucks. Passenger cars are usually constructed as unibodies, whereas large SUVs, pickups, and medium and heavy-duty trucks employ a body-on-frame architecture. These significant differences in vehicle architectures impact the materials of choice, including the use of adhesives and sealants.

Unibody architecture is the most common architecture for passenger cars. In this type of construction, the body that forms the passenger compartment is the primary structure

Figure 2: Assembly of light vehicle unibody in an OEM body shop. The body structure is known in the industry as a white body.



that provides load bearing and stiffness which influences how the car performs. The ability of the body to resist bending and twisting determine how well the car handles. Crash safety is determined by the ability of the body to absorb impact forces without allowing intrusion into the passenger compartment.

In a unibody vehicle, performance and safety are largely dictated by the materials used in construction and how they are shaped and joined to form the body. Frequently, these are steel parts that are between 1-2mm thick. A typical passenger car unibody, or BIW, is shown in Figure 2.

Steel has been the material of choice for light vehicle bodies for many years, primarily due to its low material cost and established manufacturing infrastructure at OEMs. This includes stamping and welding operations that can produce steel parts in well under a minute. However, as OEMs respond to rising fuel economy and emission standards in the US and globally, the use of lightweight materials such as aluminum and composites has been increasing. These new materials are often used in conjunction with steel, creating joining challenges for OEMs. Adhesives and sealants offer solutions to the challenges of mixed material joining, which are discussed later in this guide.

STRUCTURAL BONDING OF THE LIGHT VEHICLE UNIBODY

Function: *Localized strengthening, stiffening, crash energy management*
Commonly used adhesives: *Single component epoxy, toughened epoxy*

Structural adhesives have been used in automotive bodies for quite some time. In the past decade, however, the use of structural adhesives has grown because structural bonding of unibodies is playing an important role in improving the strength, stiffness, safety, and durability of the body, while providing opportunities to reduce weight at the same time.

Metals, primarily steel, have historically been the most commonly used material in light vehicle bodies, and spot welding has been the preferred joining method because it is fast and relatively inexpensive to conduct on a large scale. Structural adhesives are often used in conjunction with spot welds to increase vehicle stiffness and increase the fatigue life of spot welds.

As the name implies, spot welds are a series of bonds made at short intervals along a joint. The distance between the welds is known as the weld pitch. Since each weld adds process time to execute, and increases tooling and maintenance cost, it is desirable to maximize the weld pitch and minimize the number of spot welds per car. However, increasing the weld pitch can decrease stiffness and

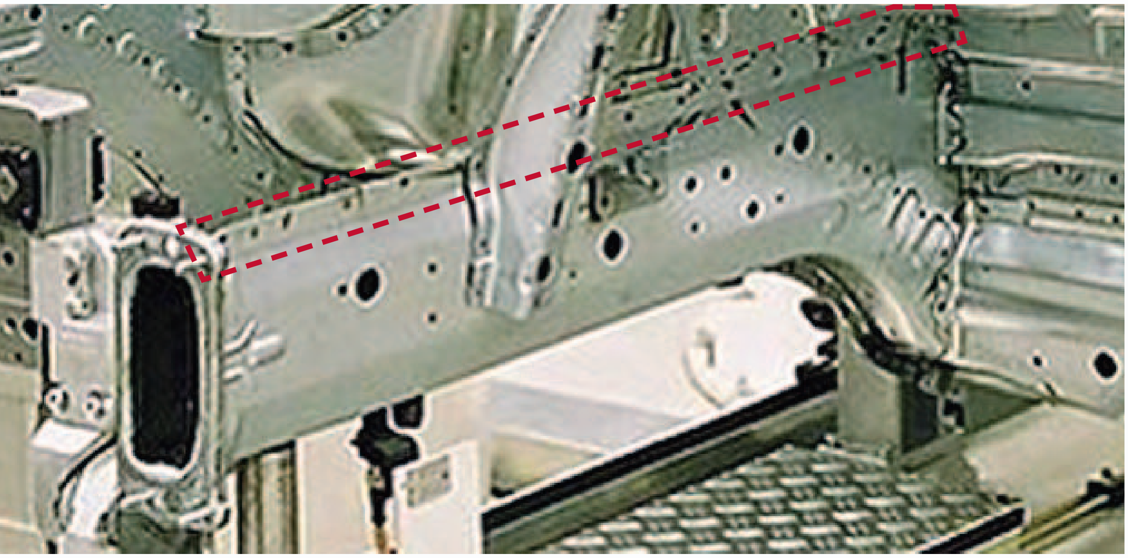


Figure 3: Light vehicle frame rail consisting of two halves that are spot welded together to form a hollow rail. Spot welds are made every few inches along the weld flange, shown in the dotted red box. Structural adhesives can be placed along the weld flange prior to joining the halves to create a continuous bond line.

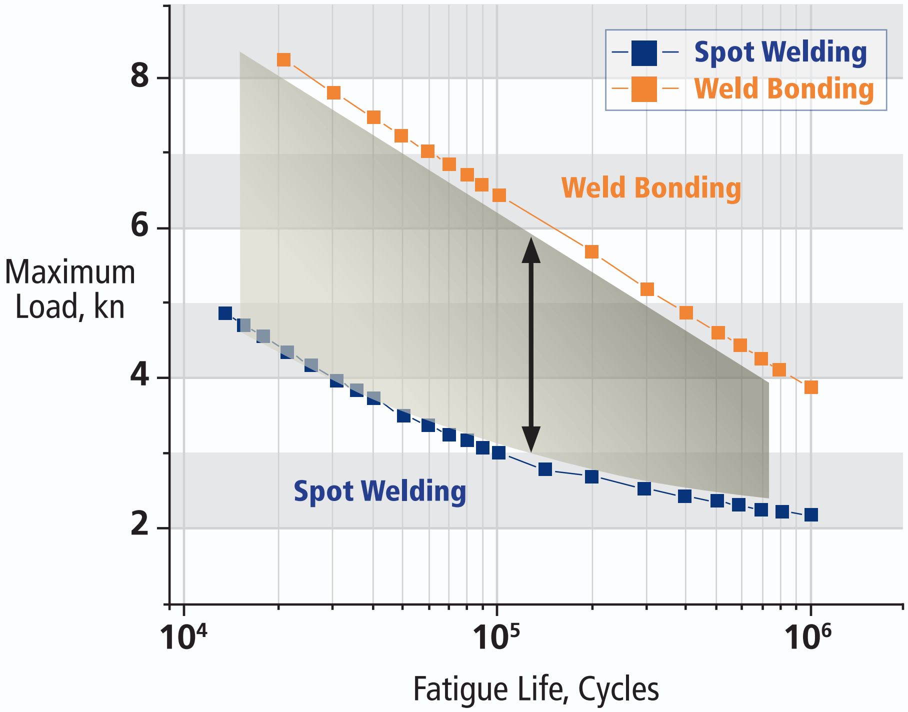
negatively affect the vehicle handling and performance. Decreasing the number of spot welds also increases the stress on each weld, reducing its fatigue life.

The addition of a bead of structural adhesive to a weld flange prior to part assembly creates a continuous bond along the length of the rail. Welds are made through the adhesive, which burns out of that area, but remains elsewhere, resulting in a continuous seam that is much stiffer and stronger than spot welds alone. In addition, the structural adhesive reduces stress at each spot weld, improving the fatigue life of the assembly.

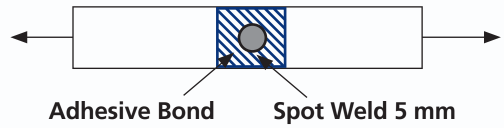
Because designs are limited by stiffness and fatigue strength in many cases, the use of structural adhesives in weld-bonding applications can allow automakers to use thinner gauges of steel, thereby reducing weight. Figure 4 (next page) shows data indicating weld bonding increases the fatigue life of a lap shear sample by a factor of about 30 for a given load.

Due to these benefits, the use of structural adhesives in weld-bonding applications is increasing rapidly, particularly in luxury and performance vehicles, where it is important to have a light and stiff body to maximize handling and performance.

Luxury vehicles such as the BMW 7 series, Mercedes S Class, and Cadillac CT6 contain over 300 linear feet of weld bonding in



- **Spot Welding:** Standard joining technique
- **Weld Bonding:** Adhesive bonding with welding secondary attachment



- Increased load-carrying capability allows down gauged substrate for weight reduction

Figure 4: Fatigue life curves for lap shear samples that have been spot welded (blue) and weld bonded (orange). The adhesive increases the bonded area, which reduces the stress on the joint and increases the fatigue life. The vertical distance between the lines demonstrates that the weld bonded sample will produce the same fatigue life at twice the loading of a spot welded sample. For a given load, the fatigue life of the weld bonded joint is nearly 30 of the sample that was welded only. Source: Dow Automotive.

each body, as the adhesives help OEMs achieve performance benefits that differentiate these vehicles from the competition. The amount of structural adhesives use in the average North American vehicle remains well below that level, as shown in Figure 5, and described in the ASC whitepaper "Adhesive Opportunities & Outlook in Light Vehicles". Figure 6 shows the location of structural adhesive in an OEM BIW.

The increase in structural adhesive use in OEM body shops is due to the multi-faceted benefits they provide, which include improving vehicle performance, safety, comfort, and aesthetics. The use of a continuous bead of adhesive along with, or in place of, spot welds or mechanical fasteners can increase the rigidity, strength, and fatigue life of structures. The additional strength and stiffness the adhesive imparts to the body allows it to be constructed with thinner sheets of metal, reducing weight, while at the same time while often improving handling and performance.

Continuous adhesive bond seams that strengthen and stiffen the body also improve levels of noise, vibration, and harshness,

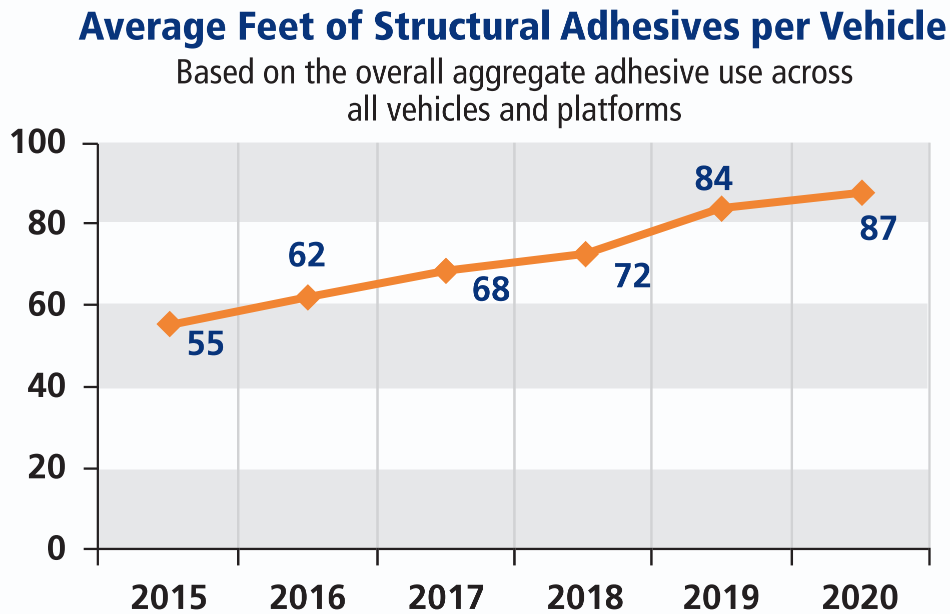
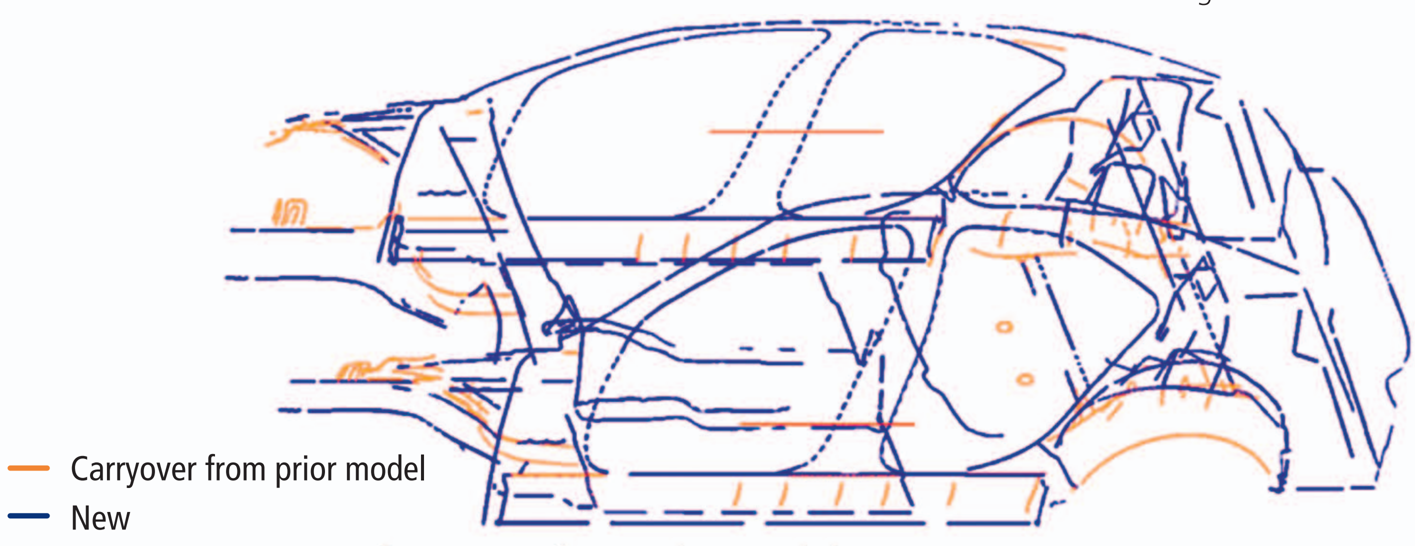


Figure 5: Average consumption of structural adhesive in North American vehicles, measured in linear feet per vehicle, over time. Source: ASC 'Grow the Vertical' Report (Ground Transportation).

or NVH, which improve consumer appeal. By filling gaps and sealing off pathways that would allow sound to enter the passenger compartment, adhesives and sealants in the BIW help reduce sound levels in the cabin at the same time they provide the structural benefits discussed earlier, representing an added value to the vehicle manufacturer. OEM body shop adhesives and sealants work as part of the overall NVH package, which generally includes expanding sealants, foams, baffles, and other materials added during or after the paint process.

Figure 6: Location of weld bonding using epoxy structural adhesive in newly developed steel unibody vs previous generation. Locations in orange were carried over from the prior model, while the blue lines show adhesive added to the new model, which uses 88 linear meters (289 linear feet) of structural adhesives. Source: Steel Market Development Institute Great Designs in Steel.



TYPES OF ADHESIVES IN THE LIGHT VEHICLE UNIBODY

Single component epoxy adhesives are most commonly found in OEM body shops due to their combination of strength, ease of use, and ability to withstand the e-coat oven temperatures. Although polyurethane and acrylic based adhesives offer the strength and toughness required for body shop applications, epoxy based formulations are routinely selected because of their ability to survive the e-coat curing process without degrading.

Standard epoxies, although strong, are brittle, and do not perform adequately for crash sensitive applications. Manufacturers have responded with "crash toughened" adhesives, which are often epoxies modified with softer compounds that increase the energy required to break the adhesive. This can be achieved by the addition of rubber toughening agents, or by grafting polyurethane or acrylics onto the epoxy backbone.

Crash toughened adhesives applied on the weld flange of a frame rail can prevent the seam from splitting, thereby absorbing more energy and improving safety.

Figure 7 below shows a test "crush column" used to evaluate adhesives in crash applications. The column on the right includes structural adhesives, which can be observed as the green bead at the edge of the column, and has remained intact. The column on the left, which is spot welded only, has separated. The structural adhesive enables the column to absorb more energy in the same amount of stroke, thereby providing options for OEMs to improve safety or reduce weight. In addition to column crush tests, tests such as the ISO 11343 impact wedge peel are used to evaluate crash toughness of structural adhesives.

Figure 7: Test "crush columns" that simulate crash performance of automotive frame rails. The column on the left is spot welded only, while the column on the right uses a bead of structural adhesive in conjunction with spot welding. The use of structural adhesive prevents the seam from splitting, and can absorb more energy in the same amount of displacement. Source: Dow Automotive

JOINING DISSIMILAR MATERIALS

As OEMs strive to reduce vehicle weight to help reach fuel economy targets and emission reduction targets, structural adhesives are being used to bond multi-material assemblies that cannot be easily joined using conventional methods. Companies such as General Motors, BMW, and others are using lightweight materials, such as aluminum and composites, in conjunction with steel to optimize vehicle weight, performance, and cost. Mixed material designs create joining challenges, as the substrates are often not compatible with conventional joining techniques, and material properties need to be considered to avoid galvanic corrosion and compensate for differences in thermal expansion. Adhesives are used as part of the solution to these issues in OEM body shops.

GALVANIC CORROSION

Galvanic corrosion is a significant concern with mixed material assemblies that can be addressed with adhesives. Galvanic corrosion occurs when materials of different electrochemical potential are in contact in the presence of an electrolyte. The more electrically active material becomes the anode, and electrons flow from it toward the cathode. The result is accelerated deterioration of the anodic material. Galvanic corrosion can be prevented by electrically isolating the materials from each other, and adhesives often serve the dual purpose of electrically separating materials while creating a strong bond between them.

An excellent example of the multi-functional benefits of adhesives in mixed material assembly is rivet bonding of a cast aluminum "shock tower" onto a steel unibody. The shock tower is the mounting point for the strut assembly onto the BIW, shown in Figures 8 & 9, and it is joined to the front frame near the firewall with rivets and adhesives.

As the car travels down the road, forces from the bumps and potholes, although damped by the shock absorber, are transmitted to the shock tower. Therefore,

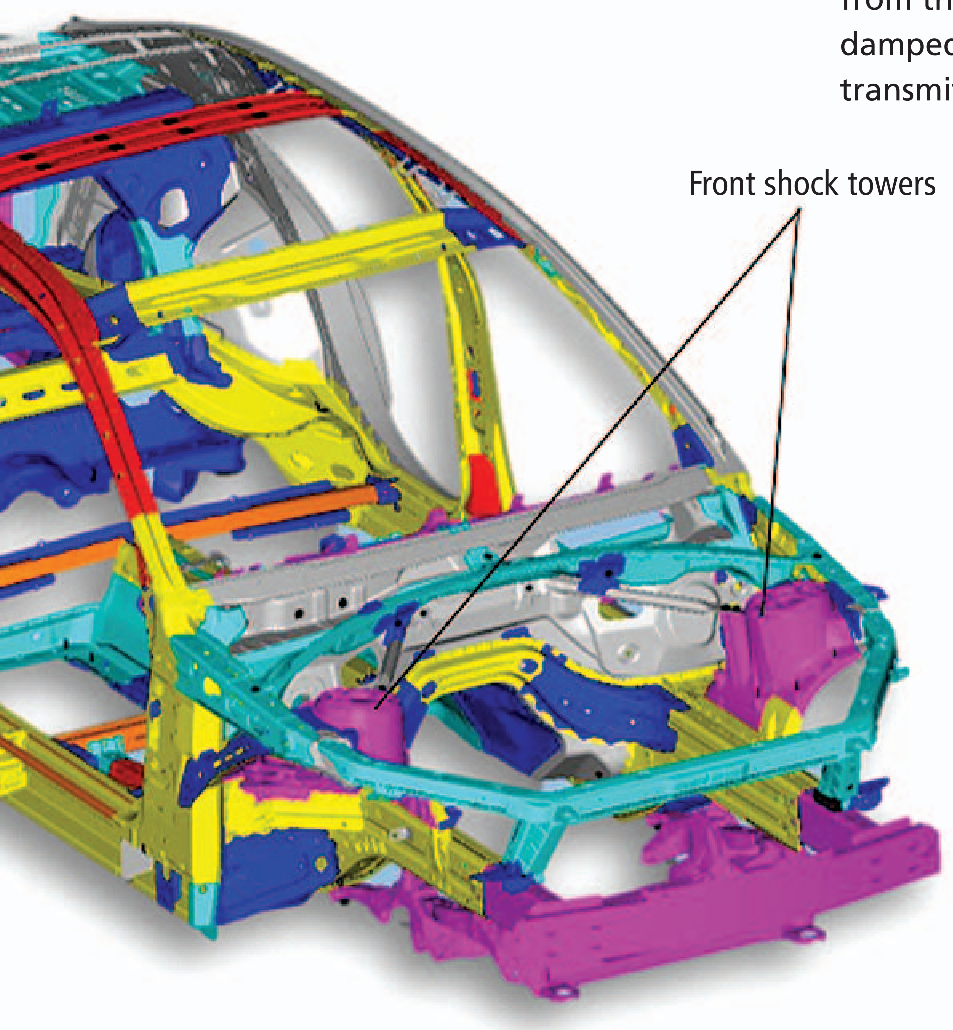


Figure 8: Location of front shock towers. Image shows aluminum parts in fuchsia attached to a unibody constructed of various grades of steel, which are shown in red yellow, and blue. Source: Steel Market Development Institute Great Designs in Steel.

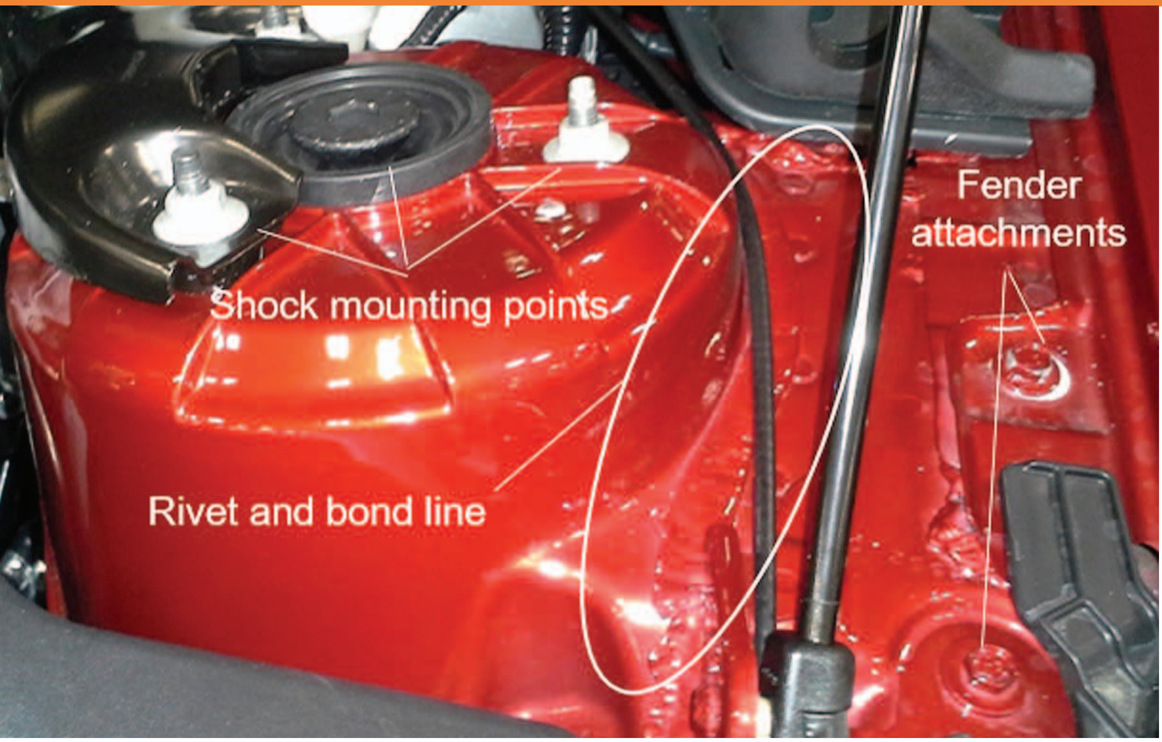


Figure 9: Cast aluminum shock tower rivet bonded to steel body in a vehicle. The location of rivets and the bond seam can be seen in the white oval in the photograph. Bolts attaching the strut, which is the top of the shock assembly, can be seen, as can the bolts attaching the fender to the body. Source: Industrial Market Insight

strength and fatigue durability of this assembly are of paramount importance. Traditionally, the shock tower was a stamped steel assembly that was weld-bonded to the frame. As discussed earlier in this guide, the use of structural adhesive in conjunction with spot welds extends the fatigue life of the assembly by distributing the load over a greater area.

Replacing the steel assembly with a cast aluminum part reduces weight, but presents some joining challenges. Aluminum castings are too thick to be easily spot welded, and the material must be separated from the steel frame to prevent galvanic corrosion. Structural adhesives help to solve both issues. A continuous bead of structural adhesive is used to electrically isolate the aluminum from the steel, preventing galvanic corrosion. Rivets are used in place of spot welds to mechanically fasten the casting and hold it in place until the adhesive is cured. Rivets used in multi-material bonding are engineered specifically for each application, and coatings are often used to reduce the potential for galvanic corrosion. The combination of rivets and adhesives result in a strong, durable, and corrosion resistant bond between steel and aluminum that can be produced within a short cycle time.

The use of structural adhesives in mixed material assemblies is not limited to rivet-bonding of aluminum castings. Vehicles such as the Cadillac CT6 use a variety of processes, including weld and rivet-bonding, to join steel and aluminum sheet. In these applications, the adhesive provides the same benefits observed in weld bonding of steel sheet or rivet bonding of aluminum, which is to stiffen an strengthen the assembly. In addition, the adhesive electrically isolates the steel and aluminum sheet to prevent galvanic corrosion.

CHALLENGES WITH DELTA ALPHA IN ADHESIVE BONDS

The mismatch in coefficient of linear thermal expansion (CLTE) presents challenges when dissimilar material assemblies are exposed to heat. The industry refers to this as "delta alpha" in reference to the Greek symbols used to represent change (Δ, delta) and CLTE (α, alpha) in equations. Because e-coat and paint operations include several high temperature curing ovens, some of the most severe conditions to which the vehicle will be exposed occur in the OEM facilities, such as the joining of steel and aluminum in the Cadillac CT6, or steel and carbon fiber composite in the BMW-7 series. Adhesive suppliers have responded with guidelines for managing "delta alpha" in mixed material assemblies.

Figure 10 illustrates the common failures that can occur when joining materials with mismatched CLTE and curing with the heat of the e-coat oven. The diagram at the lower left shows the temperature changes that would occur before, during, and after curing in the e-coat oven, which typically operates at 180°C / 360°F. The corresponding numbered diagrams refer to points on that diagram.

1) The mixed material assembly is created at room temperature, with a bead of uncured adhesive between the parts.

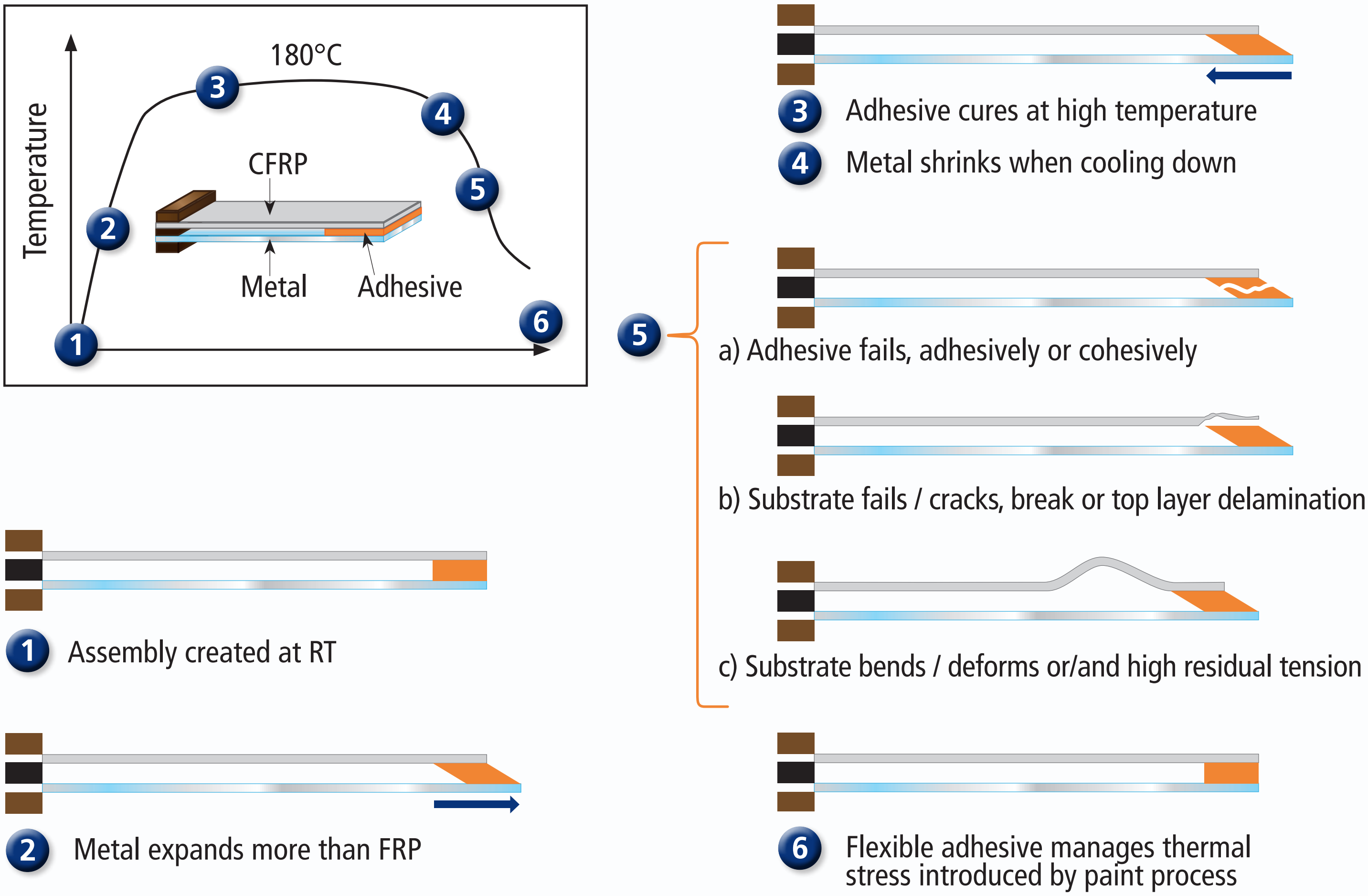
2) When heated, the metal expands more than the reinforced plastic (which contains a high percentage of carbon or glass fiber) with the adhesive still uncured.

3) The adhesive cures between the expanded materials.

4) The assembly cools with the cured adhesive between the materials. The metal shrinks more than the composite during cooing.

5) As the assembly returns to room temperature, stresses increase, which can cause 5a) adhesive failure, 5b) substrate failure, or 5c) surface distortion

6) A flexible adhesive successfully manages the stress introduced by curing at temperature.



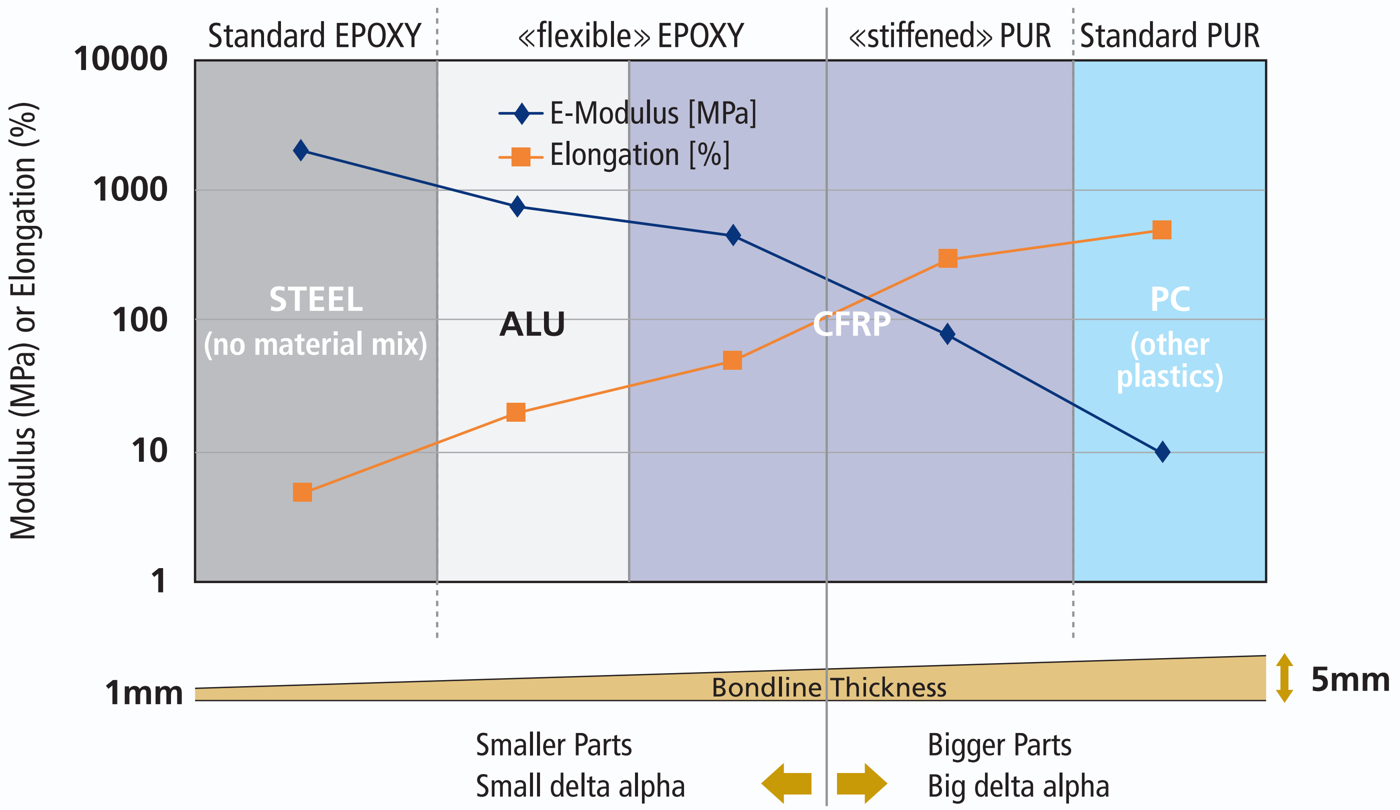
A general guideline for bonding materials with mismatched coefficients of thermal expansion is to increase bead sizes and use softer, more flexible adhesives as the "delta alpha" increases. Softer adhesives are more pliable and better able to accommodate the movement as materials grow and shrink with temperature changes. Adhesives with a lower modulus of elasticity - a measure of stiffness - and higher elongation generally provide better results when dealing with mismatched CLTE. Larger bead sizes increase the area to which the force is applied, resulting in less stress on the assembly.

Figure 10: Illustration of how thermal stresses are introduced in materials with different coefficients of thermal expansion as adhesives cure in the ecoat oven. Using thicker bond lines and lower modulus, more flexible adhesives can help manage thermal stresses. Source: Sika.

ADHESIVE SELECTION CONSIDERATIONS FOR DELTA ALPHA

Examples of the types of structural adhesives that may be appropriate to bond different pairs of substrates are shown in the Figure 11. Using steel as a baseline, the chart shows that steel is typically bonded to steel with a standard epoxy, which is the strongest, hardest, and least flexible adhesive. To bond steel to aluminum, a toughened epoxy might be suitable, as the toughening agents are softer compounds that have the effect of reducing the modulus and increasing the elongation of the adhesive. To bond steel to composites, a softer and more flexible adhesive would be suggested, such as a high modulus polyurethane or toughened acrylic. To manage the greatest mismatch of thermal expansion, a very low modulus polyurethane or sealant might be appropriate.

Figure 11: Guidelines for matching adhesive type when bonding steel to different combinations of materials. Materials with closely matched CLTE can use thinner bondlines and more rigid adhesives. With greater disparity in CLTE of substrates, thicker bondlines, and softer, more flexible adhesives can reduce thermal stresses, warping, or bond failure. Source: Sika



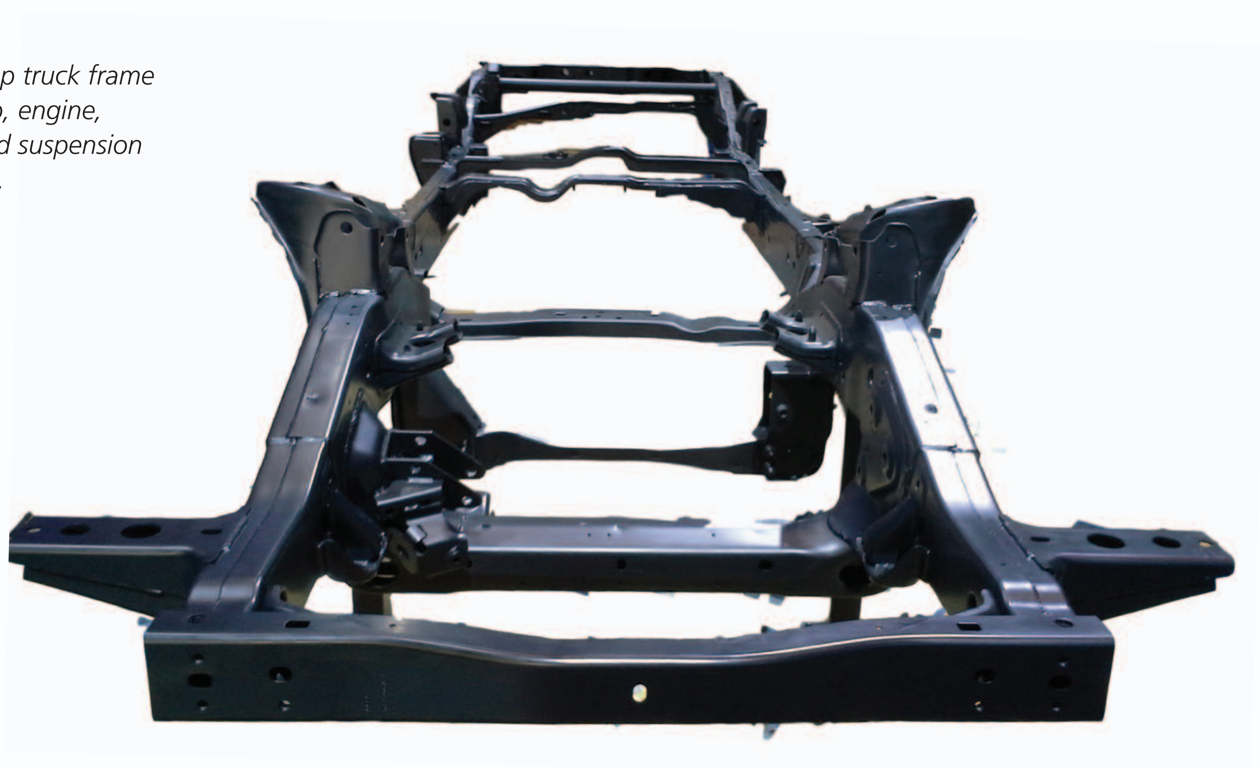
PICKUP, MEDIUM, AND HEAVY-DUTY TRUCK ARCHITECTURE

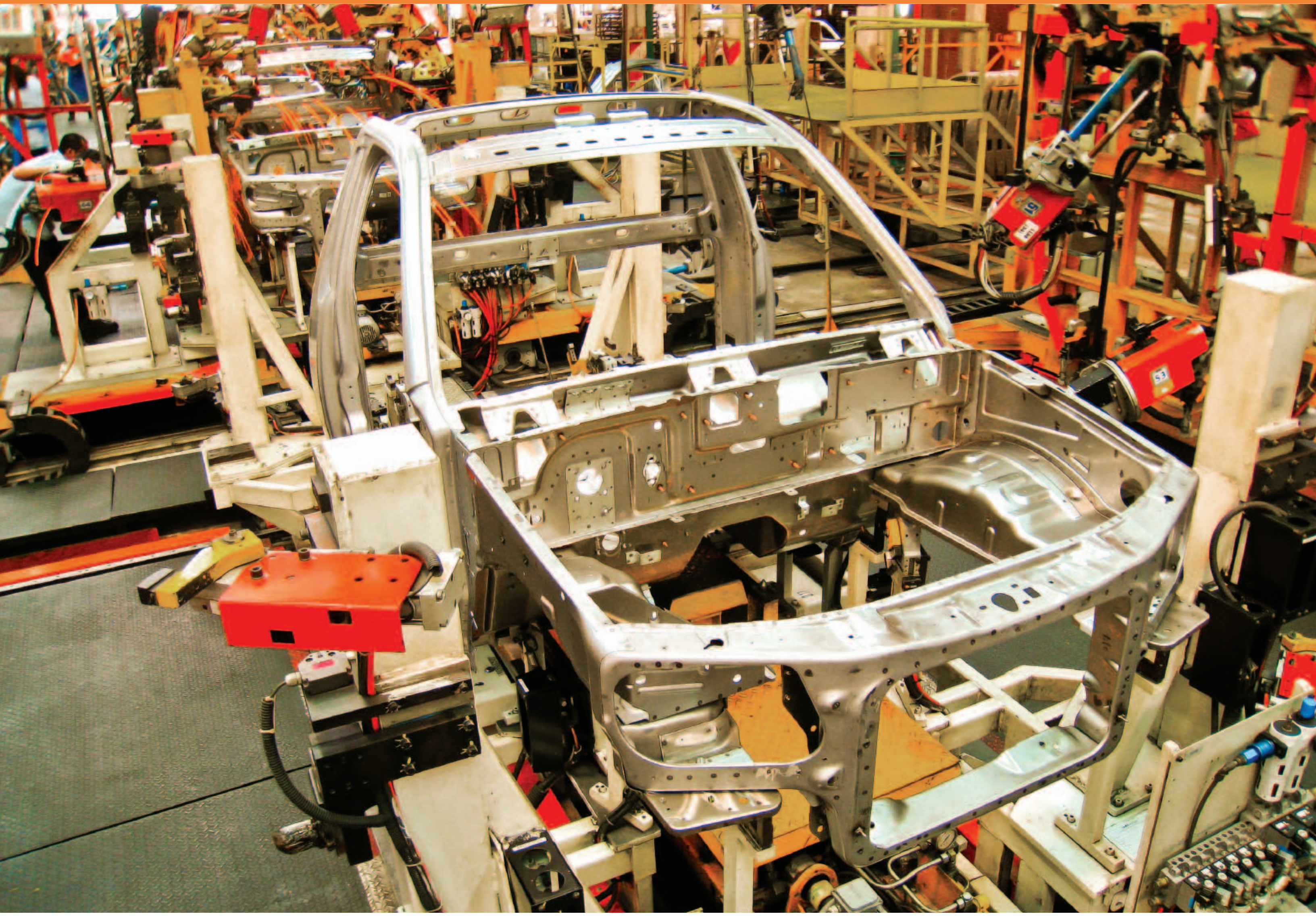
A second type of vehicle architecture, known as body-on-frame construction, is generally associated with pickup trucks, work trucks, and heavy-duty trucks. Body-on-frame construction is used for vehicles that require the ability to support and haul heavy cargo loads. In this vehicle architecture, a ladder-like frame (see Figure 12) is the primary load bearing structure, and the body, which is normally a cab (see Figure 13), sits on top of the frame.

The engine, transmission, steering, and suspension are mounted to a ladder-like frame. The frame consists of a series of heavy steel sections that are formed by stamping, roll forming or hydroforming. The thick, steel frames are joined with bolts and welds. The frame provides resistance to static and torsional loads, which dictates the handling, performance and load bearing capabilities of the truck. The frame rails are the primary point of engagement in a crash event, and dissipate crash energy.

The truck cab sits atop the frame and serves to enclose occupants and controls, improve aerodynamics, and provide the desired aesthetics. Truck cabs are assembled similarly to unibodies, using a series of stamping and moldings to create an enclosure for passengers. Structurally, less is required of the truck cab than a unibody because the frame is the load bearing structure. The cab simply houses the driver

Figure 12: Pickup truck frame to which the cab, engine, transmission, and suspension will be mounted.





and control systems, and provides an aerodynamic front end to the tractor-trailer assembly.

Figure 13: Truck cab-in-white on an assembly line.

New heavy-duty truck cabs are required to provide protection to occupants in the event of a rollover incident, but the frame absorbs most of the impact in frontal and side collisions. Adhesives and sealants make the cab stronger, safer, quieter, and more comfortable by adding localized reinforcement and keeping the elements on the outside of the vehicle. Figure 14 shows a cutaway of a frame rail that uses an expanding foam that is used to seal or reinforce at the intersection of the frame and pillar.

STRUCTURAL BONDING OF TRUCK CABS

Function: *Localized strengthening, stiffening, primary fastening of composites*

Commonly used adhesives: *Single component epoxy, two component epoxy, two component polyurethane, two component acrylic*

Materials of choice vary in truck cabs, due in part to large variation in production volumes across the spectrum of vehicles in this category. Light-duty trucks, such as the Ford F-150 and Chevy Silverado, are produced in volumes of several hundred thousand per year. Conversely, North American production of medium and heavy-duty trucks fluctuates between 200,000 and 500,000 units a year, and each model has several cab configurations. Production of a specific model of heavy truck cab can be ten thousand units or less. As a result, pickup trucks use materials and production methods similar to light vehicles and heavy-duty trucks are manufactured differently.

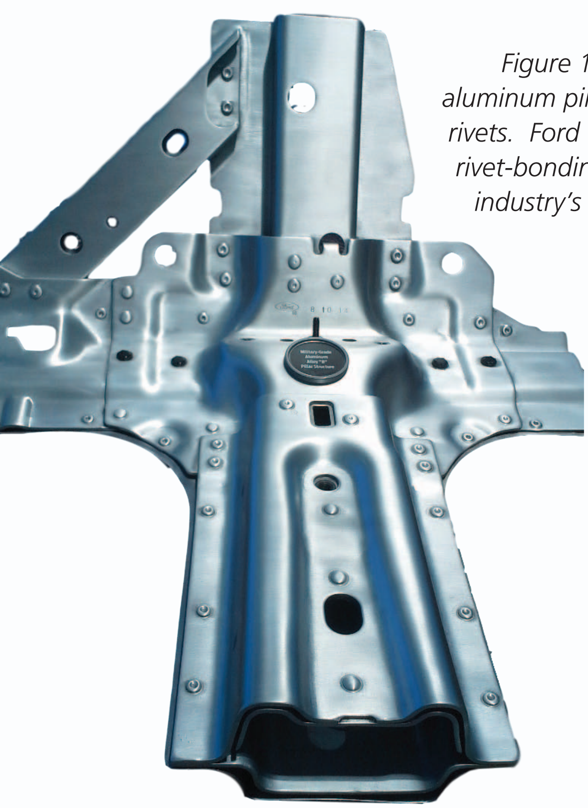


Figure 15: Ford F-150 aluminum pillar joined with rivets. Ford uses rivets and rivet-bonding to make the industry's first aluminum pickup cab.

Pickup truck cabs are manufactured very similarly to other light vehicles. The body is often constructed of spot welded steel, that is selectively stiffened and reinforced with structural adhesives as described in the section Structural Bonding of the Light Vehicle Unibody in this guide. However, Ford decided to change direction with the release of the 2015 F-150. To save weight and improve fuel economy of the truck, the cab of the new truck was manufactured with aluminum rather than steel. Ford uses riveting, rivet-bonding, and weld-bonding to assemble the cab of the truck in similar fashion to aluminum unibodies produced by Audi, Jaguar, and Land Rover. In rivet bonding, the structural adhesive supplements the rivets and, as with weld bonding, creates a stiffer, stronger, safer, and better performing structure than would be achieved with rivets alone.

Heavy truck cabs, which may be made from combinations of steel, aluminum, and composite, are processed differently than cars and use different adhesives. Composites are often used in heavy-duty truck cabs because of favorable manufacturing economics at low production volumes. Composite parts may be joined to other composites or metals, creating joining

Figure 16: A heavy-duty truck cab in production.

challenges often addressed with structural adhesives.

Truck cabs use a variety of composites, including polyester sheet molding compound and poly-dicyclopentadiene (P-DCPD), that are bonded to each other and the metals with structural adhesives. Two component polyurethane and acrylic adhesives are frequently used in these applications.

Two component adhesives are used in some heavy truck assembles for the following reasons:

- Many of these parts are molded and assembled at suppliers, rather than the OEMs themselves, so the adhesive needs to cure before, and without the thermal energy provided by the paint process.
- Paint process used for composites in heavy trucks is conducted at a lower temperature than the automobile e-coat process, allowing a broader array of adhesives to be used.
- Mixed material assemblies can benefit from the use of softer, lower modulus, adhesives to manage the difference in thermal expansion between materials in paint operations and in the field.

Figure 17: Heavy truck cab mounted to frame. The assembled cab can include optional sleeping compartments and fairings. These large components, along with the hood, are often made of composite or aluminum to minimize weight.

Hem Flange Bonding

***Function:** Joining, sealing, corrosion prevention*

***Commonly used adhesives:** Single component epoxy, Single component epoxy hybrids, two component acrylic.*

Light vehicle closure panels, such as doors, hoods, and decklids (trunk lid) are commonly made of steel, with an increasing number using aluminum or other lightweight materials to help meet fuel economy and CO2 emission goals.

The general construction of steel and aluminum closures is similar, in both cases a thin outer panel is joined to a thicker inner panel using a joining method known as hemming. Hems are commonly found at the edges of hoods, decklids, doors, and tailgates. In a hem, shown in Figure 18, the outer panel is wrapped around the inner panel to create a smooth outer surface. Adhesives join the inner panel to the outer, and seal the joint to prevent moisture intrusion, reducing the potential for corrosion. Glass beads are often added to hem flange adhesives to help maintain a consistent bond thickness and prevent the adhesive from being squeezed out during the hemming operation. In addition, the glass beads cause a small amount of deformation in the metal panels during hemming, which mechanically locks the panels in place and prevents the parts from moving out of position before the adhesive cures.

The use of an adhesive also improves the

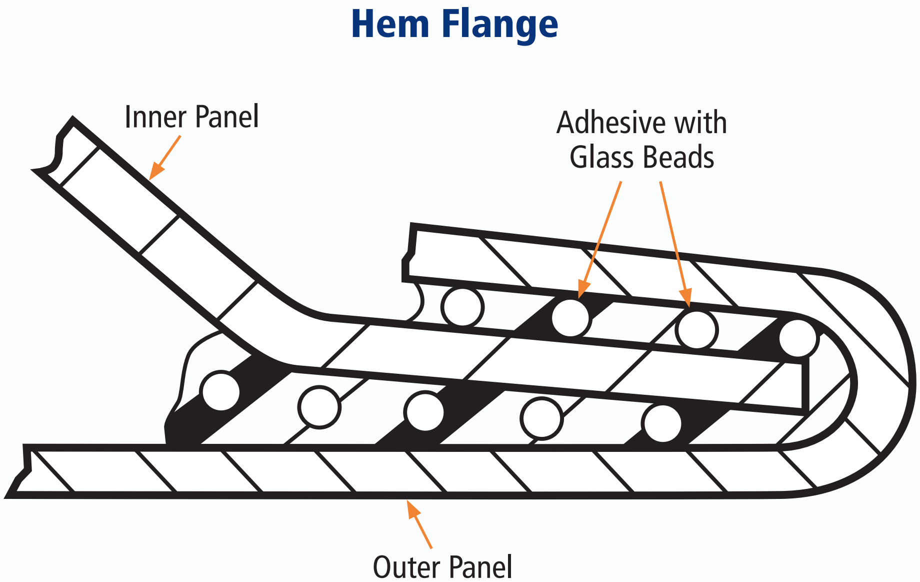


Figure 18: Schematic diagram of a hem flange, showing how a structural adhesive containing glass beads can be used to maintain a consistent bond line thickness between the inner and outer panels during hemming.

aesthetics of the hem flange by reducing the need for spot welds, which must be carefully located to avoid being detected on the exterior "class A" surface that is visible to the customer. Due to the importance of aesthetics in hem flanges, flexible adhesives or sealants are often used for this application, as lower modulus adhesives are less likely to cause the bond line to "read through" or become visible to the consumer on the class A surface.

By nature of their design, hem flanges are susceptible to peel, so tests such as the ASTM D1876 T-peel test, are frequently used to evaluate adhesives and sealants for this application.

In many cases, toughened, single component epoxy adhesives are used to create a strong, flexible bond that will survive the heat of the e-coat oven.

In some occasions, however, two component acrylic adhesives are used for hem bonding because structural acrylic adhesives develop strength quickly at room temperature. The development of green strength can improve the dimensional stability of the assembly because it prevents parts from shifting as assemblies are moved out of the weld shop or shipped to between facilities. Since viscosity increases as the adhesive builds strength, the use of two component adhesives can improve washout resistance. Acrylic adhesives used for hem flange bonding in OEM body shops are modified with epoxy resins to allow them to survive the e-coat oven temperatures.

Anti-Flutter Adhesives

Function: *Prevention of exterior panel movement*
Commonly used adhesives: *Rubber based*

As the name implies, anti-flutter adhesives prevent the thin exterior panels of the vehicle from moving due to wind resistance, which is an undesirable aesthetic and might cause unwanted noise in the cabin. In addition, it permits the attachment of the outer panels to a support structure that prevents them from denting, known as "oil canning", when they are subjected to loads.

Exterior panels, such as the door skins, hood, roof, and decklid can be as thin as 0.6 mm, and have large unsupported spans. Dollops and beads of anti-flutter adhesives join the outer panels to the substructure and reinforcing beams, as shown in Figure 19. These materials are generally low modulus,

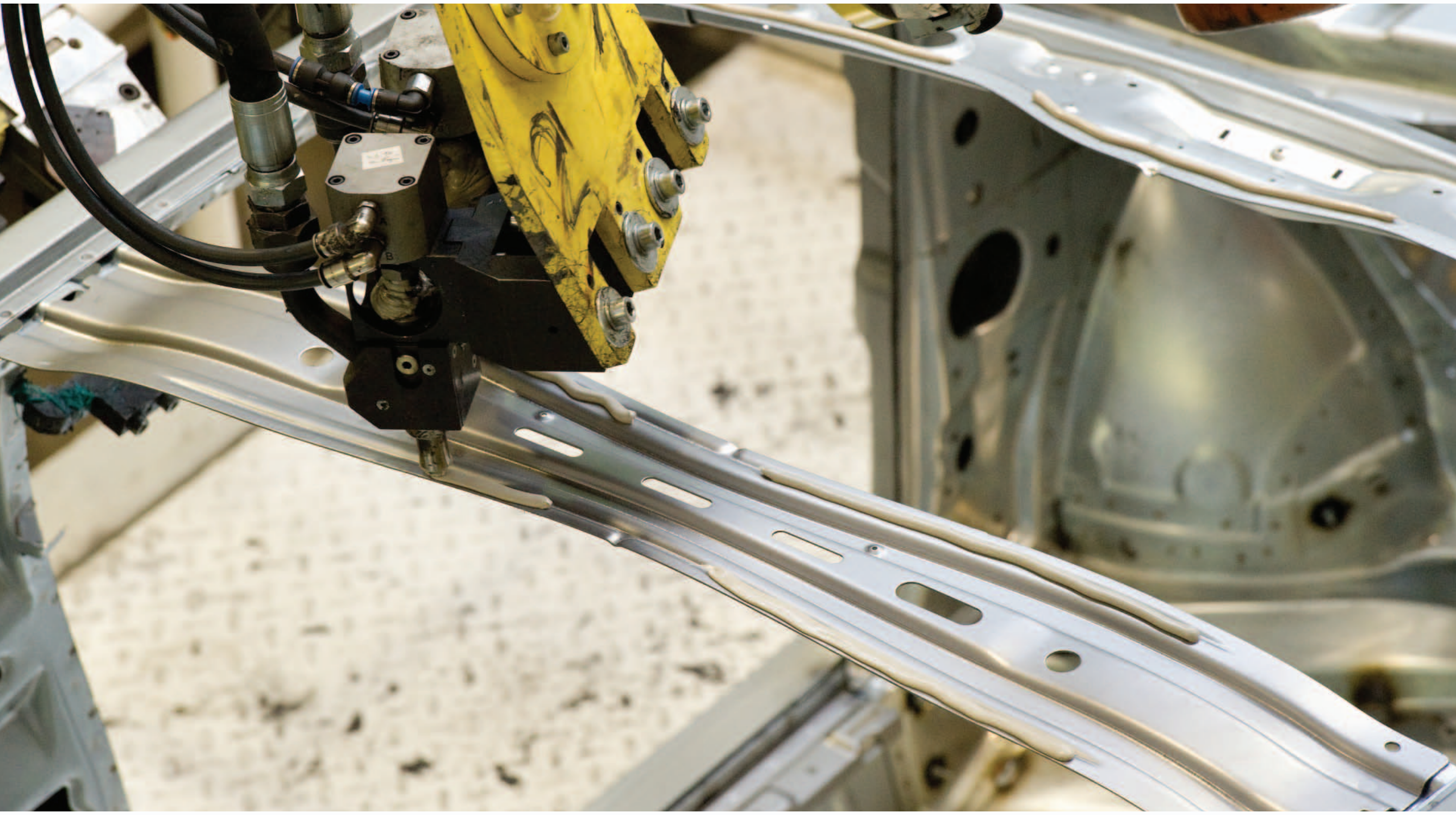


Figure 19: Anti-flutter adhesive applied on roof support prior to installation of roof panel. Source: Sika.

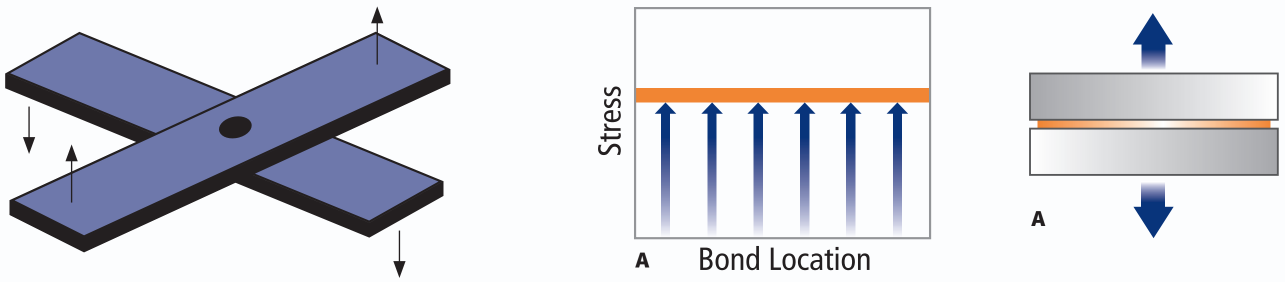


Figure 20: Cross tension tests, sometimes referred to as cross peel tests are often used to evaluate anti-flutter adhesives because they simulate the tensile stress generated as an outer panel flutters.

rubber-based adhesives, and the soft, pliable adhesives absorb vibration while reducing the potential for the adhesive to "read through," or distort the exterior surface of the vehicle. Since they are applied in the weld shop, anti-flutter adhesives must bond well to oily metals and be able to survive the e-coat and paint processes. Therefore, these must be thermoset materials that cross link during the paint operation.

Panel fluttering is the movement of an outer panel away from the inner panel. This puts the adhesive in tension, rather than shear. Cross tension tests, such as ASTM D897, simulate this condition, and are used to evaluate anti-flutter adhesives. In this test, flat samples of substrate are bonded perpendicular to each other to form a cross. The pieces are pulled away from each other, putting the adhesive in tension, as shown in Figure 20.

Anti-flutter adhesives are designed to expand and fill gaps when cured, so measurement and characterization of expansion is commonplace. Expansion of anti-flutter adhesives is commonly on the order of 50 to 100%, which allows the adhesive to span gaps between panels without causing panel distortion or read through. SAE J 1918-2002 and similar tests are used to measure expansion of sealants.

Finally, anti-flutter adhesives must function effectively and avoid trapping salts or moisture that would cause corrosion, so environmental exposure tests, such as salt spray or cyclical corrosion tests, such as ASTM B117 and SAE J2334, are frequently used in the evaluation of anti-flutter adhesives.

Body Sealing

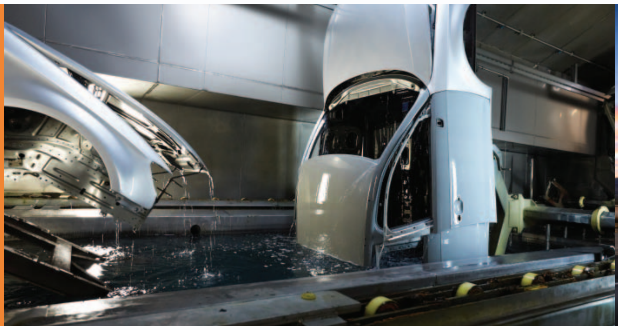
Function: *Prevent intrusion of water, dust, air, and sound into vehicle cabin*
Commonly used adhesives: *Rubber based formulations*

As the name suggests, products used for vehicle body sealing do just that, which is prevent water, dust, air, and sound from entering the interior of the vehicle. These adhesives and sealers are often placed on top of a seam, but can also be placed on flanges prior to spot welding. These are typically rubber-based products, and may have considerable expansion to ensure that gaps between panels are completely filled when the sealant has cured. As much as 200% expansion may occur during curing, although some are designed not to expand at all.

As with other adhesives used in the OEM body shop, body sealing adhesives must be tolerant of oily metal surfaces and be compatible with spot welding and paint operations. This means they must not be flammable, have high enough viscosity to resist wash out, cure in the e-coat oven and not reflow in subsequent paint operations. These are often single component products based on butyl or styrene-butadiene rubber compounds.

Since the primary function of these products is to seal out the elements, the ability to create a consistent bond, rather than the strength of the bond, is the most important attribute in these applications.

Lap shear or T-peel testing is evaluated to make sure these products can produce acceptable bonds to oily metal surfaces. Performance across a wide range of temperatures is evaluated, as well as the ability to retain bond strength following salt spray and cyclic corrosion tests, such as ASTM D117 and SAE J2334, or similar OEM tests.



Expandable Sealants

Function: *Fill cavities to prevent intrusion of air, water, sound and vibration*

Commonly used adhesives: *Ethylene Vinyl Acetate*

Automotive pillars and frame rails are hollow sections that can create pathways for water, dust, air, or sound to enter the passenger compartment. In order to prevent intrusion of these elements to make the cabin more comfortable, or prevent long-term corrosion issues, the hollow channels are filled with expandable foam sealants in certain locations. These can be applied directly to a surface as a liquid, but are often coextruded onto nylon carriers that are clipped into position in the OEM body shop, ensuring the correct amount of sealer is applied in exactly the right location. The sealer does not expand until it reaches the e-coat curing oven, which allows the liquid e-coat to flow through the channels and coat the internal surfaces before they are sealed off. It is extremely important that e-coat reaches the inner walls of the pillars and rails, because moisture that collects would cause damaging corrosion without the protective barrier of e-coat. These sealers are often highly expanded, low density ethylene vinyl acetate, which allows them to aid the corrosion resistance and noise, vibration, and harshness (NVH) performance of the vehicle without adding much weight.

Figure 21: Cutaway showing location of preformed expanding foam sealant at the intersection of a frame rail and pillar. Expanding foams keep sound and moisture from moving through the white body and entering the cabin. Source: Sika

As with other OEM body shop products, the ability to adhere to metals with a variety of mill oils and stamping fluids is important. Because the ability to fill a cavity completely without expanding beyond its limits is important, volumetric expansion (SAE J1918-2002) and density of cavity sealers is closely regulated, tested, and evaluated. The effect of salt spray and corrosion cycles, such as ASTM B117 and SAE J2334, on functional performance of the foam is likely to be required. Because the density and cell structure of foams can impact their ability to absorb sound and vibration, these are generally tested and included in material specifications for cavity sealing materials.

Surface Coatings on Metals

Materials arrive in the OEM body shop with a number of coatings applied to them. Some of these are temporary, such as mill oils and stamping fluids, while coatings for corrosion protection and bonding are permanent. All of these coatings must be taken into consideration when selecting adhesives and sealants for OEM body shops.

Steel is the most common automotive material, and there are many different alloys used in a BIW. Nearly all automotive steel has a zinc coating to prevent rust over the life of the vehicle. These thin coatings, generally 10 microns or less, are applied to the steel in coil form before it is stamped. Therefore, most adhesive bonds in the OEM body shop are made to zinc, not steel. Oil is applied to the surface of the coated steel as it is rolled into a coil at the steel manufacturer to prevent corrosion during transport and storage. In some cases, lubricants are added to the oil to aid the stamping process. Although the mill oil is removed during the paint pretreatment process, it is present when parts are bonded in the OEM body shop. Therefore, OEM body shop adhesives are designed to adhere to metals despite the presence of oil and other lubricants.

Aluminum has been used in automobile construction for many years, but has become more commonplace in the last 5 years as weight reduction and fuel economy have been prioritized by vehicle manufacturers. Aluminum does not rust like carbon steel because it forms a thin oxide layer very rapidly when exposed to air. This oxide layer can weaken adhesive bonds, so most automotive aluminum receives an organic pretreatment as it is being produced in coil form. Aluminum extrusions and castings receive similar coatings after they are formed. The organic pretreatment ensures a uniform surface for bonding and painting. The aluminum coils also receive a protective layer of mill oil that remains when adhesive is applied in the OEM body shop.

OEM Body Shop Adhesive & Sealant Chemistries

The adhesive and sealant chemistries commonly used in automotive and heavy truck OEM body shops include epoxy, polyurethane, acrylic, and rubber based chemistries. Expandable sealing and reinforcing foams serve different functions and are generally evaluated on different performance criteria than adhesives, and are not included on in Figure 22.

Figure 21 is a generalization of the relative strength and flexibility of various OEM body shop adhesives and sealants. Epoxies tend to be the strongest adhesives, but are the least flexible. Polyurethanes offer a wide range of strength and flexibility, and are far more flexible than epoxies, but not quite as strong. Properties of acrylic structural adhesives offer a balance of strength and flexibility, falling between epoxy and polyurethane. Rubber based products are the lowest strength, but most flexible, and typically used as sealants or anti-flutter adhesives than for structural applications.

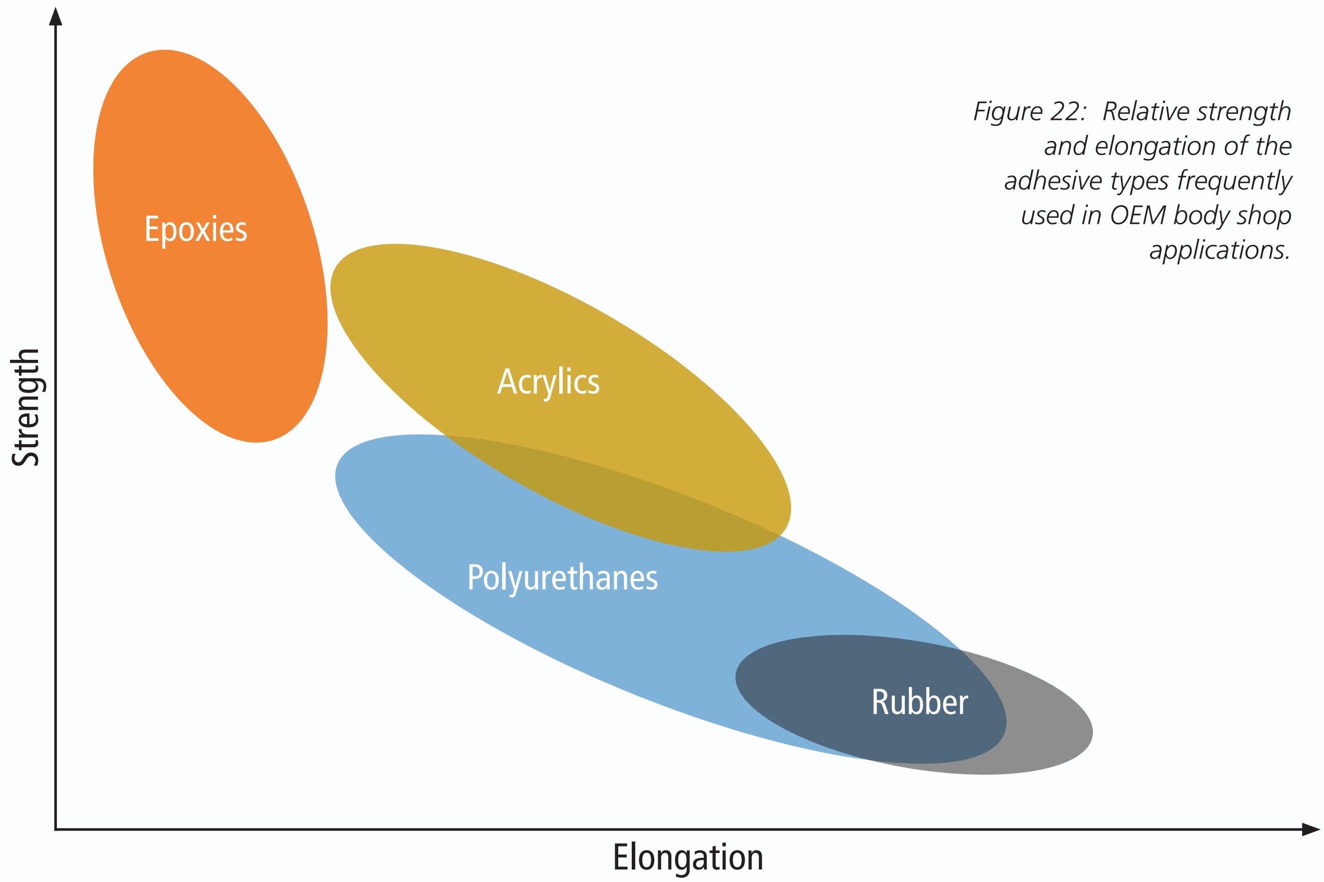


Figure 22: Relative strength and elongation of the adhesive types frequently used in OEM body shop applications.

ACRYLIC (POLY METHYL METHACRYLATE)

Acrylic structural adhesives that find use in the OEM body shop are based on polymethyl methacrylate (PMMA) chemistry. The hallmarks of acrylic structural adhesives are that they provide a balance between the strength of epoxies and the flexibility of polyurethanes. Acrylics develop handling strength relatively quickly in relationship to the open time, which is the time available to apply and manipulate parts before joining them. Acrylic structural adhesives are known for their ability to bond a variety of composites with little surface preparation, and therefore find application in some composite truck cab and hood assemblies. Acrylic-epoxy hybrids also see limited use in some hem flange bonding applications, where the ability to develop handling strength quickly is advantageous. The addition of epoxy to the formulation provides the temperature resistance required for curing in the e-coat oven. However, the strong odor of methacrylate based adhesives limit their use in automotive OEM applications.

Structural acrylic adhesives are two component formulations. One component of the formulation consists of methacrylate polymer and toughening agents, such as rubber particles, and the second part is a peroxide based curing agent. The kinetics of the exothermic reaction allow structural acrylics to develop handling strength relatively quickly, and the curing agent can be modified to create a wide range of working time suited to a variety of applications. Additives, such as rheology modifiers, are used to allow large beads to adhere to vertical surfaces without sliding or sagging.

EPOXY

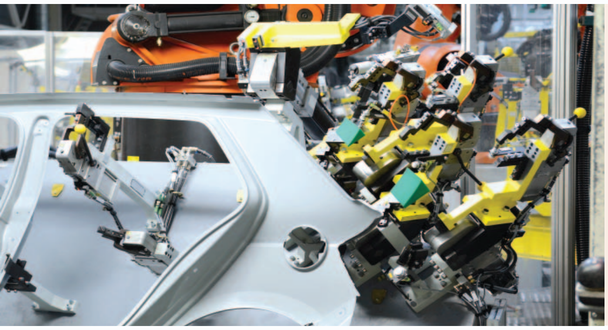
Epoxies are the most commonly used structural adhesives in the automotive OEM body shop because of their strength, ability to bond oily metals, and temperature resistance. The intrinsic ability to withstand the temperature of the automotive e-coat oven makes epoxies particularly well suited to light vehicle production. A trade-off to the high strength and modulus of conventional epoxy adhesives is that they are less flexible and have lower elongation than other structural adhesives. Standard epoxies can be brittle and lack toughness, which means they absorb less energy during failure. Toughening agents can be added to make epoxies softer, more flexible, and better suited to absorb impact energy. Crash toughened epoxy adhesives are produced using toughening additives, by modifying the epoxy backbone with urethane or acrylics, or a combination of the two methods.

Although the term epoxy refers to any number of resins which normally contain at least two epoxide groups, the most commonly used epoxies in structural adhesives are based on bisphenol A diglycidyl ethers, the polymer chain length of which can be tailored to produce the desired balance of mechanical properties in the cured adhesive. Cross linking is typically achieved with an amine curing agent, which can either be added during use (2 component) or activated with the addition of heat (1 component). Additives are used to modify the viscosity and rheology of the epoxy to make it easy to dispense, yet stay in place once it has been applied to a part, and not wash off in the e-coat process.

ETHYLENE VINYL ACETATE (EVA)

Ethylene vinyl acetate is used as a foam sealant that cures using the heat of the e-coat oven. Unexpanded preforms are placed in strategic locations inside pillars and frame rails. Upon heating, the foam expands to fill the cavity and prevents the intrusion of water, dust, or air in areas where it could cause problems. The cell structure of EVA foams can be modified depending on the use. Closed cell foams are used to direct moisture away from areas where it could collect and accelerate corrosion. Open cell foams can be used to prevent the transmission of sound from the exterior to the interior of the vehicle, and are often used as part of the strategy to reduce noise, vibration, and harshness (NVH) in the vehicle.

Ethylene vinyl acetate is a copolymer of ethylene and vinyl acetate, the properties of which vary based on the proportion of vinyl acetate in the formula. Materials with higher levels of vinyl acetate are referred to as EVA rubber and exhibit elastomeric - or "rubberlike" - properties. Many foams used in sporting and consumer goods are EVA rubber. Through the use of different foaming agents, EVA foams can be made with a variety of cell structures, helping tailor their performance to a variety of applications. EVA can be supplied as a liquid, but is frequently furnished as a solid, which is coextruded onto a carrier plastic that can be clipped into place on the assembled BIW prior to the paint operation.



POLYURETHANE (URETHANE)

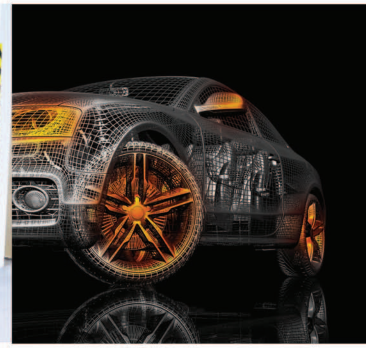
Polyurethane structural adhesives are based on thermosetting polyurethane chemistry, which is a reaction between an isocyanate prepolymer and a polyol. Polyurethanes are known for their excellent flexibility and toughness, but are not quite as strong or as heat resistant as epoxies. Polyurethanes bond well to composites and coated metals, but most are not well suited for processing at automotive e-coat curing temperatures, which is normally 30 minutes at 180°C / 360°F. Therefore, applications in automotive and truck OEM body shops are primarily for composite bonding and mixed-material assemblies. Two-component polyurethane adhesives are frequently selected because they can cure at room temperature, and develop handling strength more quickly with the addition of heat. Single component polyurethane adhesives cure by a reaction with water, not heat, and are used frequently for automotive glass bonding (an assembly operation outside the scope of this guide). Because of the lower heat resistance when compared to epoxy adhesives, the use of single component polyurethanes in OEM body shops is limited to niche dissimilar material joining applications, such as bonding aluminum or composite roofs to steel bodied vehicles, or bonding of composite intensive vehicles like the BMW i3.

Most polyurethane adhesives used in structural applications are two component formulations, and the prepolymer and polyol are mixed just prior to use. The strength and elongation of these adhesives can be modified by adjusting the length of the prepolymer chain and the degree to which they are cross linked. As a result, polyurethane structural adhesives are known for their versatility and excellent combination of strength, toughness, and flexibility. More flexible formulations with lower elastic modulus are helpful in managing differences in thermal expansion in multi-material structures, and also for minimizing bond line read through on exposed surfaces.

RUBBER BASED ADHESIVES & SEALANTS

Rubber based adhesives and sealants are applied in and on top of joints in the OEM body shop, and used in anti-flutter applications. While generally lower in strength than the other adhesives discussed in this guide, rubber based products are selected for their gap filling, sealing, and vibration damping properties. Low modulus products with the ability to expand are advantageous in these applications, and are engineered to expand from 0 to 200% as they cure. These products bond well to oily metals, and are capable of curing in the e-coat oven without degrading.

Rubber based adhesives used in OEM body shop applications include formulations based on butyl and styrene-butadiene rubbers. They contain no volatile organic compounds, and are fully compatible with paint and weld processes. These are 100% solids products that are crosslinked in the e-coat oven. The use of crosslinked rubber is important because it prevents the adhesive from softening and flowing during subsequent paint curing operations, which could cause paint defects or contamination. Rubber based adhesives typically have lower strength than epoxy adhesives, so they are used in areas where sealing, vibration damping, and avoiding bond line read through are prioritized over bond strength.



ONE COMPONENT VS TWO COMPONENT ADHESIVES AND SEALANTS

Many adhesives and sealants families used in automotive and heavy truck OEM body shop applications are available in a variety of forms. Liquid adhesives can be manufactured with the adhesive and catalyst contained in a single component that are ready to use, or with the adhesive and catalyst in separate components that are mixed immediately before use. Some single component adhesives can be supplied as a solid, which is either die cut or extruded into a shape desired by the end-user.

Single component adhesives are the most common type found in OEM body shops because they are the simplest to use and the heat required to cure them is abundant in the e-coat operation. Large volumes of single component adhesives can be stored in tanks, which is convenient for mass production of automobiles. Relatively simple pumping equipment is used to dispense the material because it does not have to be metered and mixed. Because most single component, reactive adhesives do not cure until heated, there is no worry about prematurely curing adhesive on subassemblies during breaks or shift changes, allowing production to resume quickly after the break.

Single component, heat curing adhesives can be supplied as a solid preform. In this case, the preform is extruded into a ribbon or tape, or it can be die cut into a shape desired by the OEM. The preform is placed into position by an operator. The advantage of the preform is that it allows for precise control of the volume and location of the adhesive. In addition, clip-on preforms prevent uncured adhesive from sliding off vertical surfaces. The disadvantages of preforms include the additional costs associated with their production and installation, the disposal of release liners, and the need to hold inventory of the preforms themselves.

Two component adhesives offer the advantage of room temperature curing,

Figure 23: Static mixing tips used for application of two component adhesive. Source: Ashland

which is beneficial for parts that need to be moved prior to e-coat, or for vehicles that are not painted using conventional automotive paint processes. Body parts and sub-assemblies stamped or molded at a location other than the OEM body shop may require handling strength before final curing to meet dimensional tolerances. Because the two components of the adhesive need to be carefully metered and mixed during use, the dispensing equipment is typically more complex than that used for one component adhesives. Since the material begins to cure as soon as it is mixed, production breaks need to be timed with the completion of an assembly to avoid running past the open time of the adhesive. In addition, static mixing tubes must be replaced following breaks, and a small amount of material must be dispensed and scrapped at startup to ensure proper flow and mixing of the adhesive. Furthermore, each component of the adhesive must be held in drums or in separate storage tanks.

ADVANTAGES AND DISADVANTAGES OF COMMON ADHESIVE AND SEALANT DISPENSING METHODS

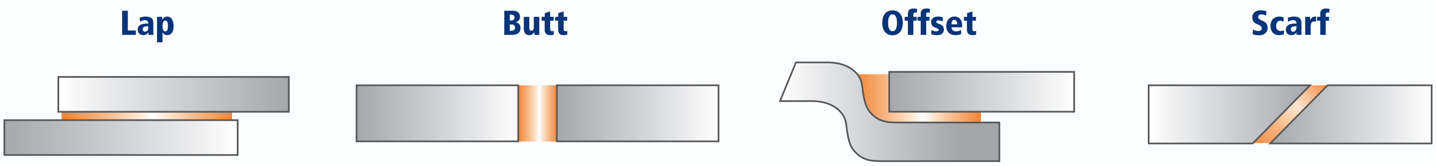
TYPE	ONE COMPONENT	TWO COMPONENT	SOLID PREFORMS
Advantages	• No mixing required • Simplifies storage & inventory management • Easier to manage start up and shut down	• Can be cured at room temperature without addition of heat or moisture • Improved shelf life vs one component adhesives • Builds green strength at room temperature, which can improve dimensional stability	• Exact control of placement and volume dispensed • Prevents sliding on vertical surfaces
Disadvantages	• Require heat or moisture to cure • Does not build green strength quickly, parts can shift during transfer to curing area	• Requires metering and mixing equipment • Waste created in mixing units at start up and shut-down	• Additional parts to inventory • More labor intensive to install • May require release liners that generate waste

Adhesive and Sealant Joint Design Considerations

Modern adhesives and sealants are remarkable materials that are capable of being used in wide variety of joint configurations. Although there are limitless possibilities of joint configurations, most are variations of lap and butt joints.

The strongest and longest lasting bonds are created when joints are designed with adhesives in mind so that stresses can be managed appropriately. The types of stresses commonly found in adhesive joints include tensile, compressive, shear, peel, and cleavage.

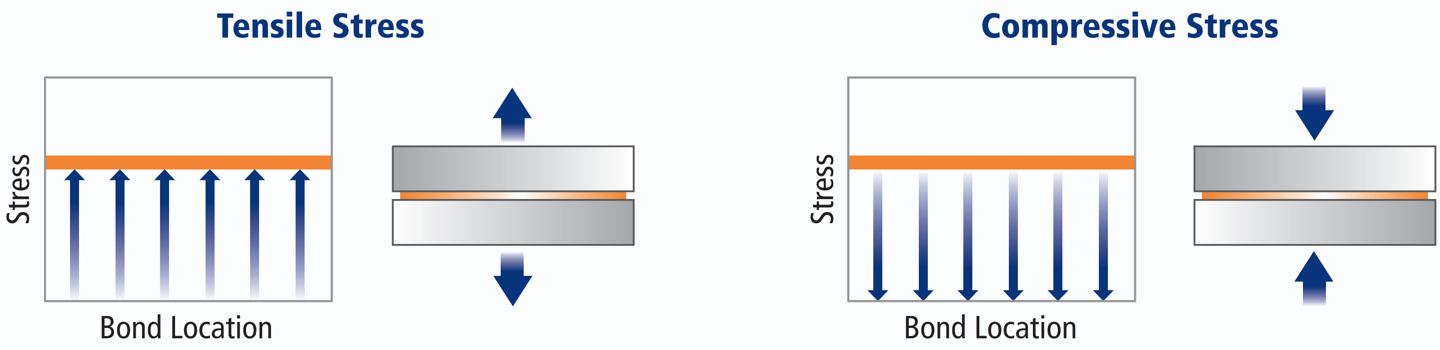
Figure 24: Common adhesive joint configurations.



TENSILE AND COMPRESSIVE STRESSES

Tensile and compressive stresses are applied uniformly across the joint. However, most adhesives perform better in compression than in tension. Adhesive bonds in compression are less likely to fail. Therefore, it is desirable to minimize tensile stresses on the joint and maximize compressive stresses.

Figure 25: Tensile or compressive stresses distribute load evenly across joints.

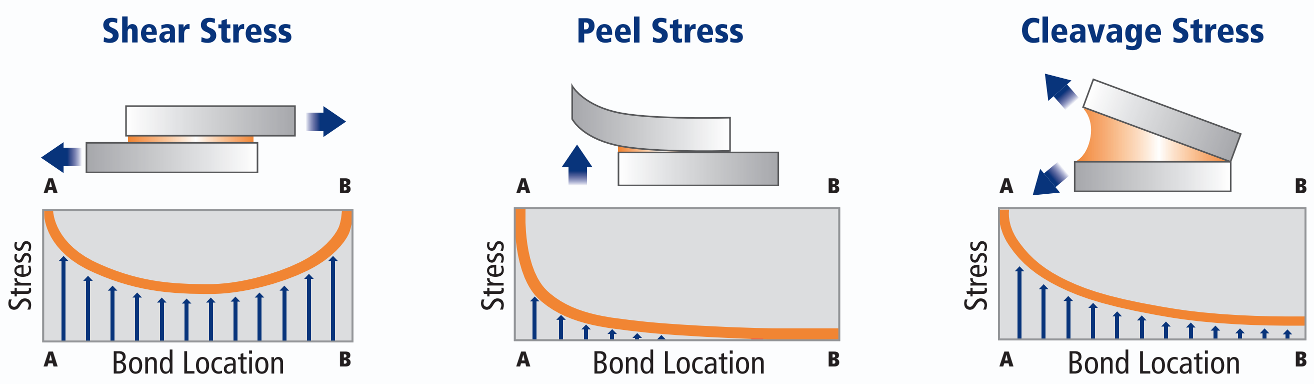


SHEAR, PEEL, AND CLEAVAGE STRESSES

A shear stress results in two surfaces sliding over each other. Shear stresses are higher at the edges of the joint than in the center. Therefore, it is better to increase the length of shear joints rather than the width, since most of the work is being done at the edge of the bond.

Peel and cleveage stresses result when a flexible or rigid substrate, respectively, is lifted away from the joint at one end. These conditions create a stress concentration at one edge of the bond. Peel creates the highest stress and should be avoided if possible.

Figure 26: Shear, Peel, and Cleavage stresses.



Auto & Truck OEM Adhesive Testing & Specifications

Automotive and heavy truck OEMs maintain their own protocols for adhesive and sealant testing, evaluation, and approval. As discussed previously in this guide, each application of adhesives and sealants in the OEM body shop has different requirements, so test protocols often vary by OEM and application.

Although there is not a single set of standards for adhesive and sealant evaluation in the land transportation industry, there are many similarities in test methods, and some of the more common tests and specification are listed in the table below.

FAILURE MODE AS A CRITERION IN OEM BODY SHOP ADHESIVE AND SEALANT TESTING

When evaluating adhesives and sealants in shear, peel, and tension testing, it is often not sufficient only to simply meet the criteria for load bearing and elongation. Failure mode is often evaluated just as critically as the strength or elongation of the bond. Many OEM specifications require a cohesive failure or substrate failure. This means that the fracture must occur within the adhesive or the substrate, rather than at the interface of the adhesive and the substrate. Adhesive failure, which is when the adhesive cleanly pulls away from the substrate, is typically cause for disqualification in OEM specifications. This criterion assures that the interface of the adhesive and substrate is not the "weak link" in the system, and provides confidence that the adhesive will be reliable in service.

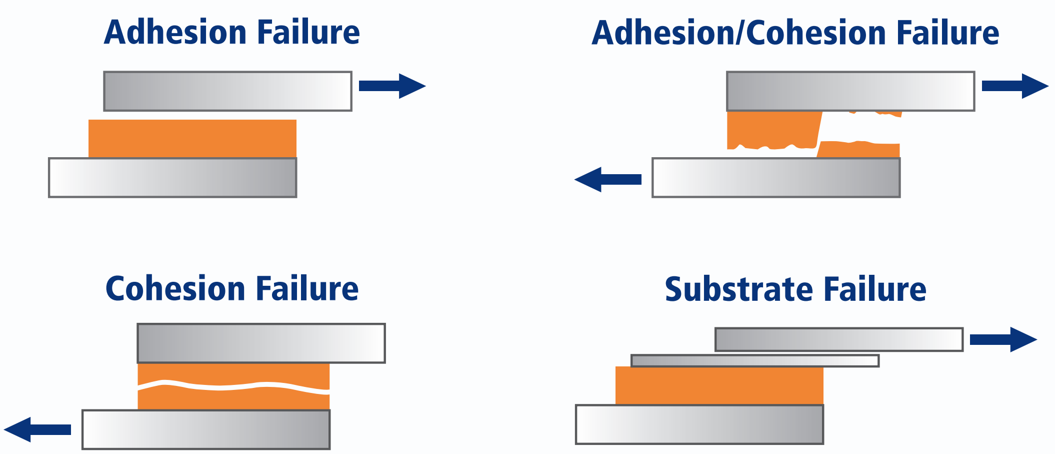
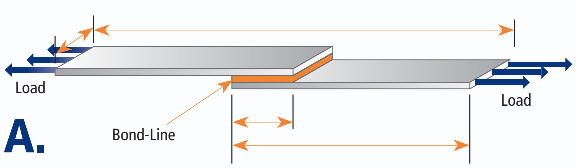
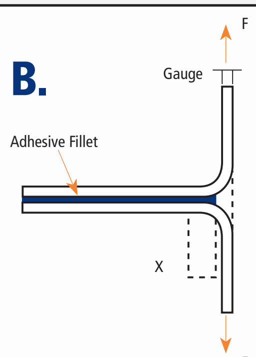


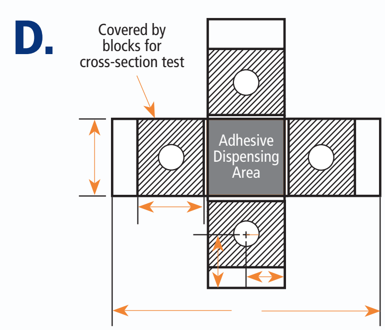
Figure 27: Adhesive failure modes

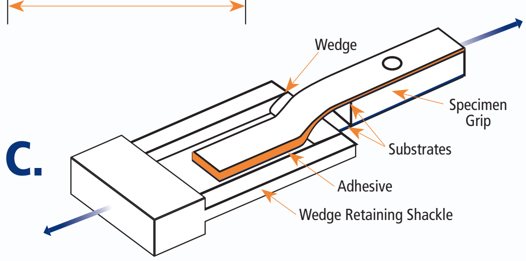
COMMON AUTOMOTIVE ADHESIVE AND SEALANT TEST STANDARDS

TEST NAME	STANDARDS	DESCRIPTION
Lap shear	ASTM D1002 (metals) ASTM D3163 (plastics) ASTM D5868 (FRP) DIN EN 1465	Determines the shear strength of adhesives when measured on a single lap shear specimen. Standard ASTM sample size is 1"x 4" with an overlap of ½" or 1". Tests often conducted as 23C, -40C, and 80C for transportation, and requirements are OEM specific. **SEE ILLUSTRATION A**
T-Peel	ASTM D1876 ISO 11339	Measures the strength of the adhesive bond in peel. Generally conducted on thin metals that can be bent. Tests may be conducted across a broad range of temperature and environmental conditions. Requirements are OEM specific. **SEE ILLUSTRATION B**
Impact Wedge Peel	ISO 11343	Measures the resistance to cleavage fracture of structural adhesives at a relatively high strain rate. Often conducted at 23C, -40C, and 80C. Results used as an indicator of toughness and crash resistance. **SEE ILLUSTRATION C**
Cross Tension (Cross Peel)	ASTM D897 SAE J 1553-1995	Determines the strength of an adhesive bond in tension. Often used for anti-flutter adhesives because the movement of outer panels away from supporting structures creates a tensile load. **SEE ILLUSTRATION D**
Expansion	SAE J 1918-2002	Method for determination of expansion and water absorption of automotive sealers.
VOC content	OEM specific	Measure VOCs released in plant or that would escape into cabin from cured adhesives.
Weldability	OEM specific	Includes a battery of tests with OEM specific criteria, such as flammability, weld squeeze force, and weld nugget formation.
Salt spray test	ASTM B117 DN50021 OEM specific	Salt spray corrosion condition used as a quick predictor of corrosion resistance. Some OEMs maintain their own standard.
Cyclic Corrosion Test	SAE J2334 VDA 621-415 OEM specific	Cycle of salt spray, temperature, and humidity conditions that is used to simulate long-term environmental exposure in field conditions. Some OEMs maintain their own standard.









Glossary of Terms

Adhesive failure: Failure of an adhesive bond by separation of the adhesive from the substrate. Adhesive failure indicates that the bond between the adhesive and substrate is the "weak link" and often signifies a test failure.

Body-in-White (BIW): The stage of the automobile manufacturing process where a series of stamped or molded panels are brought together to form the automobile body or truck cab.

Bond line read through: The visible distortion of a substrate over a cured adhesive bond line.

Cleavage: A pulling force applied at one end of a bond, exerting a prying force on the bond. Cleavage results in a stress concentration on one side of a bond and can result in failure at lower loads than observed in tension.

Coefficient of linear thermal expansion (CLTE): A material property that indicates the extent to which a material will expand in one dimension upon heating. Differences in CLTE can be significant when bonding dissimilar materials. CLTE is often represented by the Greek letter α (alpha)

Delta alpha: Refers to materials that have different coefficients of thermal expansion. This is derived by the Greek letters used to symbolize change (Δ, delta) and coefficient of thermal expansion (α, alpha) in equations.

Cohesive failure: Failure of an adhesive bond within the adhesive or sealant. Both sides of a broken test sample retain adhesive, demonstrating a strong bond of the adhesive and substrate. Cohesive failure of a test sample is desirable, as it a sign of a strong, repeatable bond.

Compression: A "pushing" force applied perpendicular to the adhesive bond that causes the bond line to reduce in size along the axis the force is applied.

E-coat process: An electrophoretic painting process that uses an electrical current to deposit a layer of paint on a metal part that is immersed in a paint emulsion. E-coat is typically heat cured for 30 minutes at 180°C / 360°F, and the heat from the e-coat curing oven is used to cure adhesives and sealants applied in the OEM body shop. OEMs often test heat resistance of adhesives and sealants at temperatures of 205°C / 400°F to account for process variation.

Modulus of elasticity: The ratio of stress applied to a substance and the resulting strain within the elastic limit, or before the material exhibits permanent deformation. A high modulus of elasticity is indicative of a strong, stiff material, while a low modulus of elasticity is a soft, pliable material. Also referred to as Young's modulus.

Peel: A pulling force concentrated along a thin line at the edge of a bond when a force is applied to a flexible substrate. Peel results in the highest stress concentration, causing failure at lower loads than observed in tension.

Shear: A force tending to cause deformation of a material by slippage along a plane parallel to the imposed stress. Shear forces cause surfaces to slide over one another.

Substrate failure: Failure of the substrate material rather than a failure within the adhesive (cohesive failure) or a failure at the interface of the interface of the adhesive and substrate. Substrate failure of a test sample is normally desirable, as it indicates a strong, repeatable bond between adhesive and substrate.

Tension: A pulling force exerted equally over a joint and oriented perpendicular to the bond that elongates the joint in the direction the force is applied.

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