



MATERIALS ENGINEERING

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Where adhesives beat mechanical fasteners

Designers find new ways to use adhesives that bond on demand.

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Structural adhesives have taken over thousands of bonding applications formerly the province of metal-joining techniques such as staking, riveting, and spot welding. Additionally, adhesives often perform better than metallic fasteners. Recent improvements in polymer cure technology have made them more “manufacturing friendly.”

Compared to mechanical joints, structural adhesives distribute loads over wider surface areas, eliminate or minimize corrosion, and damp vibration. They eliminate joint fatigue, provide electrical insulation, boost impact resistance, and reduce finishing. They can also join assemblies made from dissimilar materials including glass-to-steel-to-plastic that could not be mechanically joined. And in the case of LCMs (light-curing materials) and activator-curing acrylics, they greatly speed assembly.

ADHESIVE PRIMER

Structural adhesives transfer structural loads from one part to another. They fall into four broad polymer families: epoxies, cyanoacrylates, silicones, and acrylics. With the exception of silicones, these polymers have bond strengths on the order of 2,500 to 7,500 psi in tensile-shear mode. They also tolerate temperature



An LCM gives designers a 100% seal between the cap and the polycarbonate housing of an oxygenator. The housing passes the assembly point where the LCM is applied, the cap is slid over it, and UV light cures the adhesive in seconds.

swings as wide as 350°F and endure impacts of 10 ft-lb/in.² or greater. Structural silicones are something of an anomaly within the group. They have bond strengths of only 500 psi, but strength remains constant over a wide temperature range. Similarly, epoxy and acrylic tensile/shear strengths tend to fall as temperature rises, especially over their glass-transition temperatures. Despite these limitations, however, silicone, epoxies, and acrylics all find service in a diverse range of structural applications.

Epoxies were the first structural adhesives and have the longest tenure in vehicle, appliance, aircraft, and

The assembly of commutators for dc motors has historically involved metal processes such as soldering and brazing. However, both require postjoining finishing steps so the commutator can remain in balance rotate at high speed (typically 3,600 rpm). Securing the leads with low-mass LCMs in a hand-tool motor lets designers eliminate some postjoining finishing.



Lenses of fog-light nacelles were originally bonded and sealed to the housing using silicone. However, production was slow (24 hr) because of long cure cycles. Switching to LCM adhesives not only reduced adhesive curing time but also helped speed assembly by permitting pressure tests of bonded nacelles online.



plumbing applications. They have good strength and damage tolerance, and are relatively inert to most environments, particularly those bearing traces of salt. Thousands of automotive, appliance, and marine joints once tack-welded, staked, or bolted are now joined by epoxies.

However, handling and curing problems associated with epoxies make using them in automated-production systems difficult and slow. One-part systems need heat to catalyze. Two-part materials have a finite pot life, and

even the one-part systems can become too thick to flow with long atmospheric exposure. Dispensing lines must be frequently purged and cleaned. In both cases, the time-to-cross link is not short. So parts must sit in fixtures for a long time before they can be handled. Unfortunately, while cure times are relatively long, open times are frequently quite short. "Open time" refers to the period during which parts can be aligned after adhesive is brought in contact with one or more of the surfaces bonded.

Silicones are excellent sealants — actually more sealant than adhesive — because of their lower (500-psi) tensile/shear strengths. They are used to enclose lenses and nacelles and other containers exposed to weathering.

With exceptions, silicones have the highest temperature stability of all the adhesive families. This makes them the adhesive of choice for joints near manifolds, ducts, compressors, electrical conductors, and other heat sources. Silicones are extremely flexible and therefore good candidates for bonding joints that will see torsion and bending stresses. On the down side, silicones cure slowly. Bonded parts typically reach "handling strength" in about 30 min. Silicones also tend to migrate, depositing a slick film on surfaces they touch. And painting finished parts can be problematic.

Cyanoacrylates offer high strength with rapid cures. They cure by drawing humidity from the atmosphere. They need no heat for curing. Their rapid cure once made this class of adhesives candidates for automated-assembly processes. But limitations soon became apparent. Cyanoacrylates cure from the surface in. Therefore, joints must be thin. And although these joints are strong, they tend to be brittle, lacking toughness and durability.

Other drawbacks include a propensity for joints to cause stress cracking in some plastics and to have low moisture resistance. They also have handling problems and limited open time. Cyanoacrylates are preferred for parts that are not dynamically loaded and those where surface aesthetics are not important. This is because they cure leaving a white blush on part surfaces.

Structural acrylics are a recent addition. Chemically, structural acrylics are acrylated polymers of various types. The most common is acrylated urethanes, but there's also acrylated elastomers. They can be formulated to cure with activators and heat, as well as with photoinitiators to cure with light. Photocatalyzed acrylic adhesives are known as LCMs. Physical properties of these acrylic elastomers resemble those for epoxies but they are less chemical resistant.

Activator-curing acrylics and LCMs have several compelling advantages. One is an almost instantaneous cure or fixture. Bonded joints also have high peel strength and toughness. Compared to cyanoacrylates, they generally have superior properties, particularly in the areas of moisture and heat resistance.

There are also minimal cleanup or toxicity problems associated with LCMs. Any spill simply wipes up. And when catalyzed with light, they handle like any other

PROPERTIES OF STRUCTURAL ADHESIVES

| Material family | Epoxy (two part) | Silicone (one part) | Cyanoacrylate | Acrylic (LCM) | Acrylic |
|----------------------------------|---|--|---|---|--|
| Cure method | Reaction (two-part mix or one-part heat) | Moisture | Moisture | UV or visible light | Activator or heat |
| Time to attain handling strength | 15 min to 2 hr | 30 min | 10 to 30 sec | 0.5 to 5 sec | (Heat) 30 to 90 sec (20 to 30 min) |
| Time to attain full strength | 12 hr | 24 hr or more | 24 hr | 30 sec | 24 hr (20 to 40 min) |
| Tensile-shear strength,* (psi) | 5,000 | <500 | 3,500 | 2,500 to 4,000 | 2,500 to 3,000 |
| Useful temperature range, °F | -65 to 450 | — | -75 to 300 | -85 to 400 | -85 to 350 |
| Suitable substrate materials | Plastics, glass, metals | Glass, rubber, most plastics | Glass, rubber, most metals, thermoset plastics | Glass, most plastics (including plasticized PVC), most structural metals, ceramics, ferrites | Ferrites, metal, glass, ceramics, filled plastics |
| Properties of bonded joints | Good toughness and impact strength, excellent environmental resistance, good hardness, excellent gap filling (depth of cure almost unlimited), exothermic cure process (can damage some plastics) | Heat and weather resistance, low bond strength, excellent gap filling (depth of cure almost unlimited) | Excellent strength (with some materials, bond can exceed strength of substrate), poor impact strength, film "bloom," poor gap filling (depth of cure <0.010 in.), poor flexibility, properties degrade at high temperatures and humidity, can cause stress cracking in thermoplastics | High peel and tensile shear strength, excellent toughness and impact strength, good gap filling (depth of cure up to 0.5 in.), Selectable hardness and viscosity based on formulation | Same as for LCM except that gaps are limited to 0.020 in. and they cure only between surfaces unless they are a multicure grade which means that they are also photocatalized so that exposed surface can be cured with light. |

*Conventional tensile strengths have little relevance to adhesive bonds; strength is measured as "tensile shear" where bonded, overlapped surfaces are pulled in opposite directions, or as "peel" strength where one bonded surface is curled back over the other surface.

Values represent averages or ranges of those within polymer families.

A retrospective on conventional joints

Structural adhesives have taken over thousands of bonding applications once dominated by metal-joining processes such as welding, riveting, staking, and bolting. Here are some reasons why:

- Preload is critical in riveted or bolted joints because the joint draws its strength from the "traction" between the surfaces. Adhesives need no preload.
- Tensile loads concentrate on the fasteners or spots where joined surfaces are welded. In an adhesive joint, the entire surface of the joint carries the load.
- Dynamic joints tend to loosen or fail in fatigue. Adhesive joints have no known fatigue limit.
- High-strength fasteners are subject to hydrogen embrittlement, a phenomenon that does not apply to adhesive joints.
- Mechanical fasteners and welding demand mating surfaces conform to within a few thousandths of an inch of each other to be effective. Most adhesives, on the other hand, fill irregularities and gaps.

nontoxic waste.

Physical and environmental properties aside, the great advantages of both light and activator-curing acrylic adhesives are their fast-cure speed and ability to bond "on demand." This latter quality is related to their long open times. Structural acrylics can be applied to bonding surfaces and surfaces can be positioned in minutes or hours as long as the cross-linking process has not been initiated with an activator or curing light. Where the old cliché time is money applies, LCMs are nearly ideal. LCMs hit their handling strength in a fraction of a second (instead of minutes as with heat-activated systems). And full strength comes in a matter of a few more seconds, as opposed to hours with heat-activated systems. The LCMs present none of the handling problems associated with moisture-curing cyanoacrylates and silicones and bond well to a wide range of substrates.

Activator-curing systems bond close-fitting, opaque-metal, and ferrite surfaces in automated-assembly processes. Unlike LCMs, however, fixture rates are on the order of 30 to 40 sec. This has led to their

widespread use for bonding speaker magnets and magnets to housings for dc-motor assembly.

One-part LCMs work well in bonding applications where at least one surface is clear or for shallow potting, coating, or encapsulating. Assembled parts are ready to be handled almost as soon as the light hits the joint. Therefore, assemblies can be formed and even tested on line, in a continuous process. The net result is that the total cost of manufacturing parts with LCMs is typically 50% less than that for epoxies and almost 40% less than that for silicones. ■

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