Fundamentals of Industrial Adhesives

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Design and production engineers rely upon adhesives to provide solutions for structural bonding, cylindrical assembly, threadlocking, flange and thread sealing, and a range of other design challenges. Most any product used for work or leisure is produced using adhesives. Key applications include electrical and electronic devices, automobiles, aircraft, heavy equipment, consumer products, appliances, medical devices, loudspeakers, and sporting equipment.

Why Use Adhesives?

With their ability to bond many substrates including plastics, metals, rubbers, and glass, adhesives offer several major benefits over alternative joining methods like thermal joining and mechanical fastening. Adhesives distribute stress load evenly over a broad area, reducing stress on a joint. Since they are applied inside the joint, adhesives are invisible within the assembly. Adhesives resist flex and vibration stresses, and form a seal that can protect the joint from corrosion.

They join irregularly shaped surfaces more easily than mechanical or thermal fastening, minimally increase the weight of an assembly, create virtually no change in part dimensions or geometry, and quickly and easily bond dissimilar substrates and heat sensitive materials. Adhesives are one-size-fits-all, and assembly can be easily automated.

Limitations of adhesives include the amount of time it takes for the adhesive to fixture and cure fully, surface preparation requirements, and the potential need for joint disassembly.

Mechanical fasteners and adhesives can also work together to form a stronger bond than either method alone For example, using a mechanical fastener with a torque setting in tandem with a threadlocking adhesive improves the safety and quality of an assembly. The anaerobic threadlocker guarantees that the assembly will not fail or loosen, and that corrosion will not shorten the life of the fastener. Liquid form-in-place gasketing materials are used to dress conventional rubber, paper, and cork gasketing materials and can often completely replace cut gaskets. These liquid anaerobic gasket dressings fill surface imperfections in the mating flanges and extend the life of the gasket.

Adhesive Types

Of the multitude of adhesives currently available, there are eight families most commonly used. Each offers a unique combination of performance and processing benefits.

Regardless of application, both the adhesives and substrates must withstand the end use environment of the finished assembly. Adhesives should be compatible with the substrate and safe for the manufacturing environment, and should not slow down production.

Anaerobics are one-component adhesives that remain liquid when exposed to air. Once confined between metal substrates, anaerobic adhesives cure or harden into tough thermoset plastics that provide excellent environmental and temperature resistance.

Available in a wide range of formulations, anaerobic adhesives are commonly used for locking and sealing threaded assemblies, retaining bearings and bushings on shafts or in housings, and sealing metal flanges in place of cut gaskets. These materials are often used to enhance or replace mechanical joining methods, resulting in longer equipment service lives and reduced manufacturing costs.

Cyanoacrylates are high strength, one-part adhesives that cure rapidly at room temperature to form thermoplastic resins when confined between two substrates in the presence of microscopic surface moisture. Since cure is initiated at the substrate surface, these adhesives have a limited cure-through gap of about 10 mils (.010"). A wide variety of cyanoacrylate formulations are available with varying viscosities, cure times, strength properties, and temperature resistance.

Cyanoacrylates achieve fixture strength in seconds and full strength within 24 hours, making them ideal for high volume, automated production environments. Cyanoacrylates are frequently used to bond plastic, metal, and rubber.

Light Cure Acrylics are one-part, solvent free liquids with typical cure times of two to 60 seconds and cure depths in excess of 0.5 inches when exposed to light of the proper wavelength and irradiance. Light curing acrylics provide superior gap filling properties, and clear bond lines for improved aesthetics. Like cyanoacrylates, light curing acrylic adhesives are available in a wide range of viscosities.

Formulations are widely available with a secondary cure mechanism that allows adhesive in shadowed areas to cure completely. Light cure acrylics offer extended open times for positioning and repositioning parts, and high bond strength to a wide variety of substrates. They are available in ranging degrees of flexibility from soft elastomers to glassy plastics, and offer superior thermal, chemical and environmental resistance.

Light Cure Cyanoacrylates are hybrid technologies that combine the benefits of cyanoacrylates and light curing acrylics. Any visible adhesive fixtures instantly when exposed to proper light, while adhesive in the shadowed areas cures due to a secondary moisture cure mechanism. Light cure cyanoacrylates deliver minimized blooming/frosting, increased cure depth, rapid dry surface cure, high bond strength to elastomers, and compatibility with primers for difficult-to-bond plastics.

Ideal for high volume bonding applications, light cure cyanoacrylates are increasingly used for assembing medical devices, cosmetic packaging, speakers, electronic assemblies, and small plastic parts. Parts can be processed in seconds rather than minutes, as these adhesives deliver 60 percent of their final strength after only five seconds of exposure to light. Light cure cyanoacrylates are ideal for bonding applications involving overlapping, non-transparent parts.

Traditional **Hot Melt Adhesives** are thermoplastic resins that are re-flowed onto a bonding surface to facilitate assembly. Once cooled, the adhesive holds components together. Higher performance hot melts include ethyl vinyl acetate (EVA), polyamide, polyolefin, and reactive urethane. The primary benefits of hot melts are their ability to fill large gaps and to achieve high bond strengths as soon as they cool.

Polyamide hot melts are used in potting applications with demanding temperature and environmental conditions. Polyolefin hot melts provide good moisture resistance, superior adhesion to polypropylene substrates, and excellent resistance to polar solvents, acids, bases, and alcohols. Reactive urethane adhesives form thermoset plastics when fully processed, and perform well on difficult-to-bond plastics. These hot melts are processed at temperatures of approximately 250°F, up to 200°F cooler than other hot melt chemistries.

Epoxies are one- or two-part structural adhesives that bond very well to a wide variety of substrates, give off no by-products, and shrink minimally upon cure. Cured epoxies typically have excellent cohesive strength, very good chemical resistance, and good heat resistance. These adhesives can fill large volumes and gaps. The major disadvantage of epoxies is that they tend to cure much slower than other adhesive families, with typical fixture times between 15 minutes to two hours. While heat can be used to accelerate the cure of epoxies, the temperature limitations imposed by certain substrates such as plastics, can often preclude heat cure.

Polyurethanes are tough polymers that offer greater flexibility, better peel strength, and lower modulus than epoxies. Available as one or two-part systems, these adhesives consist of soft regions that add flexibility to the joint, and rigid regions that contribute cohesive strength, temperature resistance, and chemical resistance. By varying the ratio of hard and soft regions, a range of physical properties can be achieved.

Like epoxies, polyurethanes bond well to a wide variety of substrates and have similar fixture times, which can require racking of parts and subsequent work-in-progress. Polyurethanes offer good chemical and temperature resistance. However, long-term exposure to high temperatures will degrade them more rapidly than epoxies. When bonding with polyurethanes, moisture can impair both performance and appearance.

Similar to epoxies and polyurethanes, **Two-Part Acrylics** offer good gap filling abilities and environmental/thermal resistance. Two part acrylics can be formulated to fixture faster than epoxy and polyurethane adhesives and to offer improved adhesion to many substrates. Acrylics are highly flexible and bond well to many metals and plastics, making them good for applications where long term fatigue resistance and durability are required.

Fundamentals of Adhesive Joint Design

Stress plays a significant role in the success of a joint bonded with adhesives. Engineers must have a solid understanding of how stress is distributed across two mating substrates in order to design the strongest possible joint.

There are five types of stresses that commonly effect assemblies. Tensile stress (Figure 1) pulls an assembly apart, elongating it. Compressive stress (Figure 2) squeezes an assembly together. Shear stresses (Figure 3) pull parallel objects apart lengthwise, causing a sliding motion in opposite directions. Peel stress (Figure 4) occurs when a flexible substrate is lifted or peeled from another substrate. Cleavage stress occurs with inflexible substrates when a joint is forced open at one end.

Most adhesives offer excellent resistance to tensile, shear, and compressive stresses, but are very weak in cleavage and peel strength. In order to design the strongest possible adhesive joints, engineers should eliminate cleavage and peel forces from the basic joint design.

The best joint designs allow for maximum possible bond area, and rely upon both mechanical locking methods and the strength of the adhesive bond for long-term success. As the ends of a bond resist a greater amount of stress than the middle, by increasing the width of a bond, the bond area at each end increases and the overall joint is made stronger.

Five types of joints are commonly found in assemblies bonded with adhesives. A lap joint is formed by placing one substrate over another (Figure 5). In a joggle lap joint, one substrate wraps or molds around the other (Figure 6). A butt joint is formed by bonding two objects end to end (Figure 7). A scarf joint is an angular butt joint where the substrates are cut at an angle to increase bonding area (Figure 8). Finally, a strap joint combines a butt joint with one or two overlap joints (Figure 9a and 9b).

Any adhesive selected for an application must be able to resist the stresses that the device will encounter initially, and after exposure to the most severe factors possible in its end use environment. Heat and humidity usually have the most damaging effects on bonded joints; although exposure to solvents and ultraviolet light can also take a toll.

Environmental Exposure and Performance Concerns

Operating temperature is the single most important variable that qualifies an adhesive for a particular application. While a device mounted outside is exposed to cold, wet, sunlight, and other conditions, the maximum temperature is not likely to exceed 140˚F. An outdoor environment does not eliminate any of the potential adhesive chemistries.

However, within an electric motor housing for example, temperatures exceed the boiling point of water. At these temperatures, acrylic, urethane, and epoxy products are good candidates. Silicone and anaerobic gasketing products are used extensively to seal fluids that reach temperatures over 350˚F. Table 1 provides more adhesive temperature requirements.

Table 1: Temperature Constraints of Adhesive Technologies

Maximum Temperature	Appropriate Adhesives	Inappropriate Adhesives
160˚F	anaerobic, cyanoacrylate, epoxy, polyurethane, acrylic, light cure acrylic, light cure cyanoacrylate, most hot melts	low temperature hot melts
220˚F	urethane, acrylic, epoxy	standard cyanoacrylates
> 250˚F		cyanoacrylates
300˚F	acrylic, epoxy, most urethane	
>300˚F	epoxy, acrylic	
>400˚F	select acrylic, select epoxy	
450˚F	silicone	
<700˚F	high temperature silicones	

There are devices that operate in environments that cycle between extremes. Laboratory simulation testing is referred to as thermal cycling, thermal shock, or heat/humidity exposure. All materials expand when heated and shrink when cooled. This rate of growth/shrinkage is known as the coefficient of thermal expansion or CTE. The difference in CTE between two bonded materials will create stress on the bond joint.

There are two basic approaches to thermal cycling resistance. A very high strength, rigid adhesive may resist the applied stress. A softer, more flexible adhesive can absorb the applied stress by flexing or moving as opposed to cracking. Silicones and urethanes are typically softer and more flexible chemistries. Classic rigid chemistries include acrylics and epoxies, but many urethane modified or elastomer modified formulations are available.

Direct chemical exposure is typically limited to the edge of the very thin adhesive bond line. The actual geometry/bond joint design limits the adhesive's exposure to a chemical. Hard or dense adhesive systems like epoxies, acrylics, and anaerobic adhesives exhibit exceptional fluid resistance and may actually be fully immersed in the fluid with minor degradation. Silicones are widely known for their resistance to non-polar solvents like gasoline and oil for sealing applications, but, may swell, crack, or shrink if immersed in certain solvents. Water, particularly salt water, can cause corrosion on metallic surfaces. Adhesives typically form a protective surface seal at the bond line and actually prevent corrosion from occurring.

Epoxies, anaerobics, cyanoacrylates, and other acrylics exhibit good resistance to water, mild acids, isopropyl alcohol, ethyl/methyl based fluids, hydrocarbons, gasoline, and oils. For exceptionally harsh chemicals such as ammonia and potassium solutions; chromic, nitric, phosphoric, and sulfuric acid; or chlorine gas and pure oxygen, adhesives and sealants are not recommended.

Surface Preparation

For most applications, surface preparation is as simple as cleaning the surfaces with a solvent to remove oils, greases and other potential contaminants that could hinder bond strength. Other applications may require surface abrasion, chemical surface etching, heat treatment, plating processes or plasma treatment to obtain adequate adhesion. For difficult-to-bond substrates, surface primers can microscopically alter the surface to increase adhesion.

The most frequent causes of adhesive joint failures do not involve adhesive strength. Typically, adhesive joint failure may be attributed to poor design, inadequate surface preparation, or improper adhesive selection for the substrate and the operating environment. Thorough testing is critical during the design phase to ensure the success of an adhesive assembly during manufacturing and over the life of the device.

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