Acrylic Structural Adhesives

Features and Recent Advancements

Structural adhesives can replace welding, bolts, screws, spot welding, and other traditional attachments in a wide variety of industrial applications. Epoxy structural adhesives have historically been used to accomplish these types of applications, due to their high strength and exceptional durability. However, for many reasons which make them easier to use in a production environment, acrylic structural adhesives are becoming the preferred choice for many permanent bonding assemblies. This paper discusses the features and benefits of acrylic versus epoxy adhesives, describes the three major types of acrylic structural adhesives, and then introduces a family of relatively new acrylic adhesives (based on a patented curative technology) that provide significant advantages over traditional acrylic structural adhesives.

Structural adhesives have many potential benefits over traditional mechanical attachment techniques such as welds, rivets, screws, spot welds, and bolts. The list includes features like (1) providing uniform load distribution over the entire bond area to minimize stress concentrations, (2) eliminating the need to drill holes, perform rework on distorted substrates, remove protective coatings, or otherwise repair damaged materials that were mechanically attached together, (3) allowing the use of lighter weight materials, (4) reducing total labor cost, (5) providing a seal against moisture intrusion, (6) bonding dissimilar materials, (7) reducing the potential for galvanic corrosion, and (8) allowing unique designs and improved appearance due to hidden bond lines. The graph below shows the higher overlap shear strengths possible with structural adhesives as compared to several mechanical attachments with the same bond area.

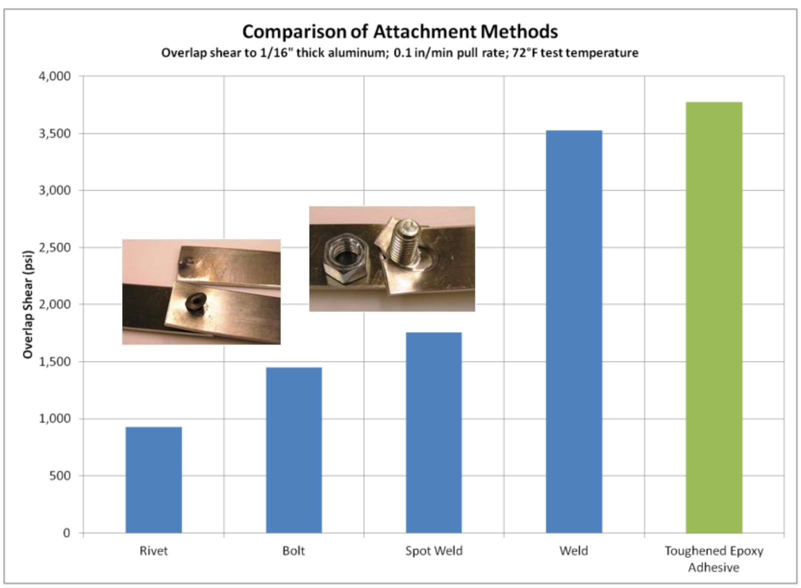

Figure 1: Comparison of total bond strength

There are actually several different types of structural adhesives that provide excellent holding power and outstanding long-term durability, but for most industrial bonding applications, by far the most common types are the two-part epoxy and acrylic structural adhesives. These adhesives have two components (Part B = base and Part A = accelerator) that are mixed together to initiate the cure which occurs at room temperature. They can range from low viscosity (for easy flow and wet-out of the surfaces) to paste viscosity (for high non-sag to stay in place during application). They also typically come in a wide selection of cure speeds, colors, and mechanical properties that can affect how well they adhere to certain materials. These adhesives are used in applications such as (1) bonding side panels and flooring materials in trucks and rail cars, (2) assembling frame and surfaces together in furniture, (3) bonding floor panels and drain pans in large air handling units, (4) constructing laptop computer housings, and (5) assembling sports equipment such as golf clubs, baseball bats, and snowboards.

Both epoxy and acrylic structural adhesives can be used for these applications, but these two adhesive chemistries also have significant differences in their use characteristics and final performance. Epoxy adhesives typically have the following benefits:

1. Highest bond strength and overall performance
2. Best durability (resistance to elevated temperatures, solvents, harsh environments)
3. Widest variety of properties (work life, cure speed, viscosity, flexibility, toughness)
4. Excellent adhesion to metals, glass, and woods
5. Long shelf life with room temperature storage

If an epoxy structural adhesive adheres well to the materials being bonded with the given surface preparation, the epoxy product will typically provide the highest performance and durability of any structural adhesive. The graph below demonstrates strength retention in an aluminum overlap shear bond after exposure to a wide variety of solvents and environmental conditions, with the epoxy adhesive providing somewhat better resistance than an acrylic structural adhesive (and both better than a urethane adhesive).

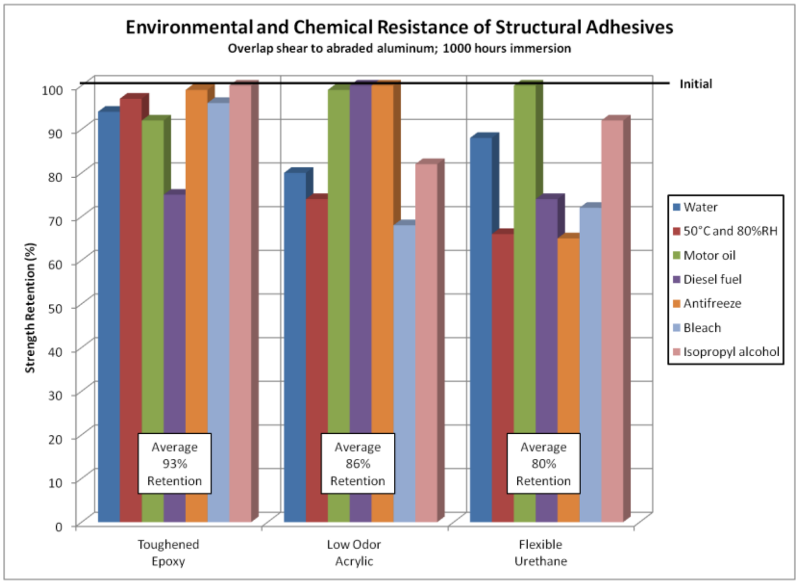

Figure 2: Strength retention after exposure to a variety of solvents and environments

However, there are several details about using epoxy structural adhesives that are disadvantages for this adhesive chemistry, particularly when compared to acrylic adhesives:

1. Clean, rough, dry surfaces (careful surface preparation) required
2. Much slower cure speed (for the same work life)
3. Lower adhesion to common plastics and paint systems

Typical surface preparation for epoxy adhesives in most industrial applications would include (1) solvent clean with acetone or isopropyl alcohol (IPA) to remove oils, contaminants, and fingerprints, (2) grit blasting or light abrasion with sandpaper or Scotch-Brite™ pads, followed by another solvent wipe to remove the abrasion debris. Conversely, acrylic structural adhesives will often provide the same level of bond strength with no or minimal surface preparation, including bonding to slightly oily surfaces such as the mill finish oil used on cold rolled steel. The graph on the next page shows this significant difference in the effect of surface preparation. The results for overlap shear strength to as-received aluminum parts increases greatly with the epoxy adhesive, from about 1,000 psi with no surface preparation up to nearly 5,500 psi with a chemical etch of the aluminum surface. On the other hand, the adhesion and bond strength with the acrylic adhesive was essentially constant for all surface preparation techniques, with all desirable cohesive failure of the adhesive during the tests. While the end user should always clean and prepare their surfaces prior to applying adhesive, the acrylic adhesive would be much more forgiving if proper surface preparation was not performed.

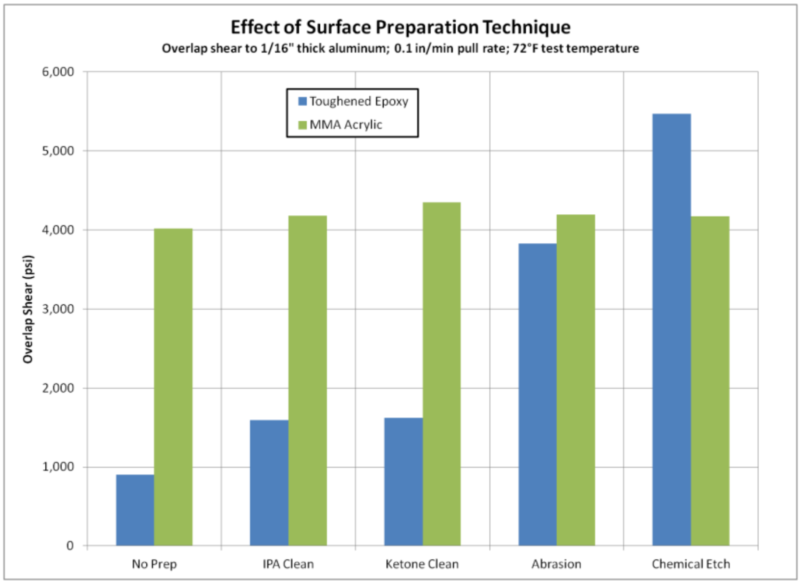

Figure 3: Effect of surface preparation on bond strength

For structural adhesives with the same amount of work life or open time (time to mix and apply adhesive and get parts assembled together), an epoxy adhesive cures much more slowly than an acrylic adhesive. A typical "5 minute epoxy" provides about 5 minutes of work life, but normally requires about 20 minutes to reach "handling strength" = 50 psi overlap shear strength and around 2-3 hours to reach "structural strength" = 1,000 psi overlap shear strength. There are acrylic structural adhesives with the same 5 minute work life that cure much faster and provide structural strength in just 10-15 minutes. The graph below demonstrates this huge difference in cure speed by showing the build of overlap shear strength as a function of cure time since mixing the two components and putting the bond together.

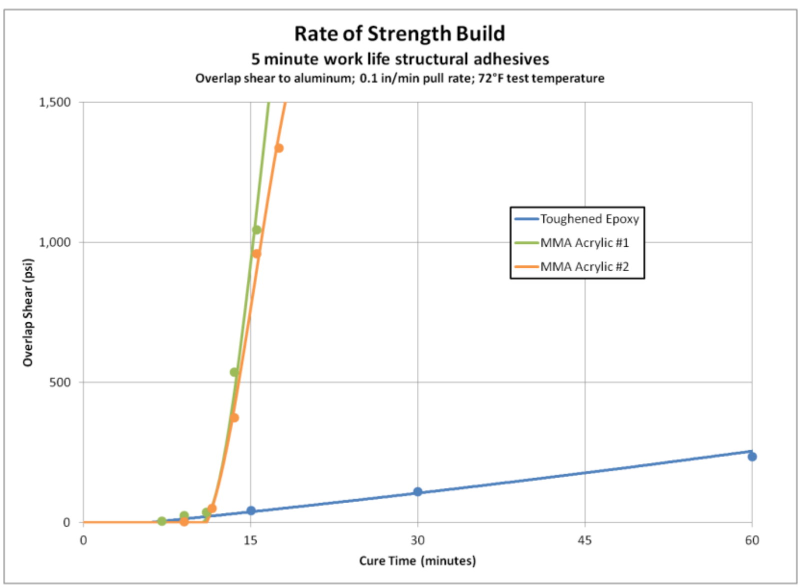

Figure 4: Rate of strength build of acrylic versus epoxy structural adhesives

With proper surface preparation, epoxy structural adhesives will typically provide excellent adhesion to bare metals, glass, and certain types of composite materials, plastics, powder coats, and paints. However, acrylic structural adhesives will usually bond all of these plus more types of polymeric materials. There are even unique formulations that will bond low surface energy (LSE) plastics such as polyethylene, polypropylene, and PTFE without the need for exotic surface preparation techniques. Acrylic adhesives also bond more types of powder coats and paint systems, which are becoming increasingly more common and more difficult to bond. The only materials that can sometimes be problematic for acrylic adhesives are bare woods, flexible rubbers, and concrete – epoxy adhesives often perform better on these specific surfaces.

While nearly every acrylic structural adhesive in the marketplace today contains the same active monomer, the end user should realize that there are actually three major families of acrylic adhesives with very different features:

1. MMA (methyl methacrylate) Acrylic
    a. Excellent adhesion and impact strength, especially on metals
    b. Strong odor, flammable
2. Low Odor Acrylic
    a. Excellent adhesion and impact strength, especially on plastics
    b. Low odor, non-flammable
3. LSE Acrylic

    Excellent adhesion to low surface energy (LSE) plastics – polyethylene, polypropylene, thermoplastic olefin (TPO), and PTFE

All of these acrylic structural adhesive types provide exceptional bond strength and durability – nearly that of epoxy adhesives – but with the advantages of having faster cure speed, being less sensitive to surface preparation, and bonding more types of materials. The two graphs on the next page show typical overlap shear strengths to several different materials, with high bond strength values and all cohesive failure mode (cured adhesive split) on the metals and epoxy composite, and all substrate failure mode (test panels broke) to the plastics and polyester composite. Any differences in measured values are due to either the cohesive strength or mechanical properties of the adhesive itself, but all results show excellent adhesion to all materials.

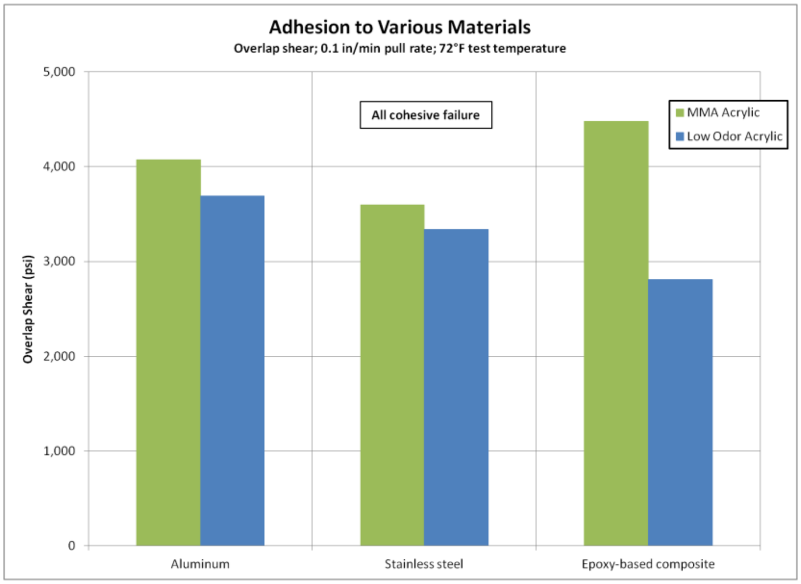

Figure 5: Bond strength to metals and epoxy-based composite

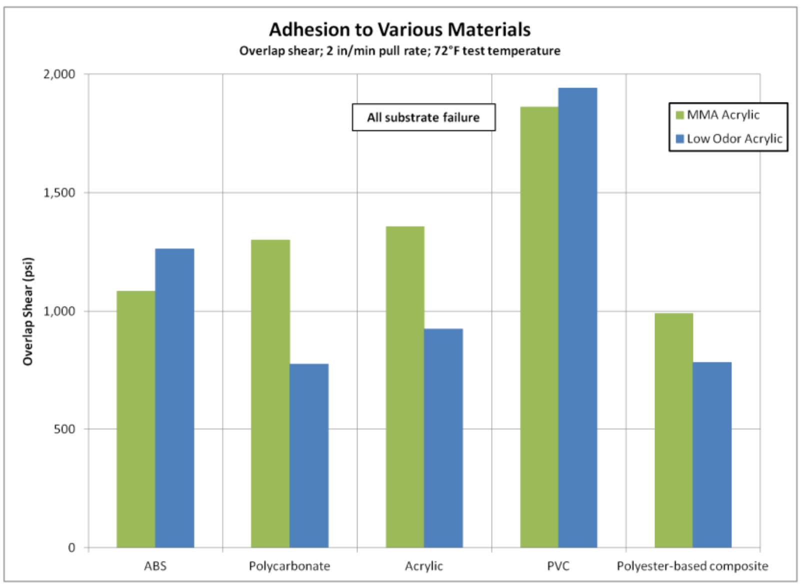

Figure 6: Bond strength to plastics and polyester-based composite

Of course, acrylic adhesives aren't perfect either, and there are some negative aspects of these products that are especially true of the MMA Acrylic family. These potential drawbacks include:

1. Strong odor (greater ventilation needed; possible worker health issues)
2. Flammable (should be stored in flammable storage cabinet)
3. Cured adhesives are naturally rigid (need to be toughened)
4. Lower high temperature limits (200-250°F for acrylics versus 300-350°F for epoxies)
5. Refrigerated storage (either required or recommended)
6. Shorter shelf life (6-12 months for acrylics versus 15-24 months for epoxies)

The graph below shows an example of these limitations, with typical acrylic structural adhesives having lower maximum operating temperature limits compared to epoxy adhesives.

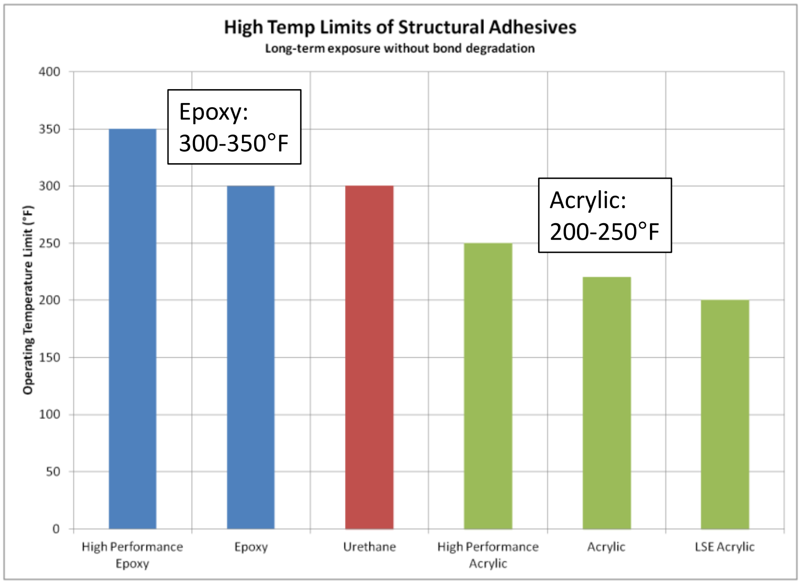

Figure 7: Maximum continuous operating temperature limits for different adhesive chemistries

To address these issues with standard acrylic adhesives, to improve their overall performance, and to make these adhesives even more user-friendly in a production environment, 3M™ invented a new-to-the-world line of "Next Generation Structural Acrylic Adhesives". These acrylic adhesives use accelerators based on a curative system used in dental restorative products – but modified for industrial-grade applications. This curative imparts many unique features to these new acrylic structural adhesives, including:

1. High toughness, peel strength, and impact resistance
2. Better high temperature resistance (up to 300°F maximum operating temperature)
3. Room temperature storage
4. 18 months shelf life
5. Color indication of proper mix ratio and adequate mixing of the two components
6. Glass spacer beads to control the bond line thickness

Products in this new adhesive line include both the "MMA Acrylic" and "Low Odor Acrylic" families, but not the "LSE Acrylic" products which still uniquely bond polyolefins and PTFE without additional surface preparation. The graphs on the next page demonstrate some of the unique performance attributes of these adhesives. Both of these tests are measures of the "toughness" of the cured adhesive – its ability to absorb energy under impact or peel loads, and its internal cohesive strength.

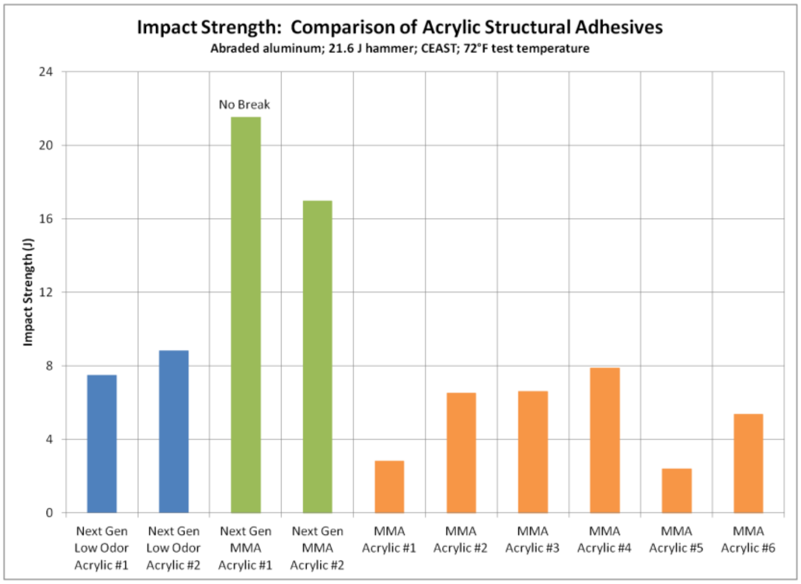

Figure 8: Comparison of impact resistance for various acrylic structural adhesives

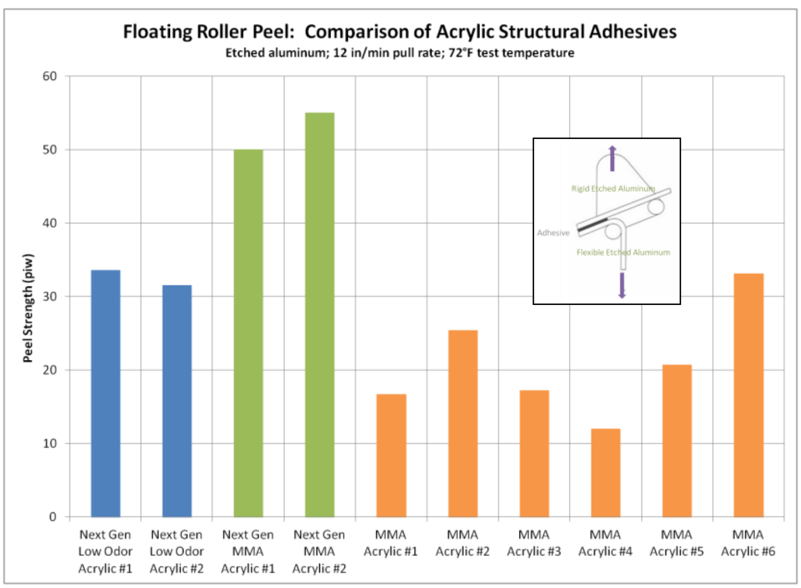

Figure 9: Comparison of peel strength for various acrylic structural adhesives

Whether studying impact resistance or peel strength of the cured adhesives, the new "Low Odor Acrylic" adhesives have equivalent or better performance than nearly every competitive acrylic structural adhesive, and the new "MMA Acrylic" adhesives have vastly improved toughness compared to those same products. In fact, the bonded aluminum lap shear specimens subjected to the pendulum impact test will typically result in distorted aluminum panels but completely intact adhesive bonds.

In addition to excellent performance, these Next Generation Structural Acrylic Adhesives also have outstanding durability and resistance to a wide variety of environmental conditions. The graph below shows overlap shear strength retention to both aluminum and PVC panels after exposing the cured bonds to 1,000 hours (about 6 weeks) of continuous exposure to these conditions, then pulling the samples shortly after removal from the harsh environment, with excellent strength retention in nearly every case. Except for a very few instances (such as continuous exposure to acetone, MEK, or high temperature water), the new acrylic adhesives provide outstanding resistance to solvents, chemicals, and high temperature/humidity.

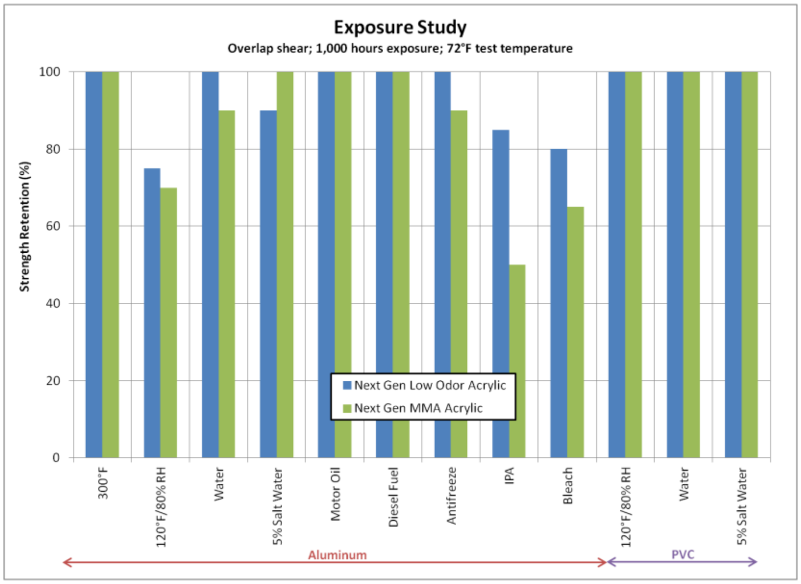

Figure 10: Overlap shear strength retention after long-term exposure to various conditions

Acrylic structural adhesives are easy-to-use products that come in a variety of packaging options. They are typically available in both small and large size two-part cartridges, which use either a manual or pneumatic hand-held applicator, and a static mixing nozzle which attaches to the end of the cartridge to ensure thorough mixing of the two components during dispensing. The cartridge systems minimize adhesive waste and are compact and portable. Otherwise, acrylic adhesives are also available in bulk containers for larger volume applications, using a meter-mix dispensing machine from qualified equipment suppliers.

Summary

Acrylic structural adhesives are extremely capable permanent bonding products with performance and durability approaching that of epoxy adhesives. With the introduction of the Next Generation Structural Acrylic Adhesives, they now have many unique features that make them easier to use in a manufacturing process:

1. Less sensitive to proper surface preparation
2. Faster cure speed
3. Bond to a wider variety of materials
4. Longer shelf life
5. Room temperature storage
6. Low odor option

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