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Adhesive Alternatives for Magnet Bonding Assembly

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ABSTRACT:

Magnet bonding is a critical processing step in many industries including but not limited to electric motor, speaker, and small engine manufacturing. Historically this was done using mechanical clips. These clips had to be custom designed for each application, required significant labor to install, and were not very reliable. Due to these manufacturing short comings adhesives soon replaced clips as a low cost and easily automatable alternative yielding higher strength assemblies. The objective of this article is to discuss the four adhesive processes used in magnet bonding and the benefits, limitations and considerations of each.

The four major process alternatives used in magnet bonding include: two step acrylics, external mix acrylics, heat cure epoxies, and induction cure epoxies. Henkel has recently launched new and innovative products under the Loctite® brand in three of these four chemistries which offer unique benefits over traditional alternatives. A real world case history will be used to show the benefit of adhesives vs. clips, the benefits and considerations of all four of these chemistries will be discussed and the specific benefits of Henkel's latest magnet bonding adhesives will also be covered.

ADHESIVES vs. MECHANICAL CLIPS

Today the majority of OEMs use adhesives to bond magnets to cans or laminations stacks but this was not always the case. Just a few years ago many electric motor assemblies were manufactured with mechanical clips, welds or rivets. These traditional fastening methods offered benefits like process familiarity, no excess chemicals in the plant, and ease of design. In early 2000 Henkel partnered with Siemens to create an Application Case History (ACH) highlighting the benefits obtained by switching from these traditional methods to liquid adhesives. This document is attached to the end of this article for reference. Adhesives offered performance advantages by providing better sound damping, vibration, and corrosion resistance. Switching to adhesives also allowed Siemens to eliminate the weight and spatial constraints of clips, decrease cost and work in process associated with welds and rivets, and increase the use of automation in the assembly process to help increase quality and minimize costs. The bullets below highlight the benefits of adhesives vs. clips, rivets, and welds.

Benefits of Adhesives

- Lower total cost
- Higher strength
- Easy to automate
- Increased sound damping
- Increased corrosion resistance
- Increased vibration resistance
- Minimizes SKU's in inventory
- Reduces weight
- Eliminates WIP versus welding
- Minimal clearance/space requirements

Benefits of Clips, Rivets, and Welds

- Familiarity in design and manufacture
- No chemicals required
- Limited clean up required

MAGNET BONDING ADHESIVE PROCESSING OPTIONS:

Magnet bonding can be achieved by a multitude of adhesive options depending on end use of the motor and manufacturing process requirements. Most major OEMs have gravitated towards on one of four major adhesive processing options to meet their needs – two-step acrylics, external mix acrylics, heat cured epoxies or induction cured epoxies. Acrylic and epoxy chemistries inherently maintain high strengths at elevated temperature and bonds well to metals and various magnet materials so it is no surprise that these are traditionally used. Acrylics tend to have lower maximum temperature resistance than epoxies. Epoxies tend to be more brittle than acrylics which can decrease their resistance to vibration and thermal cycling conditions. The following descriptions highlight the processing of these various alternatives and the major benefits and considerations of each. A summary of these descriptions in table form can be found attached to the end of this article.

Two-Step Acrylic:

Two-step acrylics require the use of a one-part liquid adhesive applied to one mating surface and a one-part liquid activator applied to the other mating surface. Both adhesive and activator are non reactive with the atmosphere until the parts are mated together. Once the parts are mated the activator initiates the reaction with typical fixture times ranging from 20 to 90 seconds. Typically the adhesive is a high viscosity (1,000 to 80,000 cP) product applied by a standard pressure time valve and the activator is a low viscosity (1 to 250 cP) sprayable material. Activators are available in solvent based and solventless versions. Solvent based activators are best suited for manual applications as the solvents tend to eliminate the possibility of over application of the active ingredient which can negatively affect bond strength. The solvents carry away this excess material by running off the part or flashing off into the air. Solventless activators are used in automated processes as the automation minimizes the possibility of over application and eliminating the solvents decreases cycle time by eliminating the need for a dry time to allow the solvents to flash off. In cases where porous magnets like ferrite are used the activator should be applied to the metal surface when possible. The active ingredients that initialize the cure are small in size and can be absorbed into small porosities in these materials. Applying the activator to the non-porous side will help minimize variation in active material present in the reaction and in return help achieve more consistent bond strengths in the final assembly. Many OEMs do not follow this practice but still achieve their desired strengths simply due to the high shear strengths achieved when utilizing two-step acrylics to bond metal to magnetic materials.

The major benefits of this technology include fast fixture, long open times, no mixing required, high impact strength, light cure versions to cure excess fillet material and acid free versions available. When comparing all of the chemistries evaluated in this report for magnet bonding the shortest cycle times can be achieved with two-step acrylics. In addition to the fast fixturing the adhesive and activator can be applied to the two mating surfaces and left for up to 2 hours before mating. After this point the activator dissipates from the surface and poor bond strength can result. This process requires no mixing of the two materials through static mix nozzles or any other means. This eliminates the possibility of poorly mixed product being a process variable contributing to poor bond strength or other performance characteristics. Acrylics are tougher and more flexible in nature than epoxies which allow them to exhibit much higher impact strength. These products are available in light cure versions which allow the OEM to cure any adhesive squeeze out from the bond line. This allows for immediate shipping or hermetic sealing of assemblies where out gassing is a consideration. Acid-free versions are available for OEMs that are required to meet certain green standards or where corrosion of the parts is a concern.

Two-Step Acrylic Continued:

The considerations with this product include limited gap fill, a need to control activator dispense, potential concerns with solvent based activators, and the fact that full cure is not achieved until 24 hours after mating the adhesive and activator. Due to the surface initiated cure of this option the ideal cure through depth is between 0.002 to 0.004 inches. Since the cure of the material is initiated by the activator typically it starts on one side of the mating surfaces and must propagate through the adhesive. As the adhesive begins to cross-link and cure the migration of active species through this material decreases and in turn the percent cure decreases as well. While some of these products can cure through depths as great as 0.040 inches the ideal circumstances to maximize bond strength are significantly smaller than this. Also inherent in this process is the need to control two dispenses – adhesive and activator. When using solvent based activators their can be concerns with operator health and safety as well as potential flammability concerns. Typical solvent based activators are only used in manual operations where production volumes minimize the possibility of creating a flammable environment in the work place. Placing the application under a simple fume hood or active charcoal air filter is a cost effective way to eliminate all of the concerns associated with solvent based activators. While two-step acrylics achieve the fastest fixture of all of the products discussed full cure will not be achieved for 24 hours. Typically the major concern on a production line is how long one has to wait after adhesive application before the parts can be moved. This is defined as the fixture time so for most applications the 24 hours to full cure is not a critical issue.

External Mix Acrylics:

External mix acrylics are a two part adhesive solution requiring the mixing of part A and B to initiate the reaction and cure the adhesive. Both parts A and B are close to 15,000 cP viscosity. Typically they are dispensed from two valve heads in close proximity to one another but about one foot above the parts – see picture on the left. When the dispense is actuated the product streams hit in midair and mix together in the air as they fall onto the part, hence the name, "external mix acrylic." Typically part A is yellow and part B is blue so that the change of color to green can be used as a visual indicator of mixing. The height above the part, angle of the valves, and product pressure can all affect the cured properties of the adhesive on the part so careful consideration should be placed on optimizing these variables for each process.

The major benefits of this product and process include fast fixturing, no liquid activator, no static mix tips, single step application, and acid free formulations are available. Typical fixture times for external mix acrylics are between 60 to 90 seconds. These are slightly slower than the two-step acrylics but faster than both the epoxy alternatives we will talk about later. It is a single application that requires no liquid activator. This eliminates the need for spray dispense systems, the concerns associated with solvents in the work place, and in general simplifies the process. Since the products are external mix they do not need static mix tips for mixing. This eliminates the capital cost for mix tips which can add up over a year of production. It also eliminates the need for purging of product between runs to ensure that the material does not cure in the nozzle. In addition acid-free versions are available for OEMs that are required to meet certain green standards or where corrosion of the parts is a concern.

External Mix Acrylic Continued:

The considerations with this chemistry include limited open time, poor control of dispense location, and the fact that full cure takes one hour. As opposed to two-step acrylics where the reaction of the two parts is not initiated until the substrates are mated, with external mix acrylics the reaction is initiated when the two adhesive parts intersect in the air. A negative side effect to the fast fixture is the short open time. The adhesive is going to cure within 60-90 seconds after dispensing – whether it is in a bond line or not. Premature curing can lead to shimming of the bonding surface due to cured product and decreased strength of the final assembly. Due to the need for the product to fall a height of approximately one foot to achieve adequate mixing it can be difficult to dispense precise bead patterns, particularly on small parts. While the beads tend to fall directly down from the point of intersection if dispense location and minimization of squeeze out for aesthetics or performance are critical this chemistry may not be ideal. Finally the adhesive will not be fully cured for 24 hours. As discussed previously fixture time is typically a bigger concern for most process lines and the fixture time of 60-90 seconds make this one of the faster chemistries in this regard.

One-Part Heat Cure Epoxies:

One-part heat cure epoxies are a single component material whose cure is initiated by applying heat. These products are typically refrigerated during storage to maximize shelf life and cured performance. They are actually made up of an epoxy resin that is liquid at room temperature and a catalyst that is solid at room temperature. Typically the catalyst will liquefy at somewhere between 200 and 300 °F and this will initiate the reaction. Typically the higher the temperature the faster the reaction will take place but there is a critical temperature that if exceeded will have a negative effect on the final performance of the cured product. After heating and cooling to room temperature the product is fully cured and will exhibit properties typical of an epoxy – high shear strength, good chemical resistance, and high durometer.

The major benefits of one-part heat cure epoxies include high gap fill, single component dispense, excellent temperature resistance, full cure in one hour, and all epoxies are inherently acid free. Since the cure of a one-part heat cure epoxy is not reliant on surface initiation in theory the gap fill of this chemistry is infinite. Due to the exothermic nature of the epoxy cure reaction however excess volumes of adhesive can create significant heat which can have a detrimental effect on the cured performance. In general cure through depths of up to 0.50" are acceptable. This is a single component product with no mixing required that utilizes a standard oven to cure – making it the simplest processing product of the group. In general epoxy chemistry is going to give you the highest temperature resistance of any organic based adhesive so these products will be your best bet for service temperatures in excess of 300 °F. Unlike the acrylic chemistries as soon as the one-part heat cure epoxies are cooled they have achieved full cure which can be a benefit in certain applications. Epoxies in general are acid free.

One-Part Heat Cure Epoxies Continued:

The considerations with one-part heat cure epoxies include the capital investment in ovens required to get started, high costs of energy required to heat the product, work in process associated with batch heating and cooling, and the average one hour cure time. Depending on the required throughput the investment in ovens required to cure these epoxies can range from \$1,000 to \$1,000,000. Depending on your production level this cost can price you out of this chemistry. On top of this initial investment in ovens the cost of energy has risen to a point where utilizing oven cure can be a very costly day to day operation. Depending on the thermal cycle required for curing these products and the temperature of the part after curing the cool down process can take between 10 minutes and multiple hours. With the move of many manufactures to a lean production line the queues of work in process inherent in batch heating can be undesirable. Finally, unlike acrylics that have a fixture time of 60 to 90 seconds heat cure epoxies require significantly longer time to cure depending on the part and oven thermal cycle. This can require costly tooling to hold the parts in place while the adhesive fixtures.

One-Part Induction Cure Epoxies

One-part induction cure epoxies are very similar to one-part heat cure epoxies in that they require heat to initiate cure. The between these products is a small change in chemical composition and a large change in the heat source utilized to initiate the cure. Instead of relying on a traditional oven for heat these products utilize induction coils that create magnetic fields to heat the parts – see image on the left. The magnetic fields created by the induction coils induce an electrical current in any metal within their field and depending on the electrical resistance of these materials they heat up at different rates. By adjusting the frequency and power of this field a significant amount of heat can precisely be generated within an assembly in a short period of time. The small chemistry difference between induction cure and tradition heat cure epoxies is that induction cure epoxies contain a small amount of ferrous metal materials in the formulation. These heat up in the induction field and help ensure rapid and even heating throughout the adhesive volume providing more consistent cured properties. Induction heating can consistently and precisely generate temperatures upwards of 200 °C in an assembly in one minute or less. This fast, high temperature generation leads to shorter cure times, faster fixturing, and a shorter overall process.

The major benefits of one-part induction cure epoxies are the fact that they are a single component, have high gap filling capabilities, have excellent temperature resistance, achieve full cure in one minute, and as epoxies are inherently acid free. Much like oven cure epoxies these products are a single part that requires no mixing and typical minimal investment and maintenance in dispensing equipment. Aside from the concern of heating above the critical temperature created by high exotherming of excessive volume these products have a maximum cure through depth of approximately 0.50 inches. Induction cure epoxies have exceptional temperature resistance and are acid free. The major benefit of this processing option vs. oven curing is the speed of cure. Because the heat is created from the "inside out" of the assembly and the speed at which the parts are able to be heated full cure of the adhesive can be achieved in a matter of seconds.

One-Part Induction Cure Epoxies Continued:

The considerations with one-part induction cure epoxies include the capital investment required in the induction coils and equipment, the fact that the parts need to cool after heating before moving on in a process, and the unfamiliarity of this technology. Like any customized product induction coil costs vary significantly based on complexity of the design. In general induction equipment can cost between $2,000 for a stand alone system to $100,000 for an automated turntable design. While the heat can be created quickly the parts still need to be cooled before they can be moved on in the process. While the overall time for induction curing is less than oven curing this is still a required part of the process that can create work in process. Finally, similarly to why adhesives were slow to take over for mechanical clips induction curing is not familiar to many of the designers and process engineers. People are slow to switch to new and unproven technology until they have seen significant benefit in the process or performance when compared to their current way of doing things.

Table I shows a summary of the benefits and limitations of the four adhesive chemistries described above.

Table 1. Comparison of Adhesive Types for Bonding Magnets

Attribute		Acrylic, Two Step	Acrylic, External Mix	Epoxy One-Part Heat Cure	Epoxy, One Part Induction Cure
Overview					
Key Benefits		Fast fixture	Fast Fixture	Single component	Single component
		No mixing	No liquid activator	High gap fill	High gap fill
		High impact strength	No static mix tips	Excellent temperature resistance	Excellent temperature resistance
		Light cure available	Acid-free available	Fully cured in one hour	Fully cured in one minute
		Acid-free available	Single step	Acid-free	Acid-free
Key Considerations		Limited gap fill	60-90 second open time	Must allow parts to cool	Must allow parts to cool
		Must control activator dispense/application precisely	Dispense location difficult to control on small magnets	Curing equipment required	Curing equipment with part specific coils required
		Activator may contain solvents	Fully cured in 24 hours	One hour cure time	
		Fully cured in 24 hours			
Performance					
Gap Fill	Ideal	0.002 - 0.004"	0.002 - 0.006"	0.004 - 0.006"	0.004 - 0.006"
	Maximum	0.040"	>0.050"	>0.50"	>0.050"
Temperature Resistance	Typical Range	-65 to 300°F	-65 to 300°F	-65 to 350°F	-65 to 350°F
	Maximum	400°F	300°F	400°F	375°F
Impact Strength (steel)		Excellent	Excellent	Good	Good
Processing					
Fixture Time	Average	1-2 min	90 seconds	30-45 min	2 min
	Fastest	15-30 seconds	90 seconds	15-30 min	30 seconds
Full Cure		24 hours	24 hours	1 hour	Once cooled it is not going anywhere
Loctite Brand Products					
		331™ - Best in class	3060™ - Best in class	9432NA™ - General purpose	E-220IC™ - Magnetic substrates*
		392™ - General purpose		3984™ - Fast cure	E-230IC™ - Non-magnetic substrates
		326™ - Fast cure		3985™ - High Viscosity	
		324™ - High temp. & impact			
		332™ - Severe environment			
		3920™ - Light cure			

INNOVATIVE MAGNET BONDERS FROM HENKEL

Henkel recently launched three new magnet bonders under the Loctite® brand to compliment their line of historically proven products in this market. These products include Loctite® 331 – a two-step acrylic, Loctite® 3060 – an external mix acrylic, and Loctite® E-220IC – an induction cure epoxy. These products were formulated as "next generation" products that represent a truly innovative leap in performance, not just a small iterative advance in technology.

Loctite® 331:

Loctite® 331 is a two-step acrylic that can be used in conjunction with Loctite® 7387 (solvent-based) or Loctite® 7380 (solventless) activator. Traditionally with this chemistry there was a trade off between fixture time and hot strength or strength measured at elevated temperature – a critical property for electric motor magnet bonding. The faster the fixture time the lower the resistance to elevated temperatures. Loctite® 331 was formulated to break this traditional limitation to create a product that not only fixtures faster than any other two-step acrylic in the Loctite® line – 20 seconds – but also is able to withstand temperatures upwards of 350 °F – the maximum for this chemistry. In addition to this major technological breakthrough this product was also formulated to be acid-free and to increase the cure through depth, two other traditional considerations with this chemistry type.

Loctite® 3060:

Loctite® 3060 is an acid free external mix acrylic designed to out perform any competitor in the market place. This material was formulated as an acid-free product that meets or exceeds the performance properties of its competitors that contain acrylic acid. Along with the launch of this adhesive the Loctite® equipment offering has been expanded to include standard fixturing, valve recommendations, and process suggestions to maximized adhesive performance.

Loctite® E-220IC:

Loctite® E-220IC is an induction cure epoxy designed to work with ferrous and/or metal substrates – ideal for magnet bonding. Extensive research was done to maximize the performance of this product optimizing all of the process variables including power, frequency, coil design, temperature profile, and time in the induction field. Along with the launch of this adhesive the Loctite® equipment offering has again been expanded to include standardized induction cure equipment as well as customized automated solutions to meet the needs of any application.

CONCLUSION:

In summary Henkel has historically been a partner with the electric motor industry, specifically when it comes to options for magnet bonding. For this bonding application there are four major processes traditionally used in the field, which include two-step acrylics, external mix acrylics, heat cure epoxies, and induction cure epoxies. Each of these chemistries has benefits and considerations inherent in the product and the associated processes that should be considered when deciding on an adhesive for a given application. Henkel has recently launched three new magnet bonders under the Loctite® brand that while falling into these traditional chemistries have significant benefits versus the existing products in the market. Henkel's broad product offering and ongoing engineering support should give you confidence that if you chose to partner with Henkel for your adhesive needs you will be getting the product and process that is right for your application.

RECOMMENDATIONS:

Henkel Corporation recommends that you test all new adhesive applications under simulated or actual end use conditions to ensure the adhesive meets or exceeds all required product specifications. This data was generated under highly controlled laboratory conditions, and may not represent actual assembly conditions. Since assembly conditions may be critical to adhesive performance, it is also recommended that testing be performed on specimens assembled under simulated or actual production assembly conditions.

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