Polymeric Material Performance in the Harsh Environments of Jettable Fluids

Susan Krawiec, Chih-Min Cheng and Robert Palmer
Emerson & Cuming
Billerica, Massachusetts

Abstract

Jettable fluid delivery and other MEM devices are being exposed to more extreme environments. These packages rely on polymeric materials as structural adhesives for various substrates. These polymer materials also provide protection from mechanical shock; extreme thermal cycles, and can withstand long exposure to harsh chemical environments of the jetting fluids. This paper will compare performance of acrylate, epoxy and silicone adhesives with exposure to the harsh environments of solvent, aqueous, UV and hot melt inks. Physical properties of the adhesives will be monitored before and after exposure to the inks.

Background

The manufacture of jettable fluid delivery and other MEMS devices requires the assembly of a variety of components. The substrates often consist of multi-layer silicon die, thin and thick wall engineered plastics, noble metals, and flexible circuits. The components can be assembled through the use of molding materials, mechanical fasteners, or structural adhesives. Structural polymeric adhesives are most often the ideal choice because they mate the substrates to form a continuous surface. They then become the barrier holding fluids within the device and also prevent the outside environmental contaminates from entering the device.

A typical device will use a number of adhesives. For example, the electrical connections from the flexible circuitry connected to the silicon jetting device have to be protected from the chemical inks within the device and from external contaminates. A uniform bead of a polymeric adhesive may be dispensed to surround these sensitive wires and encapsulate them. In addition to protecting the contacts from corrosion, the adhesive also cushions these wires from mechanical damage caused by equipment contact or dropping. This same material may also be used to fill the spaces or gaps created in the part design. Dielectric, thermally conductive or electrically conductive die attach adhesives fixture the silicon MEMS device in place orienting openings for fluid pathways from the ink reservoirs. Only adhesives are able to flow around and under components filling the area with low expansion material that will compensate for the differences in the expansion rates of the various components. Adhesive selection is dependent on many variables, but will primarily depend upon the substrates, production process options, and desired final finished product properties. There are some applications where the substrate can not withstand high temperatures. In these cases, adhesives have additional selection criteria. In addition, there is a driving force to reduce size and increase performance. For example, consumer printers have permanent electronic devices that must perform for the entire printer's life. While commercial industrial print heads fire jets almost continuously with harsh media.

Introduction

Processing

The application method selected for processing is influenced by the application. If the adhesive must self-level, fill a gap, or flow under another section of the part, it must be a lower viscosity fluid with no sag resistance. Most often this type of material will be applied by syringe. Syringe, stencil and screen applications require the adhesive to have body or thixotropic structuring. This type of rheology will help the adhesive hold its shape once it is on the substrate prior to cure. A balance must be established between applicator ease and control of the material once it is on the substrate. Stencil and screen printing are ideal for large smooth surface areas and provide the most uniform adhesive thickness.

Reliability

Adhesion

Adhesion tests often must be developed for a specific part design. Some standard tests can be used for screening various adhesives. One such test is an Instron tensile lap shear test, which can be developed for a specific grade of plastic or metal. The overlapped part can be tested at various temperatures or before and after exposure to the harsh chemical environment. If dissimilar substrates are to be bonded, a component shear strength test could be developed. In this test, a shear force is applied to an edge of a substrate, such as a die, and then pushed off of the surface it is bonded to. Often times the best test is to actually assemble a "real" part and observe performance over the anticipated useful life, while exposing the part to expected environmental hazards. Upon failure, it is important that the failure mode be determined. Distinguishing failure mode requires identification of what failed (the bond or the substrate). In addition, the mode of failure may be related to the chemical environment, mechanical or thermal stress, incomplete cure, or improper surface preparation.

Low Ionic Species

Adhesives with low ionic species such as halides may be desirable for wire bonds or lead encapsulation. Water from the ink media along with bias current during operation can extract anions such as chloride from low purity adhesive components. If the polymeric material, in conjunction with water, contacts the wire bond, corrosion will occur. Over time, the wire bond may fail and cause a short making the device fail. Raw material selection for the adhesive can control the level of extractable species and extend device life. This the adhesive design, raw materials would be specially selected to have a low level of contaminates.

Curing

Adhesives may be thermoset or thermoplastic. Once a thermoset is cured it can not be reversed or easily re-worked. A thermoplastic can be applied from solvent or melted into place with a heated applicator. Typically, it is warmed until it is fluid and then poured into a casting. The higher the melt temperature, the viscosity is lower. The material can be applied to the substrate at room temperature or the substrate may be pre-heated to extend flow and open time until it is mated with another substrate. This process can be completed in seconds with the part attaining its full strength. Re-applying heat will soften and re-melt this adhesive for repair or re-positioning. Careful adhesive selection is required to assure the adhesive does not soften during normal device operating temperatures. An alternative to thermoplastics is thermosetting hot melt adhesives. Once applied, a secondary moisture post cure crosslinks the material to an irreversible solid.

Another type of fast, low temperature curing thermoset is acrylates. UV curable adhesives are cured very close to room temperature with a high intensity UV lamp. This type of adhesive requires a line of site exposure to the UV lamp. Some UV curable compounds contain additional curative to crosslink areas shielded from the UV source. These “shadowed areas” require a second curing step consisting of either heat or moisture. Most often UV curable materials are used in open areas and are applied as coatings, encapsulants and gap fillers.

One and 2-part thermoset adhesives provide controlled curing options. In the case of a 2-part chemistry, the cure is initiated with mixing. Work life can vary from minutes to days with these products. Materials with limited work life require quick assembly, but can be handled immediately. Full properties can be reached faster with an elevated temperature post-cure. One-part thermosets have a long open time and require a high temperature cure (typically above 100^{o}C) to achieve maximum properties.

Hot melts and UV curable adhesives are the fastest curing at the lowest temperatures.

Physical Properties

The physical properties of the polymeric adhesives will depend upon the application requirements. Adhesives product ingredients selection criteria are based on the most critical design requirements. These requirements may be:

Coefficient of Thermal Expansion

If an assembly is thermal cycled, the various device substrates will expand and contract at different rates. The moving substrates can cause small fractures that may cause premature failure. Low coefficient of thermal expansion (CTE) adhesives can match the movements of the different substrates reducing component fatigue. Adhesives compounded with fillers will reduce the CTE mismatch over a wide temperature range. The filler will reduce the effect of the organic polymer movement over a wide temperature range. High filler concentration levels are needed to minimize CTE changes.

Thermal and Electrical Conductivity

Noble metals, such as silver, are compounded into adhesives to make an electrical connection between the die and the wire bonds. These metals are also thermally conductive and will, therefore, dissipate heat. Non-electrically conductive fillers such as boron nitride will simply conduct heat.

Modulus

Some assembly applications such as die attach and lead encapsulation require high modulus, or stiff support adhesives, for high strength. The adhesive must be hard and stiff to resist impact damage. Conversely, a low modulus, flexible, rubber adhesive is used for potting and gap filling. The lower modulus, allows the adhesive to move with the substrates. The adhesive absorbs and dissipates the stress so the assembly stays intact. Modulus is used monitor the resistance to harsh chemical environments.

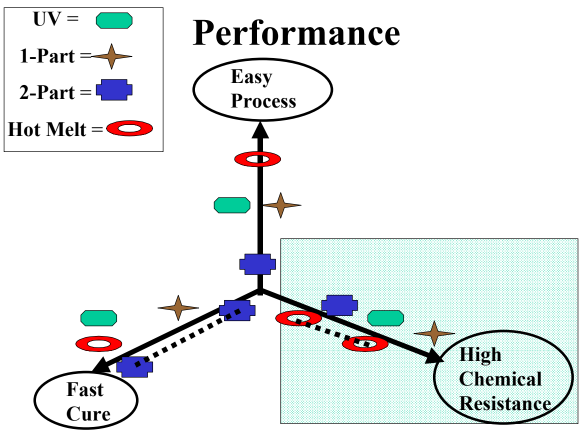
Absorption

Exposure to the environment of the ink may effect the adhesive properties. The adhesive must resist the chemical environment both in operation and storage. The ink components may be very aggressive to the adhesive and cause degradation with time. Monitoring weight variation with ink exposure is a way to identify compatible materials. See figure 1.

Reliability Testing

Adhesives may be evaluated by: analytical test methodology, mechanical tests on the assembly substrate, environmental testing in the chemical media at ambient or operating temperature. Most often a combination of tests are required to match the adhesive with the application. The ideal is to build a complete part and monitor performance over time. This “real” testing often is most important identifying the most compatible adhesive for the ink environment. Will the glue hold all the pieces together? Is there a way to identify or screen adhesive and ink combinations to find the combination that will be adaptable to an assembly process without building a finished part?

The first step is to identify which materials will withstand the ink media in the working environment. Monitoring adhesive properties after ink exposure to initial properties does this.



Approach

Work focuses on 3 types of adhesives: acrylates, epoxies and silicones with 2 test conditions with ink exposure. The first test condition is to monitor ink absorption by the inks. The longer the adhesive is immersed in the ink the greater the chance that ingredients in the ink will be absorbed into the polymer matrix. Most often there is surface absorption only. The ink does not migrate through the bulk of the adhesive mass. On occasion the ink components and the adhesive are not compatible and there will be a large weight change. The second test condition, dynamic mechanical analysis (DMA), is used to monitor flexibility changes as the cured castings are exposed to the inks. As the adhesive is aged in the ink 2 things may occur. First, the adhesive may continue to crosslink causing the modulus to increase. Second, the adhesive absorbs the ink, which in turn plasticizes the adhesive reducing the modulus.

Conclusion

Narrowing adhesive selection to a manageable few for reliability testing requires that the key properties be defined and prioritize to balance all properties for overall performance. Screening adhesive and ink compatibility for attack will identify general classes of chemistry that should perform the best. With this knowledge further adhesive selection criteria such as cure conditions or processing ease will narrow product selection further for additional product screening.

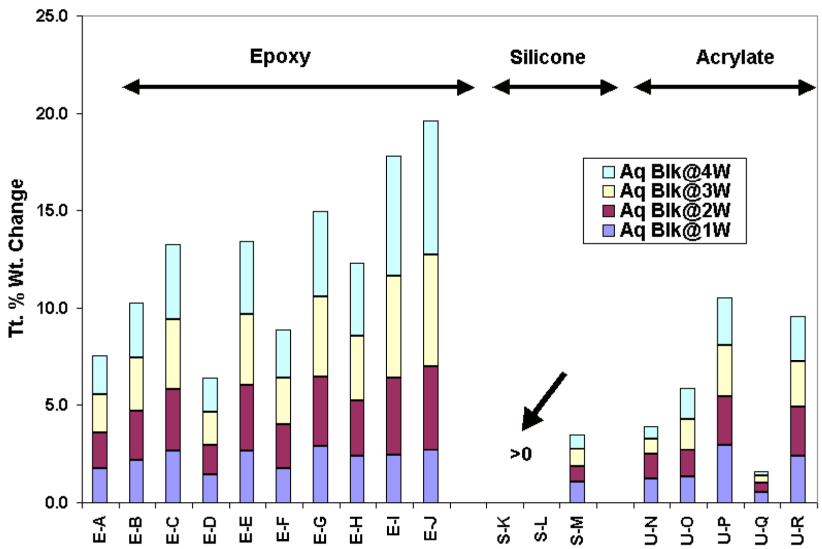


Figure 1. Percent weight change after ink immersion for 1 through 4 weeks in an aqueous black ink for epoxy, silicone and acrylate adhesives. Note: some adhesives had a weight loss.

Biographies

Susan Krawiec is a Sr. Project Supervisor in New Product Development of Emerson & Cuming Inc. Billerica MA. Currently, Susan supports the development of adhesives for the ink jet printer market. Susan holds BS in Chemistry from Merrimack College.

Dr. Chih-min (Stone) Cheng is a Sr. Development Associate in New Product Development of Emerson & Cuming located in Billerica, MA. Currently, Stone leads a group that develops structure adhesives and conductive adhesives, coatings and films for component interconnects and thermal interface applications. Stone holds a Ph.D. degree in macromolecular science from Case Western Reserve University.

Robert Palmer holds a BS degree in Finance from Bentley College. Robert has held a number of roles at Emerson & Cuming since joining the company in 1998, providing a diverse range of polymeric material applications experience. Currently, his responsibilities include global coordination of Emerson & Cuming's adhesives product line for the ink jet printer market segment. Robert is based out of Emerson & Cuming's global headquarters in Billerica, MA.