Causes for Separation in U.V. Adhesive Bonded Optical Assemblies

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ABSTRACT

This paper describes a systematic problem solving approach used to determine causes for separation that may occur in bonded optical assemblies when using an ultraviolet curing optical adhesive. Many interrelated factors in the bonding process can influence the integrity of the bond. By characterizing and diagramming these factors, separation causes can be identified and eliminated thus reducing problem solving time. The U.V. adhesive bonding process characterization can also be used a guide for process analysis and optimization.

1. INTRODUCTION

The design of optical systems often requires the use of optical adhesives during assembly. When producing systems for military or government use, Military Specifications such as MIL-O-13830 that specifies the requirements of cemented optics are used. Section 3.6 of MIL-O-13830 specifically addresses defects at the cemented interface and also edge separations. To comply with these requirements, and to eliminate defects, it is necessary to reduce causes for variation in the bonding process. To assist in this effort, a quality tool that was developed by Dr. Kaoru Ishikawa was used. The Cause-and-effect diagram, often called the Ishikawa diagram or, by reason of its shape, a fishbone diagram, is used to list possible causes for a quality problem. Using empirical studies and personal investigations, an Ishikawa diagram was developed for causes of separation in cemented optical components using ultraviolet (UV) curing adhesives (Figure 1). Although this is by no means an all inclusive list, it does provide a framework for analyzing many of the significant process variables. The diagram can be expanded to list other pertinent factors that affect UV bonding quality characteristics. Following is a description of the major branches detailing the process variables shown in Figure 1.

2. ADHESIVE

Selection of the UV curing adhesive is of course dependent on the design specifications. Design, process, and manufacturing engineering should work concurrently with adhesive suppliers and manufacturers to assure that the selected product will meet the design requirements. Physical properties such as the modulus of elasticity, coefficient of thermal expansion, viscosity, refractive index, tensile strength, elongation at failure, hardness, adhesion to specific glass types or metals, and recommended temperature range should be obtained from the supplier. The physical properties are in most cases dependent on the environment in which the adhesive was tested so they may only be valid for a certain temperature range. Testing done by the supplier will also determine whether the adhesive meets Military Specification such as MIL-A-3920 optical cement requirements for military or government applications.

Quality is an important factor in all the process variables including adhesive selection. Total Quality Control objectives such as just in time manufacturing and continuous improvements require close cooperation between suppliers and customers. Working with suppliers so that they are attuned to your quality needs could eliminate product variations such as lot to lot variances in the adhesive's properties.

Other questions that need to be investigated are proper handling procedures for the adhesive. The supplier should be able to provide information on age control for the adhesive, whether exposure to air will affect its properties, storing and disposal of the adhesive.

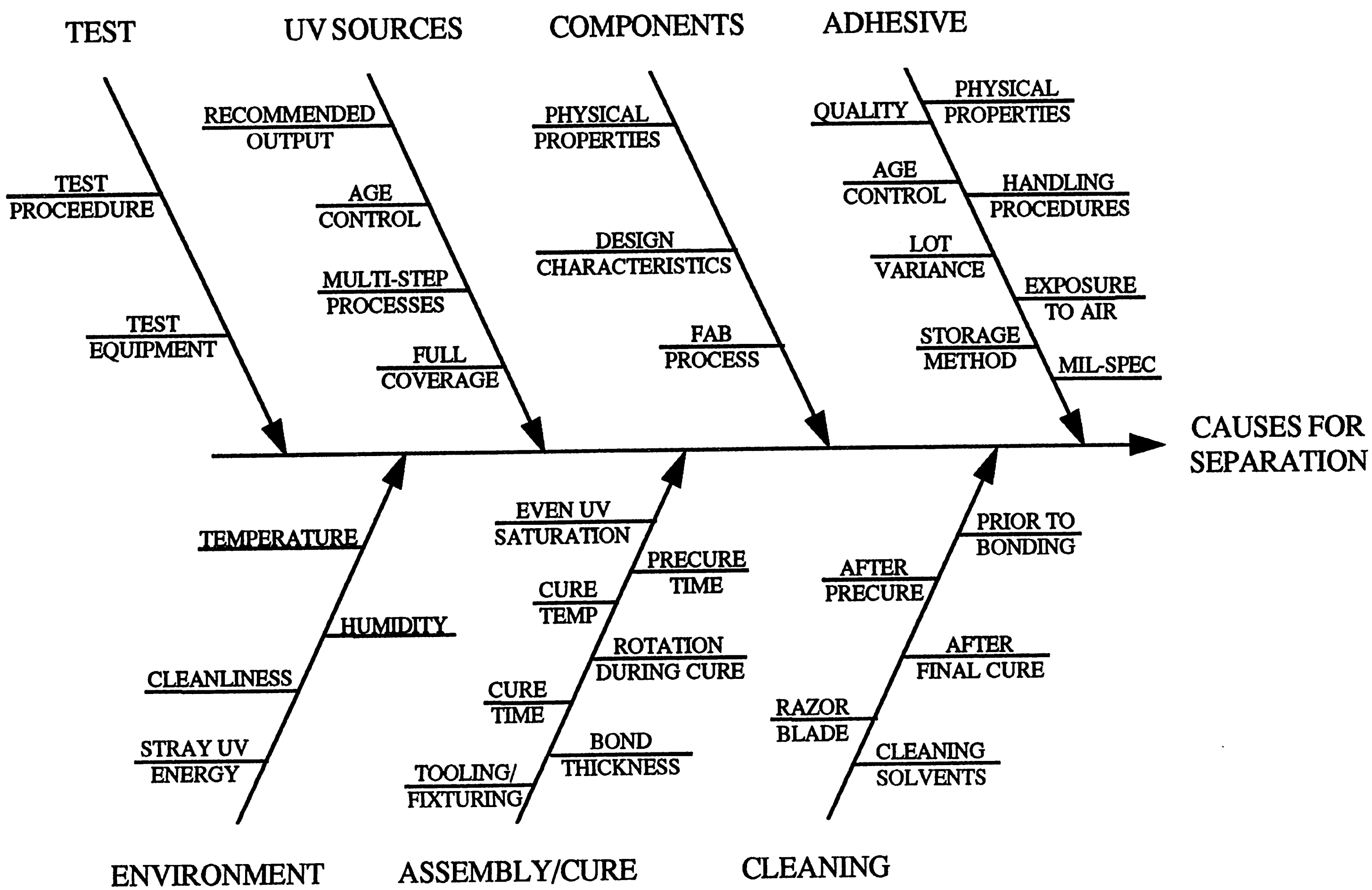

Fig. 1. An Ishikawa Diagram for UV curing adhesive process variables.

3. COMPONENTS

The process variables for the optical components to be cemented fall into two categories. The first is the physical properties or design characteristics. One of these is the coefficient of thermal expansion of the mating components. Environmental exposure testing to meet the requirements of MIL-O-13830, or subsequent thermal cycling during potting operations will cause stress at the bond interface. Stress during thermal cycling can also be caused by the design characteristics of the components. For instance, when cementing two optical elements made from the same substrate material, differences in expansion rates due to the differences in mass and heat transfer rates can cause stress. The maximum stress in these cases will often occur adjacent to the free edge of the elements sometimes leading to voids or separations. Finite element analysis can be done to determine if the adhesive's material strength is being exceeded during temperature cycling because of differences in thermal expansion rates or component design.

Defects can also occur when component design tolerances are too loose. In the case of cementing doublets or prisms, it is important that the mating surfaces do not deviate significantly in radius or figure accuracy that could cause a non uniform bond thickness that could lead to an uneven stress distribution during thermal cycling.

The other process variable category for components is the fabrication method. During the grinding and polishing operations, coolants, slurries, and other process materials come in contact with the optical elements that could contaminate the substrate and lead to separation in uncoated optical assemblies. If defects begin to occur, it may be helpful to inquire about any changes in the fabrication process of the optical components.

4. UV SOURCES

The UV sources used to cure the adhesive must emit the energy wavelength at the intensity recommended by the supplier. Although the energy output is specified by the manufacturer of UV light equipment, it is necessary to verify the intensity level by measurement. Some sources will lose intensity over time so it is good practice to implement an age control plan for UV curing equipment.

The type of source to use will be influenced by the configuration of the components that are being cemented. Full and even UV energy coverage is desirable to promote even and complete curing of the adhesive. Many UV adhesives cure by cross-linking. An uneven cure can induce residual stresses in the adhesive due to non uniform cross-linking which can cause separation. Shadowing caused by optical element shape or fixturing can also cause incomplete or uneven curing. In some cases, it may be necessary to introduce additional optics in the path of the UV energy to overcome this problem.

Some UV curing adhesives are cured using a two step process. A precure operation is done to tack components so that physical or optical alignments are maintained prior to a full adhesive cure. Determine the necessary energy requirements for each step.

5. ASSEMBLY/CURE

As mentioned above, a uniform bond layer thickness is desirable. Procedures can be developed to reduce the variation of this factor. Adhesive should be applied in measured amounts to ensure complete coverage. Components should be carefully mated without entrapping air at the bond interface. Again, consult with the adhesive supplier about the recommended bond layer thickness.

Cure times and temperatures as specified by the supplier should be followed. Element configuration or glass type should be considered when determining cure times. If an oven cure is required, verify that the equipment used is capable of providing an accurate and stable temperature.

Fixturing used during the cure process can also cause quality problems. In many cases it is necessary to hold components in a specific orientation to meet optical alignment requirements. The design of fixturing should take into account the UV energy source's path to prevent shadowing and facilitate even curing. Doublets are sometimes rotated during cure to ensure an even UV saturation.

6. ENVIRONMENT

The environment where the assembly of the optical components and the curing of the adhesives can be a source for defects. Dust and lint within the free aperture of cemented optics are treated as digs and must not exceed the stated requirements. Cleanliness of work area is an important process variable.

Temperature and humidity can also affect the bond strength of the adhesive. Some adhesives absorb moisture during curing, particularly if the relative humidity is greater than 50%. During thermal cycling, the absorbed water contracts at colder temperatures and then expands at the elevated temperature. At elevated temperatures the water can out gas from within the adhesive. Seperation results from outgassing of the adhesive combined with high stress concentration at the edges.

The recommended temperatures for both the assembly and curing processes for the optical adhesive can be obtained from the supplier.

Stray UV energy from other sources can also affect the bond. Uneven curing can result causing the same problems mentioned in section 5.

7. CLEANING

Cleaning is done primarily at two different times during the assembly process. The first is surface preparation of the optical elements prior to bonding. The intent is to remove contamination that would affect the integrity of the bond. The types of contamination that could lead to defects are dependent on the fabrication, handling, and assembly processes. Most contaminants can be removed with appropriate solvents. In some cases it may be necessary to use a fine abrasive such as cerium oxide for surface preparation prior to bonding.

Cleaning is also done after cure to remove excess adhesive. Solvents used to clean optical assemblies after the pre-cure and before the final cure of a two step UV cure should be used sparingly. The solvent can migrate in from the edges and dissolve the adhesive causing voids. Razor blades are often used to remove excess material after the final cure. Care should be taken so that the blade does not penetrate the bond layer. This not only creates a opportunity for solvents to penetrate, but will act as a stress raiser and a point for separation to initiate during thermal cycling.

8. TEST

To meet military specification requirements such as MIL-O-13830 or other specifications, temperature and humidity exposure test are conducted. It is important that the test procedure reflects the intent of the requirement and that the equipment used is capable of accurately and consistently simulating the environmental conditions.

9. SUMMARY

The intent of this paper was to provide a systematic method for characterizing the process for bonding optical assemblies using UV curing adhesives. The Ishikawa or fishbone diagram is the basis for this method. The major branches describing the process variables as developed by the author were described briefly. Again, all process variables associated with the process are not listed and the ones that are may not be applicable to every adhesive or bonding process. The fishbone diagram is a dynamic quality tool. When necessary, additions or expansion of the process variables can be made to the diagram. By providing a framework for analysis, a proactive approach to separation problems can be taken and quality optical assemblies using UV curing adhesives can be produced.