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Effects of Military Environments on Optical Adhesives

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ABSTRACT

The military environment imposes harsh conditions on adhesives. These conditions differ both qualitatively and quantitatively from typical civilian environments. Military systems must withstand exposure to moisture, temperature extremes, sunlight/ultraviolet radiation and other climatic stresses that are far in excess of what would be expected for commercial applications. Additionally, civilian products rarely consider issues such as fungus susceptibility, resistance to jet fuels and de-icing solvents, or resistance to chemical warfare agents and their decontaminants. The effect of military environments on both the optical and mechanical properties of optical adhesives are discussed for avionic display applications.

2. INTRODUCTION

The working environments for military systems are harsh. These environments can be both natural climatic and manmade, both peaceful and hostile. Such environments create stresses on materials that are both quantitatively and qualitatively distinct from civilian environments.

The extremely high reliability necessary for military systems is a constant consideration for both materials and their processing methods. Material degradation or failure that leads to system degradation or failure can have catastrophic consequences.

The optical adhesives used for military applications have the same chemistries as those used for civilian applications. The most common systems are epoxy, urethane, acrylic and silicone. Many optical adhesives are the same for both civilian and military purposes, if they have the environmental resistance needed for military systems. The processing methods run the common spectrum of adhesive science: two-part and one-part thermosets, ultraviolet (UV) cures, thermoplastic and hot-melt adhesives. Some military optical adhesives are controlled by military specifications (for example, Norland's NOA 61 meets MIL-A-3920[1]), but most are specialty materials that are the result of formulation appropriate to their unique application. Materials such as Teflon[2] and thiol/enes[3] and technologies such as electron-beam curing[4] have been used for civilian optical adhesives, and are certainly candidates for military use if their unique properties are warranted by performance.

3. AVIONICS AND OPTICAL ADHESIVES

A principle use for optical adhesives is for electronic products used for aviation (i.e., "avionics"), particularly for display technology. Head-down cockpit displays range from mono-color CRT displays to color CRT displays [such as the Kaiser Electronics' (KE) KROMA™ display currently flying on the U.S. Navy (USN) F/A-18C/D Hornet], to the flat panel, active matrix liquid crystal displays (AMLCD) currently being developed by KE and others for the U.S. Air Force (USAF) F-22, the USN F/A-18E/F, the U.S. Army RAH-66 helicopter, and the NASA Space Shuttle. Optical adhesives are needed for optical laminating materials and sealants between the many layers of the liquid crystal displays and filters.

A Head-Up Display (HUD) enables the pilot to view information while keeping his/her eyes on the sky in front of him/her. Optical adhesives are used in the combiner assemblies to encapsulate, laminate and mount the optics. HUDs are standard equipment on military aircraft and the Space Shuttle, and are starting to proliferate into civilian aircraft to permit landings under some adverse conditions.

The new generation of displays are Helmet Integrated Displays (HID), where the associated optics project information on the pilot's visor or eyepiece. The HID can be monocular or binocular. A tracker in the helmet enables the display system and associated data processor to know at all times in what direction the pilot is looking. HIDs have applications both in military and commercial areas. Helmet-mounted displays have great promise for virtual reality applications for the entertainment and other industries.

4. MILITARY ENVIRONMENTS AND TEST METHODS

4.1 Environmental Criteria

The use-environment for a military system determines the necessary design criteria and required material properties. Each military system has a user-defined "Mission Profile", which specifies the range of environmental conditions that are anticipated for that system. For example, engineers currently designing the USAF F-22 Advanced Tactical Fighter work to the published F-22 Environmental Criteria Document (ECD), which specifies the type of environments anticipated. The environmental criteria seek to ensure that the system will function in any environment; the F-22 ECD includes such unlikely environments as volcanic ash.

Military environmental criteria frequently start with an omnibus military testing standard: MIL-STD-810, "Environmental Test Methods and Engineering Guidelines[5]". This standard includes test methods for most environments which have been quantified and can be experimentally tested. Those methods relevant to optical adhesives include both natural climatic conditions and manmade environments. Climatic environments include cold and hot temperatures, solar radiation, rain, humidity, fungus and salt atmosphere. Manmade environments include explosive atmospheres, and exposure to aircraft fluids, chemical warfare agents and their decontaminants.

4.2 Temperature

The operational range of temperatures for military systems is extreme. For avionics, typical working temperatures range from approximately -50 to +80 °C, with storage temperatures even more extreme. Additionally, change of temperature can occur very rapidly, causing "thermal shock".

The coefficient of thermal expansion (CTE) of adhesives are one-to-two orders of magnitude greater than glass substrates. If the temperature range is large, troubles can result if not adequately accounted for in the design. For example[6], the CTE of commercially available low-temperature (glass transition temperature, T_g, below -60 °C) optical silicone potting materials, measured by Thermal Mechanical Analysis (TMA), is between 280 and 550 x 10^{-6} $^{o}C^{-1}$. For a 130 °C temperature range, this produces a linear dimensional change greater than 7%!

Chemical change is rarely a concern because of the thermal environment; degradation temperatures for organic polymers are not approached. Physical transitions are a concern because of the typically broad temperature range. Transitions, such as the glass transition, are frequently undesirable because of the drastic change of properties on either side of the transition (a change in the modulus of three orders of magnitude is not unusual; the CTE will usually double or triple).

The high military temperatures can render many useful materials inappropriate. Acrylics are preferred for optical pressure-sensitive adhesive applications[7], but such adhesives soften and can irreversibly creep at temperatures above 90 °C.

Polymers above the T_g may become hazy and lose optical clarity with temperature cycling because of phase separation as a function of the molecular weight, if the molecular weight distribution is broad.

4.3 Humidity and Rain

It is obvious that military hardware must withstand humidity and rain. Materials that will be degraded by moisture must be either avoided or protected. Hydrolytic stability is necessary; polyesters are avoided in military hardware. A combination of humidity and elevated temperatures may degrade some materials. Cellulosic materials (cellulose acetate, cellulose nitrate) are favored for use in optical polarizers but will degrade and lose optical clarity at high humidity and temperatures approaching 100 °C.

Prolonged exposure to humidity or humidity cycling may lead to irreversible changes in optical adhesives. Sargent and Ashbee[8] report that optical epoxies exposed to humidity cycling at moderate temperature (62 °C) for two days suffered irreversible dimensional change.

4.4 Other Climatic Environments

Other environmental conditions must also be considered during design and material selection. A salt atmosphere or salt fog condition is common for naval hardware and is highly corrosive. Although a salt environment is problematic for avionics, the polymeric materials are not usually affected.

The low ambient pressure environment at high altitude necessitates materials that will not out-gas or volatilize; condensable gases are ruinous for optical assemblies. Optical assemblies typically receive long burn-in or bake treatments to preclude such problems before going to the field. Although this requirement is stringent for avionics, it is even more critical for space applications. NASA specifications in this area are more demanding than military requirements. Differential scanning calorimetry (DSC) is a useful method to ensure that curing conditions have removed all volatiles.

Solar radiation/sunshine is another important degradative environment. Free radical generation caused by UV irradiation is a primary polymer degradation initiation reaction. At high altitudes, UV radiation is more intense because of less filtering by the atmosphere. Again, this problem is more critical for space systems which operate beyond the atmosphere. Free radical scavengers and anti-oxidants can be formulated into the adhesive to remedy this problem.

4.5 Fungus

Military systems require that materials be non-fungus nutrient. Metals, ceramics and glasses are fungus inert. MIL-STD-454 lists materials that are either fungus inert or fungus nutrient. Among optical polymer systems that are listed as fungus nutrient are cellulose acetate, epoxy resin, and polyurethane (particularly ester types). Listed fungus inert materials include polycarbonate, polystyrene, polysulfone and silicone resin. These guidelines are general and cannot attempt to describe the full range of formulations of these generic polymer types. Potential fungus nutrient materials may be treated to attain fungus resistance. Note that “acrylics” are listed as fungus inert, whereas “Polymethyl methacrylate” is fungus nutrient.

4.6 Aircraft Fluids and Chemical Warfare Agents

The specific use environment of avionic displays may require that they be resistant to or shielded against common aircraft fluids. Such fluids include jet fuel, hydraulic fluids, coolants, de-icing solvents, detergents and soaps, and fire fighting foams and Halon. No exhaustive military database for material/fluid interactions exists; standardized tests are not specified and probably not useful; exposure is usually non-standard: transient and accidental. The designer must consider the likelihood, as well as duration and conditions, of exposure. If the material is susceptible to degradation by a particular aircraft fluid, then limiting accessibility is the next strategy to reduce vulnerability. Sometimes the solution can be as simple as providing a cover to serve as a barrier during non-operation or storage.

Chemical Warfare Agents (CWA) are another design consideration. Both Department of Defense Directives and specific procurement specifications require that equipment be "chemically hardened." Excellent reference information, both general and specific, can be provided by the Chemical/Biological Information Analysis Center (CBIAC).[9] CWA are pernicious chemicals, designed to kill or incapacitate personnel. They are aggressive organic chemicals and can degrade some materials to the point of system failure, or cause the system to be inoperable safely, even by personnel fully protected in CWA-resistant apparel. Chemical hardening also means that materials must be resistant to degradation by decontamination agents, usually strong bleaches or detergents.

A less obvious consideration is absorption of CWA. Even if material properties are not affected, significant absorption of agent poses a latent threat. After the material is removed from the chemical environment, CWA will desorb from the polymer and be a hazard to personnel.

4.8 Mechanical Stress and LCD Issues

Vibration, shock, gunfire and acceleration all impose mechanical stresses that the adhesive must withstand or even be called on to ameliorate. The laminating material above the T_g can mechanically decouple two hard substrates, such as glass (the soft laminating material is a mechanical impedance barrier between the two hard substrates; efficacy of decoupling depends upon the wavelength of excitation and the relative moduli and dimensions of the materials). The laminating adhesive can even be designed to provide viscoelastic damping for vibration abatement. Low temperature silicones have T_gs below -100 °C. Larson described the use of low-temperature optical silicone laminating materials to provide stress relief in avionic and aerospace environments.[10]

Liquid crystal displays (LCD) are complex mechanical composite structures composed of layers which span five orders magnitude in modulus. The LCDs may contain the cell substrate glass, polarizers, filters, diffusers, heater layers and thin film coatings for anti-reflection and liquid crystal alignment. Active matrix displays (AMLCD) have a thin film transistor (TFT) array layer and necessary black and color dye materials. The laminating materials must join the layers and, if necessary for harsh military environments, provide vibration abatement by damping or decoupling.

Chemistries used for such adhesives include silicones, epoxies, acrylics and mercapto-esters.

An adhesive is also necessary to seal the liquid crystal cell. This is the edge-seal (synonomously peripheral seal or gasket-seal) that seals the edges of the two glass plates which contain the liquid crystal. Such edge-seal adhesives are printed onto the cell substrate, must be non-porous and impervious to the liquid crystal (typically linear aromatic and aliphatic organics) and must cure without residual volatiles that could leach into the LCD. Both thermal and UV-cure materials are used. Not all commercial LC cell sealants are appropriate for military use.

5.0 SUMMARY

The military environment is harsh. Designers specifying adhesives for military products would do well to start with the literature concerning the use of adhesives under harsh conditions[11,12,13,14]. Specific use environments must be considered, including all physical and chemical effects to which the military system may be potentially exposed.

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