CASE STUDY

EP21TDC-2LO: Adhesive for Optical Components in Laser and Space Applications

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The ability of bonding agents to withstand thermal and mechanical stress is vital in any application where even the slightest loss of structural integrity can result in performance degradation or even failure. For military and aerospace applications in particular, the stability of bonding agents plays a fundamental role in ensuring mission success when bonded structures face extremes in temperature, vibration, or acceleration. In two such applications, Master Bond EP21TDC-2LO demonstrated its ability to maintain structural integrity under the harshest conditions.

Master Bond Polymer System EP21TDC-2LO is a two-component epoxy resin compound that exhibits high thermal conductivity and excellent electrical insulation. Mixed in a one-to-three ratio, the compound fully cures overnight at ambient temperatures or in 2-3 hours at 200°F. The cured compound exhibits outstanding toughness and exceptional tensile elongation for a thermally conductive epoxy. Unlike most flexible epoxies, it passes NASA low outgassing test criteria.

With a service range of 4K to +250°F, it is particularly well suited to bonding applications that need to maintain integrity in harsh environments. Its ability to withstand thermal and mechanical stress in those environments make Master Bond EP21TDC-2LO the bonding agent of choice in many military and aerospace applications.

The following applications illustrate the reliability of EP21TDC-2LO under extreme conditions encountered in near-earth orbit.

Production uses and experimental studies of EP21TDC-2LO

Industry	Application	EP21TDC-2LO Role	Critical Properties
Military	Bonding optical components in a laser system[1]	Bonding laser system mirrors to military standards	Cure properties Stability during thermal and mechanical stress
Aerospace	Bonding heat-exchange structures in a space-borne platform[2,3,4]	Bonding dissimilar materials in the heat-exchange condenser in the Alpha Magnetic Spectrometer on the International Space Station (ISS)	Thermal stability High thermal conductivity Compatible coefficient of thermal expansion

Conclusion

Military and space-borne platforms face some of the harshest conditions experienced by any application. Despite significant stresses arising from thermal and mechanical factors, bonding agents used in critical components of those platforms must maintain structural integrity. Master Bond EP21TDC-2LO demonstrates this ability, leading to its use in mission-critical applications in military and aerospace.

Bonding optical components in a laser system

Application

Laser systems depend on the precise alignment of mirrors and prisms to deliver high-energy light beams along desired paths. To mount these optical components to a delivery platform, designers find that adhesives can provide a particularly attractive solution. Bonded mountings result in simple mechanical designs that are light and inexpensive, offering reduced interface complexity and ultimately leading to more compact systems with fewer parts. If adhesive bonds fail, however, the optical system can quickly lose alignment and even experience catastrophic failure. Loss of laser accuracy and even overall functionality is unacceptable in any production laser system, but in military systems, ineffective bonding of optomechanical components can result in mission failure or worse. The challenge of ensuring bond stability becomes particularly difficult in military laser systems required to maintain reliable operation despite harsh conditions. In airborne laser systems, the challenge is further exacerbated by cold temperatures encountered at altitude and by thermal shock associated with rapid altitude changes.

Key Parameters and Requirements

Bonding agents can simplify design of precision optomechanical systems such as military laser systems but these agents nevertheless face significant challenges. Adhesives intended for these systems must exhibit low outgassing to avoid interference with optics and must maintain stability under extremes of thermal and mechanical stress such as those specified in MIL-STD-810F. Designed to provide testing guidelines for equipment intended for harsh environments, MIL-STD-810F describes test conditions including recommended levels of thermal and mechanical stress. In tests performed at these levels, however, engineers discovered adhesive failure in a laser system developed by ASELSAN A.Ş., a Turkish Armed Forces Foundation company. To examine stress conditions and find suitable solutions, a researcher undertook a methodical examination of several adhesives when subjected to mechanical shock, vibration, and thermal shock at stress levels specified in MIL-STD-810F.

Results

In this study, the researcher conducted multiple experiments designed to reveal the most stable configurations for five different optomechanical mounts. For each mount configuration, the researcher examined the bonding properties of five different adhesives including Master Bond EP21TDC-2LO. For this study, the researcher employed two different shakers and a furnace to subject the 25 different test samples to extremes of mechanical shock, vibration, and thermal shock at MIL-STD-810F levels. To quantify the effects, the researcher used a precision autocollimator to measure any deflections in the optical system arising from adhesive instability under each stress condition.

For testing response to mechanical shock, the researcher subjected each mount to MIL-STD-810F dynamic loads including 20G for 15-23ms (functional test for flight equipment), 20G at 45 Hz (acceleration), and 40G for 6ms (crash hazard test for flight equipment). For testing response to mechanical vibration, the researcher applied a random vibration profile that exposed the mounts to fluctuations in vibration load and frequency at an overall level of 14 Grms. For testing response to thermal shock, the researcher repeatedly exposed the bonded mounts to the types of conditions encountered in airborne platforms, including a rise in temperature from 70°C from -40°C in 5 minutes (such as in an aircraft ascending from sea level to 30,000 ft) as well as sustained temperatures of 70°C and -40°C (aircraft parked in a hot hangar and aircraft in a sustained cruise at altitude).

In the face of these extreme conditions, Master Bond EP21TDC-2LO demonstrated continued stability. Although the five mount configurations demonstrated different levels of effectiveness in their design, mounts bonded with Master Bond EP21TDC-2LO showed little or even no effect at these demanding levels of mechanical shock, vibration and thermal shock.

Conclusion

Military laser systems designed for airborne platforms present particularly harsh demands for stability of adhesives used to mount optomechanical components. As demonstrated in this detailed examination of adhesive properties, Master Bond EP21TDC-2LO is an effective solution for bonding materials exposed to the harshest operating environments.

Bonding heat-exchange structures in a space-borne platform

Application

Launched aboard Space Shuttle Endeavour on Mission STS-134 in May 2011, the Alpha Magnetic Spectrometer 2 (AMS-2) is a second-generation particle physics detector. Mounted on the S3 Starboard Truss Segment of the International Space Station (ISS), AMS-2 integrates a sophisticated tracker able to precisely measure energy, velocity, and direction of origin of charged particles such as protons, electrons and antimatter particles such as positrons. Comprising silicon microstrips, front-end electronics, and mechanical structures, the AMS-2 Tracker makes 25,000 detections per second, generating 7 gigabytes of data per second – and 144 W of heat. To move this excess heat, engineers created a CO_2 cooling system able to survive the stress of launch and maintain operation in space. Within this cooling system, Master Bond EP21TDC-2LO plays a critical role in maintaining a stable bond between the critical components required to ensure reliable heat exchange.

Key Parameters and Requirements

The AMS-2 Tracker Thermal Control System (TTCS) is a sophisticated thermal management system built to manage the thermal load imposed by AMS-2 Tracker electronics, direct solar energy, and even indirect solar energy reflected by the Earth. Within the TTCS, CO_2 passes through cooling-loop condensers to dump the thermal load into a pair of radiators designed to radiate the heat into space. Although CO_2 offers advantages over other coolants, a power shutdown of the AMS-2 can cause the condensers to freeze when temperatures drop below the CO_2 freezing point (-55°C). As the condenser begins to heat up due to solar energy or power restoration, CO_2 thawing can induce pressures as high as 3000 bar (about 43,500 psi) within the condenser tubes. Although the TTCS cooling loops includes heaters to mitigate this problem, freezing simply cannot be avoided in the case of power outage. Without the use of suitable materials, a rupture in the TTCS cooling loop could occur. In turn, the increasing thermal load in the AMS-2 Tracker itself could impact detector performance, damage sensitive electronics, and create an unstable thermal event in a two-billion-dollar experiment attached to the ISS itself.

Results

AMS-2 scientists determined through experiment that Inconel 718 tubes with inner diameter of 1mm and outer diameter of 3mm could withstand the pressures encountered during CO_2 thermal cycling. By embedding Inconel tubes between two aluminum plates, scientists determined they could create a suitable condenser. The problem remained one of securing the Inconel tubes to the aluminum base plates. For this task, the team required an adhesive able to reliably bond the dissimilar materials, provide high thermal conductivity, and exhibit exceptional thermal and mechanical stability needed to withstand the harsh conditions of launch and ongoing operations in space. To meet these requirements, AMS-2 scientists selected Master Bond EP21TDC-2LO, citing not only its stability and performance characteristics but also its ability to match the differences in coefficient of thermal expansion (CTE) between Inconel and aluminum. To test the design, developers mounted the manufactured condenser on a cold plate that simulated a TTCS radiator and applied repeated cycles of CO_2 freezing and thawing. The structure bonded with Master Bond EP21TDC-2LO fully passed the tests and was accordingly built into the AMS-2 platform launched on Endeavour in 2011.

Conclusion

The cooling system integral to the success of the multi-billion-dollar AMS-2 experimental package required a bonding agent able to meet demanding requirements for adhesion, thermal performance, and long-term stability. Using Master Bond EP21TDC-2LO, scientists created a heat-exchange condenser design able to survive intense internal pressure associated with CO_2 thermal cycling while exhibiting required thermal conductivity and bond strength between dissimilar materials exposed to the extremes of space.

References

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[4]Alberti, et al., Development of a Thermal Control System with Mechanically Pumped CO2 Two-Phase Loops for the AMS-02 Tracker on the ISS, ArXiv:1302.4294, 2013.