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CASE STUDY

EP29LPSP: Applications in Plasma Physics, Astronomy, Highway Engineering and More

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Since its introduction, Master Bond EP29LPSP has been the epoxy compound of choice in a variety of challenging applications. Ideal for demanding cryogenic environments, two-part EP29LPSP can withstand temperatures as low as 4K and can resist cryogenic shock when, for instance, it is cooled from room temperature to cryogenic temperatures within a 5-10 minute window. Optically clear EP29LPSP has superior physical strength, electrical insulation, and chemical resistance properties. It also meets NASA low outgassing requirements and exhibits a low exotherm during cure. This low viscosity compound is easy to apply and bonds well to metals, glass, ceramics, and many different plastics. Curable at room temperature, EP29LPSP attains its best results when cured at 130-165°F for 6-8 hours.

In over a dozen published research articles, patents, and manufacturers' specifications, scientists and engineers have identified EP29LPSP for use in their applications due to its unparalleled performance in one or more areas. Table 1 highlights several commercial and research applications that use Master Bond EP29LPSP. Table 2 summarizes several patents that reference EP29LPSP. Following each table are brief descriptions of the role Master Bond EP29LPSP plays in each application or invention.

Table 1: Commercial and Research Uses of EP29LPSP Plasma Physics Experimental Device

Industry	Application	EP29LPSP Use	Critical Properties
Plasma Physics	Experimental device to stud magnetic reconnection events	Fabrication of flux core assemblies	Cryogenic Low outgassing
Astronomy	Infrared telescope system	Optical fiber mounting assembly	Cryogenic Low outgassing Long cure time Low shrinkage
Highway Engineering	Development of a reference surface used for calibration of a pavement profile scanner	Creation of a level, smooth 15-foot by 4-inch surface	Low viscosity Low exotherm Slow cure
Neuroscience	Experimental setup to stimulate rat neurons via a magnetic field	Construction of a magnetic coil	Low viscosity Electrical insulation Physical strength
Aeronautics	Testing of a miniature ramjet model in a supersonic wind tunnel	Bonding strain gauges to flexure beams	Sufficient flexibility at cryogenic temperatures
Particle Physics	Argon detector	Coat metal rim to electrically insulate it	Cryogenic Low outgassing Electrical insulation
Particle Physics	Radioactive decay detector	Bond flexible cable to flange	Low outgassing

Plasma Physics Experimental Device

At the Princeton University Plasma Physics Laboratory (PPPL), physicists and engineers have designed an experimental apparatus for studying magnetic reconnection, a physical process that drives solar flares, the Northern and Southern Lights, and other dramatic solar events.[1] Through the process of magnetic reconnection, magnetic field energy is converted into enormous amounts of thermal and kinetic energy, and high energy charged particles are hurled into space at up to the speed of light.

Among the key components in PPPL's apparatus, known as the FLARE (Facility for Laboratory Reconnection Experiments) device, are two flux core assemblies. Manufacturing specifications for these assemblies require the use of Master Bond EP29LPSP low outgassing epoxy resin in several steps in the fabrication process. Selected for its low outgassing and cryogenic serviceability properties, EP29LPSP is applied in three distinct ways in the assembly of the flux cores:

- **Wet wrap:** Fiberglass tape is saturated with EP29LPSP epoxy resin and used to wrap leads together into a bundle and to wrap the inner and outer layers of the toroidal flux cores.
- **Epoxy paste:** EP29LPSP resin is mixed with a fine silica powder to create an epoxy paste. This paste is then used to secure wires placed in grooves that are cut into the core as well as cables that are threaded through cross-hole regions within the core, preventing motion and potential damage to wires and cables during operation. The paste is also used to secure an aluminum shell to the inner flux core, to fill gaps, and to create a smooth surface in preparation for a vacuum-sealing membrane.
- **Coating:** A thin uniform coat of EP29LPSP is applied to machined seal grooves in a toroidal G-10 (fiberglass laminate) plate to prepare a smooth surface for sealing support leg o-rings to the plate.

Infrared Telescope System

Massive infrared telescopes, such as the James Webb Space Telescope under development by NASA, are designed to collect infrared radiation emitted from some of the furthest celestial objects, providing clues to the origins and composition of the universe. Infrared radiation detected by such telescopes is transmitted to infrared cameras, spectrographs, and other instrumentation located many miles away. To preserve thermal infrared radiation and form an image, the entire system must be cooled to cryogenic temperatures. Given such difficult operating conditions, great care must be taken to preserve the optical properties of the entire system.

Observing that optical fibers have been shown to retain their flexibility at cryogenic temperatures, researchers at the Anglo-Australian Observatory in Australia conducted an experiment to assess the viability of using optical fibers as "light guides" in infrared telescope systems.[2] All optical fibers alter the angular distribution of light to some degree, a phenomenon known as focal ratio degradation (FRD). This study examined the degree of additional FRD that results when optical fiber mounting assemblies are subjected to cryogenic temperatures (77K).

Each assembly consisted of an optical fiber housed within a flexible strain relief tube and then placed in a rigid ferrule, as is typical of optical fiber connectors used in astronomical instrumentation. Both the fiber and the flexible tube were affixed in place with an adhesive. Such assemblies are designed to allow free manipulation for connection and polishing purposes without risking damage to the optical fiber. The study tested various combinations of fiber material, flexible tubing types, and adhesive compounds. Researchers cited three important selection criteria, in addition to cryogenic serviceability, for the adhesive:

- Low outgassing, for use in a vacuum
- Long cure time, to allow time for manipulating parts during assembly
- Low shrinkage, to minimize stress on the fiber during cure

Of the six adhesives tested, Master Bond EP29LPSP produced the best results. In fact, the top-performing combination of assembly materials and EP29LPSP adhesive resulted in no additional FRD under cryogenic conditions as compared to warm conditions. The study demonstrated that the combination of appropriate materials and Master Bond EP29LPSP adhesive produce an optical fiber assembly that is serviceable in cryogenically-cooled thermal infrared telescope systems.

Magnetic Coils for Stimulating Brain Cells

Transcranial magnetic stimulation (TMS) is a non-invasive way to stimulate the motor cortex and other parts of the brain. A coil energized by a pulse generator is placed near the head of a human or animal, creating a pulsed magnetic field which induces small electric currents in the part of the brain just under the coil. By observing the resultant motor activity of the patient or subject, medical professionals can assess the damage from a brain injury or disorder, such as a stroke or multiple sclerosis.

Scientists at Bar-Ilan University in Israel designed a study to explore exactly how magnetic stimulation acts on nerve cells in the brain.[3] Thin slices of the somatosensory cortex of rats' brains were prepared for use in the study. A common-used procedure for studying the electrical activity of neurons, known as the patch-clamp technique, was modified to facilitate magnetic stimulation of individual neurons. The main component of the modification was a custom made magnetic coil.

Standard lacquer-coated copper wire was used to make the coil, which consisted of 14 turns of wire in each of two layers. The coil was constructed using a wet-winding technique, in which the coil is impregnated with an epoxy compound during the winding process. Researchers selected low viscosity Master Bond EP29SPLP epoxy for the wet-winding process. The epoxy was mixed with 25µm alumina particles to enhance heat transfer, increase electrical insulation, and strengthen the coil. The magnetic coil was positioned below the neuron under test during the experiment, which gave researchers important insights into how TMS affects neurons.

In an earlier study, researchers at the same university fabricated a custom-made mini coil for use in a TMS experiment on an awake monkey.[4] In this case, the coil was immersed in a saline solution and placed inside a chamber designed to record brain activity via multiple micro-electrodes attached to various regions of the monkey's brain. A wet-winding technique was used to build the coil, which included 32 turns of standard copper wire. Again, the coil was impregnated with Master Bond EP29LPSP epoxy mixed with 25µm alumina particles during the winding process. For this application, electrical insulation of the coil and its windings was especially important in order to minimize the risk of electric breakdown. The insulated mini-coil was tested to voltage levels up to 1200V.

Model Ramjet Drag Force Measurement

At the Naval Postgraduate School in San Diego, CA, a master's degree candidate conducted research to better understand the cold-flow performance of a miniature ramjet operating at speeds up to Mach 4.[5] A ramjet is a type of airbreathing jet engine that uses the forward motion of an aircraft to compress air flowing into the engine. With no moving parts, it is simpler than a turbine engine, which relies on a turbine-driven compressor to compress incoming airflow.

Ramjets operate most efficiently at supersonic speeds up to roughly Mach 5. The inlet at the front of the ramjet is designed to drastically slow the incoming air, which is then mixed with fuel and combusted. Combustion exhaust is expelled through a nozzle to accelerate the ramjet to supersonic speeds, providing the thrust that propels the aircraft. Ramjets are used to propel military reconnaissance planes and missile systems, their high speeds enabling these aircraft to evade most threats and interceptors. The performance characteristics of miniaturized ramjets, which have potential for mini/micro unmanned aerial vehicle (UAV) and other defense applications, are not as well understood.

The goal of the thesis project was to use a computational model to predict the drag force on a miniature ramjet in a Mach 4 airflow, and to validate the predictions by measuring the actual drag force on a miniature ramjet subjected to Mach 4 airflows in a supersonic wind tunnel (SSWT).

A scale model of a ramjet was machined, and specially designed support struts were built for mounting the ramjet model within the SSWT to prevent the model from moving up or down during testing. In the center of each strut were two flexure beams instrumented with strain gauges designed to measure drag on the ramjet during testing. Because the temperature inside the SSWT was 68K, cryogenic strain gauges were used. Careful selection of the adhesive used to bond the strain gauges to the flexure beams was critical, since the adhesive is effectively part of the strain gauge system and may affect its performance. Master Bond EP29SPLP adhesive was selected due to its ability to retain sufficient flexibility at cryogenic temperatures. Experimental results showed that the computer model under predicted the drag force on the miniature ramjet model.

Liquid Argon Detector

Master Bond EP29LPSP was selected for use in the construction of a highly sensitive liquid argon (Ar) detector designed and built as part of a Princeton University doctoral candidate's dissertation.[6] Liquid argon is used in multi-ton dark matter detectors designed to sense the presence of elementary particles of non-luminous matter left over from the Big Bang. Significant concentrations of a radioactive isotope of argon, 39Ar, in atmospheric argon reduces the sensitivity of dark matter detectors, but argon mined from underground natural gas reserves has been found to contain much lower levels of 39Ar. The levels are so low that they could not be measured by established techniques, so researchers at Princeton University designed a device to measure the concentration of 39Ar in underground argon.

A key component of the Princeton argon detector is a cryogenic photomultiplier tube (PMT), which had to be modified to reduce background radioactivity by replacing a glass feedthrough with a high purity ceramic plate. When the modified PMT failed high voltage tests in pure argon gas, researchers hypothesized that the source of the electric breakdown was the narrow space (~1mm) between the anode lead passing through the ceramic plate and the outer rim of the plate. Because the rim is metalized to form a seal with the metal PMT housing, and the housing shares the cathode potential, there is only a 1mm separation between the anode potential and the cathode potential, presenting a risk of high voltage electric breakdown.

To solve the problem, a thin layer of cryogenic Master Bond EP29LPSP epoxy was used to coat the metalized rim of the ceramic plate, the anode lead, and all other leads passing through the ceramic plate. The low outgassing property of EP29LPSP was critical for this application, because the sensitivity of argon-based dark matter detectors is highly dependent on the purity of the liquid argon used. A customized oven was designed for curing the epoxy, which requires a minimum cure temperature (55°C) that is above the maximum operating and storage temperature (50°C) of the PMT. The oven was designed to enclose just the rear end (feedthrough and leads) of the PMT in a PVC case, which had an inlet for hot nitrogen gas, so that the epoxy could be cured at 60-70°C inside the oven while the temperature-sensitive part of the PMT remained at room temperature outside the oven. The epoxy coating passed cryogenic testing and enabled the PMT to operate at 1600V.

Radioactive Decay Detector

Scientists from 25 universities around the world are collaborating on a particle physics project designed to expand our knowledge of the universe. The EXO (Enriched Xenon Observatory) Collaboration is building a series of detectors designed to observe a theorized —but not yet seen — type of radioactive decay known as a zero-neutrino double beta decay ($0\nu\beta\beta$).[7] The EXO-200 detector uses liquid xenon (Xe) enriched with an 80.6% concentration of the radioactive isotope 136Xe as the detection medium.

At the heart of the detector is a time projection chamber (TPC), a copper vessel containing liquid xenon and electronics designed to detect radioactive decay events. The TPC is housed in a vacuum-insulated cryostat, which is shielded in lead. Front-end electronics located outside the lead shield are connected to the TPC through specially designed flat 25μm polymide cables. Six rectangular copper tubes serve as conduits for the cables between the TPC and the inner wall of the cryostat. At the end of each tube is a copper flange in which feedthroughs are formed for passing the cables between the TPC and the cryostat and between the cryostat and the front end electronics.

The first step in fabricating each feedthrough was to use a small amount of low outgassing Master Bond EP29LPSP adhesive to attach u-shaped acrylic pieces around a width of the cable, forming a cup. The acrylic cup was then filled with liquid EP29LPSP epoxy, and the cable and cup were bonded to a thin copper lip on each flange. Because ultra-low background radioactivity construction materials were a necessity in the design of the detector, the low outgassing property of Master Bond EP29LPSP was key to its selection.

Table 2: Patent Grants that Reference EP29LPSP

Application	EP29LPSP Use	Critical Properties
Cryogenic refrigerator	Bond thermally insulated tubes to thermal tube couplers	Cryogenic Low outgassing Thermal shock resistant
Proton Exchange Membrane (PEM) fuel cell	Rigidizing a fluid flow plate assembly	Electrical insulation Physical strength
Structural health monitoring (SHM) system	Affix transducers to structure under test	Cryogenic Withstand vibrations
Fiber optic gyroscopes	Construction of fiber optic sensing coil	Cryogenic Low outgassing

Closed-system Cryogenic Refrigerator

Master Bond EP29LPSP epoxy was cited in a patent granted to S2 Corporation for a cryogenic refrigerator.[8] The patented device is designed to cool a sample to < 4K while isolating the sample from vibrations produced by the cooling mechanism. In a closed system cryo-cooler, a single charge of helium gas is pressure-cycled to cool the sample in a continuous refrigeration cycle. A drawback to closed system cryo-coolers is that the constant pressure-cycling transfers vibrations to the sample to be cooled, which could pose a problem for sensitive samples. The patented device provides for vibration isolation of the sample by housing it in a nested thermal insulating structure (NTIS) that is separated from the cryo-cooler via a vacuum shroud. Thermal links exchange heat between the NTIS and the cryo-cooler.

The NTIS consists of three nested thermally insulated tubes made of glass fiber and epoxy resin. The three tubes are attached to each other via two aluminum tube couplers using Master Bond EP29LPSP epoxy. Because the coefficient of thermal expansion (CTE) between the substrates (glass fiber/epoxy and aluminum) is mismatched and there is a wide temperature variation between assembly (300K) and operating (< 4K) conditions, these epoxy bonds must be able withstand several thermal cycles in addition to cryogenic operating temperatures. Due to its ability to withstand thermal shock and its low outgassing and cryogenic serviceability properties, Master Bond EP29LPSP is well-suited for this demanding application.

Fuel Cell Fluid Flow Plate Assembly

Master Bond EP29LPSP was cited in a patent issued to Plug Power Inc. for the design of a part of a fuel cell.[9] Proton Exchange Membrane (PEM) fuel cells convert chemical energy into electrical energy through an electrochemical reaction between hydrogen fuel and an oxidant. Each cell consists of a pair of fluid flow plates separated by a solid polymer electrolyte membrane that allows the passage of protons. Hydrogen fuel is fed via channels to one plate (the anode) and an oxidant is fed via channels to the other plate (the cathode). A catalyst triggers a chemical reaction at the anode, which splits the hydrogen into protons and electrons. The protons pass through the membrane and the electrons travel along an external circuit to the cathode, when they combine with the protons and the oxidant to form water, which flows out of the cell.

Multiple fuel cells are typically stacked side-by-side to generate the desired level of power. Fluid flow plate construction typically involves compressing materials, such as graphite, sealing to prevent gas permeation, and engraving fluid channels into the face of the plate. Reduction of plate thickness is limited by compression and engraving processes, which can make the material brittle or increase permeability.

The patented fluid flow plate assembly consists of a network of conducting fibers joined to form an electrical path. Spaces within the fiber matrix are filled with a rigidizing material, which may also be used to form the fluid flow channels. Master Bond EP29LPSP was cited as an appropriate material for the rigidizing substance. The epoxy electrically isolates the conductive matrix from fluid in the flow channels while strengthening the plates and fortifying the fuel channels, allowing for increased compression and thinner plates than prior designs. With a density of 1-2 g/cm^3, depending on whether or not a filler is used, EP29LPSP contributes to a lighter plate, which can be advantageous for fuel cells used in automotive designs. The overall fluid flow plate design facilitates reduced fuel cell volume for a given power output when stacking multiple fuel cells together.

Structural Health Monitoring System

Structural health monitoring (SHM) systems are designed to assess the condition of an engineering structure, identifying changes to the material or properties of the structure that might adversely affect its performance. Master Bond EP29LPSP epoxy was cited in a patent granted to Acellent Technologies, Inc., for a SHM system designed to operate in cryogenic, high vibration environments.[10] One such application is the monitoring of liquid propellant rocket engines during operation, when high stresses can lead to structural failures.

The patented device consists of a series of piezoelectric single crystal transducers affixed to a structure with a suitable cryogenic adhesive. Each transducer acts as both an actuator and a sensor, transmitting stress waves to the structure and detecting stress waves from the structure, and is connected to a remote analysis system. Master Bond EP29LPSP two-part epoxy was singled out in the patent grant as a suitable adhesive, due to its ability to withstand cryogenic temperatures and high vibrations while remaining affixed to both the transducer system and to the structure being monitored.

Fiber-optic Gyroscopes

Master Bond EP29LPSP epoxy adhesive was cited in two patent grants for ways to improve the performance of fiber-optic gyroscopes (FOGs) through unique designs of the fiber-optic sensing coil apparatus, which is at the heart of a FOG.

In the first patent, granted to Honeywell International Inc., the sensing coil apparatus consists of an optical fiber formed into a coil and placed inside an oxygen-filled hermetically sealed chamber.[11] The fiber-optic coil is held together with an adhesive, which also serves to fill gaps between the coil windings and to provide a smoother surface for winding successive layers of the optical fiber. Master Bond EP29LPSP two-part epoxy is identified in the patent description as a suitable adhesive for this application.

The second patent, issued to Morgan Research Corporation, describes a method of winding the coil so as to eliminate fiber winding crossovers and time-varying thermal gradients, which can degrade FOG performance.[12] Multiple coil layers are wound in opposite directions, and perforated separators are placed between them. A potting compound is applied to the first coil layer and, when the perforated separator is added, excess potting compound squeezes through the perforations and is used as an adhesive during the winding of the second coil layer. Master Bond EP29LPSP is cited as an appropriate potting compound for this application.

Conclusion

The success of any engineered product depends on the performance of all of its parts, including any chemical compound used to join or protect one or more parts. If an adhesive, coating, or potting compound fails, the product fails. Leading companies, research labs, and inventors around the world rely on Master Bond EP29LPSP to perform unfailingly in extremely demanding applications.

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