

# Development of Epoxy Potting For High Voltage Insulation At SLAC<sup>1</sup>

G. Gross, R. Cassel, T. Mattison  
Stanford Linear Accelerator Center, Stanford CA 94309

## ABSTRACT

An extensive series of tests has been done at SLAC to evaluate several loaded epoxy formulations for high voltage potting applications. Mixing, degassing, transfer, cure, shrinkage, bubble and void formation, bond strength, and thermal cycle resistance were studied in a variety of mold types. Recommendations are presented for several classes of applications.

## I. INTRODUCTION

A search was made in this study for epoxy resins suitable for use as insulating dielectric in a new style kicker magnet. Resins with low cure shrinkage; low, or no cure exotherm; and thermal expansion/contraction coefficients similar or close to aluminum were sought.

This new magnet is an aluminum structure with an assembly of ferrite cores and capacitor plates contained within a cylindrical aluminum can. Because the magnet design is essentially a closed aluminum structure, epoxy resins with low cure shrinkage, low cure exotherm effect, and good epoxy to aluminum bond strength are needed to be successful in making quality, void free magnet castings.

The epoxy mass needed to build the magnet in total is approx. 100 pounds. This study looked at epoxy casting techniques suitable for producing parts in the 10# - 15# range from which the magnet could be built up in a stepwise fashion.

Ten (10) commercially available epoxy resin formulations were tested for processing and casting properties including ease of mixing; vacuum air removal; rate of cure; cure exotherm effects; volumetric cure shrinkage effects; resistance to cracking and debonding from aluminum in thermal cycle tests; and bonding to cured epoxy surfaces. These resins were:

EPIC RESINS R-1037/H-5039  
EPIC RESINS R-1037/5016  
EPIC RESINS R-1055/H-5039  
EPIC RESINS S-7083-A/B  
CONAPOXY FR-1272 A/B  
CONAPOXY FR-1046/EA-87  
CONAPOXY FR-1210/EA-87  
HYSOL EE-4183/HD-3485  
HYSOL EE-4190/HD-3485  
E&C STYCAST #2741LV/CATALYST #15LV

## II. DESCRIPTION OF EPOXY RESIN EVALUATION TESTS

### TEST #1 - Small Batch Castings

500 gram batch size tests. Initial screening of epoxies for general processing characteristics such as ease of mixing, mixed resin viscosity, vacuum air removal (degassing), cure exotherm, and quality of small castings.

### TEST #2 - Button Mold Castings

500 gram castings made in closed molds with imbedded polished aluminum buttons. Used for high voltage breakdown tests. Castings also used as qualitative check of epoxy adhesion to anodized aluminum surfaces.

### TEST #3 - Closed Cylinder Mold Castings

2" diameter x 2" thick epoxy cylinder castings with imbedded 10" diameter x 0.25" thick aluminum plate at the cylinder midplane. Castings made in closed aluminum molds equipped with vertical mold overflow tubes. Tests were made both with release agent coated and uncoated molds. Tests measured epoxy resin processing and curing characteristics in 10-15 pound batch sizes. The ability of epoxies to resist cracking and/or debonding after cure while completely encapsulating an aluminum disc was measured. Quantitative determination of volumetric cure shrinkage made in these tests.

### TEST #4 - Open Cylinder Mold Castings

This test simulates the physical size, geometry, and resin quantity to be used in casting individual magnet cells. Simulated high voltage and ground plates were encapsulated in these epoxy cylinder castings. Tests measured shrinkage effects, and ability of epoxies to encapsulate magnet high voltage and ground plates without cracking.

### TEST #5 - Thermal Cycle Test Castings

12" diameter x 2" thick cylinder castings made into sandblasted aluminum molds with one mold cylinder axis face open. An 11" diameter x 0.25" thick aluminum disc was encapsulated in the mold at the midplane of the cylinder.

Cured castings and molds were temperature cycled between 40 Deg. F. and 140 Deg. F. to test resistance to epoxy

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debonding and or cracking away from the mold and the internal disc.

### *TEST #6 - Disc Composite Castings*

Epoxy to epoxy bonding evaluations. Multiple 4" diameter epoxy discs bonded together by a second epoxy potting. Epoxy bond strength tested for resistance to separation at the bond lines of the dissimilar epoxies.

### *TEST #7 - Cannister Mold Castings*

These tests simulate the final casting step needed to produce a finished magnet. Epoxy discs simulating magnet cells were bonded together in a simulated magnet body casing. Shrinkage effects, qualitative measurements of bond strength, and completeness of filling with epoxy were evaluated for each material.

### *TEST #8 - Tape Sealed Mold Castings*

12" diameter x 2" and 4" thick aluminum cylinders with end plates sealed to the cylinder body using Teflon self adhesive tape. Purpose of the test was to evaluate epoxy shrinkage dynamics in molds designed to shrink in the axial direction with the epoxy as it cures.

## III. DISCUSSION

Four (4) of the ten (10) epoxy resin systems evaluated in this study passed these tests and appear to be useful for magnet construction. These resins are:

EPIC RESINS R-1055/H-5039

EPIC RESINS R-1037/H-5039

EPIC RESINS S-7083 A/B

CONAPOXY FR-1272 A/B

The other six materials in the study were eliminated from consideration due either to failure to survive thermal cycling tests; processing problems associated with vacuum air removal (degassing); marginal pot life; or unacceptable exotherm.

### *EPIC RESINS R-1037/H-5039*

This black pigmented epoxy exhibits very slow cure rate when processed at 65 - 70 Deg. F. Estimated pot life after mixing and vacuum air removal was 4 - 6 hours. Vacuum air removal was accomplished while agitating the mixed resin and hardener for 30 minutes in a vacuum of one (1) TORR. The curing epoxy mass becomes a plastic deformable solid after 24 hours of cure, and becomes rigid after 72 hours. The manufacturers literature states that a total of seven (7) days (168 hours) are required at room temperature to reach full cure.

R-1037/H-5039 has the lowest mixed resin viscosity (2000 centipoise), and highest volumetric cure shrinkage (3% measured) of the four epoxy resins which look promising for construction of the new magnet. The slow rate of cure and low

viscosity give this resin good penetrating power in structures with small spaces and closely fitting parts. Since this resin exhibits zero exotherm when processed at 65-70 Deg. F., magnet structures can be prepared free of stress from thermal expansion contraction effects during resin cure. This material is a good candidate for the final stage epoxy casting step in manufacturing the new kicker magnet where previously cast magnet cell units must be bonded together within the closely fitting magnet outer can structure.

### *EPIC RESINS R-1055/H-5039*

This 50% silica filled, natural pigmented resin shows a slow cure rate similar to the Epic R-1037/H-5039 system. Estimated pot life at 65-70 Deg. F. after mixing and vacuum air removal is 4-6 hours. Epoxy castings curing at 65-70 Deg. F. become a plastic deformable solid after 24 hours; and rigid after 48 hours. The slow cure rate and mixed resin/hardener viscosity of 2100 centipoise make this resin an excellent choice for filling tight and/or intricate spaces.

R-1055/H-5039 responds very well to vacuum air removal (degassing). Vacuum degassing for 30 minutes with agitation typically resulted in a vacuum above the liquid resin of 0.8 TORR or less. Volumetric cure shrinkage tests showed a total of 2.7%.

A substantial portion of the cure shrinkage (estimate 50%) appears to occur while the resin is still in the liquid phase. Molds with vertical resin overflow tubes work well as backfill reservoirs to fill mold space generated as shrinkage takes place. R-1055/H-5039 is a good candidate for both the production of individual magnet cells, and for final casting and bonding of these cells into the final magnet assembly.

### *EPIC RESINS S-7083 A/B*

This resin has a faster cure chemistry than the two resins above, and noticeable cure exotherm. These properties require different handling techniques which are especially important when casting quantities of 5 pounds or larger. The resin pot life when mixed at an initial starting temperature of 65-70 Deg. F. was approximately 90 minutes. After mixing and a 20 minute vacuum degas, temperature rise in the liquid resin from exotherm and the onset of cure was approx 20 Deg. F. to 85-90 Deg. F. A higher mixed resin viscosity (5000 centipoise) make this resin system slightly less attractive for filling intricate structures. Castings two pounds and larger appear to completely cure in 24 hours or less. When curing castings weighing 5 to 30 pounds, forced air cooling of mold exteriors was needed to remove the heat of cure and keep mold temperatures at or below 90 Deg. F. S-7083 A/B showed volumetric shrinkage of 2.6%.

Epic S-7083 A/B appears to be a good candidate for casting individual cells for the new magnet. The faster cure rate of this resin make possible a faster magnet cell production rate than with the other resins.

## *CONAPOXY FR-1272 A/B*

This blue pigmented, highly filled ( 50% by weight) epoxy system has a thermal expansion/contraction coefficient which the manufacturer reports matches that of aluminum. This property makes this resin very attractive for use in magnet production because the magnet is mostly aluminum and completely encloses its epoxy insulation.

The mixed resin viscosity for Conapoxy FR-1272 A/B is 10,000 centipoise. The rate of resin transfer into molds in vacuum was slower than the rate for the other resins but still acceptable. The resin does show cure exotherm, and forced air cooling of molds containing 5 pounds or more of resin is recommended.

The rate of cure of this resin is very temperature sensitive. When constructing magnet cells, all processing (mixing, vacuum degas, and resin transfer to molds must be done at 70 Deg. F. or below. Cast parts are rigid and appear to be completely cured 24 hours after casting. Conapoxy FR-1272A/B has the lowest volumetric shrinkage (1.9%) of these four resins.

## IV. SUMMARY AND RECOMMENDATIONS

Based on the results in this study, four (4) commercially available epoxy resin systems were identified as candidates for use in constructing a new epoxy insulated kicker magnet. It is believed that techniques for successfully processing these resins including resin and hardener mixing, vacuum degassing, temperature control during resin preparation and cure, vacuum casting methods, and cure shrinkage effects are reasonably well understood.

Work should be continued with these materials to prepare working magnet prototypes for bench top testing, followed by manufacture of production version kicker magnets for evaluation in the SLC damping rings.