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Summer Projects overview

Encapsulation Processing and Silver Epoxy Investigation

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Problems:

1) It is not completely understood how variation in material processing translates to performance and aging.

2) Silver epoxies which attach aluminum covers to product have not been performing as expected.

Abstract

- Objectives are to learn which process steps are the most critical i.e. have the most impact on material properties we care about like fracture toughness, rxn. extent., adhesive strength, etc.
- I first compared all process requirements to literature to see which requirements are lacking empirical supporting evidence. The vast majority of requirements have good data to back them up. Now I am planning processing experiments to hopefully gain additional information to support or change unconvincing requirements.
- I also set up an experiment to compare three new types of silver epoxy in an effort to understand possible improvements to the system.

Processes

- Viscosity
- Material pre-heating
- Pressure requirements for cure and vacuum processing
- Encapsulation mixing
- De-airing times
- Curing

What's been done

- Extensive studies on moisture issues (short term), kinetics, glassy and gel transitions, cure studies, filler effects, rheological properties as a function of temp and time.

Need more info on…

- Material aging and degradation mechanisms
- Requirement tolerances
- Electrical breakdown mechanisms and root causes
- Filler migration

Silver Epoxies

My experiment tested the effects of surface modification, interface material, and ethanol exposure on epoxy adhesion.

Variables

- Surface modification includes blasting and sanding in order to increase surface roughness.

- Silver epoxy bonds aluminum to a dual material surface consisting of cured epoxy and aluminum. The silver epoxy bond to aluminum is thought to be much stronger than the bond to cured epoxy.

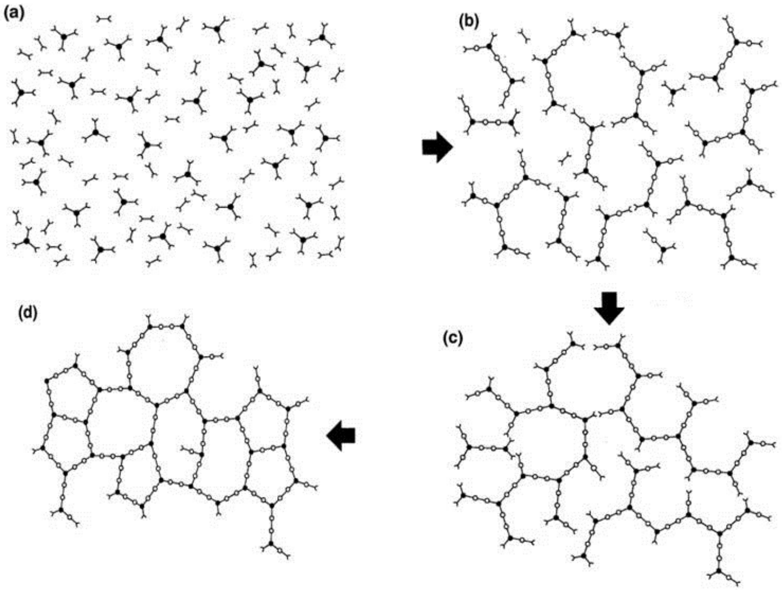
- Ethanol is used to clean the surfaces during processing and we don't know whether or not this is harmful for adhesion. Purposeful ethanol exposure in this experiment will show us.

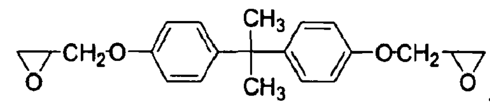
Measurements

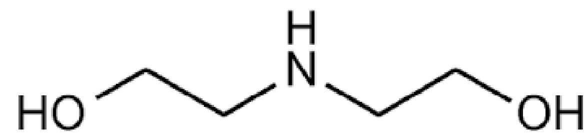
- To compare variables, we will perform two mechanical tests; a tensile pull off test and a torsional shear strength test. These will show us which variables demote adhesion and confirm that either adhesive or cohesive failure is more likely than the other.

Discussion

- Silver Epoxy test results
- Since dielectric strength is such an important property, I'd like to being a long term dielectric degradation study. It may be possible to incorporate a second property into the same long term study like adhesion.
- It would likely be very beneficial to do a study on the upper and lower limits of viscosity in the context of handling and processing.





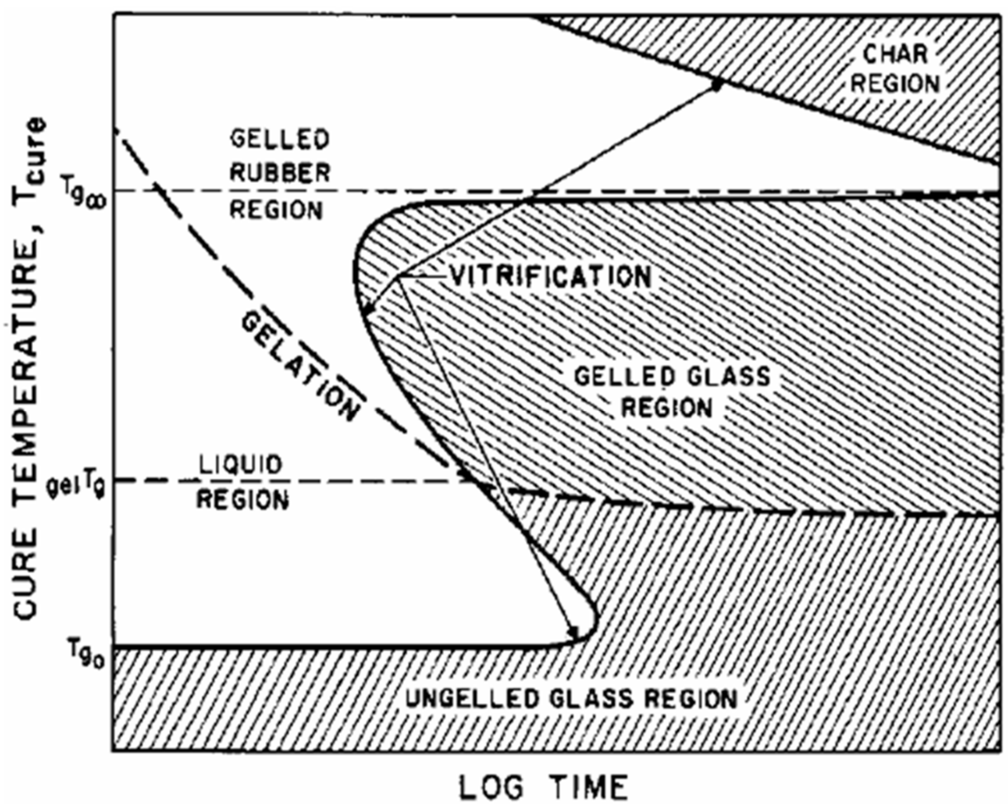


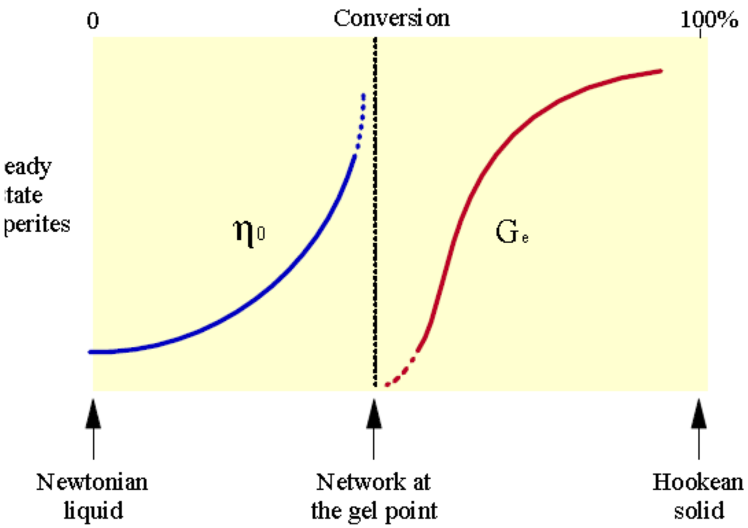
COMPARISON CHART

Material	Viscosity (centipoise)
Water @ 70°F	1-5
Blood or Kerosene	10
Anti-Freeze or Ethylene Glycol	15
Motor Oil SAE 10 or Com Oil	50-100
Motor Oil SAE 30 or Maple Syrup	150-200
Motor Oil SAE 40 or Castor Oil	250-500
Motor Oil SAE 60 or Glycerin	1,000-2,000
Karo Com Syrup or Honey	2,000-3,000
Blackstrap Molasses	5,000-10,000
Hershey Chocolate Syrup	10,000-25,000
Heinz Ketchup or French's Mustard*	50,000-70,000
Tomato Paste or Peanut Butter*	150,000-250,000
Crisco shortening or Lard	1,000,000-2,000,000
Caulking Compound	5,000,000-10,000,000
Window Putty	100,000,000

Insert shift factor plots from Bernstein here?

Taken from http://www.tru-flo.com/Technical/viscosity_chart.pdf





Determination of gel point

Electrical Stress Reduction by Altering Surface Resistance

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July 30, 2015

Problem: High electrical stresses form around sharp geometries and increase breakdown probability in high voltage environments.

Abstract

- Goal is to reduce these electrical stresses by using resistive coatings to dissipate power. Presently the only connection between source and ground is an insulator.

- Three concepts were investigated, a carbon based coating, wire windings, and finally direct write technology.

- Direct writing is the most promising method for resistive material application. This technology allows for more control over application pattern, coating uniformity, and thus better resulting electrical properties. Quantitative results pending.

Modeling

Modeling was done on the field geometry using design voltage and current values. Results showed that theoretically, it is possible to drastically cut high field stresses down to safe voltages, even around sharp geometries.

Code had electrostatic capabilities only. There was no modeling done to study the change in field strength with time or the RC delay. Additionally, a major assumption was made that the resistive coating would be uniformly spread, allowing for a more capable code should be used in the future if more fundamental proof of concept projects are successful like direct writing or winding.

These results proved to us that we can achieve the desired field stress reduction in theory. We should move on to proof of concept experiments to further investigate from here.

Carbon-Black Surface Coating

I set up a proof of concept project to learn whether or not a carbon-black solvent based coating could be used to reduce field stresses. A semi-conductive solvent based coating (trichloroethylene) was chosen as it seemed easy to apply and was low cost.

Method:

Coating application methods included dipping samples into a bowl of diluted coating, and wiping it on using foam brushes. Measurements were carried out on samples that had been wiped since they were visually more uniform. The trichloroethylene solvent was highly mobile and the carbon particles were pulled to a specific location due to the effect of gravity or airflow on the solvent. Resistance measurements were made using a standard Fluke multimeter and substrate samples of equal surface area and material composition.

Results:

The theoretical dilution factor which yields the appropriate resistance was much higher than anticipated. Determination of this factor was done by measuring the resistances of different coating samples with varying concentrations and then extrapolating.

Above dilution factors of 4, measurement variation becomes massive as the resistance vs. dilution factor curve follows a power law shape. Measurements taken on samples above a dilution factor of 10 are not valid due to non-uniformity of the coating. It is thought that there exists a threshold distribution of spacing between carbon particles, above which an electrical network can't be reliably formed.

The durability of the carbon coating isn't well known. The structure and surface area of a carbon black coating strongly affects the surface conductivity. Pure carbon black aggregates to form graphene layers with numerous faults and discontinuities usually. Resistance contributions are mostly from interfaces between the adjacent graphene layers, understanding the different mechanisms in which this occurs is complex. It has been found that compression during graphene layer assembly or measurements has a strong affect on conductivity.

Range: 0.1 to 100 S/cm at RT

Wire Winding

A commercial transformer winder is currently being investigated as a potential resistor application method. Our product has a conical geometry, making it very difficult to form wire coils on its surface.

Method

Bondable magnet wire is used in industry to create transformers and inductors. This type of wire is outfitted with a unique insulation that protects the metal as well as providing the capability to self-bond. Our initial hope was that the heat/solvent activated adhesive insulation could be used to bond it to the surface of our product during the winding process. The insulation is made of polyvinyl butyral, a type of polyurethane. Using heat guns, we empirically determined that the insulation has very good self-bonding capability, but adheres poorly to the surface of our product.

Results

Although the wire did not bond well to the product surface, it could still be useful since it can hold its shape well after treatment. Knowing this, we shifted our focus towards the development of a tacky layer which could potentially keep the wire from slipping down the product surface.

Currently, we have several prototypes for the tacky coating. They were all made using polyjet technology, which is an additive manufacturing method. We are working with operators to wind products that have this coating on them.

Direct Write Technology

Direct write technology works by depositing small, extremely precise ink filaments onto a substrate. The resolution of the filament depends on the ink nozzle and the rheological properties of the ink. We are working with resolutions between 50 to 100 μm, but direct writing is capable of 200 nm resolution. The patterns generated can range from simple one dimensional wires to very complex 3D geometries. The ink nozzle is attached to a computer-controlled translation stage.

Method for designing a writing process:

- 1) Material Basis, Functional phases and gel/solvent matrix
- 2) Resistivity of material, must understand total resistance required (Hard part)
- 3) Length of printed material
- 4) Width or diameter of extrusions (resolution)
- 5) Pitch (dl/dr)

Results

Direct writing seems to be by far the most promising method for applying a resistive material to our product. Flat coupons of the same material as our product have been printed on with success and the desired resistance value was measured. The problem of printing on the conical geometry is still being worked on but we expect this to be possible.

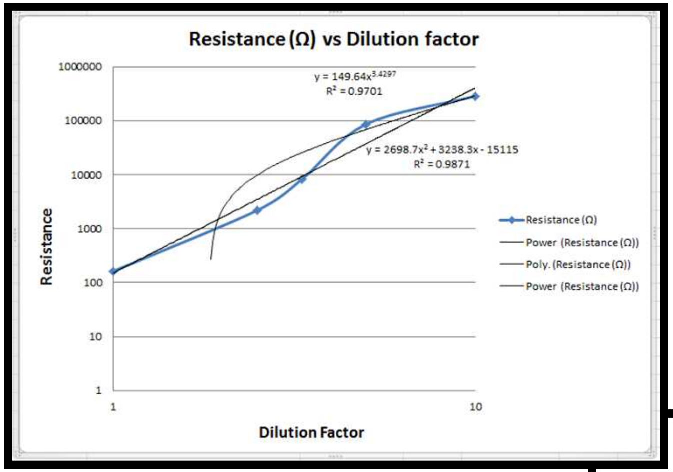
The answers to the above questions determines the fixture and motion program of the direct write system.

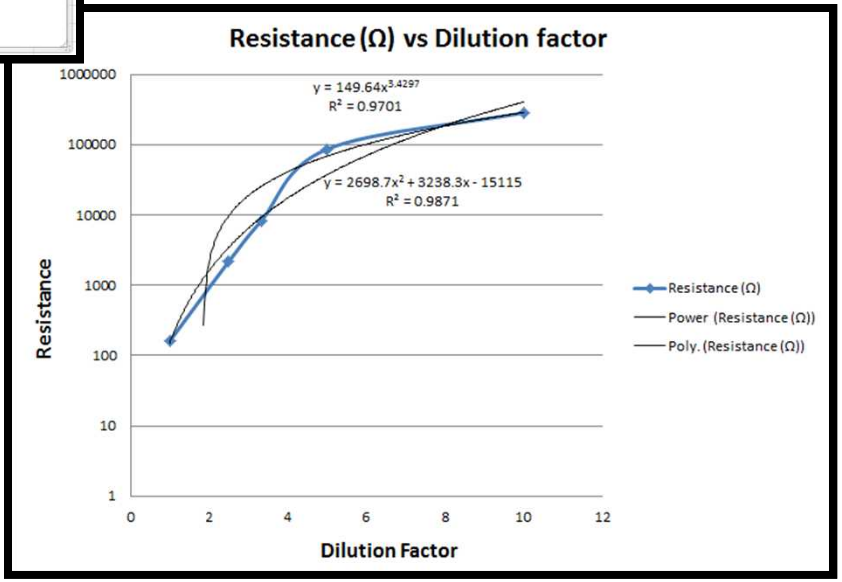
Discussion

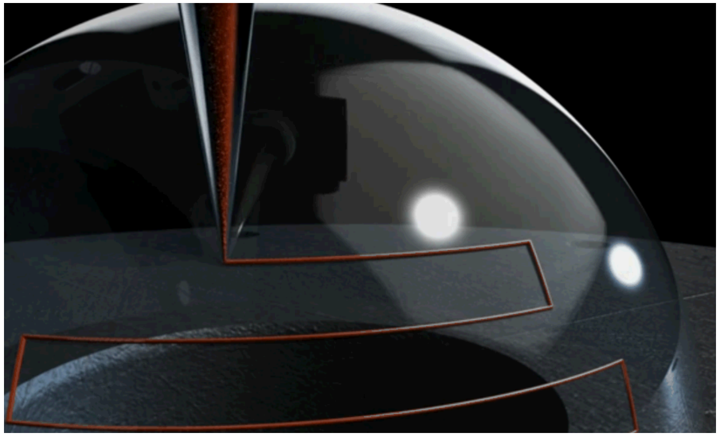
The results of my work strongly suggest that direct write technology has the capability to mitigate the problems associated with high electric field stresses. More work should be done to investigate and validate this technology.

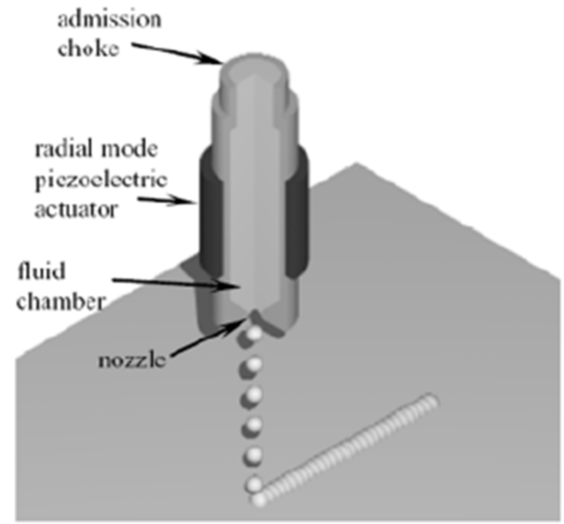
If this option is to be investigated further, better instrumentation needs to be used to measure the conductivity as the surface chemistry is varied, i.e. at different external pressures and with different application methods.

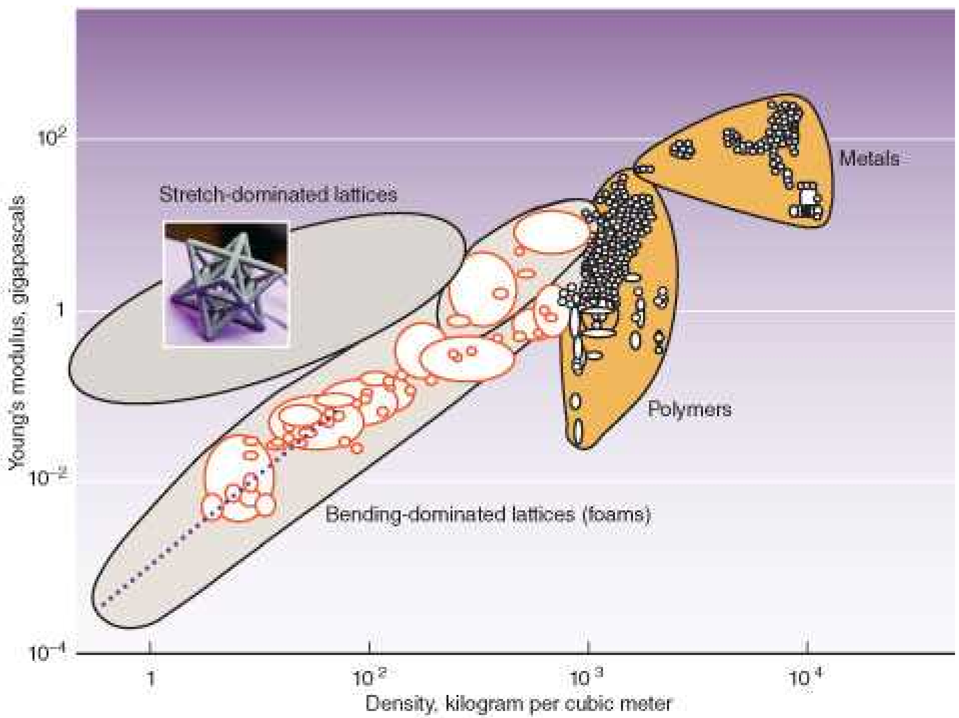
Alternative breakdown mitigations are in place and being studied.


Resistance (Ω) vs Dilution factor
1000000
100000
10000
1000
100
10
1
Resistance
1
10
Dilution Factor
y = 149.64x^3.4297
R² = 0.9701
y = 2698.7x² + 3238.3x - 15115
R² = 0.9871
Resistance (Ω)
Power (Resistance (Ω))
Poly. (Resistance (Ω))
Power (Resistance (Ω))


Resistance (Ω) vs Dilution factor
1000000
100000
10000
1000
100
10
1
Resistance
0
2
4
6
8
10
12
Dilution Factor
y = 149.64x^3.4297
R² = 0.9701
y = 2698.7x² + 3238.3x - 15115
R² = 0.9871
Resistance (Ω)
Power (Resistance (Ω))
Poly. (Resistance (Ω))




admission
choke
radial mode
piezoelectric
actuator
fluid
chamber
nozzle


Young's modulus, gigapascals
10^2
1
10^{-2}
10^{-4}
1
10^2
10^3
10^4
Density, kilogram per cubic meter
Stretch-dominated lattices
Metals
Polymers
Bending-dominated lattices (foams)

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