Mode I Fracture Behavior of Bisphenol-A Epoxy Resins

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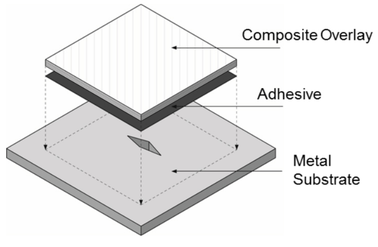
Composite Patch Applications

Composite patches are used within many industries (including aerospace, automotive, and marine) for the purpose of repairing and reinforcing structures.

- Restore load carrying capacity and prevent damage propagation
- Cost efficient repair option for large structural components
- Easily installed even on structures with complex geometries
- Resistant to corrosion, which makes them ideal for use in many environments
- 70 patches are currently installed on 12 Navy ships to reinforce and repair hulls

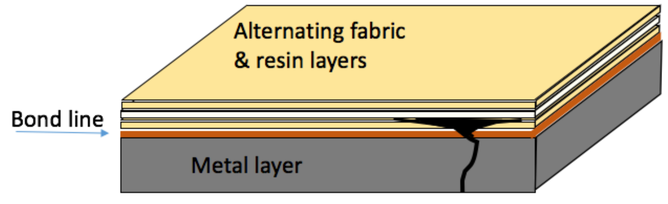
Photo courtesy of the US Navy



Research Motivation

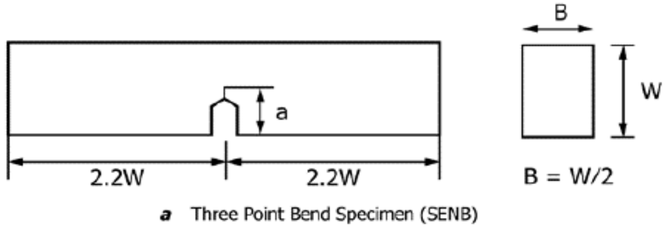
Prior work has shown that the composite patches don't fail at the bond line between the metal and epoxy, but rather the crack grows up into the resin layer causing failure in the epoxy itself.

- By studying the fracture behavior of the epoxy resin, we can improve the physics based model we have developed of the patched structure as a whole.
- 3-point bend testing is an effective method to characterize the fracture behavior and crack growth properties of the resin.
- By utilizing the total force versus crack displacement data gathered from the testing, we will be able to characterize the fracture behavior and calculate the fracture toughness.



Technical Approach

(1) Calculate proper dimension of resin samples for testing according to ASTM standards (American Society for Testing and Materials).
(2) Develop molding method to efficiently produce samples, with minimal air voids and maximized usable material in each mold.
(3) Perform a 3-point bend test to observe the fracture behaviors of Bisphenol-A epoxy resin.
(4) Analyze data for characteristic material properties of the BPA epoxy.
(5) Compare the resin properties when manufactured with slow and fast curing hardeners.

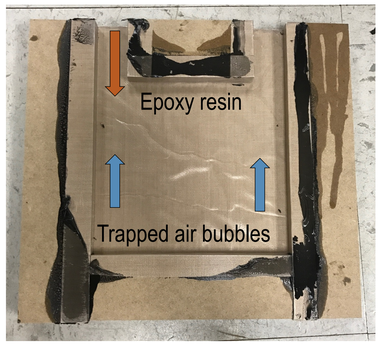


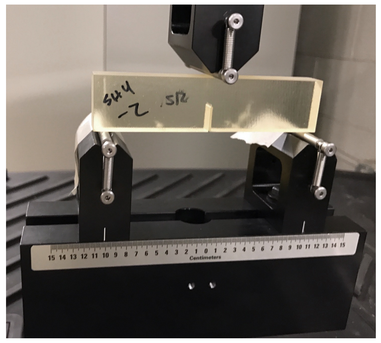
Molding and Testing Methods

We created a mold out of medium density fiberboard pieces covered in Teflon and held together by an RTV Silicone to provide a strong seal.

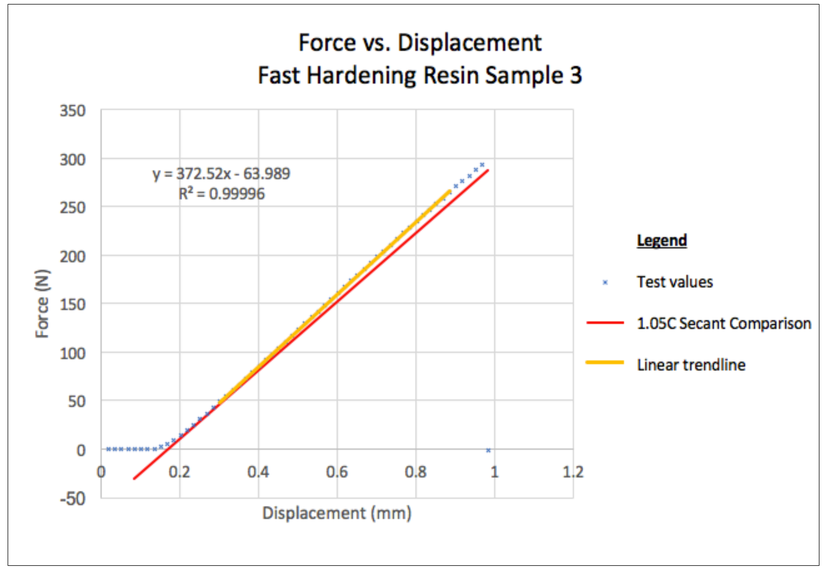
- The Teflon covering allowed for easy disassembly and removal of the epoxy resin slabs as well as quick reassembly for further molding.
- The vertical, two hole design allowed for the resin to be poured into one hole and trapped air to easily rise into the crevice contaminating only the edge of the resin samples

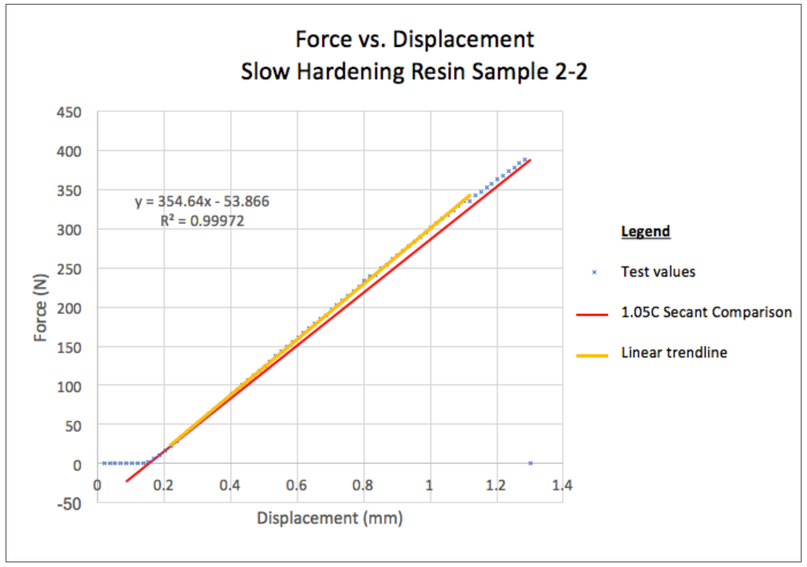
The 3-point bend test allowed us to easily gather load force versus displacement data without special fixtures or attachments.





Three Point Bend Testing Data





Fracture Toughness Comparison

Fracture toughness is the ability of a material containing a crack to resist fracture. This fracture toughness was calculated using the left formula below (where P_c is the maximum load on the sample, Q is a geometry factor given by the right equation below, H is the thickness, and W is the width).

The P_c value was determined by interpolating the force versus displacement testing data and utilizing a linear best fit line to find the maximum force along the trend line.

The fracture toughness values were then compared for the slow versus the fast hardening resins.

$$K_{Ic} = \frac{P_c Q}{H\sqrt{W}}$$

$$Q = 29.6(a/W)^{1/2} - 185.5(a/W)^{3/2} + 655.7(a/W)^{5/2} - 1017(a/W)^{7/2} + 638.9(a/W)^{9/2}$$

Fast hardener K_{Ic} values
1.636606629
2.162647673
1.603764014
1.420454073
1.481012919

Slow hardener K_{Ic} values
2.248960437
2.184141548
2.211690194
2.209694533
2.114420961
2.074908873
2.046906257

Conclusions

- **We previously knew that the composite patches tended to fail through the resin layer adjacent to the metal and then propagate beneath the first fabric layer.**
- **From the 3-point bend test data, we can see that the slow hardening resin performed better than the fast hardening resin (based on the maximum load applied and the fracture toughness values).**
  - On average, the slow hardening resin had a fracture toughness 29.79% greater than the fast hardening resin.
- **We now know that varying the resin used in the patch can alter the fracture toughness and consequently the overall strength of the patch.**
- **This data will be used to modify a detailed 3D computational model of the patch enabling improved predications of patched structural performance.**

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