To compare “traditional” micron-scale rubber toughening of DGEBA to toughening with self assembled nanoscale self assembly to toughen epoxy, we use nanoscale self assembly to toughen epoxy. When cured with a small, nucleophilic molecule, epoxy resins form a 3D, covalently bound polymer matrix. epoxy resins form a 3D, covalently bound polymer matrix. 

Therefore, this work uses nanoscale self assembly to toughen epoxy. We found that SBM is a more efficient toughening agent than CTBN, which undergoes reaction induced phase separation (RIPS) and does not self assemble on the nanoscale.

**Materials and Methods**

Carbon-halogen terminated tri-block copolymers (CTBN) (Figure CTBNx9 and CTBNx13 with 18 and 26% styrenic content, respectively). Neat epoxy was cured at 175 °C for 2 hours and post cured at 125 °C for 2 hours. CTBN modified epoxy: Mix CTBN with DGEBA at 85 °C for 4 hours with magnetic stirring. Infrared was cured at 175 °C and mixed with DGEBA for 2 hours and hand for 3 minutes under vacuum (27 inHg) with a high shear rate mixer. The resin mixture was then degassed in a convection oven at 75 °C for 3 hours and post cured at 125 °C for 2 hours.

SBM modified epoxy: DGEBA and SBM were mixed at 85 °C for 3 minutes. The resin mixture was then degassed (27 inHg at 75 °C), cast and cured in a convection oven at 75 °C for 3 hours and post cured at 125 °C for 2 hours. CTBN modified epoxy: Mix CTBN with DGEBA at 85 °C for 4 hours with magnetic stirring. Infrared was cured at 175 °C and mixed with DGEBA for 2 hours and hand for 3 minutes under vacuum (27 inHg) with a high shear rate mixer. The resin mixture was then degassed (27 inHg at 75 °C), cast and cured in a convection oven at 75 °C for 3 hours and post cured at 125 °C for 2 hours.

CTBNx9 and CTBNx13 increased fracture toughness of cured DGEBA resin by 80%.

**CTBN Modified DGEBA: Results and Discussion**

As shown in Figure 4, CTBNx9 and CTBNx13 increase fracture toughness of cured DGEBA resin. Fracture toughness increases with increasing concentration of CTBN. Therefore, this work uses nanoscale self assembly to toughen epoxy. We found that SBM is a more efficient toughening agent than CTBN, which undergoes reaction induced phase separation (RIPS) and does not self assemble on the nanoscale.

**SBM Modified DGEBA Results and Discussion**

SBM can substantially toughen cured DGEBA epoxy resins, even at small concentrations. Under the processing conditions used in this work, 10 phr SBM processed at 165 °C in DGEBA led to a 215% increase in fracture toughness.

**Conclusion**

- Compared to current toughening methods, nanostructured self-assembly of block copolymers in epoxy resins provides cost effective, efficient toughening of epoxy polymer composites.
- Large increases (over 200%) in fracture toughness were observed at no loss $T_g$.
- Future work will explore the effect of SBM as a toughening agent in carbon fiber reinforced composites.

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- Sternberg semicrystalline diagram by Donald Atkins (http://www.compositesworld.com/articles/expanded/tension-fracture-toughness-testing).

**Figure 4:** Fracture toughness of CTBN toughened epoxy polymer composites.

**Figure 5:** SEM images of the CTBNx9 rubber modified epoxy fracture surfaces.

**Figure 6:** Flexural properties of SBM toughened epoxy polymer composites.

**Figure 7:** Fracture toughness of SBM modified DGEBA.

**Figure 8:** SEM images of the CTBNx9 rubber modified epoxy fracture surfaces.

**Figure 9:** Glass transition temperature ($T_g$) of CTBN and SBM modified DGEBA.