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Fracture Toughness of Alumina Reinforced Epoxy Composites

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Introduction

- Particle filled composites are used in a variety of applications combining the mechanical properties of the matrix improved by the addition of a rigid inorganic.
- Epoxy/Alumina is used in encapsulants, dental applications, and circuit card underfill.
- This work improves the current knowledge of how filler and matrix variables affect the bulk composite properties.

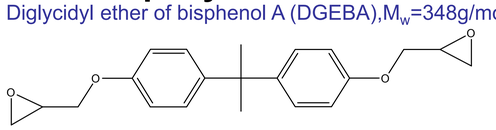
Particulate-Filled Polymer Composites: Rothon, R., Ed.; Longman Scientific & Technical: London, England, 1995, *Handbook of Epoxy Resins;* Lee, H., Neville, K.,; McGraw-Hill: New York, 1967, [1]Particle Size Analysis by Beckman Coulter LS

Objectives and Approach:

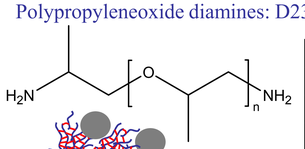
Explore Structure/Property of epoxy and alumina composites

Epoxy Resin

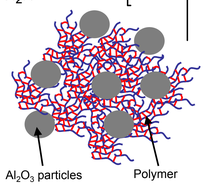
Diglycidyl ether of bisphenol A (DGEBA), M_w=348g/mol



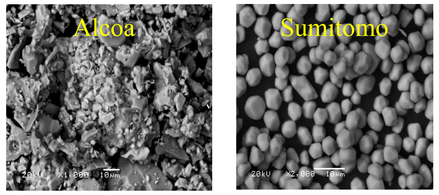
Polypropyleneoxide diamines: D230, D400 and D2000



	n	MW
D230	2-3	230
D400	5-6	400
D2000	33 (Avg.)	2000



Alumina (α-Al_2O_3)



Particle Size[1] (μm)	Sumitomo AA2	Sumitomo AA5	Sumitomo AA10	Sumitomo AA18	Alcoa T60
Mean	3.683	5.064	8.083	16.700	18.81
Mode	3.359	5.064	8.536	18.000	26.14
Standard Dev.	1.589	4.878	2.614	4.713	14.45

Vary particle size

Two different size distributions

Understand the affects of particle shape, size, size distribution, volume % loading and epoxy crosslink density on composite properties: Coefficient of Thermal Expansion (CTE), Fracture Toughness (K_{Ic}), and Modulus (G´).

Dependence of K_{Ic} on Al_2O_3 vol %.

K_c is the plane-strain fracture toughness or critical stress-field around a sharp crack and quantifies the ability of the material to resist crack propagation

$$K_{Ic} = Y\frac{3PS\sqrt{a}}{2BW^2}$$

Where:

Y = Shape Factor, dependent on crack length and specimen depth

P = Load at Failure

S = Length of Span

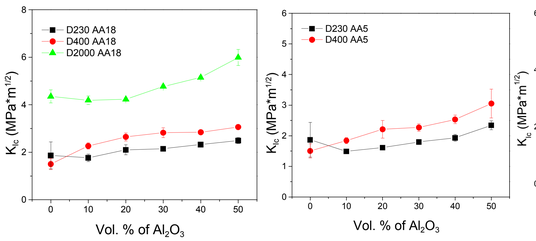
a = Crack Length

B = Thickness

W = Width

Samples tested at 40°C below T_g in a three-point-bend geometry

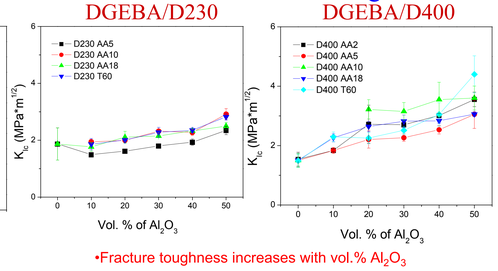
Effect of PPO Molecular Weight on Fracture Toughness



- Increase molecular weight of crosslink, increase fracture toughness

Effect of Particle Size/Size Distribution on Fracture Toughness

DGEBA/D230 DGEBA/D400

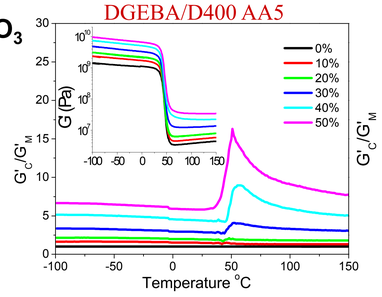


- Fracture toughness increases with vol.% Al_2O_3
- Particle size or particle size distribution has no affect on this length scale

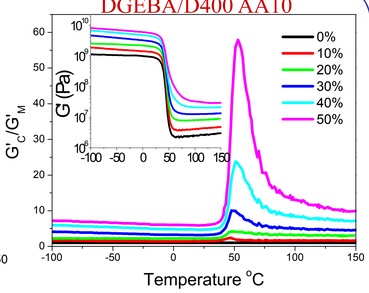
Normalized G' of Epoxy/Al_2O_3 with insets of G'

- Normalization peak increases with increasing vol. %, increasing particle size, and decreasing cross-link density.
- T_g remains constant while G' increases with increasing filler loading.
- The rubbery plateau broadens near T_g.
- Decrease crosslink density increases filler-filler interaction.

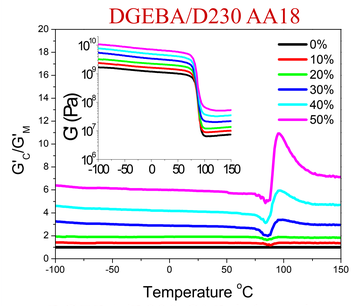
DGEBA/D400 AA5



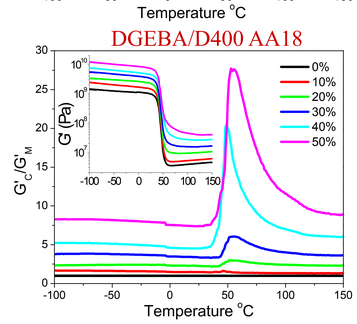
DGEBA/D400 AA10



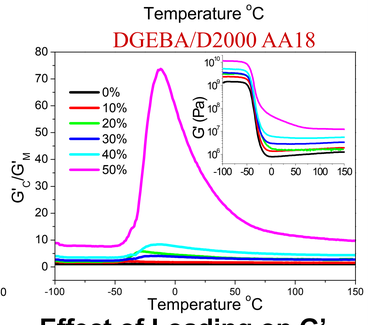
DGEBA/D230 AA18



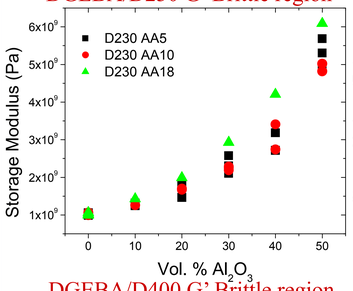
DGEBA/D400 AA18



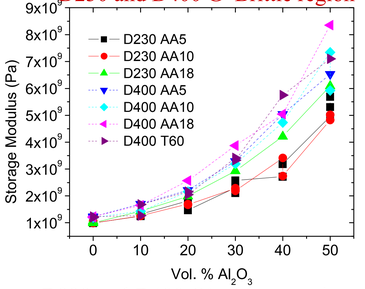
DGEBA/D2000 AA18



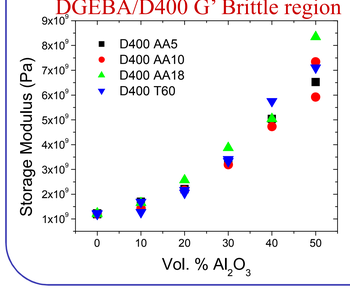
DGEBA/D230 G' Brittle region



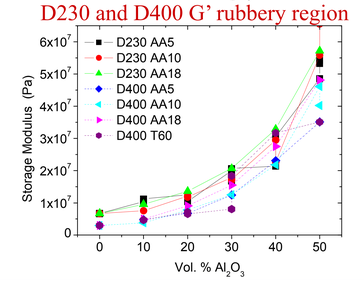
D230 and D400 G' Brittle region



DGEBA/D400 G' Brittle region



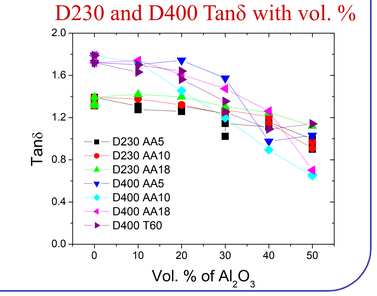
D230 and D400 G' rubbery region



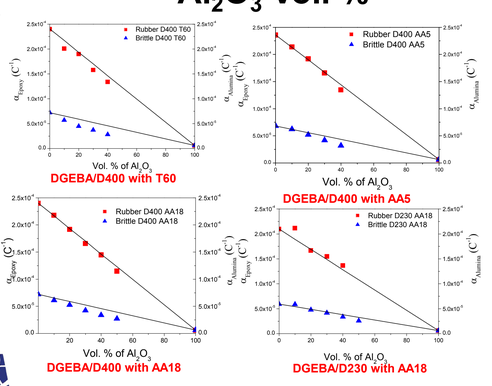
Effect of Loading on G'

- Brittle and rubbery modulus values were determined at 40 °C above and respectively below T_g the peak of the G'' modulus.
- Particle size has no affect on G'.
- H-bonding contributes to a higher D400 brittle modulus
- Modulus is weakly dependent on changes in crosslink density in the glassy region. Decrease crosslink density results in a higher modulus.

D230 and D400 Tanδ with vol. %

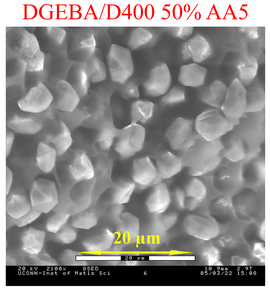


Dependence of CTE (α) on Al_2O_3 Vol. %

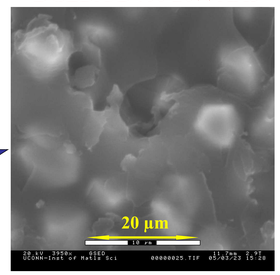


SEM of Fracture Surface

DGEBA/D400 50% AA5



DGEBA/D400 20% AA5



Blue arrow indicates direction of crack propagation

Conclusions

- Increasing volume percent of Al_2O_3:
  - Increases the storage modulus
  - Lowers CTE
  - KIc increased slightly
- Increasing the Al_2O_3 particle size:
  - Slightly increases the modulus
  - No affect on fracture toughness
- Decreasing the crosslink density:
  - Decreases the storage modulus broadening
  - Decreases fracture toughness
  - Increases the energy dissipated in the deformation of a lower cross-linked system

• Crack propagation is occurring at the Al_2O_3 surface.
• The polymer T_g is unaffected by Al_2O_3 addition.

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