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Effect of Mono and Hybrid Fillers on Tensile Properties of Filled Epoxy Composites

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***Abstract*—This paper reports the tensile properties of epoxy filled with micro particulates of Gr and SiC as mono and hybrid fillers. The particulate content was varied from 10% to 40% in steps of 10% up to 40% for both types of fillers. The reinforced SiC fillers in epoxy shows improvement in mechanical strength while Gr fillers and hybrid (Gr-SiC) fillers filled epoxy show a decrement in tensile strength of composites. The tensile moduli of the filled composites increases with increased filler fraction and are higher than the neat epoxy. Further, it is observed that, the filler fraction and filler type has significant role in strength of a particulate filled epoxy composites. The experimental strength and modulus of epoxy composites is compared with analytical equations.**

***Index Terms*— Epoxy-Ep, Graphite-Gr, Silicon Carbide-SiC, composites, tensile strength, tensile modulus.**

I. Introduction

Epoxy is a choice material for engineering applications for the following reasons like ease of processing, excellent resistance to heat, moisture, chemicals and exhibit good dimensional stability [1, 2]. However epoxies are brittle, exhibit poor resistance to crack propagation [3]. Hence fillers are used in epoxy to improve mechanical, thermal and tribological properties [4]. The fillers used can be metallic, non metallic, organic, natural etc. Further, the fillers may be micro or nano sized or whiskers where each has its own advantage and disadvantage. The present study looks in to development of epoxy composites filled with micro particulates of SiC and Gr as mono and hybrid and to find the effect of filler on tensile properties. Determination of strength is very important for the intended engineering applications. The stress induced in a body when it is subjected to two equal and opposite pull and as a result an increase in length is observed. Such a stress is called tensile stress [5]. The modulus of elasticity assess of bonding strength between atoms in a material. Higher modulus materials are stiff and they don't deflect easily [5]. Further, tensile strength and modulus of epoxy composites are compared with theoretical equations.

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II. EXPERIMENTAL

There are various analytical equations developed by various researchers to predict tensile strength and tensile modulus of a particulate filled epoxy composites. Following sections describes the various analytical equations to predict tensile strength and tensile modulus of filled epoxy composites [6, 7].

A. Theoretical Models to predict tensile strength

Wong's model

$$\sigma_c = \sigma_m [1-0.15(V_f/V_m)] \quad (1)$$

Nicolais-Narkis model

$$\sigma_c = \sigma_m (1-1.21V_f^{2/3}) \quad (2)$$

Nielsen's model

$$\sigma_c = \sigma_m (1-V_f^{2/3}) K \quad (3)$$

Tavaman's Model

$$\sigma_c = \sigma_m [1-bV_f^{2/3}] \quad (4)$$

b = 1.1 for densely packed hexagonal packing in the plane of highest packing

b = 1.2 for poor adhesion and spherical particles fraction of filler and matrix respectively.

B. Theoretical Models to predict tensile modulus

Reuss Equation:

$$Ec = \frac{EmEp}{Ep(1-Vp)+EmVp} \quad (5)$$

Maxwell Equation

$$E = Ec\{1+1.5[\frac{(Ed-Ec)}{(Ed+2Ec)}]\phi\} \quad (6)$$

Hamilton Crosser Equation**:**

$$Ec = Em\left[\frac{Ep+(n-1)Em-(n-1)Vp(Em-Ep)}{Ep+(n-1)Em+Wp(Em-Ep)}\right] \quad (7)$$

Where E_c, E_m, E_p, are tensile modulus of composite, matrix and particles respectively

W_p is the particles weight fraction and 'n' is a shape factor.

Iso Stress Equation:

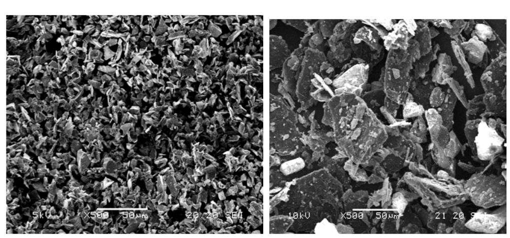
$$Ec=\left[\frac{Vm}{Em}+\frac{Vp}{Ep}\right]^{-1} \quad (8)$$

Where Ec, Em and Ep are respectively modulus of composite, matrix and reinforcement

V_m = Volume fraction of matrix, V_p = Volume fraction of reinforcement

C. *Materials*

Micro particulates of SiC size less than 60 µm (Gransilica India) and Gr particulates of size 20 µm (SD fine chem. ltd India) were the reinforcements. Epoxy resin of type LY556 (RT cure) and an amine hardener HY951 (Huntsman India Ltd) was the host matrix. The resin and hardener were mixed in the ratio 10:1 by weight.



a) SEM of SiC particulates b) SEM of Graphite particulates

Fig1.SEM of particulate fillers

D. *Specimen preparation and Testing*

The predetermined amounts of reinforcements were preheated to remove any moisture present in it and were dispersed in epoxy. The mixtures were stirred continuously until the reinforcements were properly distributed. Hardener was added to the mixture with continuous stirring, followed by pouring the mixture in to a prepared mould. The specimens were allowed to cure in the mould for 24 hours at room temperature followed by post curing at 50^0 C for 30 minutes, 70^0 C for 60 minutes and 85^0 C for 120 minutes. The tensile test is conducted on a flat dog bone type specimen having dimensions 165 X 20 X 3mm as shown in fig2. ASTM D 638 test procedure was followed to evaluate the tensile properties [8]. The tensile tests were conducted on LYOD'S universal testing machine. The specimen was fixed between the cross heads and is pulled at a constant loading rate of 1mm/min till the specimen breaks. For each composite type, tests were conducted on 5 specimens and the tensile strength and modulus were the average value of 5 specimens.

$$St = P / b\, d \quad (9)$$

$$E = (\Delta P / \Delta L)*(L / b\, d) \quad (10)$$

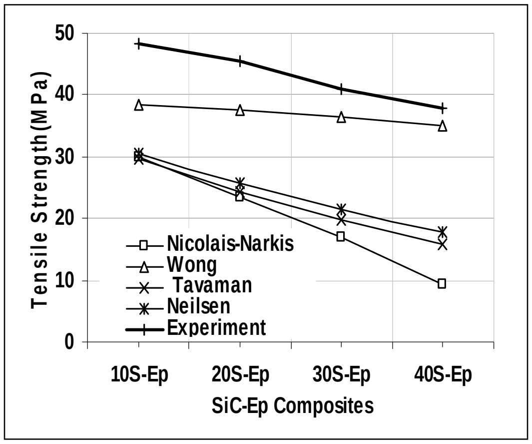
Where, S_t = ultimate tensile strength (MPa), P = load (N), b = width (mm) and d = thickness (mm)
E = modulus of elasticity (G Pa), $\Delta P / \Delta L$ = slope of plot of load as a function of deformation with in the linear portion.

Fig2 Image of cast tensile specimens

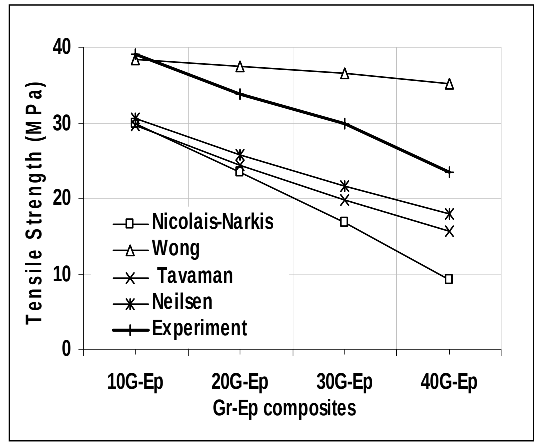
III. Results and Discussion

A. *Tensile strength*

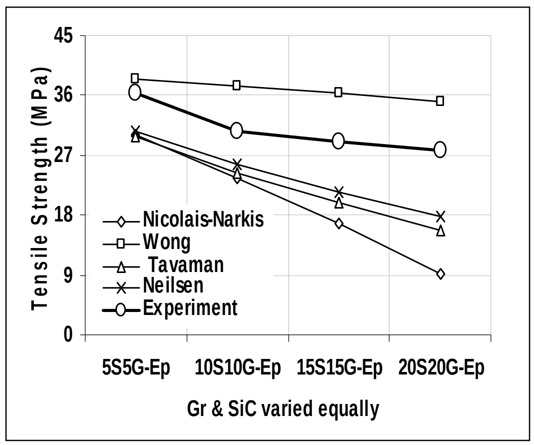
Neat epoxy exhibits a tensile strength of 39MPa. Fig 3(a) presents the tensile strength of SiC-Ep composites. The tensile strength of 10S-Ep composite was found to be 39.49 MPa, a marginal improvement over neat epoxy. Further, 20S-Ep composite exhibits a tensile strength of 42.82 MPa, improvement of 7.77% over neat epoxy. Tensile strength reduces to 40.8 MPa for 30S-Ep composites and filling 40% SiC to epoxy reduces the strength of SiC-Ep composites to 33.8MPa. The increased strength of SiC-Ep up to 30% SiC could be due to following factors such as higher inherent strength of SiC and better interfacial adhesion between epoxy and SiC. Further increased SiC up to 40%, leads to poor interface due to agglomeration of particulates. The tensile strength of Gr-Ep composites is presented in fig 3(b). Tensile strength reduces to 33.84MPa for 10G-Ep composites and 30.93Mpa for 20G-Ep composites. Drastic reduction in tensile strength at 20.92MPa and 21.54MPa was observed for 30G-Ep composites and 40G-Ep composites. This can be attributed to low density of Gr. For a given weight fraction, more Gr particulates are to be filled. Further at higher fraction of fillers, more Gr particulates are accommodated leading to less coverage of resin. This weakens the interfacial strength of matrix and filler. Added to this, the inherent strength of Gr particulates are very low due to its layered structure. Hence when they are combined with epoxy, composite strength decreases. Hence SiC reinforced epoxy composites exhibit higher tensile strength than Gr reinforced epoxy for the given filler loading. Fig 3(c) presents the tensile strength of hybrid (Gr-SiC)-Ep composites where hybrid fillers are varied equally. Equal fraction of hybrid fillers decreases the tensile strength of hybrid (Gr-SiC)-Ep composites. The deterioration of strength is attributed to increased fraction of Gr particulates. However the strength of hybrid (Gr-SiC)-Ep composites is higher than Gr-Ep composites and lower than SiC-Ep composites. Tensile strength prediction by models such as Nicolais-Narkis, Wong, Tavaman and Neilsen predict strength based on the filler fraction and not on filler characteristics. Hence for a given filler fraction, the strength will be same irrespective of filler type. However, prediction by Wong's equation is nearer to experimental values.



a) SiC-Ep composites



b) Gr-Ep composites

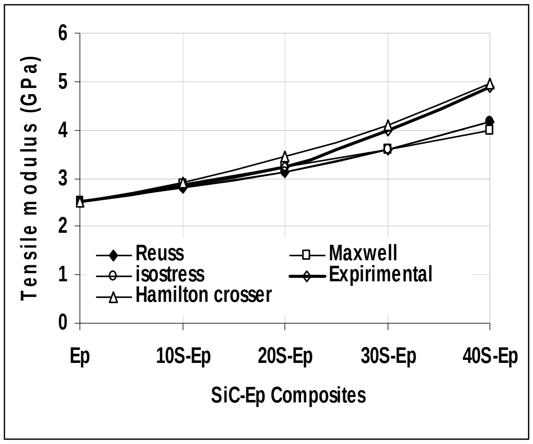


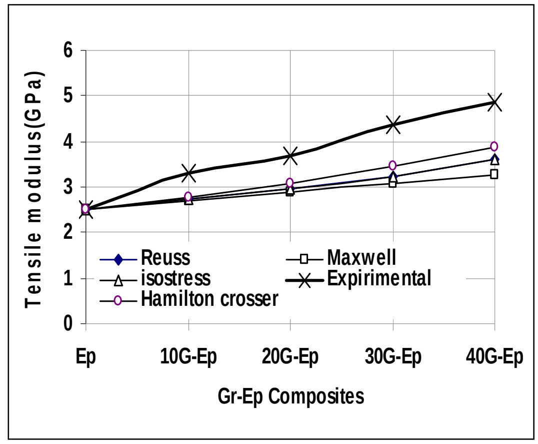
c) Hybrid (Gr-SiC)-Ep composites

Fig 3 Tensile strength of SiC-Ep, Gr-Ep and hybrid (Gr-SiC)-Ep composites

B. Tensile modulus

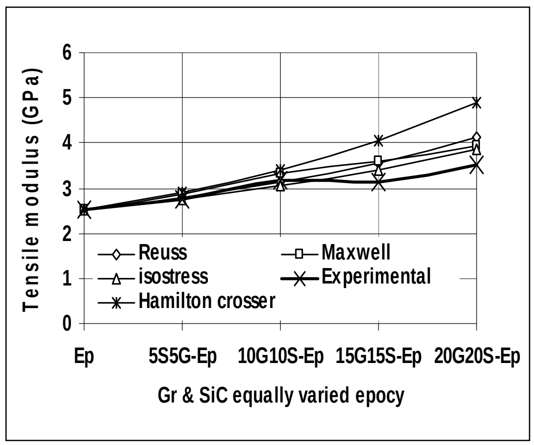
Cured epoxy exhibits a tensile modulus of 2.51GPa. Fig 4(a) compares the tensile modulus experimental and prediction of SiC-Ep composites. 10S-Ep composite exhibits 3.13GPa. Further increased SiC loading increases the modulus for 20S-Ep composite to 3.25GPa, 30S-Ep composite to 3.58GPa and 40S-Ep composite to 3.86GPa. The epoxy, known for brittleness is reinforced by a hard SiC, increases the modulus of epoxy composites. Tensile modulus arrived from Reuss, Isostress; Maxwell and Hamilton crosser is in agreement with experimental value up to 20 percent SiC loading. For composites 30S-Ep and 40S-Ep composite Hamilton crosser's prediction is nearer to experimental value where as lower tensile modulus was predicted by Maxwell, Reuss and isostress. Fig 4(b) compares the tensile modulus experimental and prediction of Gr-Ep composites. Tensile modulus increases to 3.86GPa for 10G-Ep composites and further increases to 4.38GPa for 20G-Ep composites and 4.95GPa for 30G-Ep composites. The maximum tensile modulus of 5.56Gpa was observed for 40G-Ep composites. Increased tensile modulus of Gr–Ep composites can be attributed to increased Gr particles for a given weight fraction, which increases the stiffness of Gr-Epoxy composites. Comparing modulus experimental and prediction, experimental modulus is higher than prediction. Fig4 (c) presents the effect of varying Gr and SiC equally on tensile modulus of hybrid (Gr-SiC)-Ep composites. Tensile modulus increases 2.75GPa and 3.19GPa for 5G5S-Ep and 10G10S-Ep composites and comes down to 3.13GPa for 15G15S-Ep composites. A marginal rise in tensile modulus to 3.50GPa was observed for 20G20S-Epcomposites. At higher fraction, the rise in modulus is lower due effect of SiC fillers.





a) SiC-Ep composites

b) Gr-Ep composites



c) Hybrid (Gr-SiC)-Ep composites

Fig 4 Tensile strength of SiC-Ep, Gr-Ep and hybrid (Gr-SiC)-Ep composites

Reinforced micro particulate fillers reduce tensile strength of epoxy polymer. Reinforced fillers reduce mobility chain in polymer matrix which reduces the elongation at break. The size, shape and distribution of particle in a matrix have a role in strength of a polymer [9, 10]. As the tensile strength of SiC is higher than Gr, SiC rich hybrid epoxies show higher tensile strength than Gr rich hybrid epoxies. Increased fillers reduce the interfacial adhesion of between fillers and matrix leading to non effective transfer of load [11, 12]. At higher filler loadings, particle to particle contact makes the interface weak leading to lowering of tensile strength. Further brittle fillers reinforced with brittle matrix acts as a stress raisers causing weakness in the structure [13]. Particle size higher than 80nm makes adhesion poor at the interface leading to poor strength of the composites [9, 14 and 15]. Further filler concentration above 10% makes the stress transfer ineffective and also the dispersed particulates in epoxy have different moduli and poison's ratio from the resin creates stress concentration and this magnifies the stress surrounding the particle leading to lowering of strength [16].Hence maximum degradation of strength was observed at 40wt% hybrid filler loading. Tensile modulus increases with increased concentration of hybrid (Gr-SiC) fillers. This is due to restriction on the mobility of the particulate fillers during testing [17].

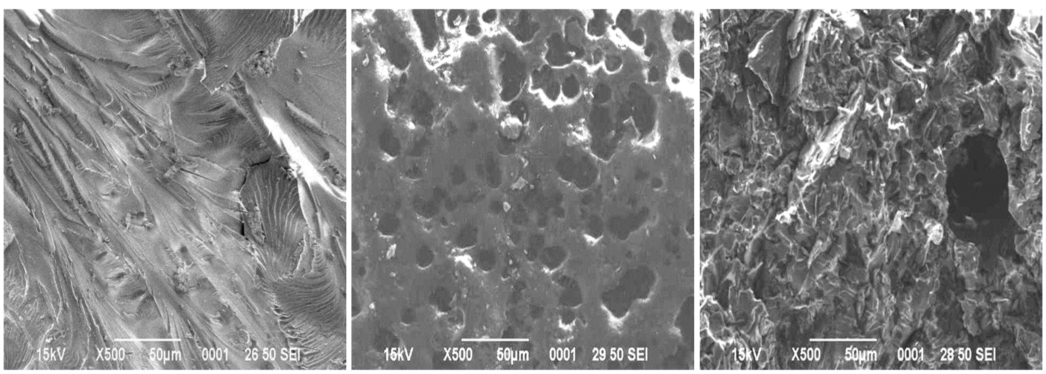
C *SEM of Fractured surfaces of hybrid (Gr-SiC)-Ep composites*

Fig 5 presents the fractured images of epoxy and its composites. The image of neat epoxy shown in fig 4(a) appears smooth and occurrence of fan blade marks, formation of crack before failure is an indication of a brittle failure is a characteristic of fractured epoxy [18]. The image of 10S10G-Ep composites is presented in

TABLE I. TENSILE STRENGTH OF EPOXY COMPOSITES

Tensile Strength						Tensile Modulus				
Type	Nicolais -Narkis	Wong	Tavaman	Neilsen	Expt	Reuss	Maxwell	Isostress	Hamilton crosser	Expt
10S-Ep	29.99	38.35	29.76	30.60	48.37	2.79	2.88	2.79	2.93	2.84
20S-Ep	23.52	37.54	24.33	25.66	45.36	3.14	3.24	3.14	3.44	3.25
30S-Ep	16.83	36.49	19.77	21.52	40.94	3.58	3.61	3.58	4.09	3.98
40S-Ep	9.24	35.10	15.71	17.83	37.74	4.16	3.97	4.16	4.96	4.88
10G-Ep	29.99	38.35	29.76	30.60	38.98	2.72	2.70	2.72	2.78	3.3
20G-Ep	23.52	37.54	24.33	25.66	33.74	2.96	2.89	2.96	3.09	3.7
30G-Ep	16.83	36.49	19.77	21.52	30	3.24	3.08	3.24	3.46	4.36
40G-Ep	9.24	35.10	15.71	17.83	23.42	3.59	3.27	3.59	3.88	4.86
5S5G-Ep	29.99	38.35	29.76	30.60	36.25	2.79	2.87	2.76	2.92	2.75
10S10G-Ep	23.52	37.54	24.33	25.66	30.55	3.13	3.34	3.04	3.42	3.19
15S15G-Ep	16.83	36.49	19.77	21.52	28.91	3.56	3.57	3.40	4.06	3.13
20S20G-Ep	9.24	35.10	15.71	17.83	27.86	4.13	3.93	3.85	4.90	3.50

fig 5 (b) where in the fillers is reinforced in equal proportion. The image clearly indicates removal of particulates due to load and still part of composites are connected. Fig 5(c) presents the image of 15G15S-Ep composites having a big crater and cracks.



(a)Epoxy b) 10S10G-Ep composite c) 15S15G-Ep composite

Fig 5 SEM of hybrid (Gr-SiC)-Ep composites

IV. CONCLUSION

Epoxy filled with mono SiC fillers exhibit higher tensile strength than neat epoxy, Gr-Ep composites and hybrid (Gr-SiC)-Ep composites. However tensile modulus increases irrespective of filler type. Gr-Ep composites exhibit higher modulus than predicted by analytical models. Strength predicted by Wong's equation exhibits a reasonable correlation with strength determined by experiment.

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