Investigation on Tribological and Mechanical Properties of Filler Reinforeced Epoxy Composite

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Abstract:- Epoxy resin was reinforced by various fillers silica, graphite and coconut shell powder. These mixtures were prepared by mechanical stirrer and compression molding machine. Investigation on tensile strength, modulus and strain rate, impact strength, hardness and wear behavior are presented as per the ASTM standards. Tensile strength does not increase with addition of filler particles whereas tensile modulus of material significantly improved due to their rigid filler particle on matrix. On considering impact strength the best result obtained presences of higher amount of coconut powder. Hardness of composite materials increasing with increase in filler content and the maximum hardness obtained on 10, 10 and 30 wt% of Si, Co and Gr filled epoxy composite. The wear and friction coefficient were carried under dry condition at normal load (30N), sliding velocity (1.5 m/s) and sliding distance (1.2 km) using pin-on-disc tribometer. Incorporation of particles significantly reduced the friction coefficient and wear rate, then lower friction occurred on S5 samples as 0.37. On other hand, lower wear rate traced on S3 sample as 4.44 × 10^8 mm^3/Nm.

Keywords: Polymer matrix, mechanical, pin-on-disc tribometer, dry sliding, friction and wear

1. INTRODUCTION

Epoxy composite found wide range of application on structural materials for aerospace, automotive and chemical industries due to their inert in chemical environment, thermal resistance, good mechanical properties, electrical insulation and adhesive strength. In the field of tribology, polymer matrix composites were slowly replacing traditional metals/materials due to less weight to strength ratio, self-lubricant property, low thermal coefficient of expansion, low wear rate and friction coefficient. They were mainly employed as cams, gears, bushes, thrust washers, sliding plates and sealing washers in hydraulic cylinder. It's not possible to employee a neat epoxy on above application because of brittle property, poor resistance to crack propagation and fracture toughness. To overcome these drawback of epoxy, nano silica with different particle size [1], nano rubber particle [2] enhanced a fracture toughness of epoxy composite. To increase wear resistance of matrix various filler and reinforcement were added with different size, shape, orientation and content. The tribological behaviour of thermoplastic and thermosetting polymer were improved by incorporating inorganic fillers like ZrO_2, TiO_2, ZnO and Ti3SiC_2 [3-6]. On considering a size of particle, micro and nano sized filler predominantly enhanced a wear rate of composite but different wear mechanism was occurred [7]. Silicon dioxide (SiO_2) is also known as silica. Even though fracture toughness and wear resistance increased [8,9] on addition of SiO_2 on epoxy composite, and also tend to decrease on mechanical strength and hardness of composite [7]. But post curing at oven increased the tensile property of SiO_2/epoxy composite [10]. Addition of silica formed a tribofilm on counter face under water lubrication which reduced a friction and wear rate of composite [11].

Most investigation revealed that solid lubricant such as graphite and MoS_2 enhanced a wear and frictional characteristics. Addition of graphite particle to mineral oil improved a lubricant characteristic which reduced friction up to 24% and also found that viscous property does not changes at higher temperature [12]. MoS_2 filled PC decreased the wear and friction coefficient of composites which also increased heat dissipation under running condition [13]. On comparing these two solid lubricants, graphite provided a better performance over MoS2 due to that the MoS_2 oxidized with MoS_3 under sliding condition [14]. Coconut (Cocos nucifera) was a member of the palm family. The coconut palm was used for decoration as well as for its many culinary and non-culinary uses; virtually every part of the coconut palm has some human use. Coconut shell powder had lignin content of 29.35% by it mass [15]. Coconut shell consists of C (74.3%), O (21.9%), Si (0.2%), K (1.4%), S (0.5%), P (1.7%), and O/C
(0.29%). Even though coconut fibre has lower tensile strength, it possesses higher elongation at break and impact strength than soft wood and barley husk [16].

Epoxy materials have great potential on tribological applications, but in certain cases, the low hardness, strength, Young's modulus, and heat resistance, as well as high friction coefficient and wear rate of pure epoxy does not meet the requirements. To overcome these defects the epoxy was reinforced with various filler particles such as graphite, silica and coconut shell powder. In this present work mechanical properties such as tensile, impact & hardness and tribological performance were analysed.

2. EXPERIMENTAL PROCEDURE

2.1. Materials and preparation of composite

In this study, epoxy resin and its consistent hardener was used as polymer matrix which brought from Covai Seenu and Company at Coimbatore, Tamilnadu, India. Graphite (GR030PI), silica and finely grained coconut shell were used as filler particle. A definite amount of fillers was stirred well with epoxy resin for 10min. The hardener (10%) was added at resin to hardener ratio of 100:15 ml and stirred mechanically for 5min. Subsequently, mixture was poured into mould at 32℃ and closed mould allowed for 8hr to take solidification and then removed composites plate was post cured at 70℃ for 1h. The dimension of composites plate was 240 x 220 x 4mm. The composition of epoxy resin and wt% of fillers are shown in Table 1. Tribological pin (Φ10mm, L=25mm) were prepared by pouring mixture into tribomould and allowed to cure for 8h.

2.2 Hardness of the composites

A Rockwell hardness test was employed to find hardness of a composite materials. The Rockwell determines hardness by using measuring the intensity of penetration of an indenter (1/16" ball) under a load (60kgf). To obtain a consistency test, the five locations was selected to measure the hardness and average value was plotted.

2.3 Wear and friction testing procedure

According to standard ASTM G99, friction and wear behaviour of composite materials have been investigated against alumina disc using pin on disc tribometer and its schematic diagram is shown in figure 1. The experiment was carried under dry condition at ambient temperature, load (30N) and velocity (1.5m/s) for 1.2km. Initially the pin was cleaned with ethanol and weighed. Next, the pin was mounted on pin holder and test have been carried out for above condition. Before weighing, specimen was cleaned in ethanol and mass loss were measured. Test was replicated for three times and average value was taken in order to obtain uniformity. The wear rate was calculated by using below equation (1).

$$wear\ rate = \frac{m}{F_N L}\ [mm^3/(Nm)] \qquad (1)$$

where, m is mass loss (mm^3), F_N is frictional force (N) and L is sliding distance (m).

Table 1. weight % of filler and symbols used to identify composite

S.No	Material Code	Matrix (Epoxy) Weight fraction (%)	Silica Weight fraction (%)	Coconut Weight fraction (%)	Graphite Weight fraction (%)
1	S0	100	0	0	0
2	S1	70	10	10	10
3	S2	60	10	10	20
4	S3	50	10	10	30
5	S4	60	10	20	10
6	S5	50	10	20	20
7	S6	40	10	20	30

2.4 Mechanical properties

The mechanical and impact properties were measured as per ASTM standards. The tensile properties such as tensile modulus, strength and strain rate were conducted on universal testing machine. As per ASTM D638, dog bone shape specimen (L=165mm, B=19mm, W=4mm) used for tensile test. The impact test has been conducted as per ASTM D 256 on izod – impact tester with dimensions of L=49mm, B=13mm, W=4mm. Test is replicated for three times and average was taken in order to consistency.

Figure 1 Friction and wear test rig (a) computer display (b) lubricant system (c) load setup (d) disc and pin holder

3. RESULT AND DISCUSSION

3.1. *Mechanical Properties*

The impact strength and tensile properties of a filled and unfilled epoxy composites were listed in Table 2. Due to poor interaction between epoxy and filler particles, tensile strength is decreased with incorporation of filler particles. Among filler reinforced epoxy S6 provided a better tensile strength whereas lower strength on S3. Tensile strength of specimen was increased at 20 wt% than 10wt% filled coconut powder and also strength increasing with increase in graphite content. Tensile modulus of epoxy composite increased with addition of filler content this may due to integration of rigid filler particle in to matrix. The higher tensile modulus obtained for S5 composite while lower for S0 and S4 composites. Tensile strain (%) of filled epoxy behaves between 1.9 to 2.74, but neat epoxy strain rate showed 4.32%. The impact strength of material was increased to 4.64 kJ/m^2 for S4 as compared to 2.84 kJ/m^2 for neat epoxy resin. On other hand impact strength behaves very similar to neat epoxy this may because of poor interaction between of filler particle and epoxy composite which also shows optimum amount of filler content can improve impact strength of material. The lower amount impact strength obtained as 2.12$kJ/m^2$for S2 and S3 composite. Impact strength may be reduced due to their poor shock absorption/resistance under higher deformation rate of ceramic material than neat epoxy.

Table 2. Mechanical properties of epoxy composite

S. No	Material Code	Tensile Strength (MPa)	Tensile Modulus (MPa)	Tensile Strain (%)	Impact Strength (kJ/m^2)
1	S0	31.29	724.39	4.32	2.84
2	S1	20.36	841.65	2.42	2.84
3	S2	23.04	952.11	2.42	2.12
4	S3	19.01	1001	1.9	2.12
5	S4	22.68	827.94	2.74	4.64
6	S5	24.31	1095.33	2.22	2.84
7	S6	26.48	1003.29	2.64	2.84

3.2. *Hardness*

The hardness of composites was significantly increased with addition of filler particles to epoxy. The higher hardness obtained for S3 & S6 composites whereas lower hardness obtained for neat resin & S1 composites among filler reinforced specimen. Figure 2 reveals that hardness of composite were increased with increase in coconut shell powder and graphite. This results because of ceramic powder were hard in nature than neat epoxy which increased the resistance of the material against the penetration of the indenter.

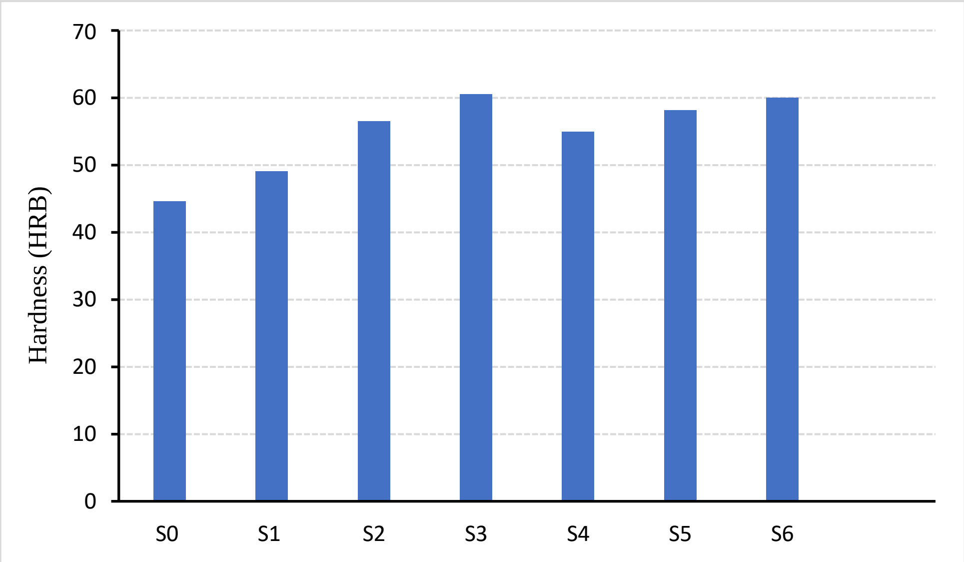

Figure 2. Hardness of epoxy composites

3.3. Effect of Coefficient of Friction

Figure 3 shows the friction coefficient of filled and unfilled epoxy composite. The coefficient of friction reduced up to 20-60% on particles reinforced epoxy composites than unfilled epoxy. The lower coefficient of friction obtained for S2 and S5 (20% of Gr), it clearly reveals that the friction coefficient is significantly depended on graphite content. Further addition in graphite content of 30%, friction coefficient was increased. Addition of coconut particle (20 wt%) significantly reduced the friction coefficient up to 20% than coconut particle of 10wt% and it clearly revealed that friction coefficient also depends upon graphite and coconut shell powder whereas silica does not make much contribution on friction coefficient.

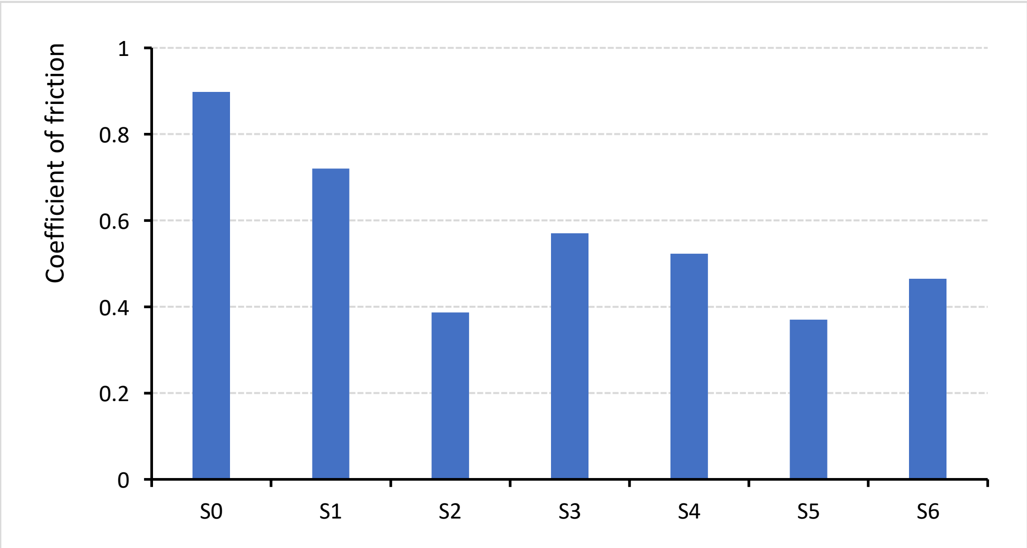

Figure 3. Friction Coefficient of Epoxy Composites

3.4. Effect of Wear Rate

The incorporation of filler particle significantly reduced the wear rate of composite. The lower amount of wear rate was obtained for S3 as 4.44×10^8 mm^3/Nm whereas higher wear rate obtained on unfilled epoxy as 12.45×10^8 mm^3/Nm. Figure 4 shows that wear rate reduces with increase in graphite content on composites, the lowest wear rate on 30% of Gr for both set. Addition of coconut powder leads to increase the wear rate. Even though lower friction coefficient obtained for 20% of graphite, lower wear rate occurred for 30% of graphite, this may be strong adhesion of filler particles on epoxy composites. A S4 sample behaves very similar to neat epoxy, it may be abrasive wear between composite and counter surface.

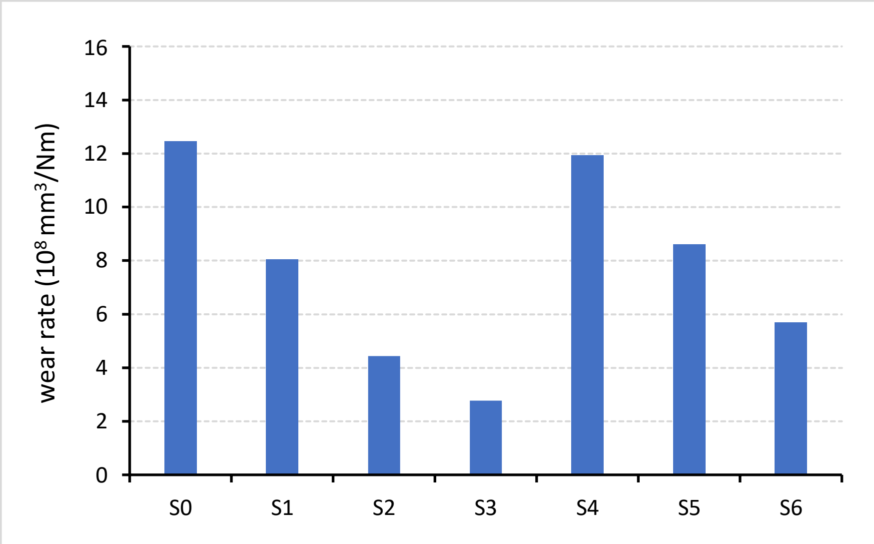

Figure 4. Wear rate of epoxy composites

4. CONCLUSION

A mechanical and dry sliding wear behaviour of graphite, silica and coconut powder filled epoxy resin were investigated and the following conclusions were drawn.

- Hardness of composite were improved by addition of various filler particles. Higher hardness obtained for S3 and S6 as 60.5 and 60HRB whereas lower hardness obtained on 45HRB (approx.) on neat epoxy.
- Tensile strength of material does not improve due to poor interaction between epoxy and filler content. On other hand tensile modulus of composite increased up to 1095 MPa due to rigid filler particle in to matrix.
- Higher tensile strain rate occurred on neat epoxy due to good plastic deformation than reinforced composite. Higher impact strength obtained for 10 wt% of Si, 20 wt% of CO and 5 wt% of Gr filled Epoxy as 4.64 kJ/m^2.
- The friction coefficient of composite was from 0.898 to 0.37 due to addition of filler particle. A sample with 10 wt% Si, 20 wt% of Co and 20 wt% of Gr provided better friction coefficient.
- A friction coefficient is increasing with increase in coconut shell powder and also with increase in graphite content which provides best result for 20 wt% filled Gr.
- A sample with 10 wt% Si, 10 wt% of Co and 30 wt% of Gr provides a lower wear rate 2.77 $\times 10^8$ mm^3/Nm, and higher wear rate on neat epoxy and S4 composite are obtained as 12.45$\times 10^8$ mm^3/Nm, and 11.94 2.77 $\times 10^8$ mm^3/Nm. The wear rate increase with increase in coconut shell powder because of abrasive wear behaviour.
- Friction coefficient does not correlate wear rate. Even though lower friction obtained for S5 composite, lower wear rate occurred for S3 composite this may be strong adhesion of filler in composite and resistance to abrasive wear between counter surface and composite.

REFERANCE

1. Milad Zamanian, Mehrzad Mortezaei, Babak Salehnia and J.E. Jam, "Fracture toughness of epoxy polymer modified with nanosilica particles: Particle size effect". Engineering Fracture Mechanics 97 (2013) 193–206.
2. Hong-Yuan Liu, Gong-Tao Wang, Yiu-Wing Maia and Ying Zeng, "On fracture toughness of nano-particle modified epoxy". Composites: Part B 42 (2011) 2170–2175.
3. R.V. Kurahattia, A. O. Surendranathan, A.V. Ramesh Kumar, C. S. Wadageri, V. Aurad and S. A. Kori, "Dry Sliding Wear behaviour of Epoxy reinforced with nanoZrO2 Particles". Dry Sliding Wear behaviour of Epoxy reinforced with nanoZrO2 Particles. Procedia Materials Science 5 (2014) 274 – 280.
4. Siddhartha, Amar Patnaik, Amba and Bhatt, "Mechanical and dry sliding wear characterization of epoxy–TiO2 particulate filled functionally graded composites materials using Taguchi design of experiment". Materials and Design 32 (2011) 615–627.
5. Fei Li, Ke-ao Hu, Jian-lin Li and Bin-yuan Zhao, "The friction and wear characteristics of nanometer ZnO filled polytetrafluoroethylene". Wear 249 (2002) 877–882.
6. Jianguang Xu, Hanbing Yan and Daguo Gu, "Friction and wear behavior of polytetrafluoroethene composites filled with Ti3SiC2". Materials and Design 61 (2014) 270–274.
7. Bernd Wetzela, Frank Haupert and Ming Qiu Zhang, "Epoxy nanocomposites with high mechanical and tribological performance". Composites Science and Technology 63 (2003) 2055–2067.
8. Y.L. Liang and R.A. Pearson, "Toughening mechanisms in epoxy–silica nanocomposites (ESNs)". Polymer 50 (2009) 4895–4905.
9. J. Abenojar, J. Tutor, Y. Ballesteros, J.C. del Real and M.A. Martínez, "Erosion-wear, mechanical and thermal properties of silica filled epoxy nanocomposites". Composites Part B 120 (2017) 42-53.
10. M. Zappalorto, A. Pontefisso, A. Fabrizi, M. Quaresimin, "Mechanical behaviour of epoxy/silica nanocomposites: Experiments and modelling". Composites: Part A 72 (2015) 58–64.
11. C.P.Gao, G.F.Guo, F.Y.Zhao, T.M.Wang, B.Jim, B.Wetzel, G.Zhang and Q.H. Wang, "Tribological behaviors of epoxy composites under water lubrication conditions". Tribology International 95 (2016) 333–341.
12. Chang-Gun Lee, Yu-Jin Hwang, Young-Min Choi, Jae-Keun Lee, Cheol Choi and Je- Myung Oh, "A Study on The Tribological Characteristics of Graphite Nano Lubricants". International Journal of Precision Engineering and Manufacturing 10 (2019) 85-90.

13. B. Ben Difallah, M. Kharrat, M. Dammaka and G. Monteil, “Improvement in the Tribological Performance of Polycarbonate via the Incorporation of Molybdenum Disulfide Particles”. Tribology Transactions 57 (2014) 806-813.
14. Hui-Juan Zhang, Zhao-Zhu Zhang and Fang Guo, “Studies of the Influence of Graphite and MoS2 on the Tribological Behaviors of Hybrid PTFE/Nomex Fabric Composite”. Tribology Transactions 54 (2011) 417-423.
15. Chinthani D Liyanage and Mevan Pieris, “A Physico-Chemical Analysis of Coconut Shell powder”. Procedia Chemistry 16 (2015) 222 – 228.
16. Andrzej K. Bledzki, Abdullah A. Mamunas and Jürgen Volk, “Barley husk and coconut shell reinforced polypropylene composites: The effect of fibre physical, chemical and surface properties”. Composites Science and Technology 70 (2010) 840–846.