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# Optimization of tribological parameters in abrasive wear mode of carbon-epoxy hybrid composites

B.N. Ramesh [a], B. Suresha [b,*]

[a] Department of Mechanical Engineering, Adichunchanagiri Institute of Technology, Chikkamagalur 577 102, India
[b] Department of Mechanical Engineering, The National Institute of Engineering, Mysore 570 008, India

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ABSTRACT

Abrasive wear performance of fabric reinforced composites filled with functional fillers is influenced by the properties of the constituents. This work is focused on identifying the factors such as filler type, filler loading, grit size of SiC paper, normal applied load and sliding distance on two-body abrasive wear behaviour of the hybrid composites. Abrasive wear tests were carried on carbon fabric reinforced epoxy composite (C-E) filled with filler alumina ($Al_2O_3$) and molybdenum disulphide ($MoS_2$) separately in different proportions, using pin-on-disc apparatus. The experiments were planned according to Taguchi L18 orthogonal array by considering five factors, one at two levels and the remaining at three levels, affecting the abrasion process. Grey relational analysis (GRA) was employed to optimize the tribological parameters having multiple-response. Analysis of variance (ANOVA) was employed to determine the significance of factors influencing wear. Also, the comparative specific wear rates of all the composites under dry sliding and two-body abrasive wear were discussed. The analysis showed that the filler loading, grit size and filler type are the most significant factors in controlling the specific wear rate of the C-E composite. Optimal combination of the process parameters for multi performance characteristics of the composite under study is the set with filler type as $MoS_2$, filler loading of 10 wt.%, grit size 320, load of 15 N and sliding distance of 30 m. Further, the optimal parameter setting for minimum specific wear rate, coefficient of friction and maximum hardness were corroborated with the help of scanning electron micrographs.



## 1. Introduction

Fibre reinforced polymer composites (FRPCs) have emerged as structural materials due to their high specific strength/stiffness and ease of fabrication. These are extensively used in applications requiring resistance to abrasion. Common applications are chute liners, conveyor aids, vanes, gears, pumps handling industrial fluids, abrasive contaminated water, bushes and seals in agricultural and mining equipment [1]. In FRPCs, matrix material plays an important role. Various types of polymers are used as matrices and among them epoxy, a thermosetting resin is commercially used engineering material due to their good mechanical strength, hardness, thermal and chemical stability. The fibre reinforcement in polymer matrix improves the load bearing capability [2–4]. Among the different types of fibres used (carbon, aramid and glass) the wear rate of composite reinforced with carbon fibres is less than that of glass fibres [3]. Furthermore, woven fabric reinforced polymer composites yield better wear characteristics [5,6]. Modi et al. [5] found that there is an increase in wear resistance of carbon fabric reinforced composites and the same is attributed to their balanced properties due to the simultaneous existence of parallel and anti-parallel fibres. Grove and Budinski [6] discussed the fabric form of fibre reinforcement for self lubricated bearing. The fabric reinforcement to a neat polymer improves the wear resistance of the reinforced composites in many investigations [7–11]. In abrasive wear situations carbon fabric proves better than glass fabric reinforced composites. Among the different fabrics used for fibre reinforced polymer composites, carbon fabric offers high strength and improved wear resistance. Carbon fibres help in imparting additional lubricity because of layer-lattice structure of graphite which is also responsible for the reduction of coefficient of friction and wear rate. Apart from these the carbon fabrics also improves thermal conductivity and mechanical properties [11].

The tribological characteristics of fabric reinforced polymers can be modified by the addition of functional fillers [12–15]. These fillers not only reduce the cost but also modify the properties of the

* Corresponding author. Tel.: +91 821 2480475/481220; fax: +91 821 485802.
*E-mail addresses:* sureshab1990@nie.ac.in, sureshab2004@yahoo.co.in (B. Suresha).

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polymer reinforced composites. Bijwe et al. [12] found that incorporation of solid lubricants namely polytetrafluroethylene (PTFE) and $MoS_2$ into the glass fibre reinforced polyethersulphone (PES) composites improved the sliding wear performance while the abrasive performance deteriorated. Patnaik et al. [13] studied the glass fibre reinforced epoxy (G-E) filled with $Al_2O_3$ and silicon carbide (SiC) revealed that the abrasive wear was increased with increase in abrading distance but it is less sensitive to sliding velocity in the composite filled with SiC. In the investigation conducted by Suresha and co-workers [14] on the abrasive wear behaviour of G-E composites filled with $Al_2O_3$ showed improved abrasion resistance while G-E filled with graphite performed badly in comparison with unfilled G-E composite. However, the addition of graphite filler in the carbon fabric reinforced epoxy composite exhibited decreased wear rate [15]. In this investigation, the graphite filler was treated with organo-reactive silane coupling agent which improved the interfacial adhesion with the epoxy and/carbon fibre. The filler type, shape, size and chemical treatment plays an important role on the tribological as well as mechanical properties of FRPCs. From these investigations it was found that the functional fillers like $Al_2O_3$, SiC, graphite, and $MoS_2$ have profound influence on the abrasion characteristics.

Wear is an intrinsic material property, but it also depends on operating conditions. To have a better understanding of the abrasive wear behaviour, fibre reinforced composite constituents and operating conditions are desirable. Several forms of wear equations have been developed by various researchers [16–21] for the abrasive wear of composites. These wear models expressed wear rate/volume as a function of reinforcement, mechanical properties of the composite such as breaking strength, elongation at break, hardness and operating conditions such as normal load and friction coefficient. Experimental investigations of the researchers [12–15,18] have shown that abrasive wear behaviour of FRPCs was influenced by the operating conditions such as grit size of the abrasive, normal load, and abrading distance. The abrasive wear is thus a phenomenon which is influenced by the properties of the materials coming in contact and the operating conditions. The main drawback of the above wear models and experimental investigations was that they do not explain the influence of the individual parameters affecting the abrasive wear of the composite.

To study the effect of individual factors for optimization of single response situation, conventional and Taguchi method can be applied. But in the tribological problems there is a need for the optimization of multiple responses. To solve optimization problems with multiple responses by the above technique, the optimization of each response is calculated individually and then overall optimization is determined by engineering experience. This approach cannot deal with too many responses because of the possibility of erroneous judgements [22,23]. To overcome this, Taguchi method is integrated with grey relational analysis for the optimization of multiple responses. GRA provides a comprehensive index, grey relational grade (GRG), to represent the performance of all responses. Grey based Taguchi method has been used to solve optimization with multiple responses in various fields such as submerged arc welding process parameters in hardfacing [24], flank milling parameters [25], turning operations with multiple performance characteristics [26], machining parameters in drilling hybrid aluminium metal matrix composites [27] and thin-film sputtering process with multiple quality characteristic in colour filter manufacturing [28].

Most of the above findings are based on either randomly oriented or unidirectionally oriented or woven fabric reinforced polymer composites. Carbon fabric reinforcement is a good choice since for bearing applications both high modulus and high strength are desirable. Hence, in the present research article, carbon (T300) woven fabric reinforced epoxy composite with powdered $Al_2O_3$ and $MoS_2$ as filler materials has been taken up for investigation with the intention of characterizing them for their two-body abrasive wear behaviour using SiC abrasive paper. The present investigation is also aimed to optimize factors influencing the two-body abrasive wear of C-E hybrid composites. The study is henceforth formulated into an optimization problem based on grey analysis together with Taguchi method, so that the optimum tribological parameters for multiple responses such as specific wear rate ($k_s$), coefficient of friction ($\mu$) and hardness of the composite can be predicted.

## 2. Experimental details

### 2.1. Materials and sample preparation

The composite materials considered in the present investigation consists of bi-directional carbon fabric of about 6–8 μm diameter as reinforcement. LY 556 epoxy resin with HY951 grade room temperature curing hardener with diluents DY 021 (all supplied by Hindustan Ciba Geigy) mix was used for the matrix material. The filler materials used ($Al_2O_3$ and $MoS_2$) are of particle size ranging from 20 to 25 μm. The composition and the level of purity of the fillers are listed in Table 1 taken from suppliers data sheet ($Al_2O_3$ – Sigma Aldrich and $MoS_2$ – Tianjin Okeyon International Trade Co. Ltd.). The fillers were treated with 2% organo-reactive silane coupling agent.

Pre-calculated amount of epoxy resin and $Al_2O_3$/$MoS_2$ filler were mixed using high shear mixture (T-T18 ULTRATRURRAX Basic) at an operating speed of 2000 rpm for 10 min. The temperature during mixing was maintained at about 50 °C. Eight layers of fabrics were used to obtain 3 mm thick laminates. The carbon-epoxy composite were prepared by hand layup procedure followed by compression moulding. The panels have been cured using autoclave facility (pressure 7.35 MPa and temperature 390 °C). Table 2 shows the details in respect of designation and weight percentage of carbon fabric, epoxy and microfillers used in the present investigation. The test samples for two-body abrasive wear of size 8 mm × 8 mm × 3 mm were prepared from the laminate using diamond tipped cutter.

### 2.2. Barcol hardness

The Barcol hardness test characterizes the indentation hardness through the depth of penetration of an indenter, loaded on a material sample and compared to the penetration in a reference material. The method is most often used for composite materials. The governing standard for the Barcol hardness test is as per ASTM: D-2583-13a. The hardness of the materials tested for unfilled C-E composites and C-E hybrid composites. The Barcol hardness of hybrid composites is higher than that of the unfilled C-E composites. At least three specimens of each composition were tested and the average values are listed in Table 2.

### 2.3. Wear test details

A pin-on-disc setup, (as per ASTM: G-99-05 (2010), Make: Magnum Engineers, Bangalore) used for the sliding wear and two-body

**Table 1**
Composition of microfillers (wt.%).

| | | | | | |
|---|---|---|---|---|---|
| *$Al_2O_3$* | | | | | |
| $Al_2O_3$ | | Si | | Na | Mg |
| 99.8 | | 0.05 | | 0.08 | 0.06 |
| *$MoS_2$* | | | | | |
| $MoS_2$ | Fe | Pb | $MoO_3$ | $SiO_2$ | KoH |
| 98.5 | 0.03 | 0.02 | 0.02 | 0.2 | 0.5 |