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Investigation into Tribological Performance of Graphite Reinforced Corn Cob Ash Epoxy Composites using Taguchi Approach.

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ABSTRACT:The dissertation work focuses on the utilization of the graphite particles as a secondary reinforcement in the matrix of the corn cob ash (CCA) epoxy resin by aiming to create epoxy composites that are wear-resistant and low-friction. The study was aimed to employ waste materials rich in silica as ceramic reinforcement along with graphite as a secondary reinforcement. The focus of present research is on exploitation of a silica rich waste as a particle reinforcement along with graphite as a secondary evaluation of the impact of the reinforcing on the tribological performance of the epoxy resin matrix. The wight percentage of the CCA was chosen as 6% and composites of graphite wight percentage 3,5 and 7% were constructed and afterwards evaluated for their tribological performance by the use of the pin-on-Disc tribometer. The Taguchi technique was utilised to create mathematical models of the composite's friction and wear response in terms of graphite content, normal load, and sliding speed. After Taguchi analysis the process was checked once again with the help of 'Regration analysis', Grey relational analysis was performed to get the optimum parameters for the experimentation. The warn Surfaces were investigated using electron micrographs to have a greater comprehension of the composites' wear process.

KEYWORDS: Epoxy composite, silicon rich waste material, Taguchi's orthogonal array, secondary reinforcement.

I. INTRODUCTION

Polymers and their composites have emphasised their potential to swap traditional engineering materials through its special attributes including flexibility in the design, low cost, easy production and light-weight weight nature. Pure polymers have lower resistance to the wear but they'll be modified acceptable for the tribological applications by mixing with additives or reinforcements. Polymer composites are a combination of polymers (thermosets or thermoplastics) and various continuous and noncontinuous reinforcements/fillers, which are generally added to polymers to improve workability. Polymer composites are rapidly being employed in numerous technical disciplines. Polymer functions as a matrix resin which penetrates the reinforcing bundles and binds to the reinforcement. Polymer composite materials are employed mostly in aerospace and automobile industries. Polymer tribology is distinct from the tribology of metallic materials. When compared to metals and ceramic materials, polymers are used differently in frictional interactions, and this difference is mostly due to their chemical and physical structures as well as their surface and bulk characteristics. Wear of polymers occurs primarily through an adhesive process, whereby the polymeric material is deposited over the mating counterpart as a result of adhesive pressures. The process begins with the creation of adhesive connections between the relatively hard metal surface and the soft polymeric substance. increasing strength, stiffness, and lowering adhesion phenomena can reduce the amount of polymer material that deposits over the metal counter face, hence reducing the actual contact area between the composite and the metal counter face. While the polymer composite can be further strengthened with solid lubricants to reduce frictional resistance at the contact.

II. LITERATURE REVIEW

M. Alajmi et al [1] have investigated the properties of graphite/epoxy composites that are calculated from a tribological standpoint. For adhesive wear tests, graphite samples weighing between 0 and 7 percent were employed. The tribological characteristics of the composites were severely harmed by the presence of more graphite (>5%) in the composites. The interface temperature was positively impacted by increasing the graphite content of the epoxy matrix; as the graphite content increased, there should be between 5% and 7% graphite content in polymeric composite materials. The weight percent of the graphite has a considerable impact on the tribological performance of the composites, they said in their conclusion. The wear performance of the epoxy composites somewhat increases with a low graphite content (one weight percent). Given the considerable improvement in wear and frictional properties, the intermediate weight % of graphite in the epoxy composite is thought to provide the best tribological performance. The tribological characteristics of the composites were significantly degraded when there was a larger percentage of graphite (more than or equal to five weight percent) in the composites.

Ricardo Baptista et al [2] investigated how different amounts of graphite filler impact the mechanical characteristics of epoxy resin and carbon fibre reinforced epoxy composites. Due to a more homogenous dispersion of graphite platelets, the findings for graphite-reinforced epoxy resin reveal that 7.5, 10 and 11.5 weight percent graphite offer the greatest balance of mechanical (modulus, strength, strain) attributes. The very same trends are seen when carbon fibre is utilised as the reinforcing phase. Overall, this research shows that using graphite as a matrix filler in carbon fibre reinforced epoxy enhances mechanical characteristics to a degree.

As per research on the dry sliding wear behaviour of glass epoxy composites with graphite, S. Basavarajappa et al [3] claimed that composites made of polymers are arising as feasible alternatives to metal- and alloy-based products in many fundamental and advanced industrial applications. An actual evaluation of the relative the effectiveness of glass epoxy composites influenced by graphite filler under various applied loads, sliding distances, and sliding velocities was performed using a pin-on-disc device. However, adding graphite to glass-epoxy composite resulted in decreased weight loss, its value falls as how much graphite there is in the composite increases. In this experiment, higher weight loss was found under circumstances of increasing applied stress. Graphite was used as the filler material during the manual lay-up method used to manufacture the glass-epoxy composites. The lamination was dried in natural lighting for about 24hrs.

K.M. Subbaya et al [4] have investigated the Grey-based Taguchi method for evaluating the SiC filled carbon-epoxy composites wear out. To assess mechanical and tribological characteristics, they produced a carbon fabric reinforced epoxy composite (C-E) and added varied weight fractions of silicon carbide filler as secondary reinforcement. In order to maximise the number of experimental runs, they constructed the tests by the use of Taguchi L-9 orthogonal array. Four process parameters, including filler content, grit size, load, and abrading distance, are used with pin-on-disc machinery. two-body abrasive wear experiments were performed. The following results were derived from all of the experiments: adding SiC particles to C-E composite significantly enhanced wear resistance. By using 10% SiC, the C-E composite's highest wear resistance was attained. According to observation, the filler content and abrasive grit size are the two variables that have the most effects on the abrasive behaviour of C-E composite.

Zhenguo Zhu et al [5] the pin-on-disk configuration was used to study the friction and wear behaviour of the resin/graphite composite under dry sliding conditions. The findings demonstrated that the resin/graphite composite outperformed the unimpregnated graphite in terms of mechanical and tribological characteristics. Furan resin was used to lower the friction coefficient. The creation of an insufficient and unstable transfer layer was the cause of the graphite's abrasive wear. A consistent and complete transfer layer was created, especially at higher loads, as a result of the interaction between both the wear debris of the furan resin and the graphite, allowing a resin/graphite composite to have a relatively low friction coefficient and wear rate.

Onkar Mestry et al [6] Corn cob ash was used in the epoxy matrix as a particulate reinforce, they hoped to create wear-resistant epoxy composites with reduced friction utilising a silica-rich waste resource. The tribological performance of composites with CCA weight percentages of 2%, 6%, and 10% was then evaluated using a Pin-on-Disc tribometer. They examined the worn surfaces of the composites with a JEOL JSM IT-200 scanning electron microscope (SEM).

S. Shankar et al [7] have investigated the dry sliding wear behaviour of composites made with aluminium and palmyra shell ash ($AlSi_{10}$mg). The mechanical and tribological characteristics of a silica-rich ash particle (Palmyra shell ash) bonded with composites made of an aluminium alloy ($AlSi_{10}Mg$) were investigated. The findings demonstrated the dry sliding wear resistance of Al-Palmyra shell ash composites was almost equal to that of fly ash and rice husk ash reinforced Al-alloy composites, and that these composites outperformed unreinforced alloy. The weight % of the Palmyra shell ash particles had a significant influence on the wear and friction properties of the composites.

Friedrich et al [8] have examined the present and potential tribological applications of polymer composites and came to a conclusion that although the use of polymer-based composites for tribological applications is increasingly prevalent, and the structural design of these composites is highly important. These materials heavily depend on the engineering system in which they must function. They had to glide against a metallic counterpart in the majority of the situations, and in order to do so, they used their capacity to lubricate themselves to lower the coefficient of friction. They were made very wear-resistant with the assistance of special reinforcements. This has been shown in numerous applications, including papermaking machines, automobile parts, and other mechanical engineering facilities, in addition to on a laboratory size.

V.K. Srivastava et al [9] have investigated the wear and friction characteristics of bushing bearing of composites of short glass fibre loaded with graphite in dry sliding. In their work, the epoxy glue and graphite particles were combined before the short glass fibre was added. Graphite was shown to have a significant influence on the wear and friction characteristics of glass fibre reinforced epoxy resin composites via experiments. Additionally, it was found that wear rose with load and duration, but that its value dropped when graphite content increases in the composite, regardless of the applied load and sliding time. However, friction reduced when graphite content increases regardless of time and only rose with the length of the sliding process.

Mehmet Bagciet al [10] have investigated how the Taguchi technique may be used to optimise the testing criteria for the erosion of glass fibre reinforced epoxy composite materials. In their research, they chose glass fibre reinforced epoxy composite resins materials for experimentation and investigated the erosion wear behaviour of these materials under various impact velocities of 23m/s, 34m/s, and 53 m/s and by utilizing aluminium erodent particle sizes of 200 lm and 400 lm and at impingement angles of 30°, 60°, and 90° along the fibre directions of and 45°. The tests are planned using Taguchi's orthogonal arrays strategy.

Boon Peng Chang et al [11] have investigated the use of talc-reinforced response surfaces to improve the wear performance of composites made of ultra-high molecular weight polyethylene (UHMWPE). In this work, the analysis of variance (ANOVA) method was used to build observable models that illustrated the relationship in-between the responses of average coefficient of friction (COF) and wear rate of UHMWPE and the control variables of filler content, sliding speed and load. In order to decrease UHMWPE wear, the Response Surface Methodology (RSM) was used to forecast the control variable optimization. In the end, they came to the conclusion that talc incorporation might reduce the rate of wear and the average COF of UHMWPE.

Ashutosh Pattanaik et al [12] have investigated the dry sliding wear behaviour of epoxy fly ash composites by use of Taguchi's optimization. For their research, they created a composite out of fly ash and epoxy resin, carried out wear tests on a pin-on-disk device, and then compared the findings using Taguchi design of experiments. Following percent reinforcement, track diameter, speed, and time, they determined that applied normal load had the greatest impact on the rise in wear, coefficient of friction and frictional force.

III. METHOD

By incorporating reinforcement particles into a matrix or binder material, the composite structure needed for the current investigation was created. Epoxy resin, a thermosetting polymer, is employed as the binding ingredient. As it hardens and settles throughout the moulding process and cannot be re-softened. The resin plus hardener, which are combined in a certain ratio, are the key components that make up the epoxy composition. In order to do this, a two-component hardener (tri-ethylene tetra amine) and epoxy formulation containing resin (diglycidyl ether of bisphenol) were purchased from ATUL Polymers in India.

Ash of corn cob was utilized as the primary filler ingredient in the epoxy matrix to create the composite samples. Corn mature ears with the husk and silk removed were sun-dried to create corn cob ash (CCA) (fig. 1.a). The leftover corn was burned over a stove flame outside (fig. b). The burned corn was broken up into little pieces as indicated in figure (fig c). The coarse corn particles that are black to dark grey in colour suggest a high carbon content, which is undesirable. As a result, these coarse bits were heated once again by being placed on a plate. At this point, the charred fragments started to turn from black to grey, indicating that the carbon concentration had decreased. The heating procedure took place for an hour, and the finished result, illustrated in (fig. d) was fine grey-coloured ash of corn cob (CCA). To achieve micro-sized particles, the powder of CCA was then run through a 300 mesh size sieve. On the resultant CCA, no more physical or chemical treatments were performed.

Fig. 1. Corn cob ash (CCA) preparation sequence

Graphite, a material made of carbon atoms stacked in a layer-like pattern, has an extremely minor frictional coefficient ranging from 0·1 to 0·2 when sliding over another cleaned surface, therefore indicating that it may utilised as a solid lubricant. Since it is one of the most inert materials, graphite has excellent chemical stability; nearly no organic solutions or harsh chemical reagents cause it to react. Graphite is the best material for reducing friction because of its lamellar structure. It can increase the strength of composite materials when amorphous carbon is employed as the adhesive agent. To improve the load-bearing behaviour and wear-resistance performance of self-lubricating polymeric materials, graphite may also be used as a filler.

As indicated in Table 1. four unique samples were generated, each supplemented with a constant weight fraction of CCA and a variable weight fraction of graphite in an epoxy matrix. A sample excluding graphite (A sample of neat CCA-epoxy) worked as the control. The weight fractions of ash of corn cob and graphite that were chosen were 6 percent and 3, 5, and 7 percent , respectively. A defined quantity of CCA powder and graphite powder were added to a beaker after a weighed amount of liquid epoxy resin was deposited there. To ensure that the CCA and graphite particles were uniformly scattered, the mixture was agitated for 10 minutes. Next, the resin, graphite, and CCA mixture was added the specified and weighed quantity of hardening component, followed by another round of stirring. To generate pins for tribological testing, the resulting material was inserted into cylindrical plastic moulds with a 12 mm diameter and a 25 mm height. Similar to this, moulds with accurate dimensional requirements for the samples for the relevant tests were utilised for further mechanical testing. To make it easy for specimens to be removed from moulds, silicone mould release spray was added to the interior surfaces of the moulds. The samples were allowed to cure for 24 hours at room temperature. Samples were post-cured in an oven at 55°C for 30 minutes, then 70°C for an additional 30 minutes. All specimen pins that will glide against the steel counter disc had their surfaces polished with fine sandpaper with a 600 grit size.

Table 1. Sample nomenclature and composition

Sample	Composition
E6CCA	Epoxy + 6wt.% CCA
E6CCAG3	Epoxy + 6wt.% CCA + 3wt.% Graphite
E6CCAG5	Epoxy + 6wt.% CCA + 5wt.% Graphite
E6CCAG7	Epoxy + 6wt.% CCA + 7wt.% Graphite

The formula based on which the quantity of corn cob ash must be added is provided beneath.

$$\%W_{cca} = \frac{W_{cca}}{W_{cca} + W_r}$$

(Eq. 1) (Eq. 1)

Where,
$\%W_{cca}$= weight percentage of CCA, W_{cca}= weight of CCA powder, W_r= weight of resin.

Epoxy and hardener were mixed in the proportion of 100:10 so, as wt.% of CCA was kept as a constant ie. 6%CCA in this study so amount of CCA required was calculated firstly and it was 0.702 gm. As graphite was used as secondary reinforcement and the amount of graphite was varied so the weight of resin was changed to new value which was 11.702 gm (W_r = 10gm epoxy + 1gm hardener + 0.702 gm CCA). So, the amount of graphite which was added as secondary reinforcement was calculated with the help of following formula.

$$\%W_g = \frac{W_g}{W_g + W_r}$$

(Eq. 2)

On rearranging the equation

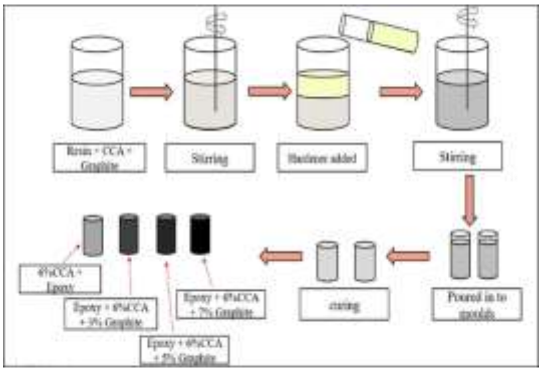
$$W_g = \frac{W_r * \% W_g}{1 - \% W_g}$$

(Eq3) (Eq. 3)

Where, (Eq. 2)
$\%W_g$= weight percentage of graphite, W_g= weight of graphite, W_g= weight of graphite.

Following fig. 2. will provide an idea of composite fabrication

Fig. 2. Pathway of composite fabrication



IV. EXPERIMENTATION

1) Density measurement

For the purpose of calculating volume loss owing to wear, produced composite samples' densities were necessary. The ASTM-D792 protocol was used while measuring density. Archimedes' principle density measurement is another name for the procedure.

This testing required a weighing balance with a reading precision of 0.0001 gm. For the test, cylindrical samples having a 1.2 cm diameter and a 2.5 cm height were employed. It was made sure that specimens were spotless and dust-free. First, the specimen was suspended by a hanging wire and weighted in the air. The digital balance's measurement was reported as "a," or the mass of the sample in air (Figure 4.1). Setting the analytical balance to zero before putting the cylindrical specimens allowed you to get the reading without include the mass of the wire. By submerging the sample in a water-filled beaker, the second reading was obtained. The mass of the sample in water was noted as "b," the value that the balance reported.

For calculating the density of the sample following formula was used,

$$\rho_{ce} = \frac{a}{a-b} * \rho_w \qquad \text{(Eq. 4)}$$

Where,
ρce= density of composite sample experimental (gm/cc), ρw= density of water (gm/cc), a= sample's mass in air (gm),b= sample's mass in water (gm).

The approach covered above offers experimental or real composite density. Additionally, the density may be assessed theoretically by taking into consideration the respective densities of the filler material (CCA particles, graphite) and matrix (epoxy resin). The method of calculation is

$$\rho_{ct} = \frac{w_g}{\left(\frac{w_r}{\rho_r}\right)+\left(\frac{w_g}{\rho_g}\right)}$$

Where,

ρct= density of composite sample theoretical (gm/cc), ρg= density of graphite (gm/cc), ρr= density of resin (gm/cc), wg= mass of graphite (gm), wr= mass of resin (gm).

Here, as wt.% of CCA is kept constant and wt.% of graphite is varied so the resin is the mixture of CCA + resin + hardener. So, while calculating density of the resin densities of the resin, hardener and CCA were taken together.

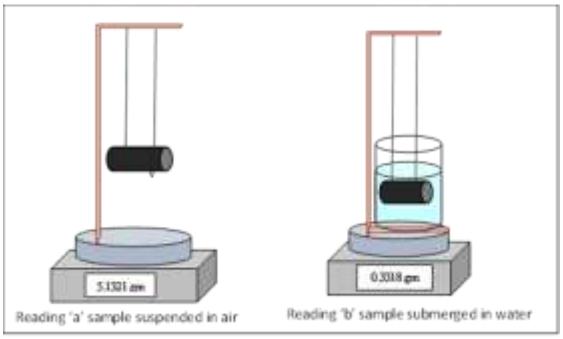


Fig. 3. Schematic diagram for density measurement procedure

2) Hardness Test

The hardness of the composite was tested using ASTM D785 procedure on the Rockwell hardness testing equipment. Different methods are included in the ASTM D785 Rockwell Hardness test technique for determining the indentation hardness of plastic materials.

3) Tribological testing

A significant portion of the experimental effort included tribological testing, which was done in accordance with ASTM-G99 guidelines. Through the use of simulation, the tribological characteristics of reinforced epoxy-CCA-graphite composites were investigated. To verify that the wear mechanism experienced by each material pair in the test is comparable to that of the real system, friction and wear test simulation should be used. A standard pin-on-disc test device spins the disc while the pin remains still. Fig. 4. nonrotating ball, a hemispherical end cylinder, or even a rectangular parallelepiped may be utilised in place of the cylindrical body and flat end tip of the pin that was used in this experiment.

Fig. 4. Schematic Pin on disk operational principle

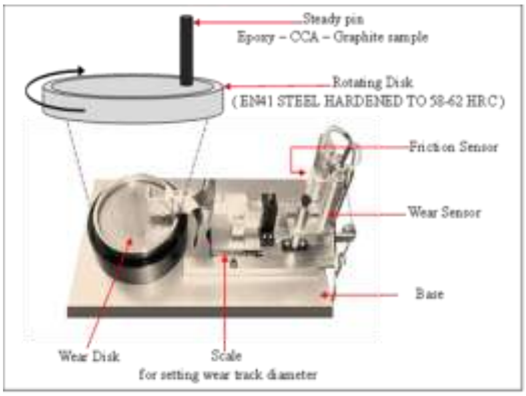


Fig. 5 Schematic view of the setup of pin on disk

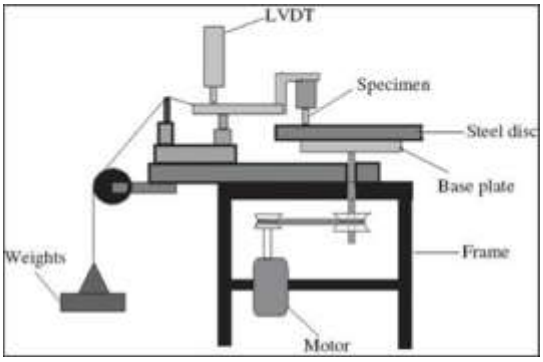
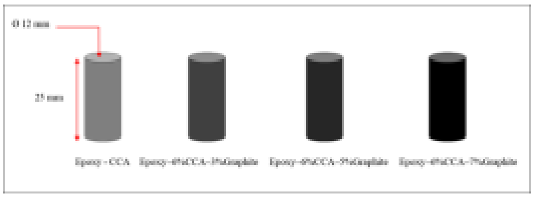


Fig. 6. Schematic view of pins used for test



V. DESIGN OF EXPERIMENT

R.A. Fisher created the design of experiment (DOE) in the 1920s in England as a statistical method for investigating the effects of many factors at once. Genier Taguchi, a Japanese engineer who created the Taguchi technique in the 1940s, suggested a framework for design of experiment. The levels of the factors that should be modified and how they influence the process are organised using the Taguchi experiment array design. rather than doing every conceivable experiment. On the previously mentioned pin-on-disc tester, the wear tests for created composite specimens were carried out under dry sliding circumstances (DUCOM). The experiments were designed using the Taguchi's L9 orthogonal array.

In these three parameters with three levels were selected.Next table 2 represents the level and parameters.

Table 2. Level and parameters used in Experimentation

	Parameter		
Level	%Graphite	Load (N)	Speed (rpm)
1	3	10	100
2	5	20	200
3	7	30	300

The Taguchi's orthogonal array was obtained using the 'Minitab software'. The Taguchi L9 array is which is used to perform the experiments given in bellow table 3.

Table 3. Experimental design using Taguchi's L9 orthogonal array

Sr. No	Parameter		
	wt.% Graphite	Load (N)	Speed (rpm)
1	3	10	100
2	5	20	200
3	7	30	300
4	3	10	200
5	5	20	300
6	7	30	100
7	3	10	300
8	5	20	100
9	7	30	200

VI. WEAR MEASUREMENT

Materials volume loss is the crucial a consideration that must be made when calculating the wear coefficient. Additionally, it serves as a gauge for wear. It may be found using the following techniques.

1) Mass difference method

$$Volume\ loss\ (\Delta V) = \frac{1}{\rho} * (\, m_1 - m_2 \,) \qquad \text{(Eq.6)}$$

Where,

ρ= density of pin (gm/cc), m_1= pin's mass before test (gm), m_2= pin's mass after test (gm).

2) Wear depth method

This technique uses a combined LVDT and pin on disk configuration to assess the wear depth (h). Equation gives the volume evacuated from the substance.

$$Volume\ loss\ (\Delta V) = \frac{\pi}{4} * (\, d^2 * h \,) \qquad \text{(Eq.7)}$$

Where,

h= wear depth (mm), d= pin diameter (mm).

3)Specific wear rate

The wear factor or specific wear rate (Ks), is a measure of loss of volume of material per unit sliding distance per unit load, is used to quantify the wear of polymers and polymer composites. Ks stands for it, and equation provides the answer.

$$Wear\ factor\ (k_s) = \frac{\Delta V}{N * L} \qquad \text{(Eq.8)}$$

Where,

ΔV= volume loss (mm^3), L= sliding distance (m), N= normal load (N).

VII. CHARACTERIZATION OF CCA AND GRAPHITE

For the purpose of determining the elemental composition, powder shape, and particle size, CCA was characterised. The elemental composition and morphology were investigated using the energy dispersive X-ray spectroscopy (EDS) and scanning electron microscopy (SEM) techniques, respectively. Both were done using a JEOL (manufactured in Japan) SEM equipment. SEM was used for CCA at higher magnifications between 2000x and 2500x. The MALVERN particle size analyzer, which operates on the theory of laser diffraction, was used to do the particle size analysis. The CCA powder was dissolved in water to provide the sample for testing. The CCA and water mixture was then subjected to a 15-minute ultrasonic treatment. This was done to disperse particle sizes evenly throughout the water and break up CCA powder agglomerates. The presence of a diluted solution was confirmed (low concentration of CCA).

Using the same procedure as the CCA the SEM and EDS were also done for the graphite and morphology and elemental composition were investigated respectively.

Analysis of wear mechanism

SEM analysis was also performed on the worn surfaces of pins. Nevertheless, in this instance, the SEM imaging was done at a lesser magnification, between 200x and 500x. As the conductive natured graphite was present in the epoxy-CCA-graphite composite it was directly subjected to electron microscopy.

(Eq. 6)

VIII. RESULTS AND DISCUSSION

1)Characteristics of CCA and Graphite

(Eq. 7)

SEM photos of CCA at low is shown in Figure 7. The CCA particles are agglomerated and have an amorphous shape, as shown in Figure

7(A), Figure 7(B) shows the CCA powder's EDS spectrum. The EDS analysis verified that silicon was a significant ingredient in the CCA powder. The spectrum also showed the existence of oxygen (O) and potassium (K) in addition to silicon.

Fig. 7(A) SEM micrograph of CCA particle, (B). EDS spectrum of CCA

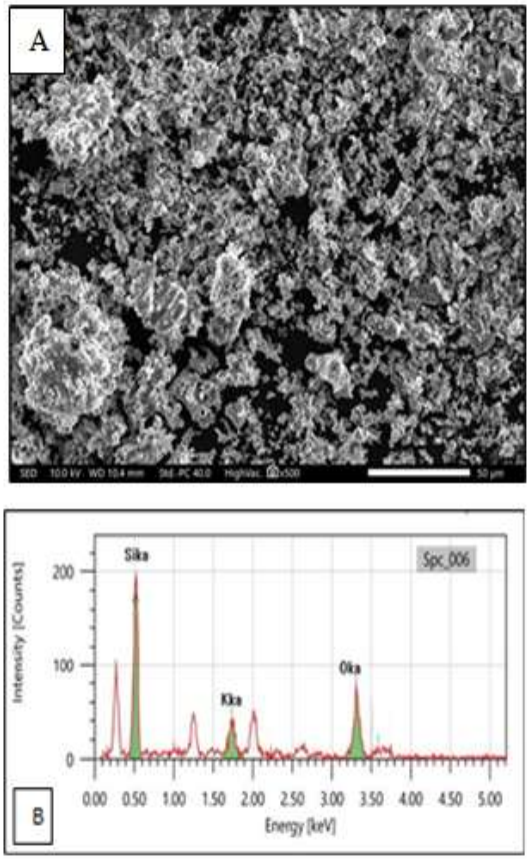


Table 4. Result of mass particle distribution of CCA

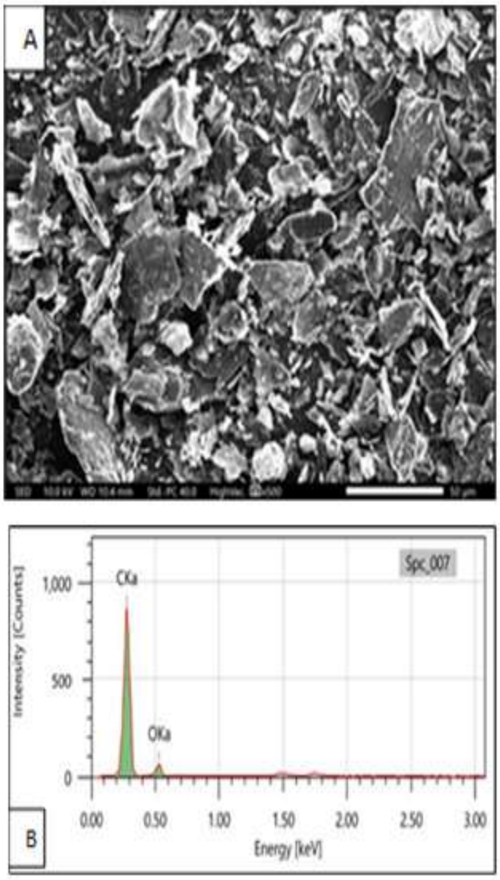
Element	Line	Mass%	Atom%
Graphite(C)	K	86.39±0.67	89.42±0.69
Oxygen(O_2)	K	13.61±0.75	10.58 ±0.58
Total		100	100

Similar as the CCA the SEM and EDS analysis for the graphite was also performed, from SEM it was seen that the graphite particles have plate like spherical structure as shown in fig.8(A). and the fig.8(B). shows the EDS analysis of graphite which verified that the graphite had the significant amount of the carbon along with the oxygen.

Table 5. Result of mass particle distribution of Graphite

Element	Line	Mass%	Atom%
Silica (Si)	K	52.12±1.55	71.51±2.12
Potassium(K)	K	7.22±0.65	5.64±0.51
Oxygen(O_2)	K	40.66±2.19	22.83±1.23
Total		100	100

Fig. 8(A). SEM micrograph of Graphite particle, (B) EDS spectrum of graphite



2) Density and hardness of the composite

Table 6. displays the theoretical (ρ_{ct}) and experimental (ρ_{ce}) densities of each created composite. It was found that when the fraction of graphite particles in the epoxy-CCA matrix rises, so does the density but in very small manner this happens because epoxy-CCA has a larger density than graphite. Where on the other hand in epoxy-CCA composite the density increase was observed more cause the CCA has a more density than the epoxy resin. Therefore, the total density of the composite grows slowly as the graphite percentage does. The amount of porosity created during

composites' curing is represented by the void fraction. A higher graphite percentage provides additional protection against trapped air escaping during solidification. As a result, it was discovered that graphite content increased the empty fraction. In Fig.9. the values are visually depicted for easier comprehension. Experimental density is represented by the yellow column while theoretical density is represented by the orange columns. Green line signifies the void faction.

The hardness of composite of epoxy-CCA-graphite sample is shown in fig.10. It was discovered that the proportion of graphite increased with composite hardness. The use of graphite enhances the composite's capacity to support loads, which in turn raises the impact resistance. An increase in hardness is another indication of strong adhesion between both the graphite, CCA particles and epoxy matrix. From above graph it was observed that the hardness of the composite of epoxy-CCA was increased after addition of the graphite and it went on increasing as the percentage of graphite was added.

Specimen	ρ_{ct} (gm/cc)	ρ_{ce} (gm/cc)	%Void friction
E6CCA	1.1835	1.1538	2.5095
E6CCAG3	0.0999	0.0987	1.2012
E6CCAG5	0.1656	0.1632	1.4492
E6CCAG7	0.2297	0.2256	1.7849

Table 6. Result of density measurement

Fig. 9 Trend of density and void friction variation with Graphite content

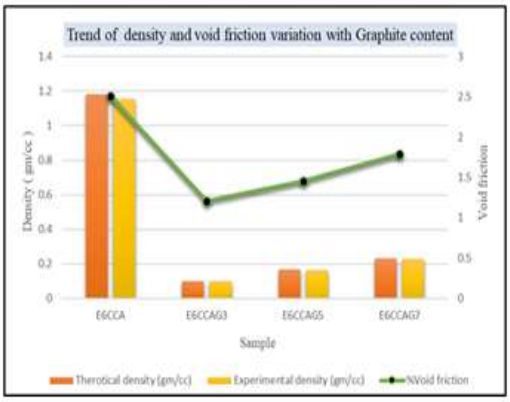
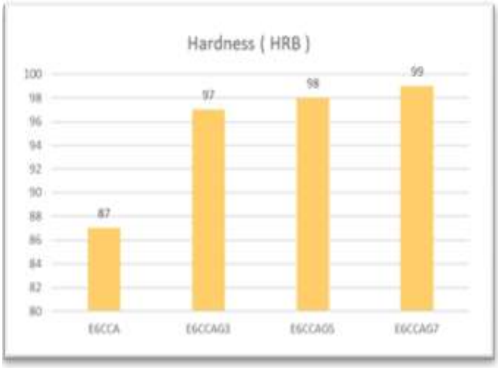


Fig. 10. Rockwell Hardness of the composite



3)Arithmetical analysis

Table no.7 shows the outcomes of the tribological tests taken according to the Taguchi's L9 orthogonal array designed experiment . The specific wear rate and responses coefficient of friction (COF) listed here are the average values got from the three experimental runs afterwards regression analysis was performed on the results obtained by experimentation by using statistical software MINITAB 19 eq.9 and eq.10 are the quadratic equations developed for the responses of coefficient of friction and specific wear rate respectively based on the data obtained from the experimentation.

Table 7 Experimental results for specific wear rate and coefficient of friction as per Taguchi's L9 orthogonal array

Run No.	Processparameter			Experimental results	
	A	B	C	D	E
1	3	10	100	0.400005	3.76840
2	5	20	200	0.347241	0.77080
3	7	30	300	0.392118	1.54162
4	3	10	200	0.414913	0.61990
5	5	20	300	0.331114	3.09980
6	7	30	100	0.238289	1.61190
7	3	10	300	0.306922	0.66990
8	5	20	100	0.236954	0.40190
9	7	30	200	0.267845	0.29770

$$D = 0.4856 - (0.02730 * A) - [\,0.00373 * B] + [\,0.000258 * C] \qquad \text{(Eq.9)}$$

$$E = 4.08 - (0.393 * A) - [\,0.0268 * B] - [0.00078 * C] \qquad \text{(Eq.10)}$$

Where,
A=wt.% graphite, B=Load(N), C=Speed(rpm), D=Coefficient of friction (μ), E=Sp. Wear rate (K_s) ($\times 10^{-5} mm^3/Nm$).

From the main effect plot fig. 11(A) and fig.11(B) and test results it is seen that the coefficient of friction decreases as the wt.%

graphite and load increases but it increases as the speed increases and the specific wear rate also decreases as the wt.% graphite and load increases but for increasing speed it decreases first then increases continuously respectively. On the basis of the regration analysis we can plot the normal probability for the coefficient of friction and specific wear rate as shown in fig 12(A),(B) respectively.

Fig. 11(A). Main effect plots for Coefficient of friction, (B) Specific wear rate

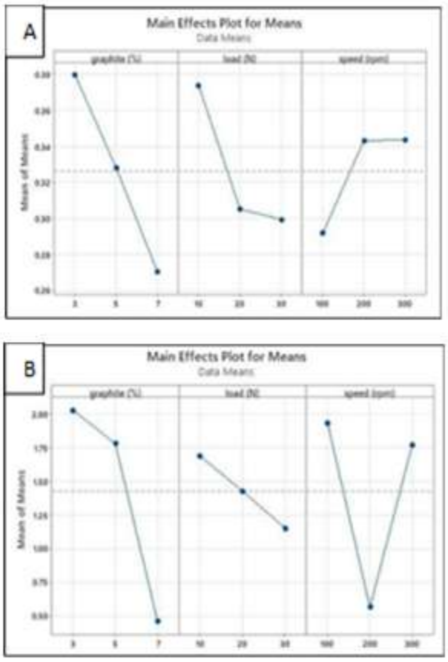
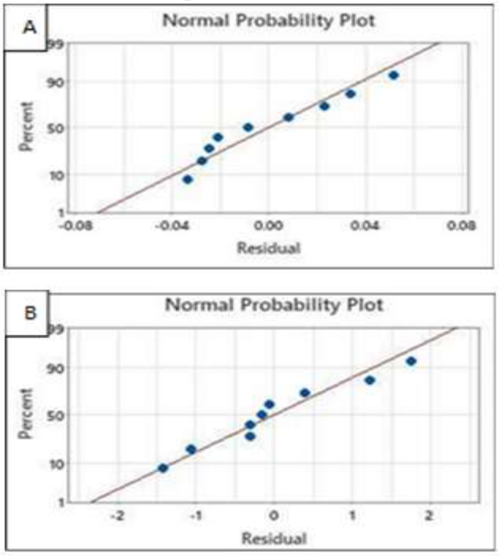


Fig. 12.(A) Residual plot for coefficient of friction, (B) specific wear rate



4)Gray relational analysis for the optimization

The effect and in a multi-response situation are unclear and complicated. This was referred to as grey, which shows inaccurate and ambiguous information. With the support of the grey relational analysis, the suggested approach evaluates the complex instability among the several responses in the provided system and optimises it. As a result, a multi response optimization issue is transformed into a single relational grade optimization problem. Steps involved in the Gray relational analysis are

a) Step-1

First, the data must be normalised to remove any varying units and to lower the variability. Due to the fact that one data's variance differs from another data's, it's fundamentally essential. In order to create an array between 1 and 0, an appropriate value is deduced from the original value. Generally speaking, it is a technique for transforming the original data into equivalent values. If the reaction are to be brought down, the bellow formula is meant to normalise the answer and scale it into a range that is acceptable.

$$x_i^*(k) = \frac{max\ x_i(k) - x_i(k)}{max\, x_i(k) - min\, x_i(k)} \quad \text{(Eq.11)}$$

Where,
i= 1..., m; m is the number of experimental data,
k=1..., n; n is the number of replies,
$x_i(k)$ = original data, $x_i(k)$ = original data,
$x_i^*(k)$=pre-processed data,max $x_i(k)$= biggest value of xi(k), min $x_i(k)$ = lowest value of xi(k),
x= intended value.

b) Step-2

In this step calculation of the grey relational coefficient $\xi_i(k)$ from the normalized values with the help of following formula is done

$$\xi_i(k) = \frac{\Delta_{min} + \xi\, \Delta_{max}}{\Delta_{oi}(k) + \xi \Delta_{max}} \quad \text{(Eq.12)}$$

$$\Delta_{oi} = \|x_0(k) - \mathrm{x_i}(k)\| \quad \text{(Eq.13)}$$

Where,
Δ_{oi}=deviation sequence of the comparability sequence & reference sequence,x_0(k) = reference sequence,x_i(k)= comparability sequence,
Δ_{min} = smallest value of the absolute differences,
Δ_{max} = highest value of the absolute differences,
ξ= identification coefficient, always taken as 0.5.

c) Step-3

In this step the grey relational grade (GRG) is discovered as follow

$$\gamma_i = \frac{1}{n}\sum_{k-1}^{n} \xi_i\ (k)$$

Where,
n = number of response characteristics,γ_i= required grey relational grade for ith experiment. n= number of response characteristics.

The connection between the comparability sequence and the reference sequence is represented by the grey relational grade, which serves as a general representation of all the worth attributes. So, using grey relational analysis in conjunction with the Taguchi’s technique, the multi-response optimization issue is reduced to a single response optimization problem.

d) Step-4

In this step the rank of results is obtained depending on which the optimal conditions can be seen very easily.

From the table it can be concluded that parameters of the run no. 8 that is level-2 of wt.% graphite, level-2 load and level-1 speed are the optimum parameters for the testing of the composite. Result of Grey relational optimization is shown in following table

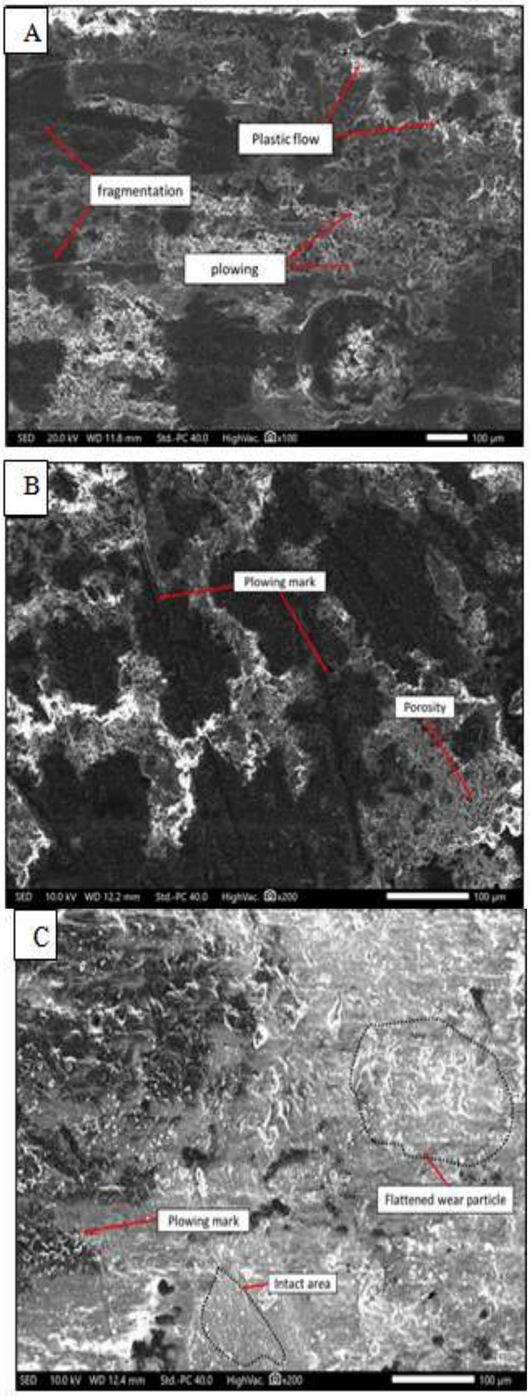
Table 8 Grey relational optimization values

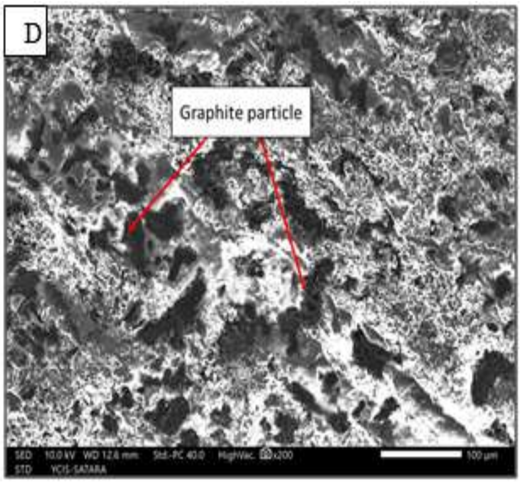
Run No.	Evaluationof Δ_{oi}		Grey relational coefficient		GRG	Rank
	μ	K_s	μ	K_s		
1	0.0000	0.0000	0.2500	0.2500	0.2500	9
2	0.8449	0.8637	0.4329	0.4400	0.4364	4
3	0.7818	0.6416	0.4104	0.3681	0.3893	7
4	0.7498	0.9072	0.3999	0.4575	0.4287	6
5	0.8676	0.1926	0.4415	0.2766	0.3591	8
6	0.9981	0.6214	0.4991	0.3627	0.4309	5
7	0.9016	0.8928	0.4552	0.4516	0.4534	3
8	1.0000	0.9700	0.5000	0.4854	0.4927	1
9	0.9566	1.0000	0.4792	0.5000	0.4896	2

5)Analysis of worn surfaces

The worn surface of epoxy-CCA sample had revelled the effect of the mechanism of adhesive wear. The plastic natured flow of the epoxy can be observed form the fig. 13(A). The surface revels fragmentation of the material which is the effect of adhesion. Over the surface of the sample with 3% epoxy-cca-graphite, there is the existence of a flat, extended plateau. The E6CCAG3's unbroken surface is seen in the fig. 13(B), whereas the other parts show surface 6characteristics that are undulating. The morphology of the worn surface for the E6CCAG5 sample is illustrated in fig. 13(C). by a few mild ploughing marks. Particles crowd together when particle reinforcement concentration is increased, as shown in fig. 13(D) for the E6CCAG7 sample.

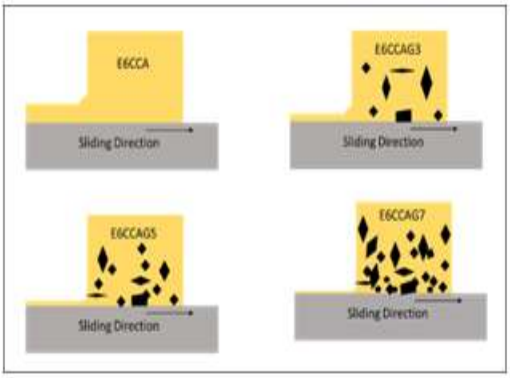
Fig. 13(A) SEM micro image of epoxy-CCA component, (B) E6CCAG3 component, (C) E6CCAG5 component, (D) E6CCAG7 component.





In this the matrix contains the graphite particle as a reinforcement due to which the contacting surface was easily deformed easily during the sliding. As the only epoxy-CCA composite was tested on pin on disk then it was seen that there is wear and as we went on increasing the graphite reinforcement from 3, 5 and 10 wt.% the amount of wear was reduced as the reinforcement % increased. This happened because of the self-lubricating nature of the graphite. It can be explained through the following fig. 14 which shows the thickness of the graphite film deposited on the metal surface.

Fig. 14. Transition of composite metal contact with graphite content variation



IX. CONCLUSION

The current study aimed at developing wear resistant, low friction composite and finding the tribological effect of secondary reinforcement of graphite in the epoxy-CCA composite. The conclusions of the experimentation are as mentioned bellow.

- The SEM analysis of the corn cob ash (CCA) shown the amorphous morphology while EDS confirmed the presence of the Silicon (Si) and oxygen (O). Depending on the particle size it was decided to use the CCA as a primary reinforcement.
- Graphite, which comprises of carbon atoms stacked in a layer-like pattern, has an extremely low coefficient of friction ranging from 0·1 to 0·2 when sliding over another clean surface, therefore indicating that it may be utilised as a solid lubricant. Because of its softness and slickness, graphite has a powerful lubricating effect. So, it can be used as a secondary reinforcement.
- On the addition of the graphite particle as a secondary reinforcement the in the epoxy-CCA the density hardness increased on the other hand coefficient of friction and specific wear rate decreased.
- Taguchi's L9 orthogonal array provided the experiment design and the based on the grey relational analysis the optimum value was confirmed and it was nearly same as the experimental value.
- The lowest coefficient of friction and wear factor observed with epoxy-cca-graphite composite was 0.2369 and 0.2977 ×10-5mm3/Nm.

X. FUTURE SCOPE

The reinforcement of graphite with epoxy-CCA was tremendously effective on decreasing the coefficient of friction and increasing the wear resistance. Scope of future work is that to produce a multi reinforcement oriented composite and study its tribological and mechanical properties.

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