Evaluation of the Properties of Eco-friendly Brake Pad Using Coconut Shell Powder as an Filler Materials

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Abstract

The Aim of the study is to develop a natural new fiber as an filler materials. Here Coconut shell powder which is one of the natural legnocellulosic material with outstanding potential in brake pads. Keeping CSP constant (10-20 php) in break pads as a filler.

In this present investigation, Composite Materials for the application in brake or friction materials were fabricated using Phenol Formaldehyde (PF) and Epoxy Resin (ER – VP 401 Grade) as matrices and varying proportions of Glass Fibre (GF) as reinforcement. Other constituent elements like coconut shell powder (CSP), Alumina (Al2O3), Calcium SulfateDihydrate (CSD – Gypsum), Barium Sulphate (BS), Graphite and Antimony Sulphide (AS) were added to bring in other properties like thermal conductivity, thermal stability, strength etc., which are essential for friction materials. These PF – GF and ER – GF composites were subjected to Three Body Abrasion (TBA) test under varying sliding distance conditions. Values of Wear loss, Wear Volume and Specific Wear Rate were computed for the designed materials and two commercially available brake pad materials. SEM micrographs for the fabricated materials and commercial materials were also considered for the analysis and comparison. Analysis of the results have shown that ER – GF composite material had significantly superior abrasion characteristics and compressive strength in comparison with PF – GF by using CSP Eco-friendly filler materials compared with commercial materials.

Keywords

Three Body Abrasion, Eco Friendly Coconut Shell Powder, Phenol Formaldehyde,Epoxy Resin

I. Introduction

Nowadays the concept of Asbestos has been replaced by number of eco friendly filler materials like Almond shell nut powder and egg shell powder as a filler material in break pads but Coconut Shell Powder (Coco's nucifera) is one of the best thermosetting materials, available in very Low Cost, more versatile part of the Coconut and being an organic in nature, acts as an high filler eco-friendly content with high strength of composites increases compression strength and thermal resistivity. So as CSP the percentage (10 – 20) kept as constant increases tensile strength with high insulation properties, reduced tool wear and it is renewable resource used instead of asbestos.

Apart from their application in car bodies, composite materials play a pivotal role in braking system of automobiles, making their study and analysis intriguing and necessary. The composite materials find their role in forming good automotive brake pads. Almost all the automotive brake pads today are made of various constituent materials in various matrices and different fillers [5,7]. One of the major constituent materials of today's brake pads is asbestos. For many decades, asbestos has been used by the automotive industry in brake pads and linings, clutch facings, and gaskets.

Thus, it has become necessary to minimise the risk posed by the adverse effects of asbestos. An alternative solution should be found to tackle the problems associated with asbestos by finding a replacement [11, 13]. In the present investigation, an attempt has been made to develop a new hybrid composite material with optimal mechanical and tribological properties without asbestos. These new composite materials of Epoxy and Phenol as matrices have been fabricated using glass fibre as reinforcement with eco-friendly filler materials, according to the ASTM standards. A series of mechanical and three body abrasion tests have been conducted and the results are tabulated and compared with the test results obtained for the commercially available brake pad materials. Scanning Electron Microscope (SEM) photographs have been considered to analyse the fracture of matrix, reinforcement and filler materials, which could illustrate the wear characteristics of the fabricated materials considered for the study [16,18]. Two commercially available friction materials have been considered for the study of their abrasive properties and these are compared with those of the designed and fabricated materials.

II. Materials Used

PF and ER materials were used as matrices. 60% of PF and 30% of ER by weight were kept constant. For PF, Glass Fibre as reinforcement was added in percentages by weight of 6, 9 and 12. The percentage of CSP filler was (10–20 php) and this was kept constant. Other filler materials like CSD, BS, Al2O3 etc., were added to imbibe several other properties requisite of friction materials.

*Coconut shell powder was obtained from the grounding coconut shell and it is analyze by particle size analyzer and obtained as an average filler size 304 µm.

For ER, weight percentage variation of Glass Fibre was 6, 9 and 12. Percentage of CSP by weight was 40. The weight percentages of other fillers were kept constant. Hardener (H – 172 Grade) and Zinc Stearate ($C_{36}H_{70}O_4Zn$) were added to facilitate hardening and to bring in mould release characteristics for the composites being processed [1,2,9,10].

The base composite mixture for PF which was in the powder form, was converted into laminates using compression moulding hot press at the temperature range of 135ºC to 145ºC under 108 bar pressure. For ER based composite mixture which was in the liquid form, the same equipment was used. The picture and the specifications of the equipment are shown in Plate 1 and table 1 respectively.

Plate 1 Compression moulding Hot press

Table 1: Hot press specifications

Particulars	Specifications
Capacity	750 k N
Max. Day Light	150 mm
No. Of Day Light	2
Platen size	350mm X 350mm
Ram Diameter	200 mm
Heating Capacity	400ºC
Max Pressure	210 bars

Table 2: Chemical Composition of Coconut Shell Powder

Composition	Wt%
Lignin	30.1
Pentosans	28.2
Cellulose	27.7
Moisture	6
Solvent Extractives	5.3
Uronic Anhydrides	2.3
Ash	0.5

Specimens required for the (TBA) test were fabricated from both PF and ER based hybrid composite materials according to ASTM G-65 standards. The specimens required conforming to ASTM D-695 standards for compression strength tests were made from them. The test specimens were coded as A1, A2 and A3 for PF matrix composites for 6%, 9% and 12%by weight fraction of GF reinforcement respectively. Test specimens of ER matrix composites were coded as C1, C2 and C3 at 6%, 9% and 12% weight fraction of GF reinforcement respectively. Specimens required for the tests were fabricated from the commercially available two brake materials coded as CAB1 and CAB2.

III. Experimental Program

A. Three Body Abrasion Test

Plate 2 is depicting the equipment used for the three body abrasion test. Its specifications are given in Table 2.

Plate 2 Three body abrasion test set up

The specimens were subjected to three body abrasions under various abrading distances such as 300m, 600m, 900m and 1200m. Other test conditions as shown in table 2 were kept constant [14-17].

Table 3: Specifications of Three Body Abrasion Test Rig

Particulars	Specifications
Sample Geometry	76mm X 26mm
Abrasives	Quartz Sand (200-250 mesh)
Rotation Speed	200rpm
Abrading Distances	300m, 600m, 900m, 1200m
Load Applied	23N
Dead Weight	1kg

The abrasive material used was quartz sand having 200-250 mesh size. All the specimens (PF matrix) pertaining to A1, A2 and A3 series were subjected to this test under similar other constant parameters [12, 15, 21]. The results thus obtained are shown in tables 3, 4 and 5 and illustrated in graphs 1, 2 and 3.

B. Compressive Strength Test (ASTM D-695)

Universal Testing Machine (UTM) was used to investigate experimentally, compressive strength of test specimens of PF and ER series and commercial brake materials CAB1 and CAB2.

IV. Results and Discussion

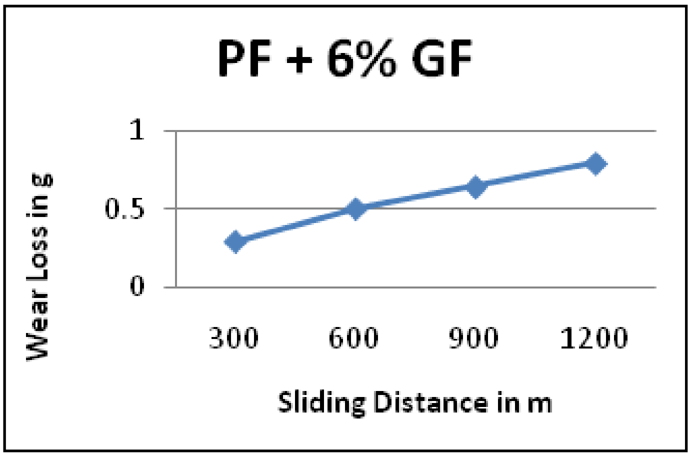
A. Three Body Abrasion Test Results

Table 3: Three body Abrasion test for PF with 6% GF at load of 23N – A1 series

CSP keeping 10 php as a constant

Sliding Distance m	Wear loss gm	Wear Volume cm^3	Specific Wear Rate cm^3/N-m
300	0.2967	0.1703	0.0247
600	0.5052	0.2900	0.0210
900	0.6440	0.3697	0.0179
1200	0.7934	0.4555	0.0165

Php = parts per hundreds of total polymer



Graph 1: PF + 6% GF

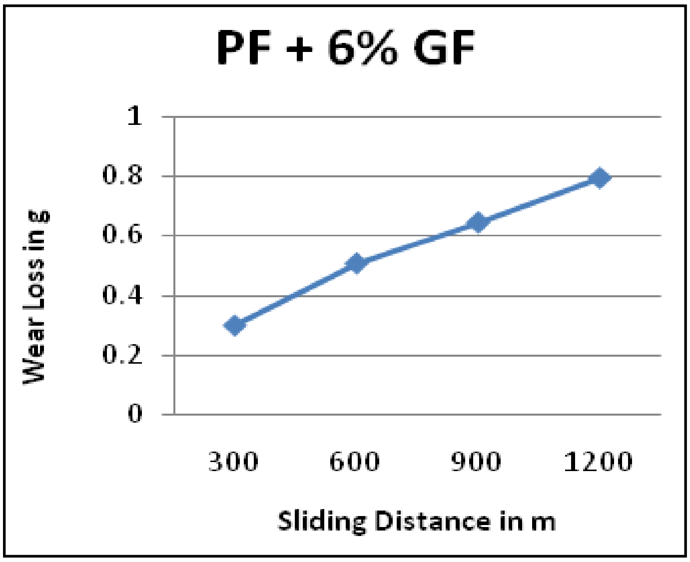
B. Three Body Abrasion Test Results

Table 4: Three body Abrasion test for PF with 6% GF at load of 23N – A1 series

CSP keeping 20 php as a constant

Sliding Distance m	Wear loss gm	Wear Volume cm³	Specific Wear Rate cm³/N-m
300	0.3012	0.1792	0.0327
600	0.5431	0.3120	0.0198
900	0.6912	0.3887	0.0160
1200	0.8093	0.4843	0.0153

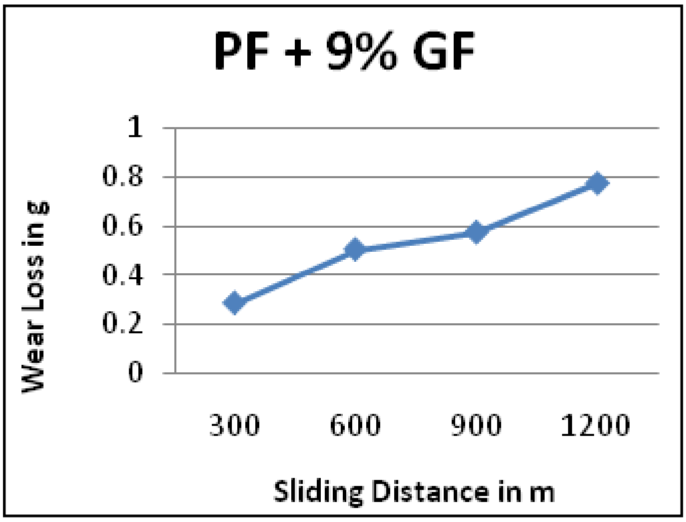
Php = parts per hundreds of total polymer



Graph 1.1: PF + 6% GF

Table 4: Three body Abrasion test for PF with 9% GF at load of 23N – A2 series

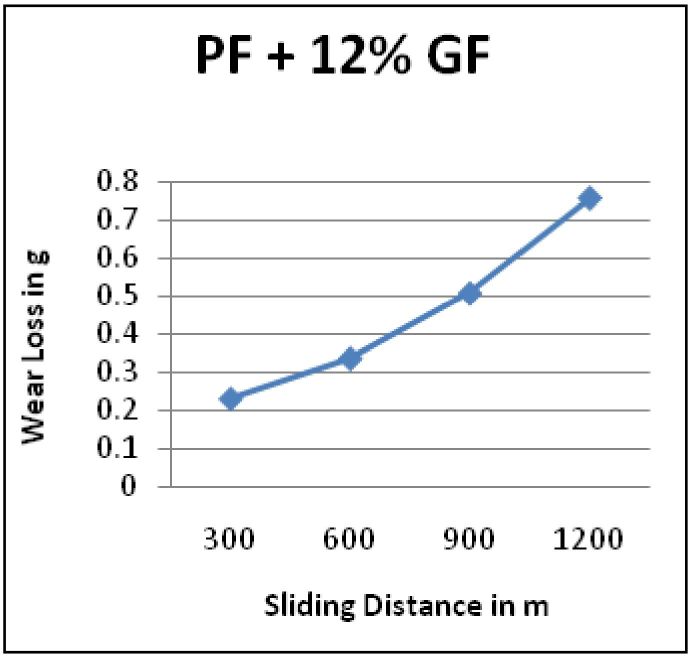
Sliding Distance m	Wear loss gm	Wear Volume cm³	Specific Wear Rate cm³/N-m
300	0.2832	0.1611	0.0233
600	0.5019	0.2854	0.0207
900	0.5711	0.3248	0.0157
1200	0.7713	0.4386	0.0159



Graph 2: PF + 9% GF

Table 5: Three body Abrasion test for PF with 12% GF at load of 23N – A3 series

Sliding Distance m	Wear loss gm	Wear Volume cm³	Specific Wear Rate cm³/N-m
300	0.2312	0.1302	0.0189
600	0.3364	0.1895	0.0137
900	0.5066	0.2853	0.0138
1200	0.7554	0.4255	0.0154

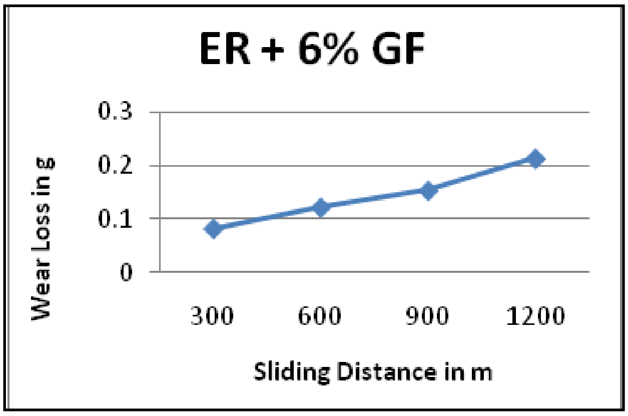


Graph 3: PF + 12% GF

Regarding ER matrix (C1, C2 and C3 series), same test conditions were employed [18, 20, 22, 24, 25]. The results are tabulated in Tables 6, 7 and 8 and illustrated in graphs 4, 5 and 6.

Table 6: Three Body Abrasion Test for ER With 6% GF at Load of 23N – C1 Series

Sliding Distance m	Wear loss gm	Wear Volume cm³	Specific Wear Rate cm³/N-m
300	0.0808	0.0486	0.0070
600	0.1208	0.0726	0.0053
900	0.1526	0.0917	0.0044
1200	0.2129	0.1280	0.0046

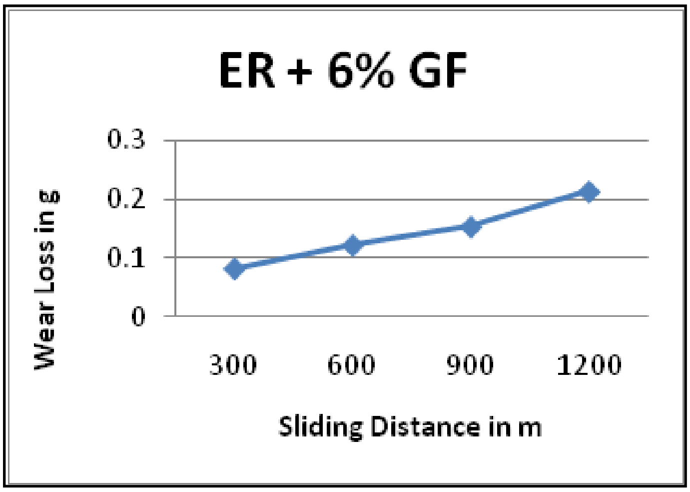


Graph 4: ER + 6% GF

Table 6.1 Three body Abrasion test for ER with 6% GF at load of 23N – C1 series

CSP keeping constant 20 php

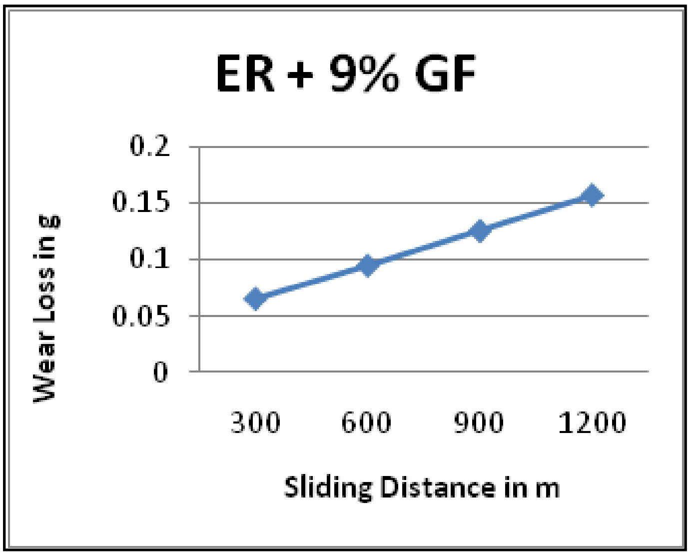
Sliding Distance m	Wear loss gm	Wear Volume cm³	Specific Wear Rate cm³/N-m
300	0.0902	0.0530	0.0068
600	0.1304	0.0875	0.0050
900	0.1652	0.0988	0.0040
1200	0.2645	0.1340	0.0041



Graph 4.1: ER + 6% GF

Table 7 Three body Abrasion test for ER with 9% GF at load of 23N – C2 series

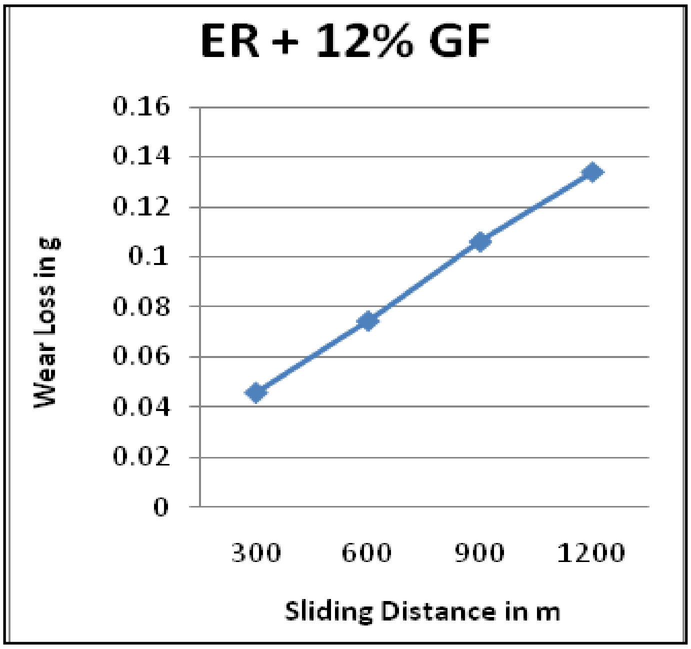
Sliding Distance m	Wear loss gm	Wear Volume cm³	Specific Wear Rate cm³/N-m
300	0.0656	0.0370	0.0054
600	0.0948	0.0534	0.0039
900	0.1253	0.0706	0.0034
1200	0.1567	0.0883	0.0032



Graph 5: ER + 9% GF

Table 8 Three body Abrasion test for ER with 12% GF at load of 23N – C3 series

Sliding Distance m	Wear loss gm	Wear Volume cm³	Specific Wear Rate cm³/N-m
300	0.0458	0.1292	0.0187
600	0.0745	0.1879	0.0136
900	0.1062	0.2830	0.0137
1200	0.134	0.4220	0.0153



Graph 6: ER + 12% GF

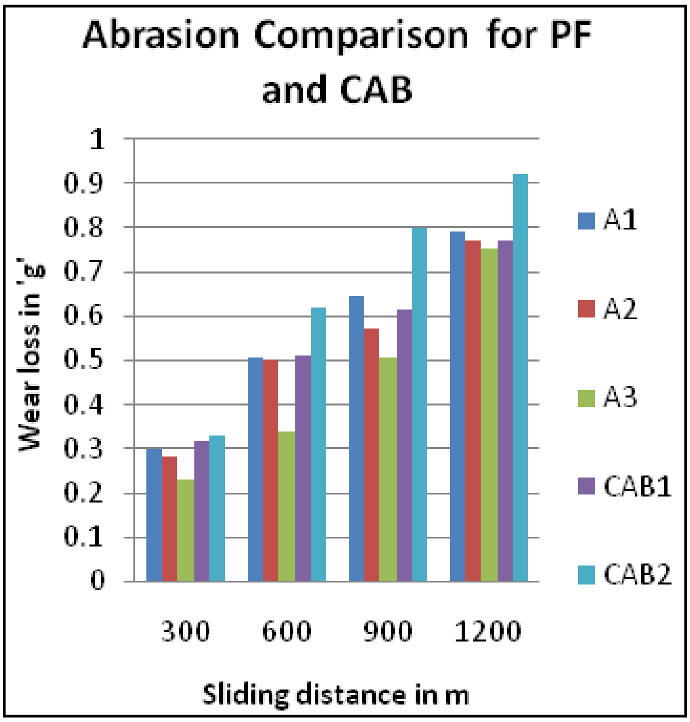
Specimens of CAB1 and CAB2 were also subjected to this test and the results are illustrated along with the results of PF and ER series composites in graphs 7 and 8.

Table 9: Three body Abrasion test for Commercial Material at 23N load – CAB1

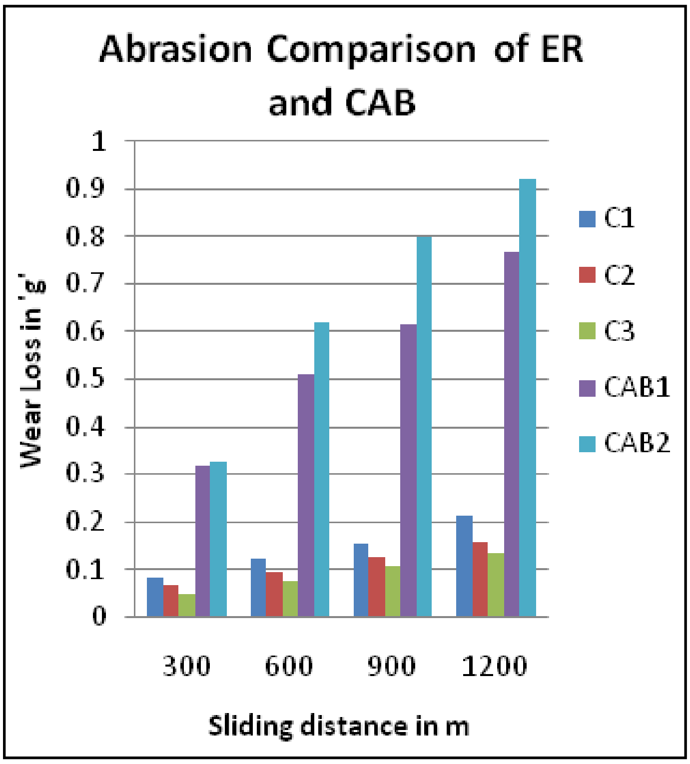
Sliding Distance m	Wear loss g	Wear Volume cc	Specific Wear Rate cc/N-m
300	0.3167	0.749	0.0253
600	0.5099	0.2816	0.0204
900	0.6151	0.3397	0.0164
1200	0.7692	0.4248	0.0154

Table 10: Three body Abrasion test for commercial material at 23N load – CAB2

Sliding Distance m	Wear loss g	Wear Volume cc	Specific Wear Rate cc/N-m
300	0.327	0.2020	0.0293
600	0.6196	0.3827	0.0277
900	0.8009	0.4947	0.0239
1200	0.921	0.5689	0.0206

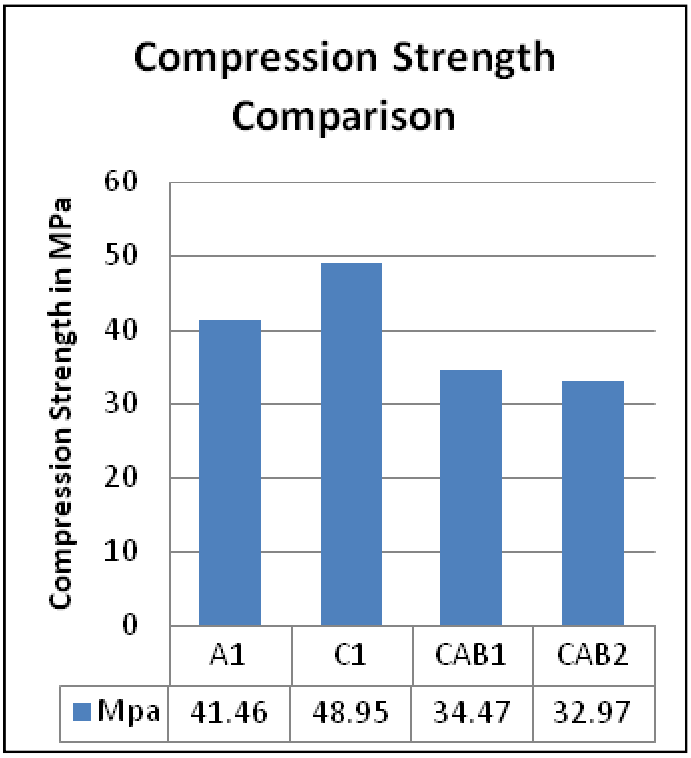


Graph 7 Abrasion comparison of PF composites (A1, A2 and A3) and commercial friction materials (CAB1 and CAB2)

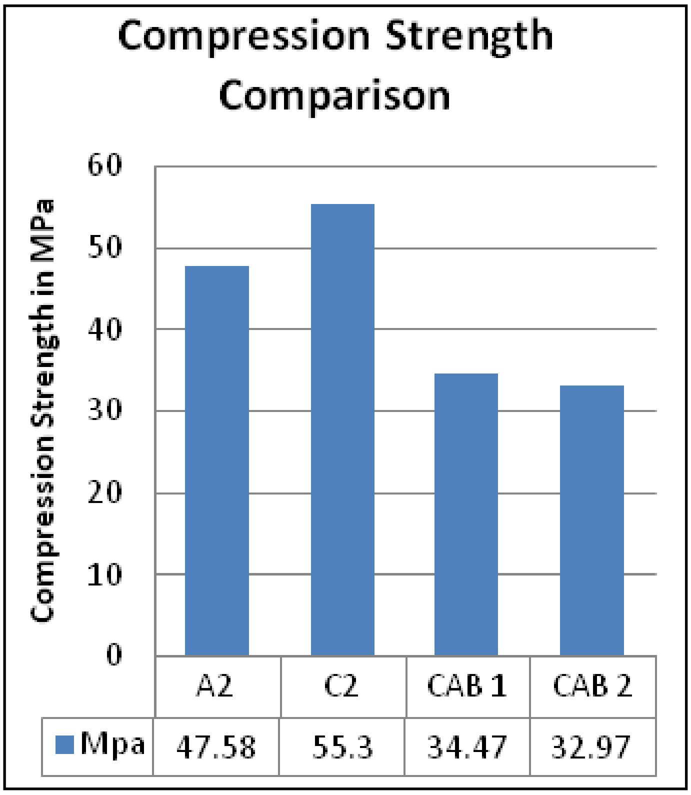


Graph 8 Abrasion comparison of ER composites (C1, C2 and C3) and commercial friction materials (CAB1 and CAB2)

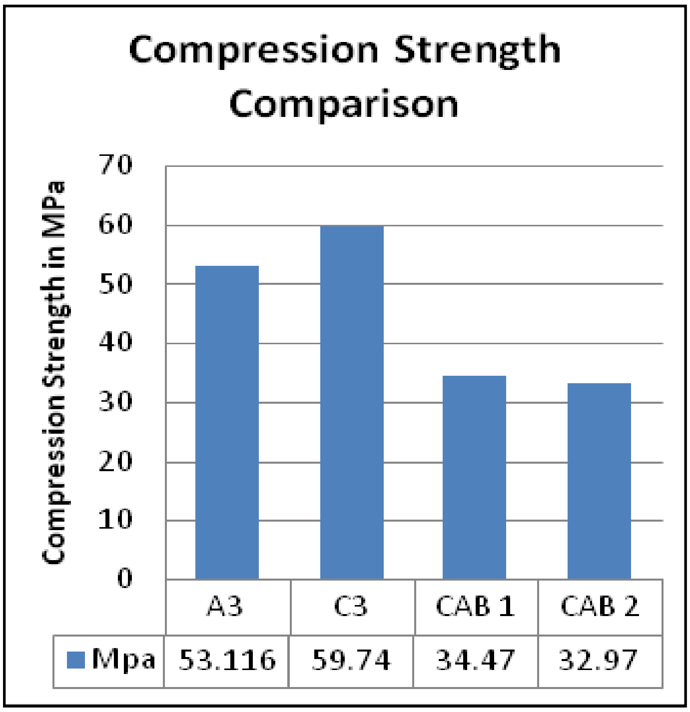
B. Compressive Strength Test Results:



Graph 9 Comparison of Compressive Strength of PF and ER composites of 6% glass fibre (A1 and C1) with commercial materials (CAB1 and CAB2)



Graph 10 Comparison of Compressive Strength of PF and ER composites of 9% glass fibre (A2 and C2) with commercial materials (CAB1 and CAB2)



Graph 11 Comparison of Compressive Strength of PF and ER composites of 12% glass fibre (A3 and C3) with commercial materials (CAB1 and CAB2)

C. Morphology of worn out test specimens depicted by SEM photographs:

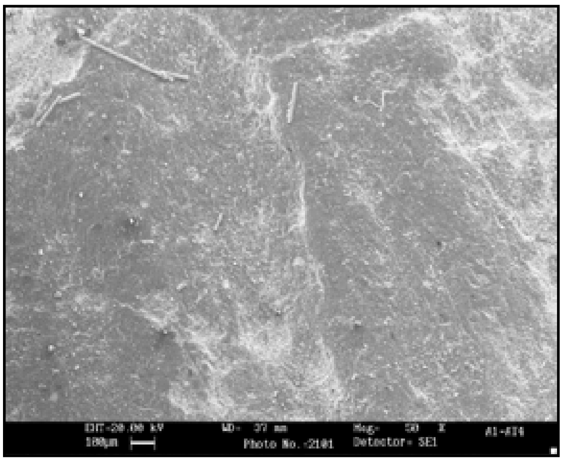


Plate 3 SEM photograph depicting morphology of A1 composite (6% GF in PF matrix)

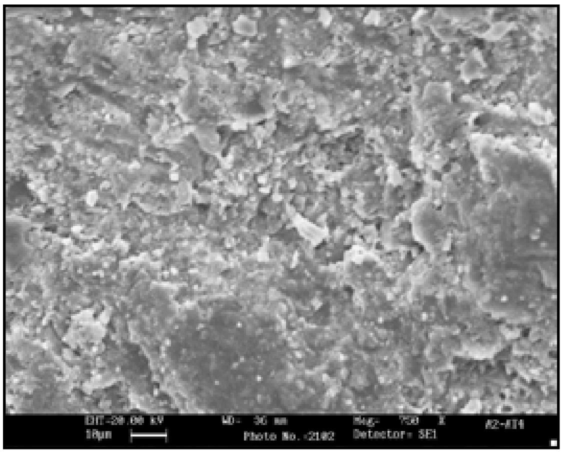


Plate 4 SEM photograph depicting morphology of A2 composite (9% GF in PF matrix)

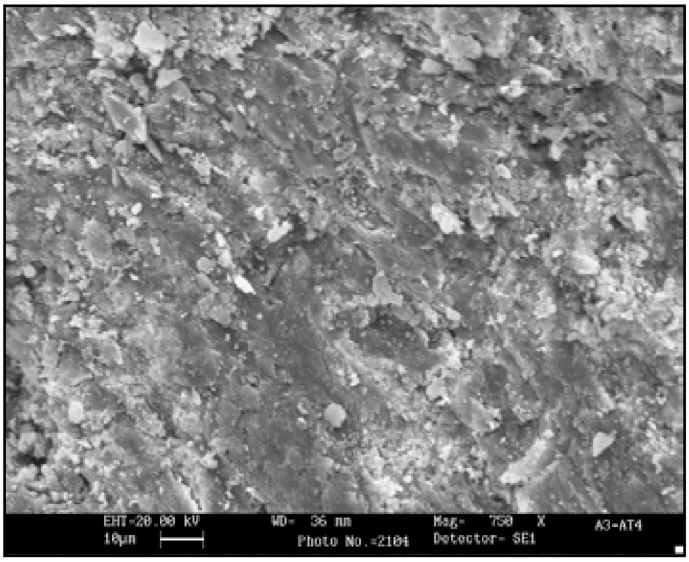


Plate 5 SEM photograph depicting morphology of A3 composite (12% GF in PF matrix)

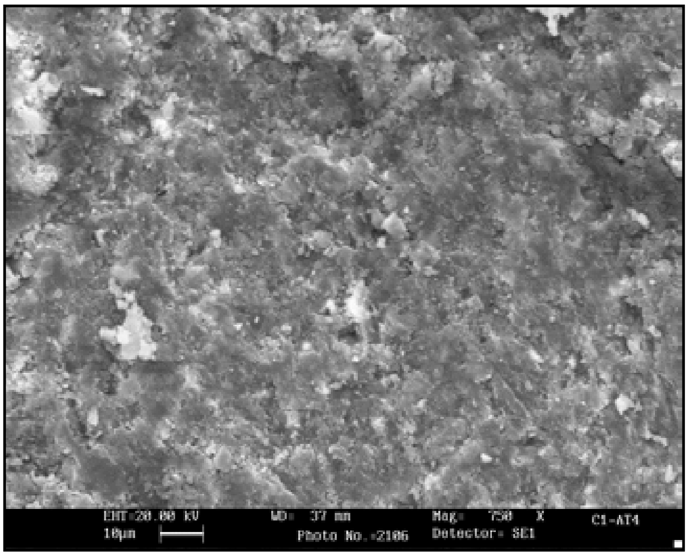


Plate 6 SEM photograph depicting morphology of C1 composite (6% GF in ER matrix)

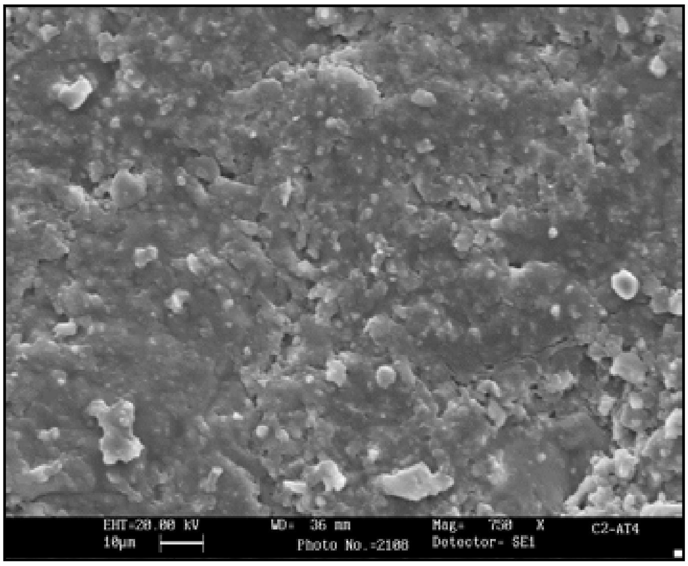


Plate 7 SEM photograph depicting morphology of C2 composite (9% GF in ER matrix)

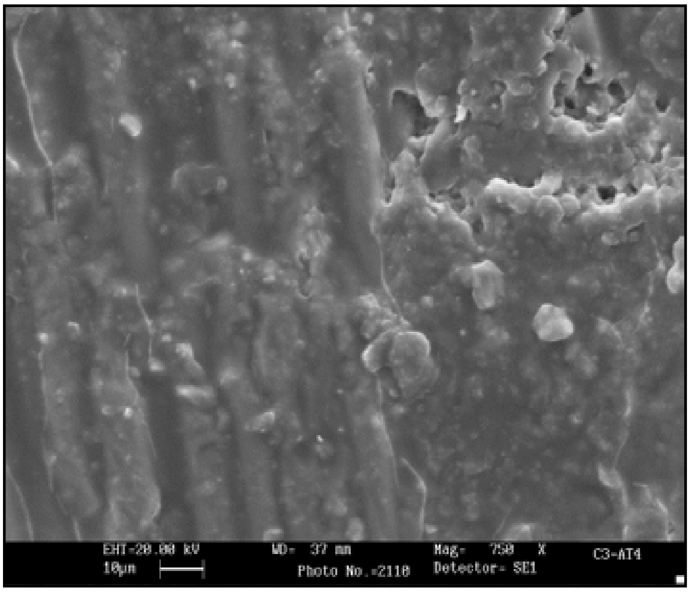


Plate 8 SEM photograph depicting morphology of C3 composite (12% GF in ER matrix)

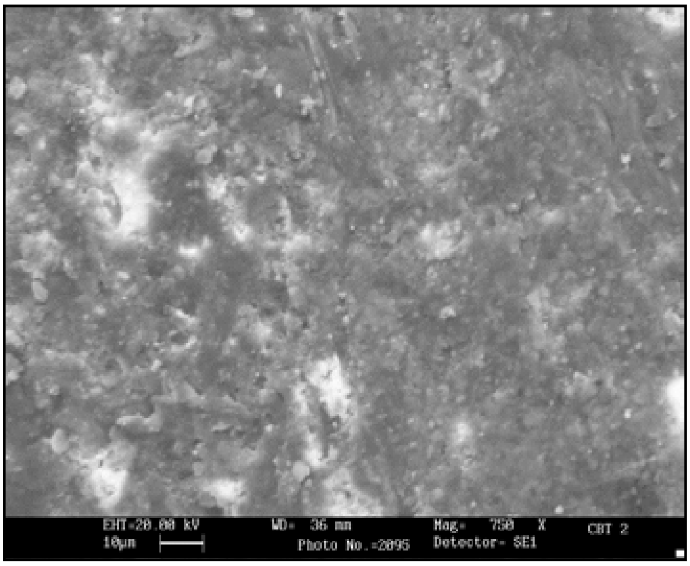


Plate 9 SEM photograph depicting morphology of CAB1 friction material

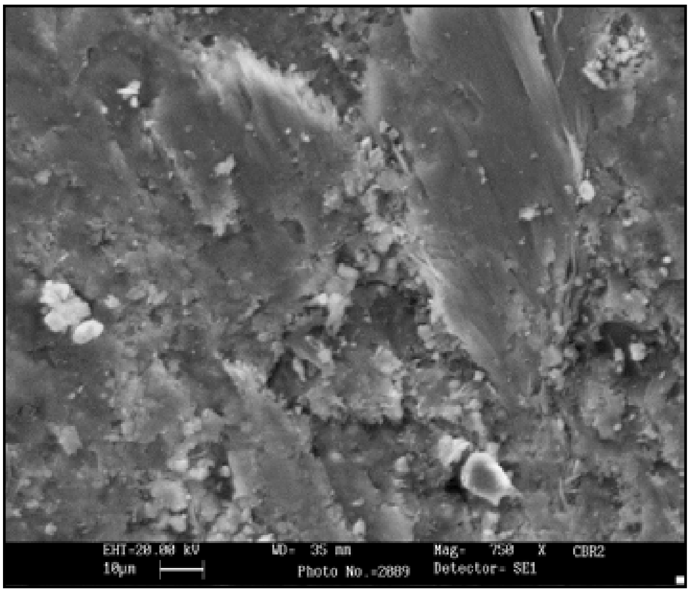


Plate 10 SEM photograph depicting morphology of CAB2 friction material

From the graphs 1,1.1, 2 and 3, it is seen that, as the sliding distance is increasing, wear loss also increases. At the maximum sliding distance of 1200m, wear loss is observed to be 0.7934 grams for A1. For A2 and A3, the values are 0.7713 grams and 0.7554 grams respectively. From these results, it is obvious that the wear loss has decreased as the percentage of glass fibre has increased. It seems that the addition of CSP and other filler materials have not contributed to the decrease in wear loss significantly since their presence in the matrix is kept constant, only the GF reinforcement is varied. Here in grap 1.1 CSP has been varied upto 20% php in A1 series it shows wear loss has decreased as the percentage of glass fibre has increased.

Similarly from graphs 4,4.1 5 and 6, for the ER matrix, similar trends and observations could be made. One important observation is that at 12% GF reinforcement and all other fillers' quantities being constant, at the maximum sliding distance of 1200m, the wear loss is 0.1340 grams. As one can observe, this value is significantly less than the value for PF matrix at the same sliding distance which is 0.7554 grams.

In graph 4.1 by varying CSP value upto 20 php as a constant in C1 series even though the wear loss very less 0.2645 compared to A1 i.e., 0.8093 but CSP does not effect the wear loss but increases the compressive strength due to its Cellulose composition in its structure.

The values for the two commercial brake materials CAB1 and CAB2 at the same sliding distance are 0.7620 and 0.9210 grams respectively. These two values are significantly higher than the minimum values of wear losses of A and C series composites.

When comparison is made between A and C series composites, the minimum loss occurred for C series composites at the maximum sliding distance. The comparative decrease in wear loss when C series composites are implemented is about 0.6214 grams which is about 82.26%, which is very significant. The obvious choice is ER matrix for the brake materials at 12% glass fibre reinforcement.

When ER matrix composite with 12% GF reinforcement is compared with CAB1, the percentage decrease in wear loss associated with the designed composite is 82.41. Similarly, when C3 composite is compared with CAB2, the percent decrease in wear loss is 85.45, which are very significant wear loss decreases.

From the graphs 9,10 and 11 it could be observed that, the compression strengths for PF and ER matrices and 12% GF reinforcement are 53.11MPa and 59.74 MPa respectively. This clearly indicates that ER matrix is preferred over PF matrix. When these values are compared with compressive strengths of commercial friction materials, which are 34.47 MPa and 32.97 MPa, clear indication is that, either PF or ER could be used as matrix and preference could be given to either of these depending on other criteria like cost and process ability etc. The order of magnitude of increase in compression strength of the fabricated composite in comparison with commercial friction material is 45 percent.

D. Structure and Form of Abraded Surfaces

In order to consolidate the analysis of results done for A, C series composite materials and commercial friction materials, SEM micrographs depicted in plates 3 through 10 are considered.

It is observed from plate 3 (50X) that at the maximum sliding distance, no plateaus are formed. Since modulus of PF matrix is comparatively lesser, one can see that the glass fibres are not fragmented or fractured, but have been moved bodily in the matrix and have got detached from the matrix. It is also observed that other filler materials have also done the same thing since some furroughs indicating the ploughing of the matrix by these particles. Some abrasive particles have also got embedded in the matrix and have caused the furroughs. This has led to higher wear loss. It is also quite evident from plate 3 (750X) that some weight fraction of fillers are held in the crevices formed between the fibres of the glass strands and are not embedded in the matrix. Some weight fractions of the fillers are embedded in the matrix as can one see, the particles held in the matrix indicated by dark spaces. Easy bodily removal of these un embedded particles has also contributed to the higher wear rate. Also, it is observed that CSP has abraded without any resistance and got embedded in the matrix.

Plate 4 (750X) is indicating the formation of number of plateaus wherein, some of the filler materials are embedded in the matrix. They indicate more fractured glass fibres along with the other wear resistant fillers in the matrix due to percentage of glass fibre in the matrix is higher. More even distribution of these is seen both in the plateaus and in the matrix. Obviously, it has become difficult for the abrading particles to exert forces required for detaching the particles and fractured glass fibre from the matrix as well as the plateaus. This has resulted in a comparative lower wear loss for the material which has 9% glass fibre. One can also observe that CSP got abraded and distributed more evenly along with other filler materials offering more resistance for the abrasion of other filler materials and glass fibres.

From plate 5, it is observed that more number of plateaus having larger areas is formed after abrasion. The plateaus have formed a skin which is highly wear resistant. This is because, as can be seen from plate 5, the abrasive particles, abraded glass fibres and other fillers have got evenly distributed in the matrix. It has become difficult for the abrasive particles and some hard filler materials to further fragment the glass fibres and other abrading particles and dislodge them from the matrix. The synergetic effect of these observations has led to the lowest wear loss in A3 composite material.

From plates 6, 7 and 8, the following analysis could be made so as to ascertain the reasons behind C series composites showing lesser wear losses compared to A series composites.

Various researchers have already established that ER matrix is preferred over PF matrix because of their higher modulus and thermal stability. As can be seen from plate 6 that, at 6% by weight concentration of GF, the various filler materials bringing abrasive nature to the composite have got evenly distributed in the matrix and also, few of GF fragmented or fractured particles. There is no ploughing of the matrix by these particles owing to the higher modulus of it. Few plateaus have also formed wherein; the distribution of these particles is more even. Since dislodging of these particles from the matrix is difficult, lesser bodily movement of these particles is not seen compared to A series composites, only the abrasion of these particles have contributed to the wear loss. These factors have contributed to significant lesser wear rate compared to PF matrix at the maximum sliding distance and load.

From plate 7, it is quite evident that more number of plateaus have formed and more number of abrasive particles and fractured glass fibres are present on them. One can clearly see the demarcation between the plateaus. These plateaus have formed a wear resistant skin between the matrix and the abrading medium. No furroughs are seen on the plateaus which indicate that the bodily movement of the particles has not occurred. Only possibility of wear with respect to this skin is the wear of these particles which calls for higher shearing forces coming on these particles which contributes to lesser wear loss at a particular shearing force. Also, beneath the plateaus, the dark spaces indicating the matrix have the evenly distributed abrasive particles and some glass fragments. One must note that the plateaus must be abraded before dislodging the particles from the matrix. These aspects have contributed to lesser wear rate in ER matrix compared to PF matrix for 9% GF at the same sliding distance and same load.

From plate 8, it is seen that most of the surface being abraded is covered with fragmented glass fibres and abrasive particles with uniform distribution of them. For obvious reasons mentioned above, the composite with 12% glass fibre has abraded much less compared to PF matrix composite at the same speed and load contributing to comparatively minimum wear loss.

From plate 9, it could be seen that the presence of finer abrasive particles have got uniformly distributed in the matrix. Significant matrix dilation is also not observed. Only possibility of wear of this material is the abrasion of these particles which require higher shear forces. Plate 10 shows severe damage to the matrix and the abrasive particles and reinforcing asbestos fibre are not distributed evenly in the matrix, but there is isolated distribution. Hence, it is easier for the abrading particles to dislodge these abrasive particles at lower magnitudes of shear force.

V. Conclusion

From the study, it is found that, CAB1 has comparatively lesser wear rate (18%) compared to CAB2. But, wear losses of both CAB1 and CAB2 are significantly higher than A series (2.59%, 22.07%) and C series (81.81%, 84.78%) composites respectively.

CAB1 has comparatively more compressive strength (4.35%) compared to CAB2. But, compressive strengths of both CAB1 and CAB2 are significantly lower than A series (35%, 32.97%) and C series (42.29%, 44.89%) composites respectively. By using eco-friendly coconut shell powder increases the compressive strength, Wear rate, Fair bonding, Thermal resistivity. In A1 series only in PF +6% G.F matrix CSP has been kept constant upto 20 php even though it does not effect wear loss and increase up 0.8093 in C1 series but in A1 series wear loss is .2645 so by applying CSP as a constant filler material is one of the best compared to commercial available filler material and gives high compressive strength in C1 series.

Finally by all above research conditions It could be emphatically concluded that, from both wear and strength considerations, C3 is the best composite for the considered tribological applications.

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