Investigating suitability of natural fibre-based composite as an alternative to asbestos clutch facing material in dry friction clutch of automobiles

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Abstract. This paper aims to study experimentally the suitability of natural fiber based composite as a facing material in single plate dry friction clutch in automobiles by comparing their mechanical properties. The clutch which is an important component of automobile has advanced technologically over the period of time. At the same time, it has impacted environment because of its non-biodegradable material and is harmful to human health. Asbestos has been replaced by the materials like Kevlar, Ceramic, Feramic and Feram Alloy as friction material in single plate dry friction clutch by Original Equipment suppliers of automobiles. Meanwhile asbestos clutch facing is being sold in spare parts market and still used in reconditioning of old clutch plates. So, there is an urgent requirement to find a new environment friendly and non-hazardous dry friction clutch facing material. Therefore, this paper investigates the suitability of using Coconut Shell Powder/Coir/Epoxy Resin composite in the place of asbestos as clutch facing material by comparing their mechanical properties like tensile strength, compressive strength, hardness and flexural strength by conducting different tests on the composite material specimens fabricated in the laboratory with different ratios of ingredients.

1. Introduction
The major concern of manufacturing industries today is the use of non-biodegradable and non-renewable raw materials [1]. Nowadays, environment friendly plant based natural fibres are used for manufacturing composites made up of polymers [2]. Green composites are biodegradable and they are produced from plant based raw materials including fibres [3]. The polymer composites reinforced by natural fibres have good strength and modulus. So, they are used to produce environment friendly products. One of the important fibres used is coconut fibre. It is cultivated in tropical countries where its fruit is used as food and its shell and husks are disposed as agriculture waste. So, they have potential to be used as low cost reinforcement and filler material to manufacture natural fibres composites [4]. Recent study has concluded that some mechanical properties were changed by the inclusion of coconut fibre in polymer composites. That is the hardness and impact strength have increased. But the ultimate tensile strength is not good [5]. Another recent study has proved that the addition of fibres of date palm has improved mechanical and thermal properties of composites made up of epoxy resin [6].
Since natural fibres have superior mechanical properties and eco-friendly and bio-degradable characteristics it is considered as a substitute for synthetic one by researchers [7]. Most of the works published recently are related to characterisation of fibre reinforced polymer composites and comparison of their mechanical properties and application performance with that of conventional composites [8]. The search for alternatives for synthetic fibre and resin system arises due to non-renewable and non-biodegradable character of petroleum resources [9]. Natural fibres are easily available, light in weight, biodegradable, renewable and low in cost. So, they are demanded increasingly for commercial use in various industries recently due to its advantages [10]. Plant fibres are obtained from different agricultural sources and it is preferred to be used as in composites because it is available abundantly in different geographical locations and is being used historically [11].

Asbestos is hazardous. So, it is banned in many developing and developed countries. But some countries are still using it in various applications. So, it is the time to conduct research and develop an alternative to asbestos [12]. Further the use of asbestos leads to the diseases such as asbestosis, mesothelioma and lung cancers. So, its use is avoided in producing brake pads. For example, asbestos fibre in brake pads can be replaced by planar fibres [13]. The other main advantages of using natural fibre reinforced composites are their easy disposability and eco-friendly character [14]. Also biocomposites are mainly made by natural fibres [15]. Since automobile industry is one of the major environment polluting industry the use of natural fibre is inevitable for the sustainable development of automotive industry [16]. For example the glass-fibre sheet molding compound in automobile has been replaced by natural fibre reinforced composites recently. It has reduced energy consumption avoided the environmental impacts made by previous compound [17]. From the above discussion it is concluded that the plant based natural fibres have good scope to replace synthetic fibres to achieve the sustainable development of industries particularly the automobile industry. So, this paper aims to investigate suitability of using natural fibre based composite as an alternative for asbestos clutch facing material in single plate dry friction clutch of automobiles by comparing mechanical properties.

2. Clutch Facing

Clutch assembly is one of the indispensable components of automotive transmission. Clutch is used to transmit power from engine to road wheels along with other components like flywheel, gear box, propeller shaft and differential. The heart of the clutch is facing. It should possess certain suitable mechanical and thermal properties to be used as friction material.

3. Polymer Matrix Composites

Most widely used composites are polymer matrix composites. Their manufacture is easy with simple procedure as it does not involve the application of high pressure and high temperature. Their mechanical strength can be improved by reinforcing them by other materials. Moreover, simple basic equipment is required for manufacturing polymer matrix composites [6].

3.1. Composites Reinforced with Natural Fibre

As the composites reinforced with natural fibre are biodegradable. Also, they are recyclable either completely or partially, renewable and cheap. So, they are widely used in various industries at present. Achievement of high strength and stiffness on the basis of weight is the main goal of designing fibre-reinforced composites. For any engineering material to be qualified as a clutch facing material is that it should possess good strength and stiffness.

4. Materials used

4.1. Coconut Fibre

The husk present in the fruit of the coconut palm is the source for extracting coconut fibres. It has good strength to weight ratio and can withstand heat and salt water. The properties of coconut fibres used is given below in table 1.
Table 1. Properties of fibre.

| S.No | Property of fibre                  | Value          |
|------|-----------------------------------|----------------|
| 1.   | Specific gravity [kg/m³]          | 1177           |
| 2.   | Water absorption [%]              | 93             |
| 3.   | Tensile strength [MPa]            | 95-118         |
| 4.   | Modulus of elasticity [GPa]       | 8              |

Coconut fibre is available abundantly in tropical countries like India, Malaysia, Philippines, Madagascar, Maldives and Sri Lanka.

4.2. Coconut Shell Powder
In tropical countries coconut shell is available abundantly as agricultural waste material. The addition of shell powder increases tensile modulus and tensile strength. But it decreases the impact strength slightly compared to epoxy resin used without any ingredients. So, it is concluded that the addition of coconut shell particles has improved properties of epoxy polymer composite to be used in eco-buildings. Moreover, the strength of concrete has enhanced compared to conventional concrete mixture by the integration of coconut shell. Hence coconut shell powder is used as reinforcing filler material in Coconut Coir/Epoxy resin composite to improve their strength.

The reinforcing material used in the current study is coconut shell powder of size between 200-800μm. It was prepared by grinding the completely dried shell in a grinding machine. The coconut shell powder used as filler material has high strength and modulus. The density of coconut shell is 1.60 g/cm³ approximately.

4.3. Epoxy Resin
Epoxy resin is a thermosetting polymer. It is used for manufacturing composite materials reinforced with natural fibre. Epoxy is highly cross linked and amorphous polymer. Epoxy resin SY-12(319) has been taken for this study.

4.4. Hardener
The curing agent used in this study is Hardener SY31 (B). Its Specific viscosity is 10-20 cps. Its composition in composite has been varied to check its impact on material characteristics.

5. Fabrication
The fabrication of two sets of samples containing three laminae each were made. The first sample set was made by varying proportion of resin and coconut shell powder. The second sample set was made by varying proportion of coconut coir and shell powder.

5.1. Compression Moulding
Compression moulding is the widely used method to fabricate composite laminae. In this method preheated laminae material is placed in a mould cavity which is open and heated. Then the mould is closed and pressure is applied. This heat and pressure help the laminae to cure. In this study the laminae were prepared in Compression Moulding Machine at IIT (Madras).

5.2. Stirrer Set Up
The stirrer set up at IIT (Madras) with the specifications as given in the table 2 has been used for the preparation of sample.

5.3. Two sets of samples prepared
Two sets of samples were prepared as per the ingredients given in table 3.
Table 2. Specification.

| S.No | Specification | Value       |
|------|---------------|-------------|
| 1.   | Applied pressure | 25 bar     |
| 2.   | Temperature    | 25 degree C |
| 3.   | Time           | 4 hours     |
| 4.   | Stirring time  | 45 min      |
| 5.   | Thickness      | 5mm         |

5.3.1. First set of sample. In the first set of samples the weight of coconut coir was fixed as 106g for all the three samples. The resin weight taken was 4 times the weight of the coir for all the 3 samples. The weight of the shell powder taken were 20%, 30% and 40% that of the resin for samples 1, 2 and 3 respectively. The amount of hardener taken was 10% of the Weight of Resin and Shell Powder combined for preparing all the three samples. The first set of three laminae samples were prepared in the compression moulding machine as shown in figure 7(a). In these samples the proportion of resin and shell powder were varied.

5.3.2. Second set of samples. Another three laminae of second set of were made as shown in figure 7(B). They were made by varying proportion of coconut coir and shell powder. The weight of the shell powder taken were 20%, 30% and 40% that of the coconut coir for samples 1, 2 and 3 respectively. But the weight of coconut coir and resin were fixed as 106g and 4 times the weight of the coir for all the 3 samples respectively. The amount of hardener taken was 10% of the Weight of Resin and Shell Powder combined for preparing all the three samples.

Other steps for the preparation this set of samples were same as that of the first step as mentioned above.

Table 3. Details of Sample.

| SNo | Ingredients | SET 1 | SET 2 |
|-----|-------------|-------|-------|
| 1   | Coconut Coir Weight | 106g | 106g |
| 2   | Resin Weight | 424g (4 times the wt. of coir) | 424g (4 times the wt. of coir) |
| 3   | Shell Powder Weight (g) | 0.2*424 = 84.8g | 0.3*424 = 127.25g |

Other steps for the preparation this set of samples were same as that of the first step as mentioned above.
6. Testing
In order to find the best proportion of the ingredients in a composite material the following tests were carried out. The tests carried at IIT (Madras) were,

1) Tensile test
2) Compression test
3) Flexural test
4) Hardness test
5) Wear test
6) SEM analysis

6.1. Tensile Test
Resistance to the applied tension force is Tensile strength. Universal Testing Machine was used to conduct tensile test.

6.2. Compression Test
Resistance to the applied compression force is called compressive strength of the material. Compression test was also carried out in a Universal Testing Machine.

6.3. Flexural Test
Flexural strength is found by this test. How much the highest stress a material can withstand before yielding in a flexure test is called as flexural strength. Flexural Test was carried out in Instron universal testing machine.

6.4. Hardness Test
Resistance of any solid material to permanent shape change under applied compressive force is hardness. This technique is widely used to test the degree of cure of a fibre reinforced composite material.

6.5. Wear Test
Since the clutch facing material is used in wear application the wear test was conducted to find out wear performance composite laminae and to compare it with that of asbestos facing. The Pin on Disc Wear Testing Machine was used in this study.

Figure 1. Fabricated samples.
6.6. Scanning Electron Microscope (SEM) Analysis
A Scanning Electron Microscope (SEM) is generally used to study composition, surface topography, presence or absence of voids, distribution of various ingredients throughout the lamina and the bond between various ingredients in a composite material.

7. Results and discussion

7.1. First Set of Samples

7.1.1. Tensile Strength. The graph below in figure 2 shows that tensile strength is maximum for asbestos materials. It is because of good tensile property of asbestos compared to natural fibres. It is followed by sample 1 which has relatively nearer to that of the asbestos material. Tensile strength is lower for sample 2 and sample 3. It is due to the variation in the composition of coconut shell powder in the samples. In sample 1, coconut shell powder is 20% of resin weight. But in sample 2 & 3 it is 30% of resin weight and 40% of resin weight respectively. This shows that increase in coconut shell powder concentration reduces tensile strength. It is due to weakening of bond strength.

![Figure 2. Tensile strength (first set).](image)

7.1.2. Compressive Strength. The graph in figure 3 indicates that compressive strength is maximum for asbestos materials, as could be seen that it has higher range when compared to other samples. It is then followed by sample 1, sample 2 and sample 3. This difference in compressive strength is also due to varying proportion of shell powder present in different samples. It is inferred from the above graph that the increase in coconut shell powder concentration reduces compressive strength. It is due to weakening of bond strength.

![Figure 3. Compression strength (first set).](image)
7.1.3. **Flexural Strength.** From figure 4 it can be seen that asbestos materials has higher flexural strength which is relatively followed by sample 2. Sample 3 and 1 has the lower value of flexural strength. It is concluded that optimum mixture of shell powder improves flexural strength.

![Figure 4. Flexural strength (first set).](image)

The sample 2 which is a mixture of coconut coir (106g), resin {(424g) (4 times the weight of coir)}, shell powder (30% of resin weight i.e. 0.3*424 = 127.25g) and hardener (10% of the weight of resin and shell powder i.e. 0.1 * (424+127.2) =55.12g) gives the maximum flexural strength. This is the optimum value for the composition of different ingredients. But for lower (20%) and higher (30%) shell powder composition, flexural strength is low.

7.2. **Second Set of Samples**

7.2.1. **Tensile Strength.** It is clear from the graph shown in figure 5 that the tensile strength of sample-3 is more than that of the other samples (19 MPa). But it is less than asbestos for the displacement of 4mm approximately. Comparatively less proportion of shell powder in sample 3 has improved tensile strength. The samples used for the test are shown in figure 6.

![Figure 5. Tensile strength (second set).](image)
7.2.2. Compressive Strength. The graph in figure 8 shows that the tensile strength of sample-2 is more than that of the other samples (123 MPa). But it is less than asbestos for the extension more than 3mm approximately. Optimum quantity of shell powder has its influence on compressive strength. The samples used for testing are shown in figure 7.

7.2.3. Flexural Strength. The test results plotted in the graph which is shown in figure 9 establishes that the flexural strength of sample-3 is more than that of the other samples (46.022 N/mm²). But it is
less than asbestos for the extension more than 0.8mm approximately. It is also because of varying proportion of different ingredients such as shell powder, coir, Resin and hardener. It is concluded that Flexural strength is good with lowest shell powder content among three samples shown in figure 10.

Table 4. Hardness results of two sets of samples.

| Samples  | First set (BU) | Second set (BU) |
|----------|---------------|-----------------|
| Sample 1 | 22            | 27              |
| Sample 2 | 20            | 30              |
| Sample 3 | 18            | 22              |

![Figure 9. Flexural strength (second set).](image1)

![Figure 10. Samples after flexural testing (second set).](image2)
7.3. Barcol Hardness
Table 4 shows the result of both the sets of samples in Barcol Units. From the above values of different samples, it is concluded that if the proportion of shell powder decreases the Hardness increases in the first set of samples.

Moreover, it is also concluded that decrease in amount of shell powder has improved hardness in second set of samples. The little bit higher value of sample 2 may be because of the place where the indenter placed might had high concentration of resin.

7.4. Wear Test
The following table 5 shows the specifications of wear testing machine. The wear test was conducted on the best samples (Sample 1 of First and second set of samples) only which have good mechanical properties. Table 6 Shows the results of wear test for best samples of two sample sets.

| S.No | Specification                  | Value                               |
|------|--------------------------------|-------------------------------------|
| 1.   | Cylinder size                  | 150 mm diameter and 500mm length    |
| 2.   | Material of coarser abrasive sheet | 60 Grade                           |
| 3.   | Equivalent revolution          | 84 times                            |
| 4.   | Rotational Frequency           | 40-41 rpm                           |
| 5.   | Load applied                   | 1 Kg                                |

As coconut coir and shell powder have low wear resistance compared to asbestos weight loss is more in coconut coir / shell powder-based composite compared to that of asbestos based one. Wear resistance can be improved by pre-treatment of coconut coir shell powder. The low wearing resistance of coconut coir and shell powder can be improved by heat treatment particularly.

7.5. Comparison of Mechanical Properties of First and Second Set of Samples
The following table 7 explains the comparison mechanical properties such as Tensile, Compressive and Flexural strengths and Hardness and Wear property of two of samples sets.

| Tests carried | Samples                        | Asbestos | First set | Second set |
|---------------|--------------------------------|----------|-----------|------------|
| Tensile (kN/mm²) | Asbestos                      | 0.029    | 0.019     | 0.018      |
|                | First set                     | 0.015    | 0.015     | 0.015      |
|                | Second set                    | 0.015    | 0.015     | 0.019      |
Compressive (kN/mm²) | 0.105 | 0.078 | 0.068 | 0.056 | 0.067 | 0.068 | 0.056
Flexural (MPa) | 3.987 | 2.227 | 2.764 | 2.527 | 2.5928 | 1.944 | 2.800
Hardness (BU) | 28 | 22 | 20 | 18 | 27 | 30 | 22
Wear (%) | 7.49 | 9.89 | - | - | 8.35 | - | -

The above result shows that mechanical properties are higher for Asbestos Materials when compared to that of Coconut Coir/Shell Powder/Epoxy resin composite. It is due to inferior qualities and mechanical properties of coconut coir and shell powder compared to Asbestos.

The non-treated coconut coir and shell powder have poor mechanical properties. If they are treated before processing these properties can be improved. Fibre treatment with NaOH and heat treatment of shell powder can be performed to improve the mechanical properties.

However Sample 1 of both the sets of samples have relatively closer valve of mechanical properties to that of Asbestos materials, So it has been selected as a best suitable material among the 3 samples to be used as replacement for asbestos facing in single plate dry friction clutch assemblies.

7.6. SEM Analysis (First Set of Samples)
The following figure 11 shows the SEM view of the best sample that is first sample of the first sample set.

![SEM view of coconut coir / shell powder / fibre / epoxy resin composite (sample 1 of first set of sample).](image_url)
From the above figures the microstructure of our composite material is studied. This is done for sample-1 of first set of samples which is the best sample selected for our application based on the mechanical properties test results discussed above. It is also concluded that bonding is good in all samples. No major void can be found in it. So mechanical properties of Sample 1 of the first sample are comparable with that of Asbestos.

7.7. SEM Analysis (Second Set of Samples)
From the figure 12 the microstructure of our composite material is studied for further. This is done for sample-1 which is the best sample selected for our application based on the above test results and are shown and discussed. Figures 12 show the microstructure of sample-1 of Second Set of samples which is the best sample selected for our application based on the mechanical properties test results as discussed above.

![SEM view of coconut coir / shell powder / fibre / epoxy resin composite (second set).](image)

From the SEM photographs it is found that even though coir is randomly arranged. It is well distributed and arranged with resin and shell powder at some places. But at other places it is not so. This is one of the reasons for inferior mechanical properties. At the same time, it has good mechanical properties at the places of uniform distribution.

8. Conclusion
On the basis of analysis of test results, it is concluded that sample 1 of the first set of samples is the best among the six samples. Sample 1 has high Tensile, Compressive, Flexural, Hardness and Wear strengths than that of other five samples. At the same time Sample 1 has comparatively lower values
than that of Asbestos Materials. Hence by improving the mechanical properties through NaOH treatment of fibre and heat treatment of shell powder, Coconut Coir / Shell Powder / Fibre / Epoxy Resin Composite can be made as the best alternative for asbestos facing material in single plate dry friction clutch of automobiles. Moreover, the above discussion allows one to conclude that there is a great scope for using eco-friendly coconut shell/coir/epoxy resin based composite material as a replacement for environmentally hazardous asbestos clutch facing material in automobiles.

9. References

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