

# Effect of the Properties of Natural Resin Binder in a High Friction Composite Material

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**Abstract:** In this paper, a high-friction composite material based on the combination of binder, friction modifiers, fibers and fillers is investigated. In the binder, up to 20% of phenol are replaced by cardanol with various weight ratios of 100/0, 95/5, 90/10, 85/15, 80/20. Cardanol may react both through the phenolic group and the double bond of the side chain yielding addition, condensation and polymerisation reactions that allow the synthesis of tailor-made products and polymers of high value. In the present work, mechanical, thermal and wear characteristics of cardanol based phenolic resin with organic ingredients were manufactured and tested. An analysis of microstructure characteristics of composites was carried out using scanning electron microscope. The effect of environment on the composite was investigated in water, salty water and oil. The results showed that the addition of cardanol reduces the wear resistance and increases the compressibility which reduces the noise propensity.

**Keywords:** *Cardanol, wear, friction, porosity.*

## Introduction

Designing composite friction material is often based on experience or a trial and error method to make a new formulation. It has long been claimed as a problem of multistage optimization right from selection of ingredients to processing till reaching at appropriate set of performance criteria<sup>[1]</sup>.

High friction materials have application in automotive, aerospace and industrial brake systems<sup>[2]</sup>. In general more than 10 ingredients have been used for obtaining high friction materials which comprises binder, filler, friction modifier and reinforcement for maintain wide range of load, speed, temperature, humidity etc<sup>[3]</sup>. Phenolic resin is used as binder in friction materials due to their low cost and good combination of mechanical properties, such as high hardness, compressive strength, moderate thermal resistance, creep resistance and very good wetting capability with most ingredients<sup>[4]</sup>. In recent years composite materials are directed in developing natural resin that can provide with enhanced and reliable performance. Cost of the natural resins are less compared to the traditional synthetic resins<sup>[5]</sup>.

In this research work, Phenol Formaldehyde (PF) was mixed with cardanol formaldehyde (CF) to obtain Cardanol Phenol Formaldehyde (CPF) resin, which is used as a binder for friction material. The phenolic nature of the material makes it possible to react under a variety of conditions to form both base catalyzed resoles and acid catalyzed novolacs<sup>[6]</sup>.

Cardanol is a source of unsaturated hydrocarbon phenol and behaves as an excellent monomer for thermosetting polymer production<sup>[7,8]</sup>. Cardanol Formaldehyde is synthesized from CNSL (Cashew Nut Shell Liquid) either by polycondensation with electrophilic compounds, such as formaldehyde, furfuraldehyde or by chain polymerization through the unsaturation presents in the side chain using acid

catalysts or by the functionalization at the hydroxyl group and subsequent oligomerization to obtain a functionalized pre-polymer.

Usually composite friction materials consist of 5-25 vol% of fibrous ingredient which influences the wear life<sup>[9]</sup>. Calcium carbonate, antimony trisulfide, graphite, calcium silicate, vermiculate, alumina, cashew dust and silicon have found wide application in manufacturing of friction material, since it exhibits very good property of self lubrication, high temperature resistance, abrasiveness and severity index towards moisture absorption is very less, respectively.

## Experimental work

### Materials

Cardanol and cashew dust (Satya Cashew chemicals pvt. ltd., Chennai), phenol formaldehyde (Esterkote pvt. ltd., chennai), rock wool fiber (B M marketing and trading pvt. ltd., chennai), Calcium carbonate, antimony trisulfide, graphite, calcium silicate, alumina and silicon (All from metro scientific company, chennai) and steel fiber (Ryan international, mumbai) were used during investigation.

### Sample preparation

All the ingredients were weighed using an analytical balance instrument and mixed using a blender (electron EBR 100) for 6 min at 10000 rpm in room temperature (30 °C). Fibers (Steel fibers and Rock wool fiber) were added initially followed by the required quantity of filler (calcium carbonate), abrasive (alumina), lubricants (antimony trisulfide and graphite) and friction modifiers (vermiculate, calcium silicate and cashew dust) added

simultaneously. Finally binder material was added<sup>[10]</sup>. Table 1. shows the ingredients of the friction material investigated in this work. For analyzing hardness, bulk density, compressibility, porosity and wear properties of the specimen, two different molds (size: 150 × 150 × 3 mm and φ5 × 32 mm) were used for pressing.

The die was preheated to 180 °C and pressure of 160 kg/cm<sup>2</sup> was applied over a mixture for a molding time of 6 min. Molding involves several stages: initial molding, elastic-plastic deformation and particle fracture or fragmentation<sup>[11]</sup>. During the initial stage, rearrangement of powder particles, which leads to the filling of large voids and the break up of particle bridges. In the elastic-plastic stage, the applied pressure is further increased and plastic deformation occurs locally at the inter particle contact points. In the final stage of molding, plastic deformation becomes widespread, accompanied by shearing, generation of new oxide-free surfaces, cold welding of contacting surfaces and accompanied by reduction in porosity.

Subsequently it is post cured at a constant temperature of 180 °C by placing the samples (Dimension: 150 × 150 × 3 mm and φ5 × 32 mm) in a preheated furnace for 4 hrs. Because the particles of a material are joined together and gradually reducing the volume of pore space among them, enhances curing uniformity, reduces thermal expansion.

### Test and analysis

Specimens were sectioned and examined using scanning electron microscope (SEM) model EVO MA15 to determine mixing of friction materials. Prior to SEM evaluation, the specimens are coated with gold using plasma sputtering apparatus Edwards sputter coater model S150B.

The chemical resistances of the phenolic composite was determined at room temperature. Chemical resistance of the friction material was measured by the following method described in ASTM D 570-77 with various chemical reagents (water, salt water, SAE 20w-40). Hardness of friction material specimen was measured using Rockwell hardness tester. Bulk density was measured by the water displacement technique that was recommended by SAE J380. Compressibility

measurement was performed using a compression tester and the results are obtained from the slope of the height change as a function of applied pressure. The crosshead speed of the machine was kept at 0.5 mm/min. Porosity and specific wear were also measured for hybrid phenolic composites. Porosity( $\Phi$ ) is calculated by using the following equation

$$F=(V_p/V)*100$$

Where  $V_p$  is porous volume and  $V$  is Bulk volume.

Wear test was conducted using DUCOM wear and friction monitor - TR 20 with grey cast iron as the counter part with a diameter of 120 mm. All the testing procedures were operated by a WinDucom data acquisition system on a computer using the ASTM G-99 standard. The size of a single composite material is 8 mm diameter and a length of 32 mm.

$$\text{Specific wear rate} = V_i / (F*s)$$

Where  $V_i$  is the the wear volume,  $F$  is the normal load and  $s$  is the sliding distance.

## Results and Discussion

The effect of varying Cardanol Formaldehyde resin on chemical resistance of PCF composite shown in Figure 1. From the figure it is observed that water absorbed by the PF composite is increased by 0.21% and

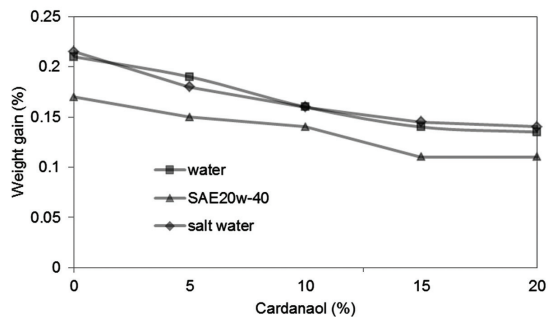


Figure 1. Increase in Cardanol (%) vs weight gain for water, salty water and lubricating oil.

Table 1. The ingredients of the friction material investigated in this work.

Raw materials	Specimen	Specimen	Specimen	Specimen	Specimen
	0%	5%	10%	15%	20%
Phenol formaldehyde resin	20	15	10	5	0
Cardanol formaldehyde resin	0	5	10	15	20
Calcium carbonate	20	20	20	20	20
Alumina	10	10	10	10	10
Antimony trisulfide	4	4	4	4	4
Graphite	4	4	4	4	4
Cashew dust	10	10	10	10	10
Calcium silicate	7	7	7	7	7
Vermiculate	3	3	3	3	3
Rockwool fiber	8	8	8	8	8
Steel fiber	12	12	12	12	12
Silicon	2	2	2	2	2

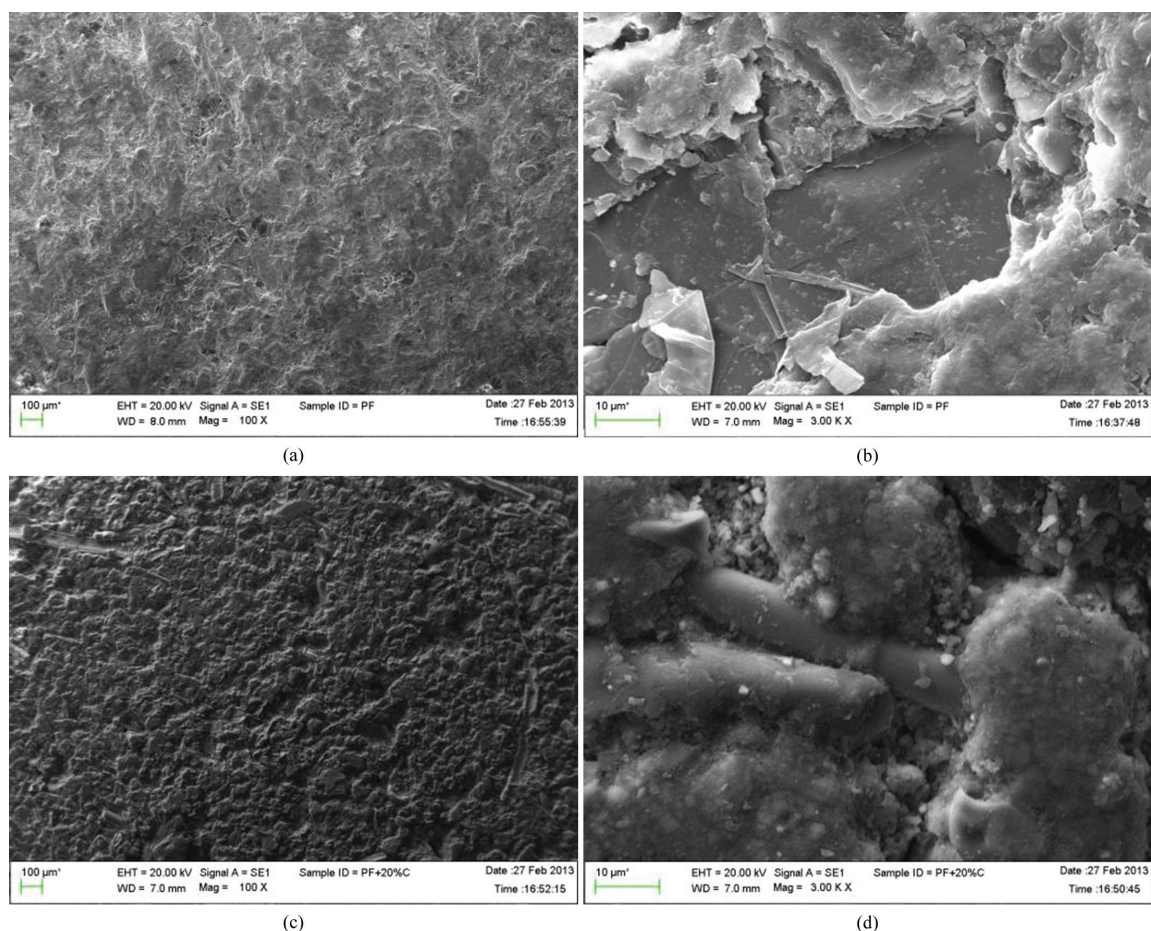
it is higher than the other CPF composite. The sample with 15% cardanol have the lower value (0.135%). Lubricating oil absorbed by the PF composite is about 0.17% and the sample with 15% and 20% of cardanol have the lower value (0.11%). Salty water absorbed by the PF composite is increased by 0.22% and the sample 15% cardanol have the lower value (0.14%). By increasing the cardanol content in the resin, a reduction of the weight gain was observed. This is largely due to the fact that the cardanol molecule contains a long alkyl group which is hydrophobic in nature<sup>[12]</sup>. This hydrophobic nature leads to the segregation and apparent repulsion between the water and non polar substance. In contrast, the long alkyl chain can cause negative steric effect on the crosslinking<sup>[13]</sup>. The morphology of PF and CPF composites are shown in Figure 2. Good dispersion of filler into the matrix is observed in Figure 2d.

The bulk density and compressibility of the friction materials are investigated by varying Cardanol Formaldehyde content in CPF resin and shown in Figure 3. It is observed that the friction material of sample PF composite has a bulk density of 1.66 gm/cm<sup>3</sup>, while the other four CPF composite materials (5%, 10%, 15%, 20%) possess a density in the range of 1.54-1.3 gm/cm<sup>3</sup>.

Thus the 20% CPF composite has the lower bulk density. This is due to the presence of alkyl group in cardanol CPF composite when compared to PF composite<sup>[13]</sup>. The compressibility of CPF composite is found to increase with increase in Cardanol Formaldehyde loading. The reason for this trend is attributed to the internal plasticizing effect of Cardanol moiety<sup>[14]</sup>.

The effect of Cardanol Formaldehyde loading on hardness and porosity of CPF composite is shown in Figure 4. The cured PF composite has a porosity of 12%. On increasing CF resin the CPF composite is found to have increased porosity of about 16% for 20% CPF composite. PF composite has high hardness due to the fact that binder resin has higher crosslinking density showing high strength after cure<sup>[15]</sup>. But cardanol reduces the hardness since this polymeric material does not impart high crosslink density to the cured CPF composite<sup>[16]</sup>.

Wear rate of CPF composite is less compared to PF composite as shown in Figure 5. Porosity of CPF composite is high which is an important factor for friction material such as noise dampening and wear resistance<sup>[17,18]</sup>. Increase in porosity reduces the wear during sliding<sup>[19]</sup>. Here CPF composites have low mass loss after wear test compared to PF composite.



**Figure 2.** SEM images taken from the specimen depending on increase in Cardanol ( a. PF composite, b. PF composite of 3000 magnification, c. 20% CPF composite and d. 20% CPF composite of 3000 magnification.).

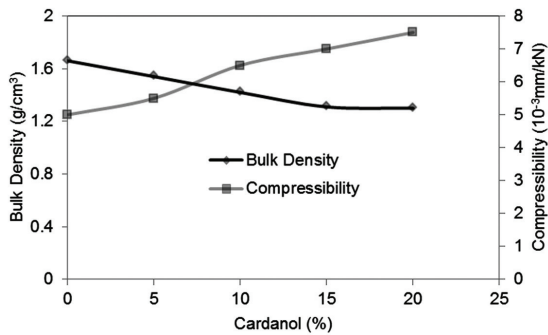


Figure 3. Increase in Cardanol (%) vs bulk density and Compressibility.

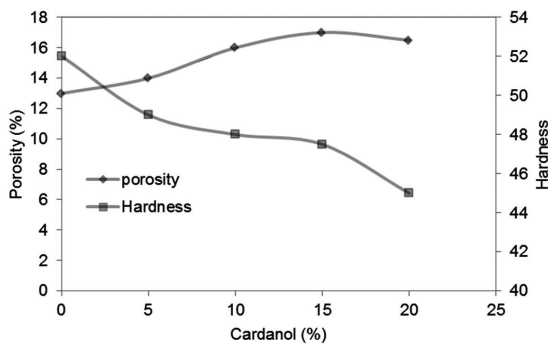


Figure 4. Increase in Cardanol (%) vs. Porosity and Hardness.

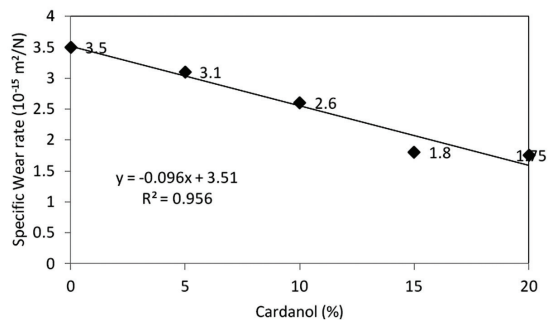


Figure 5. Increase in Cardanol (%) vs specific wear rate.

## Conclusion

The increase in percentage of cardanol reduces the absorption of water, salt water and lubricating oil. This is due to alkyl group present in Cardanol molecule imparts hydrophobicity to the cured CPF composite.

Porosity of CPF composite is high which is an important factor for friction material. Thus CPF composite can be considered as potential candidate for wear resistant and noise dampening applications.

Bulk density and hardness reduced by adding cardanol in PF composite due to alkyl group of cardanol playing the role of internal plasticization and hence the material become flexible and elastic compared to PF composite.

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