Engineering Transactions, **72**(3): 327–341, 2024, doi: 10.24423/EngTrans.3203.2024
Institute of Fundamental Technological Research Polish Academy of Sciences (IPPT PAN)
Université de Lorraine • Poznan University of Technology

Research Paper

Effects of Combined Coconut Shell and Pistachio Shell as Filler and Frictional Additive on the Properties of Particulate Type of Green Friction Composites

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Nowadays, cost effectiveness and environment friendliness are crucial requirements for any frictional material along with good frictional stability. Conventional filler materials, such as fly ash, are harmful and create pollution. In contrast, coconut shell and pistachio shell are inexpensive, abundant and green materials, which are otherwise considered agricultural waste. Coconut shell has good heat resistance but poor friction resistance, whereas pistachio shell has good abrasion resistance but poor thermal stability and mechanical properties. Therefore, this study presents the use of a firsthand blend of coconut shell and pistachio shell as cost-effective filler and frictional additive to develop a green frictional composite material. The material samples are prepared and tested for physical, mechanical and tribological properties using different blends of coconut shell-pistachio shell powder and binder. The developed friction composites show low water and oil absorption, high flame resistance, thermal conductivity, hardness, higher wear resistance and improved coefficient of friction (COF) for lower amounts of coconut shell and pistachio shell. As the developed frictional composites use natural waste (25% to 35%) instead of fly ash or other pollutant ingredients, they contribute to minimizing pollution and waste disposal problems.

Keywords: frictional material; green frictional composite; filler; binder; coconut shell; pistachio shell.

1. Introduction

Friction materials are diversified composites used in brake pads, brake disks, clutch facings, and friction disks. They comprise friction additives (abrasive and lubricant), reinforcing materials, fillers, and binders. Abrasives such as metal and non-metal oxides or carbides are used to increase COF and wear resistance, whereas lubricants such as graphite and MoS2 are used to reduce wear [1, 2]. Metals, glass, carbon, ceramic or organic fibres are used as reinforcing materials to improve strength as well as friction properties [1, 2]. Filler materials are primarily employed to improve manufacturability and reduce production costs. Inorganic materials such as molybdenum trioxide, calcium carbonate, mica, vermiculite, barium sulphate, fly ash, and rubber are used as filler [3–5]. Phenolic resin is commonly used as binder due to its higher heat resistance.

Unhygienic, disposal, environmental harms and cost are the main concerns regarding the use of fillers such as asbestos or fly ash in friction materials. To reduce these concerns, researchers have suggested using natural organic materials such as cashew [5], periwinkle [6], saw dust [7], gum arabic and eggshell [8], cow bone [9], palm kernel shell, pistachio shell (PS) [10, 11], sugarcane fiber [12], coconut shell (CS) [13], peanut shell [14], rice husk [15], sugarcane bagasse [16], walnut shell [17], natural rubber, palm, jute, groundnut husk, coir and jute [18–20] as filler or reinforcing constituents in friction or composite materials.

Presently, environmental and cost concerns have motivated researchers to investigate the suitability of industrial waste as well as biodegradable materials, such as agricultural waste and natural materials in friction composites. Natural materials are abundant, renewable and cost-effective. Coconut husk residues are available in abundant quantities in many parts of the world, but are often treated as a waste material. Researchers have studied the effect of varying the size and amount of coconut husk powder on the heat resistance of automotive brake pads and observed that coconut husk particles result in good thermal stability and heat resistance, however, they weaken friction resistance [21, 22]. CS was used as a reinforced brake pad material and was found to reduce noise and vibration [23]. PS are produced in large quantities in Iran, the USA, and Turkey and have high strength and modulus properties. Researchers [10] studied the tensile and flexural strength for polymer composite material (not as a friction material) and observed significant losses in these properties at high particle content of PS. Karaağaç [11] observed significant improvements in abrasion resistance, but reduction in thermal stability and mechanical properties when incorporating PS into a rubber compound (also not as a friction material). Thus, while coconut husk particles result in good thermal stability but poor frictional resistance, whereas, pistachio shell particles provide good abrasion resistance but poor thermal stability. Obviously, a combination of CS and PS, which has not yet been investigated, can be considered as a lucrative material option for friction composites, and its effect on the requisite properties must be explored. Therefore, in the present study, friction composites are developed by using the different blends of CS and PS, and their physical, mechanical and tribological properties are studied along with the effects of load and speed. Since CS and PS are abundant and cheap, the manufacturing cost of the friction materials can be reduced. In addition, this approach will help to reduce waste disposal problems and improve the economy of farmers.

2. Materials and methods

The effectiveness of friction composites depends on the appropriate selection and composition of constituents. Generally, the initial formulation of composites is based on experience, past studies and a trial-error approach [1, 4]. In the present work, graphite and silicon oxide are used as friction additives, copper as a reinforcing material, phenolic resin as a binder, and CS and PS as filler materials for the preparation of frictional composite samples. CS and PS is crushed and ground in grinding machines, and subsequently, sieved in a shaker machine to obtain powder with 60 μm particle sizes, as shown in Fig. 1 (a, b). Further, carbonization of equal quantities of coconut shell powder (CSP) and pistachio shell powder (PSP) is performed in a muffle furnace at a temperature of 280°C to remove moisture (Fig. 1c).

a) b) c)

Fig. 1. (a) CSP, (b) PSP, (c) carbonized blend of CSP-PSP.

Generally, researchers have employed 10% to 30% filler materials in friction composites. In this study, friction composite material (FCM) samples are developed by varying the quantity of CSP-PSP and binder, as shown in Table 1. Each

Table 1. Compositions of the developed friction composite materials (Vol %).

Ingredients		Friction composite materials		
		FCM1	FCM2	FCM3
Filler and friction material	CSP-PSP	35	30	25
Binder	Phenolic resin	20	25	30
Reinforcing material	Copper	25	25	25
Friction additives	Graphite	10	10	10
	SiO_2	10	10	10

sample is produced in dry conditions using a ball mixture for 20 min. The prepared mixture is moulded at 160°C for 10–15 min under a pressure of 150 MPa in a hot press to produce the friction composite specimens, which are further heated at 200°C for 4 hours in oven for post-curing. Thus, a disc-shaped specimen of each FCM is produced with an internal diameter of 80 mm, an external diameter of 100 mm and a thickness of 6 mm (Fig. 2).

FCM1 FCM2 FCM3

Fig. 2. Specimen of the developed FCMs.

3. Results and discussion

3.1. *Physical and mechanical properties*

The specimens of FCM are tested as per ASTM D792 standards to determine their density. Oil absorption tests and water absorption tests are conducted according to ASTM D570-99 to determine the oil and water absorption capabilities of composites. A good friction material should possess good resistance to high heat and temperature; hence, flame resistance tests are performed in a furnace. As friction materials operate at high temperature, thermal conductivity plays an important role. The thermal conductivity of the composites is determined using a guarded hot plate instrument. Hardness is measured using a Rockwell hardness tester with a spherical steel ball of 1.588 mm diameter and a total force of 980.7 N. The test results for the developed composites are presented in Fig. 3.

Density for FCM1 is low, indicating that increasing the amounts of CS and PS could reduce the weight of the friction materials. Water and oil absorption are lower for FCM3, which indicates that a minimum amount of CS and PS in the selected range should be preferred to provide higher resistance to water and oil absorption. The higher value of flame resistance for FCM3 indicates that the minimum amount of CS and PS along with a higher amount of binder results in better temperature resistance of the composite. It is observed that the effect of the CSP-PSP blend on the thermal conductivity and hardness of the friction

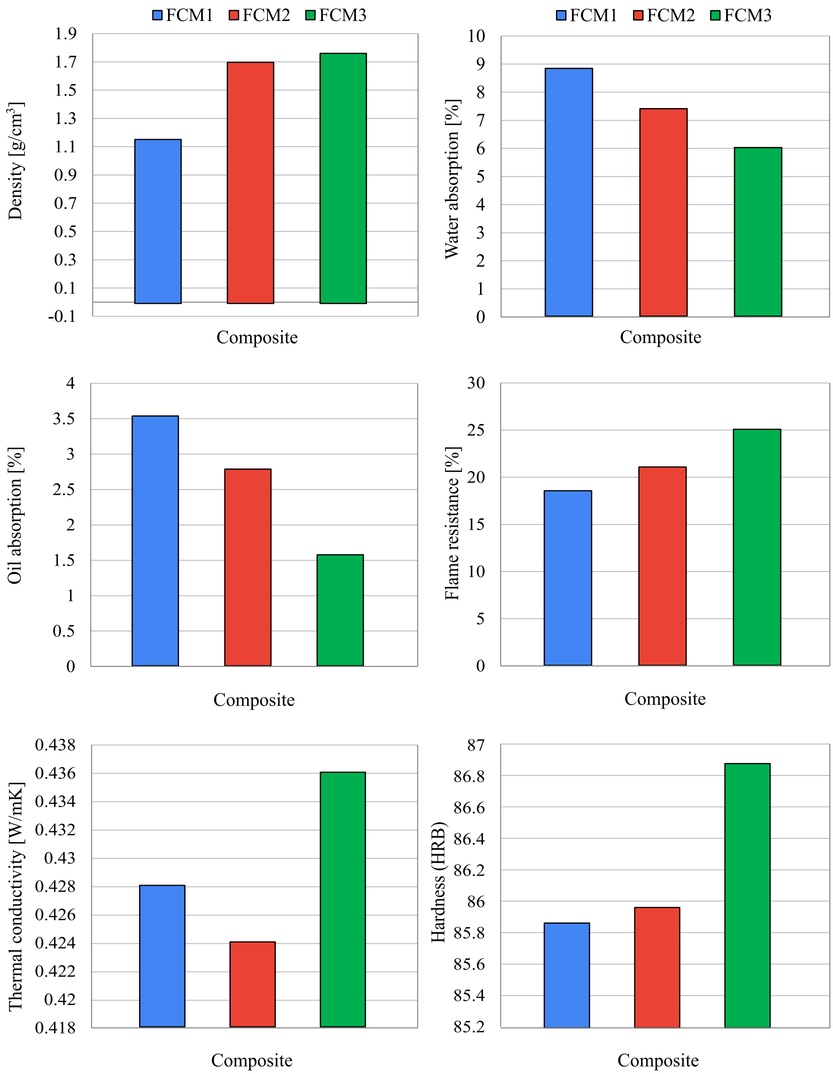


FIG. 3. Physical and mechanical properties of the developed friction composites.

composites is very small. However, thermal conductivity and hardness are higher for FCM3, which indicates that a lower amount (25%) of CP-PC powder is sufficient for achieving better thermal conductivity and hardness.

3.2. Tribological properties

Wear and the COF of the composites are estimated with a computerized pin-on-disc test rig (DUCOM make) as per ASTM G99 standards for different rotational speeds and loads. Each test is performed with a new composite pin sample of 13 mm width and 50 mm length, and rotor discs of a wear track diameter 70 mm, and a thickness of 8 mm (Fig. 4) in dry lubrication condition with loads of 10, 30, 50 N, and disc speeds of 400, 600, and 800 rpm. The test sample is fixed on a load arm, pressed against the rotating disc maintaining a constant sliding speed of 8 m/s for 200 s. Total wear of each sample is determined from the weight and thickness of the samples before and after the friction test. The friction force is continuously monitored during the test run to determine the COF.

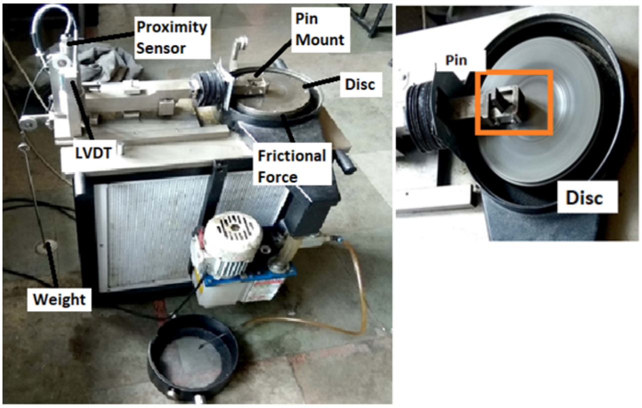


FIG. 4. Pin-on-disc test rig.

The wear behavior of composites for the test duration is depicted in Fig. 5. For FCM1, wear initially increases at fast rate up to 77 μm, further increases

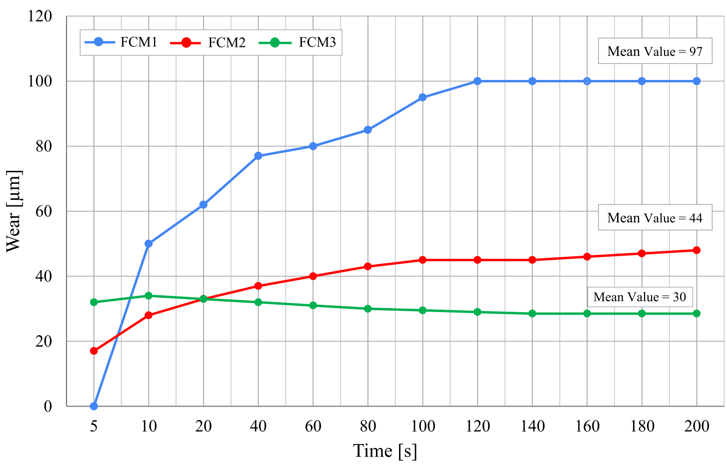


FIG. 5. Wear behavior of the developed friction composites.

at a moderate rate, and then remains constant at 100 μm. For FCM2, wear initially increases at a moderate rate up to 37 μm, then increases at slow rate up to 48 μm. However, for FCM3, wear decreases at a very slow rate, and by the end of the test, remains almost constant at the lowest value of 28.5 μm. Thus, FCM3 demonstrates lower and more constant wear, making it the best composite in terms of wear resistance.

The wear curves for FCM1 andFCM2 show that wear is maximum and increasing for these composites; while wear for FCM3 it is almost stable and at a minimum value. This initially appears to be due to the highest hardness of FCM3 (Fig. 3). However, both FCM1 and FCM2 have comparatively low and similar hardness, yet the wear of FCM2 is less than FCM1. This suggests that the higher amount of binder, which results in better packing of all constituents (density), is mainly responsible for the reduced wear. Thus, the effect of the binder is observed to be more predominant than that of the CS-PS blend on wear.

The representation of the time dependence of the COF is depicted in Fig. 6. It is observed that for FCM1 and FCM2, the COF increases slowly with the mean value of 0.270. Initially, a decrease in COF is observed, likely due to the presence of an unstable friction layer at the start of the test run [24]. For FCM3, the COF increases initially and then decreases at a moderate rate, with a mean value of 0.276. The sudden increase in COF is attributed to the resistance provided by the closely packed constituents, causing more frictional force. As the test run continues, particles become detached, causing reductions in frictional force. The mean values of COF for all three composites fall within the standard range [23, 25]. All composites exhibit relatively close and stable COF values without rapid changes, which indicate the formation of a stable friction layer

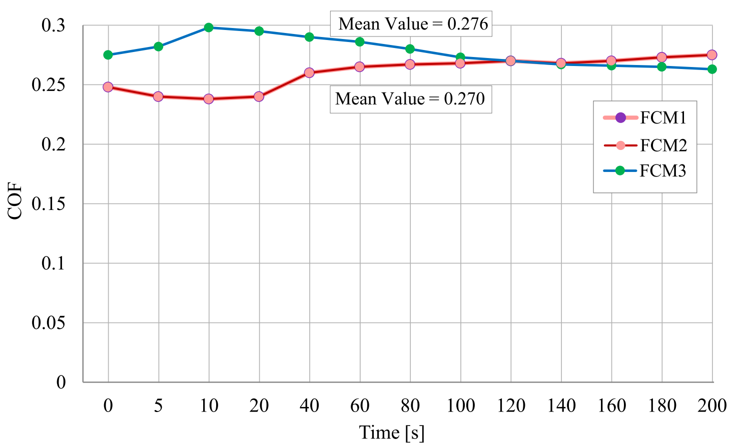


Fig. 6. Variation of COF of the developed friction composites.

after a short run [26]. The higher mean value and stable, decreasing trend of COF over the long run make FCM3 a better composite with regard to COF performance.

From Fig. 7, it is observed that as the amount of CS-PS decreases and that of binder increases, the mean value of wear decreases significantly. Whereas, as the amount of CS-PS decreases, the mean value of COF increases slightly. Thus, the mean values of wear and COF show that variations of CS-PS have a strong effect on wear behavior but a weaker effect on COF.

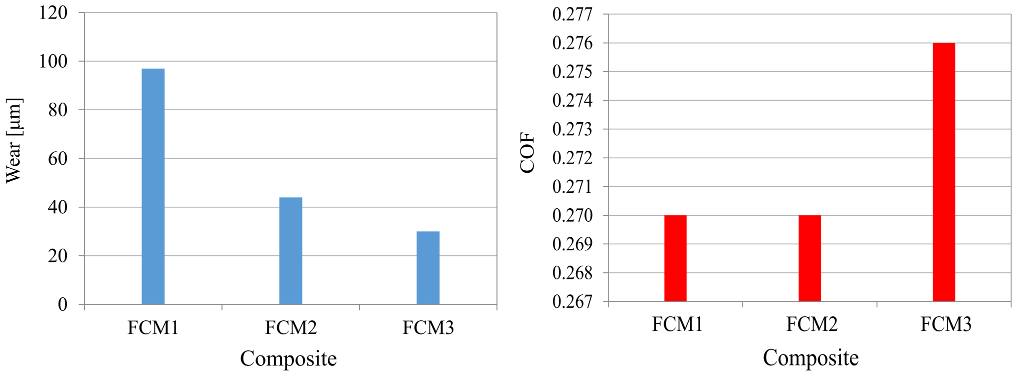


Fig. 7. Wear and COF of the developed friction composites.

The investigated values of different properties for the developed composite materials, compared to the desired or standard reference values typically required for frictional applications such as brake discs, clutch plates, and industrial machinery components, are depicted in Table 2. The ranges of investigated values of density, hardness, and COF of the developed composite materials are within the desired range for brake disc friction materials. The in-

Table 2. Comparison of investigated and reference values for frictional applications.

Property	Investigated values	Standard/Reference values
Density [g/cm^3]	1.15–1.8	(1.82–1.91) & 1.89 [7]; (1.03–1.23) [27]
Water absorption [%]	6–9	0–6.5 [28]
Oil absorption [%]	1.5–3.5	0–45 [29]
Flame resistance [%]	18.5–25	$\geq$ 20 [3]
Thermal conductivity [W/mK]	0.424–0.436	0.4–0.5 [28]
Hardness (HRB)	85.9–86.9	80–100 [30]
Wear [μm]	30–98	$\leq$ 100 [2]
COF	0.27–0.276	>0.2 [23]; (0.16–0.45) [25]

vestigated values of water absorption are slightly higher than the range of reference values, and hence can be accepted. The investigated values of oil absorption are well within the range of reference values and investigated values of wear are well below the threshold value for clutch plate materials. The ranges of investigated values for thermal conductivity and flame resistance are within the required range for industrial machinery components. Therefore, the developed composite materials show potential for applicability in frictional components such as brake discs, clutch plates, and industrial machinery components.

For a good friction material, density, water and oil absorption, and wear should be low, while flame resistance, thermal conductivity, hardness, and COF should be sufficiently high. These characteristics are observed for FCM3, although it has a higher density. Therefore, the effects of load, speed and microstructure on FCM3 are further investigated.

3.3. Effect of load

The wear and COF of FCM3 for 10, 30, and 50 N loads at a constant speed of 600 rpm is presented in Fig. 8. As the load increases, wear initially increases slowly and then increases at a moderate rate, reaching a maximum value of 64 μm. With the increasing load, debris are spread and the actual contact area increases [31]. Thus, friction resistance increases, causing an increment in wear. With a further increase in load, more and larger debris are formed by removing material from the laminated area, causing a higher amount of wear. At higher loads, increased frictional heat causes faster dislocation of particles from interfaces, which also accelerates the growth of debris. As the load increases, COF initially increases and then decreases. The initial increase in COF at 10–30 N is due to mechanical interlocking of loosened hard particles between the interfaces. As the load increases further, hard particles are compressed into smaller

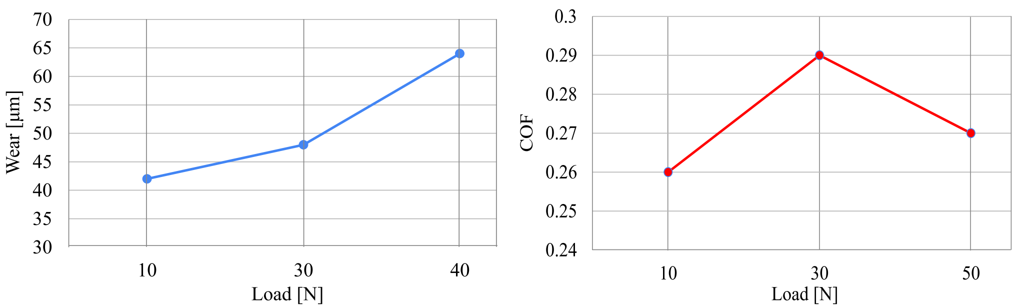


FIG. 8. Effect of load on wear and COF for FCM3.

particles to form a very thin and compacted layer, which reduces the COF. In addition, more heat at higher loads destabilizes the interface material, which increases the oxidation wear of the composite [32].

3.4. Effect of rotational speed

The wear and COF of FCM3 at rotational speeds of 400, 600 and 800 rpm with a constant load of 50 N are shown in Fig. 9. As the speed increases, wear increases continuously, reaching a maximum value of 74 µm. It is observed that with an increase in speed, the friction coefficient decreases first and then increases. This wear and COF behaviour at different speeds are primarily due to friction temperature at the interface [33]. At lower speeds, the moisture and oxygen are absorbed, which lubricate the contact interface, causing a reduced friction coefficient and wear. While at higher speeds, the higher temperature causes thermal decomposition of the surface material [26, 34]. In addition, more particles will be deformed, broken, and spread, which results in an increased friction coefficient and wear [35]. Thus, as load and speed increase, wear also increases. However, the COF increases for lower load and higher speed values, and vice versa.

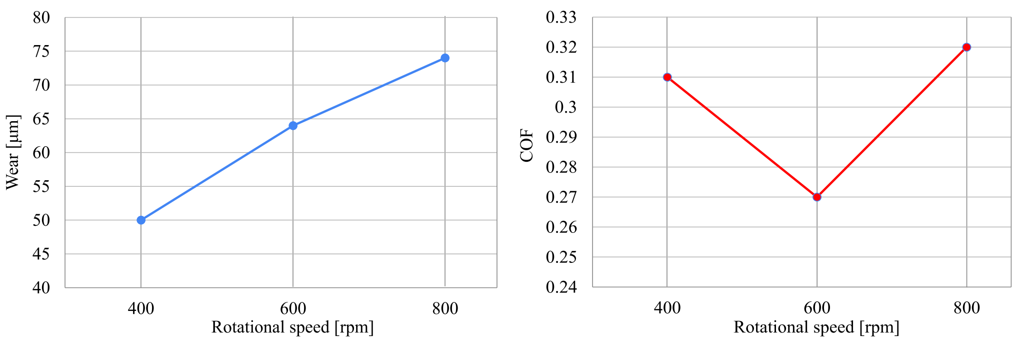


Fig. 9. Effect of rotational speed on wear and COF for FCM3.

3.5. Microstructure of the wear surface

After the friction test, the wear surface of sample FCM3 is examined using FE-SEM and energy dispersive X-ray analysis (EDS), as shown in Fig. 10. The EDS analysis results are shown in Fig. 11. Figure 10 displays the presence of grooves, delamination and debris on the friction surface. The EDS pattern shows the direct presence of copper and silica dioxide, whereas the graphite, an allotropic form of carbon, indicates the presence of carbon.

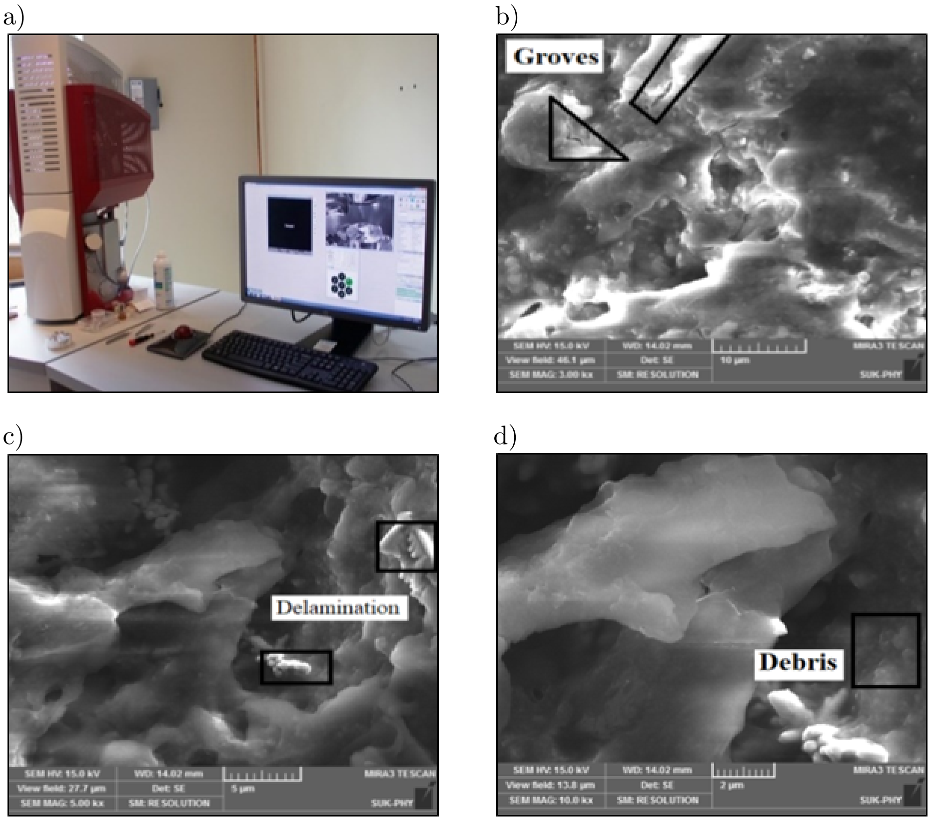
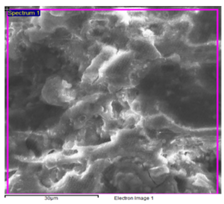


FIG. 10. Microstructure of the wear surface of FCM3:
a) setup, b) groves, c) delamination, d) debris.

Element	Weight [%]	Atomic [%]
C K	45.83	67.41
O K	20.42	27.57
Si K	16.55	3.38
Cu L	17.20	1.64



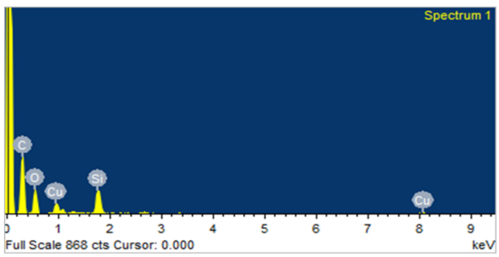


FIG. 11. EDS analysis results for FCM3.

4. Conclusions

The presented study experimentally investigated the effects of varying the blend of CS and PS (25 to 35%) on the physical, mechanical and tribological properties of friction composites in detail. The conclusions are summarized below.

- It is observed that the effect of the blend of CSP-PSP on the thermal conductivity and hardness of friction composites is very small. Lower amounts of CS and PS (25%) resulted in lesser water and oil absorption, higher flame resistance, thermal conductivity, and hardness, but higher density of the friction composite.
- Higher wear resistance and improved COF are observed for a lower amount of CSP-PSP in the friction composite. The change in the amount of CSP-PSP shows a strong effect on wear behavior and a negligible effect on COF.
- An interesting finding of the study is that the effect of the binder is more predominant than the effect of CSP-PSP filler and frictional, additive material on the wear, which indicates that the close binding of ingredients is a more important factor than hardness for better wear resistance.
- Lower and stable wear, with higher but decreasing COF over the long run, is observed for a lower amount of CSP-PSP.
- Therefore, FCM3 emerges as an effective FCM, comprising lower amount (25%) of CS and PS blend, along with 30% of binder, 25% of reinforcing material, and 20% of friction additives. Thus, the investigation suggests using a low amount of CS and PS for better mechanical and frictional properties.
- The investigation also reveals that the developed frictional composite contributes not only as a filler material but also as a reinforcing material. Hence, it is truly identified as a filler and frictional additive material.
- As the developed frictional composite uses a natural waste (CS and PS) instead of fly ash or other pollutant ingredients, it contributes to minimizing pollution as well as waste disposal problems. Hence, in a true sense, it is a green FCM.

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Received October 21, 2023; accepted version July 15, 2024.
Online first September 12, 2024.