FRICTION AND WEAR DISPLAYED BY THE SCRATCH OF EPOXY REINFORCED BY NATURAL FIBERS

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ABSTRACT
The present work investigates the possibility of reinforcing epoxy by natural fibers such as wood, rice straw and palm fibers to be used as floor material. The abrasion resistance of the tested composites was investigated by scratch test where friction coefficient as well wear scar width were determined.

The experiments revealed that friction coefficient increased as the content of the wood fibers reinforcing epoxy matrix increased. Besides, friction coefficient decreased with increasing load, because the stress applied by the indenter exceeded the yield strength of epoxy so that the resistance to scratch decreased. In addition to that, the adhesion of wood fibers into epoxy matrix was relatively tougher compared to rice straw and palm fibers. Rice straw and palm fibers caused friction values lower than that observed for wood fibers.

Wood fibers reinforced composites showed slight wear increase with increasing their content, while composites reinforced by rice straw and palm fibers showed minimum values at certain content of fibers. In addition to that, as the load increased wear increased. The low content of straw and palm fibers strengthened and resisted the abrasion of the matrix. While, the increase of fiber content decreased the strength of the bond between the fibers and the epoxy matrix leading to the increase of the material removal during scratch. Based the above the experimental observation, the abrasion resistance was enhanced at certain content of rice straw and palm fibers, while composites reinforced by wood fibers can be recommended to be applied as floor materials due to their high value of friction coefficient.

KEYWORDS
Friction coefficient, wear scar width, epoxy, natural fibers.

INTRODUCTION
The application of floor materials made of epoxy resins is limited due to their brittleness. Paraffin oil and recycled rubber particles were added to epoxy, [1 - 3]. It was revealed that as the rubber content increased friction significantly increased.
Composites filled by oil and rubber displayed values of friction coefficient that were much higher than the recommended values for safe floor materials. It was suggested that the proposed composites can be used as floor material, where addition of oil into epoxy matrix was intended to decrease the brittleness of the proposed composites.

Although epoxy has several industrial applications, [4], it suffers from brittleness that reduces its use, [5]. The mechanical properties of epoxy matrix filled by butadiene-acrylonitrile rubber were discussed, [6 – 8]. It was found that addition of rubber particles could enhance the ductility of epoxy. Besides, rubber particles could help to concentrate the stress and plastic deformation in epoxy matrix.

Fracture toughness could be enhanced by using block copolymer, [9]. Significant enhancement of the fracture toughness was achieved by block copolymers. They could reduce the effect of voids and shear yielding of the matrix, [10, 11]. The blending process was responsible for cavitation of the rubber leading to the shear deformation of the epoxy matrix and consequently fracture toughness was significantly improved. It was proved that, [12], rubber addition into epoxy matrix was able to overcome the brittleness of epoxy resins.

The tribological and mechanical properties of used polymeric materials were investigated, [13, 14]. Recycled polymers can be applied in applications due to their good mechanical and tribological properties. Toughening of epoxy by blending with waste ground rubber particles was discussed, [15 - 20]. The proposed composites have wide application in automotive industry such as spoilers. Rubber possesses pronounced deformations and higher contact area when loaded on the surface asperities of rigid counterface, then higher values of friction coefficient can be expected, [21 - 23]. Besides, abrasion resistance of epoxy floor surface can be improved by the rubber.

Filling epoxy by oil leads to the trapping of oil inside the matrix in form of infinite number of pores, where they work as oil reservoirs. Oil leaks up to the sliding surface and forms oil film during friction. That behavior is responsible for the friction decrease displayed by composites filled by oil, [24 – 28]. The oil trapped in pores after solidification of the composites is fed into the sliding surface.

The present work proposes epoxy composites used as floor material to withstand the abrasion and reduce the brittleness of epoxy that limits its applications. Wood, rice straw and palm fibers are proposed to reinforce epoxy matrix. The tested composites were investigated by scratch test where friction coefficient and wear scar width were determined.

**EXPERIMENTAL**

The scratch wear tester was used to carry out by the experiments, Fig. 1. The scratch track was made by an indenter with apex angle 90° and tip radius of 0.1 mm. The indenter of TiC insert of 2800 kp/mm² hardness is mounted to the loading lever. The values of applied loads were 2.0, 4.0, 6.0, 8.0 and 10.0 N. Load cell connected to digital
monitor was used to measure the scratch force, Fig. 2. The experiments were performed at room temperature. Optical microscope of an accuracy of ± 1.0 µm was used wear scar width, while friction coefficient was determined by the ratio between the friction force and the normal load.

![Fig. 1 Arrangement of scratch test rig.](image1)

![Fig. 2 Details of scratch.](image2)

Epoxy was reinforced by natural fibers of wood, rice straw and palm, where the tested composites were molded of 5.0 mm thickness on the surface of a wooden block of 40 × 40 × 40 mm³. Tested composites consisted of epoxy filled by wood, (0 - 1.0 mm size), rice straw (0 - 1.0 mm size) and palm fibers of (0 - 3.0 mm size) were added in contents of 2.5, 5.0, 7.5, 10, 12.5, 15, 17.5 and 20 wt. %. Every experiment was repeated five times then the average values were calculated.

RESULTS AND DISCUSSION
The results of friction coefficient displayed by the scratch of the tested epoxy composites are shown in Figs. 3 – 5. Friction coefficient displayed by epoxy composites reinforced by wood fibers showed an increasing trend with the increase of the content of the wood fibers, Fig. 3. Test specimens free of fibers displayed the lowest friction values. As the fiber content increased, friction coefficient increased. The reinforcing action of the fibers was responsible for the friction increase. It was noticed that friction coefficient decreased with increasing load. It seems that the stress applied by the insert exceeded the yield strength of epoxy composites. In that condition, the load increase weakened the epoxy matrix so that the resistance to scratch decreased. The highest value of friction coefficient (1.1) was observed for composites filled by 20 wt. % wood fibers at 2 N load.

Friction coefficient resulted from the scratch of epoxy composites reinforced by rice straw, Fig. 4, displayed relatively lower values than that observed for composites reinforced by wood fibers, where the highest friction coefficient value did not exceed 1.1. It seems that the adhesion of wood fibers with epoxy is relatively stronger than the adhesion between straw fibers and epoxy. As a result of that the abrasion of the tested composites became easier.
The tested composites reinforced by palm fibers showed the same trend of friction observed for composites reinforced by rice straw, Fig. 5. Based on the experimental observation, it can be recommended that composites reinforced by wood fibers can be applied as floor materials to withstand abrasion.

**Fig. 3** Friction coefficient displayed by composites reinforced by wood fibers.
Fig. 4 Friction coefficient displayed by composites reinforced by rice straw fibers.

![Graph showing friction coefficient vs. filling material content for different loads (2N to 10N).]

Fig. 5 Friction coefficient displayed by composites reinforced by palm fibers.

![Graph showing friction coefficient vs. filling material content for different loads (2N to 10N).]

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<tr>
<th>Filling Material</th>
<th>Wood</th>
<th>Rice Straw</th>
<th>Palm Fibers</th>
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<td>Content, wt. %</td>
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<td>Friction</td>
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Fig. 6 The evidence of the scratch track on the tested composites.

![Scratch tracks for wood, rice straw, and palm fibers.]

The track of the wear scratch for the tested composites is illustrated in Fig. 6. The results of wear, measured by the wear scar width after the scratch of the tested composites, are illustrated in Figs. 7 - 9, where composites reinforced by wood fibers showed slight wear increase with increasing the wood content, Fig. 7. It was revealed that as the load increased wear increased.
Fig. 7 Wear scar width displayed by composites reinforced by wood fibers.

Fig. 8 Wear scar width displayed by composites reinforced by rice straw fibers.
Wear scar width displayed by composites reinforced by palm fibers decreased down to minimum then significantly increased with the increase of the content of rice straw, Fig. 8. The lowest wear values were observed at straw content ranged from 2.0 to 8.0 wt. %. The same trend was displayed by composites reinforced by palm fibers, Fig. 9. It seems that the straw and palm fibers at low content strengthened the epoxy matrix and consequently resisted the abrasion of the matrix. When the fiber content increased, the bond of the fibers inside the epoxy matrix was weakened leading to the increase of the material removal during scratch. Referring to the above observations, the abrasion resistance was enhanced at certain content of rice straw and palm fibers.

CONCLUSIONS
1. As the content of the wood fibers reinforcing epoxy matrix increased, friction coefficient increased, while composites free of fibers showed the lowest friction values.
2. Friction coefficient decreased with increasing load.
3. Friction coefficient resulted from the scratch of composites reinforced by rice straw and palm fibers displayed relatively lower values than that observed for composites reinforced by wood fibers.
4. Wear of composites reinforced by wood fibers slightly increased with the increase of wood content. While wear of composites reinforced by rice straw and palm fibers showed minimum values then increased with further increase of the content of the fibers.
5. It was revealed that as the load increased wear increased.
REFERENCES