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1. Dry Gas Seal Simulation with Different Spiral Tapered Grooves 1
Ibrahim Shahin
Mohamed Gadala
Mohamed Alqaradawi
Osama Badr

2. Analysis of Primary and Secondary Lateral Suspension System of Railway Vehicle 19
Mohd Hanif Harun
W Mohd Zailimi W Abdullah
Hishamuddin Jamaluddin
Roslan Abd. Rahman
Khisbullah Hudha

3. Water-lubricated Pin-on-disc Tests with Natural Fibre Reinforced Matrix 41
Ramdziah Md. Nasir

4. Computation of Temperature Distributions on Uniform and Non-uniform Lattice Sizes using Mesoscopic Lattice Boltzmann Method 53
D. Arumuga Perumal
I.M. Gowhar
S.A. Ananthapuri
V. Jayakrishnan

5. Kinetics of Tapioca Slurry Saccharification Process Using Immobilized Multi-Enzyme System Enhanced with Sg. Sayong Clay 67
Siti Noraida Abd Rahim
Alawi Sulaiman
Nurul Aini Edama

6. Identification of the Maximum Stress Value that Occur at the Wing-Fuselage Joints at 1-G Symmetrical Level Flight Condition 79
Abdul Jalil, A.M.H.
Kuntjoro, W.
Abdullah, S.
Ariffin, A.K.

7. Ergonomics Intervention in Steel Panels Handling for Improving Workers' Well-Being Outcomes 93
Huck-Soo Loo
Nor Hayati Saad
Mohd. Ridhwan Mohammed Redza

Journal of Mechanical Engineering *Vol. 11, No. 2, 41-51, 2014*

Water-lubricated Pin-on-disc Tests with Natural Fibre Reinforced Matrix

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ABSTRACT

In this study, natural fibre such as paddy straws and cockle shell was chosen due to its abundance and renewable natural fibre reinforced matrix. The fibres were reinforced with polymer using conventional compression molding. The specimen lubricated with water, were slided at different sliding speed using the rotating pin-on-disc friction and wear tests. The best performance under lubricated boundary condition was found for bio-shell cockle reinforced matrix followed by paddy-straw reinforced matrix while pure polypropylene has the highest wear rate and coefficient of friction. With the addition of cockle shell powders or paddy straw, wear rate and coefficient of friction of the material decreases with a minute degree of changes in their properties. The wear mechanism was identified using SEM.

Keywords: *Water lubricated; paddy straws; shell composites; wear; frictional force*

Introduction

Substituting conventional fibres such as glass, carbon and aramid [1] with natural fibre is considered important due to the increase in environmental consciousness amongst consumers. Biofibres, biocomposites [2] and composite shells [3] have been chosen to be the reinforcement material for composites because of its low cost, low density, high specific strength and modulus, no health risk, easy availability in some countries and renewability. Sisal fibre jute [4], flax bast fibres [5], flax, coir, sisal leaf fibres and wheat straw [6], cotton, hemp [7] and

ISSN 1823-5514

kenaf [8], reed fibre [9], cellulose [10], and many more researchers have done their work on natural fibre. With all these advantages of natural fibres being the reinforcement material for plastics, it is proven that natural fibres are one of the most suitable materials to be used.

In recent report, car manufacturers had launched a Go Green campaign and virtually in Germany (Daimler Chrysler, Mercedes, Volkswagen, Audi Group, BMW, Ford and Opel) have used natural fibre for dashboards, car panels, and door trim panels [12]. Biocomposites has become common in modern furniture industry to replace wood. Jute-reinforced polyester resins used for building in Madras house [2]. Plastic/wood fibre composites are being used in large number of applications in decks, docks, window frames, and molded panel components [13]. It was also found that the wood pulp fibre being responsible to replace the asbestos fibre in the global fibre cement industry in an Australian research [14]. With various types of application of biocomposite, it shows that natural fibres has the potential and indeed could be a compatible substitute in replacing technical fibres.

Amongst literatures on the mechanical properties; dynamic mechanical analysis, abrasion test, thermal conductivity and electrical were found least. Previous studies on specific wear rate have been reported elsewhere by an author [15-16]. This paper will report the specific wear rate and friction coefficient of water-lubricated pin-on-disc tests with natural fibre reinforced matrix particularly focusing on wear mechanisms in paddy straws and cockle shells reinforced matrix.

Methodological Approach

Fabrication of bio-shell and paddy straws polypropylene matrix composite

Different types of shells (*Anadara granosa*) has also been identified including cylindrical curved shells, conical shells and spherical shells but the focus of the research is cockle shell due to its structural shape. In this work, both paddy straws (*Oryza Sativa*) and shell were reinforced with polypropylene matrix. The polypropylene pellets were supplied by Dr. Rahmatullah Holdings (M) Sdn Bhd. The paddy straws were obtained from the Kampung Titi Serong, a village in Parit Buntar Perak, Malaysia and shells from night hawkers. The paddy straws (15 cm long) were dried directly under the sunlight for seven days, six hours per day to maximize the drying rate.

The polypropylene (PP) pellets were weighted into 200 g and one third of the mass of the polypropylene are inserted into the mold. 20 grams (10% wt.) of the cut paddy straws were arranged on the pellet alternately. The layers were heated in the furnace for 6 hours at 200°C. Control materials made of pure polypropylene were also fabricated inside the furnace at 200°C for 6 hours.

Specimens were cut to dimensions of 10 m × 10 mm × 50 mm for the pin-on-disk test using Computer Numerical Control (CNC) cutting machines. The density measurement was carried out using gas pycnometer Micromeritics Accu Pyc 1330. The polished specimen was weighed using a Shimadzu AUW220D electronic weighing machine with sensitivity 0.1mg to record the initial weight. The polished specimen of each bar was tested for its wear and friction using the DUCOM TR-20 pin-on-disc tester with test ball diameter (*E52100 steel*) ∅ 10 mm for rotary as in Figure 1. Details of the experiment were described by author elsewhere [15].

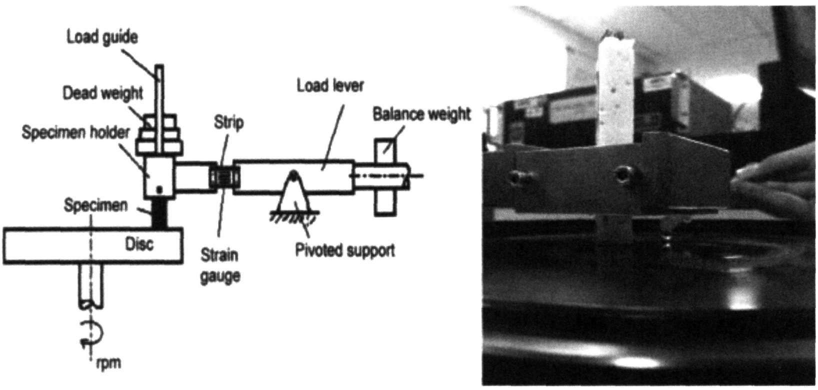

Figure 1: Schematic diagram of tribometer for wear and frictional tests

Results and Discussion

The results of density measurement are shown in Table 1. From the results shown in Table 1, it can be seen that the density of bio-fibre and bio-shell is higher as compared to the density of pure polypropylene.

Table 1: Results of the Density Measurement Using Gas Pycnometer

Specimen	Weight (g)	Density readings (g cm^{-3})			
		1	2	3	Mean
Biofibre composite	0.85976	1.1925	1.1696	1.1098	1.1573
Bioshell composite	0.43145	1.1056	1.1406	1.1252	1.1238
Pure polypropylene	1.04981	1.0564	1.0461	1.0488	1.0504

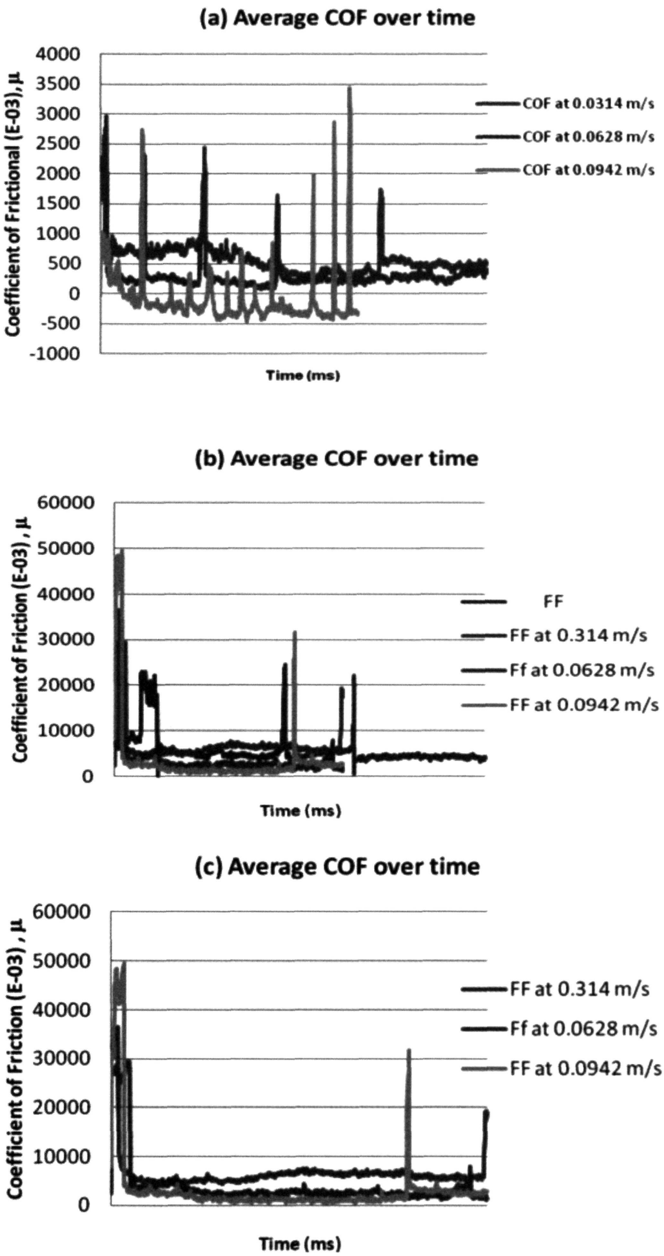

Figure 2: Effect of speed on frictional force of lubricated (a) bio-fibre (b) bio-shell (5%) (c) pure propylene, over time at constant load (10N)

Composites and polypropylene that has been cut into a bar shape with the cross section being 10 mm × 10 mm × 20 mm were tested to find its wear rate and frictional force. Speed of the disc was varied between 200 rpm, 400 rpm and 600 rpm. at constant applied load 10 N. The test was done under lubricating environment in this case distilled water.

Figure 2(a)-(c) shows the average coefficient of friction (COF) of bio-fibre and bio-shell composite under lubricating environment at different sliding speed. From Figure 2(a), it was observed that there is a variation of high and low frictional force applied to the bio-fibre. This variation is due to the presence of distilled water when it is applied during the wear test. The lubricant plays a role to reduce the frictional force of the specimen for the same amount of wear. However, it can be observed as well that there are primarily two groups of frictional force based on the research data in Figure 2. The first group being the value of the frictional force lies between 5 – 10 N (low load and pressure) while the other group's frictional force lies in between 17 – 20 N (high load and pressure). This is because at a certain point of the wear test, lubricant is not present, hence, increasing the frictional forces to the higher group.

In this research, lubricant is not applied continuously towards the specimen as can be seen in Figure 1 because lubricant that is applied continuously towards the specimen will create a layer of liquid in between the specimen and the rotating disc. If there is a layer which exist permanently between the specimen and rotating disc, the frictional force will portray a negative value as shown in Figure 2(a) and (b). However, with the method of applying lubricant as mention when lubricant is absent, it will produce a large variation of frictional force as shown in Figure 2. Hence, in order to analyse the data of frictional force applied to the specimen, the mean of the data under lubricating environment is only taken. Pure polypropylene has the highest coefficient of friction with its COF being 0.60 followed by bio-fibre composite with COF being 0.54 and bio-shell composite with COF being 0.50 as extracted from Figure 2.

Wear rate of pure polypropylene is the highest under lubricating environment while bio-shell composite has the least wear rate as shown in Figures 3(b) to (c). This shows that after adding the reinforcing material such as paddy straw or powder shell into the polymer matrix, it reduces the wear rate as compared to the polypropylene alone. The wear rate is reduced by two (2) times with the addition of paddy straw while the addition of powder shell will reduce the wear rate by four (4) times. The addition of reinforcing material increases the ultimate tensile strength, reducing its ability to chip easily; hence reducing its wear rate. As shown in Table 2, it is observed that wear rate of a specimen is directly proportional to volume loss after the wear test is done. As volume loss increases, wear rate of a specimen increases since the total test time for each specimen. It can be concluded that as the speed of rotating disc increases, the total volume loss of decreases, which means the wear rate decreases as lubricant increases.

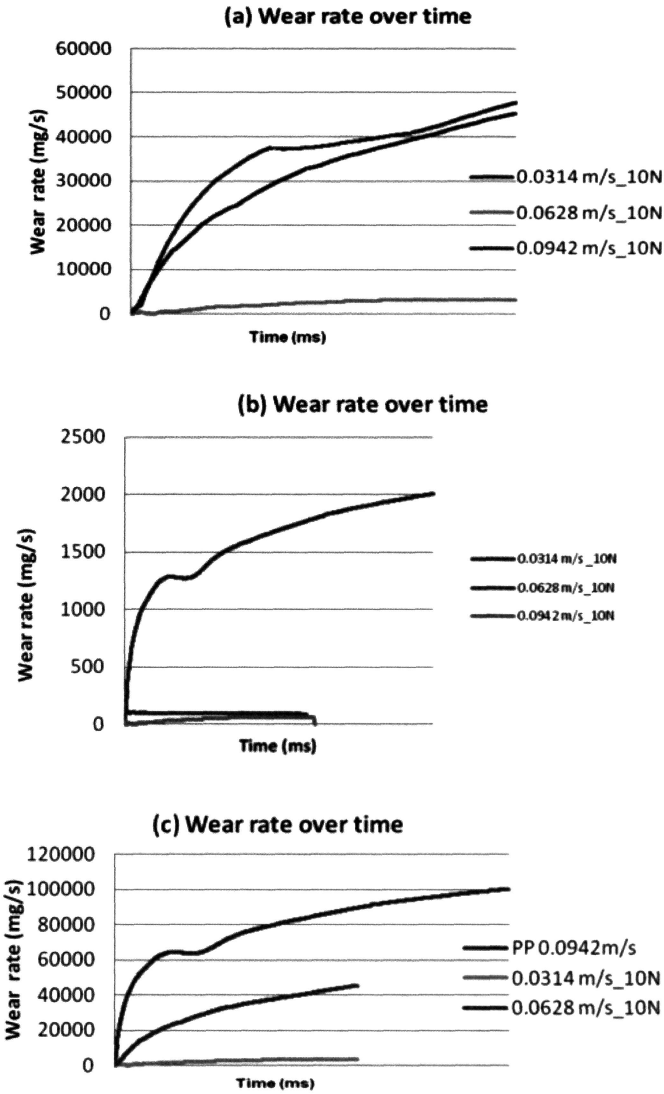

Figure 3: Effect of speed on wear rate of lubricated (a) bio-fibre (b) bio-shell (5%) (c) pure polypropylene, over time at constant load (10N)

Table 2: Comparison wear rate and frictional force for bio-fibre composite, bio-shell composite and pure polypropylene under lubricating environment with testing speed of 200 rpm, load of 10 N and sliding distance of 50 m

Specimen	Volume loss (cm^3)	% increase in abrasion resistance	Surface area (cm^2)	Sliding distance (m)	Time (min)	Wear rate (μ min^{-1})	% error
Bio-fibre composite	0.00404	33	1	50	30	26.93	0.003
Bio-shell composite	0.00008	99	1	50	30	0.53	0.001
Pure polypropylene	0.00602	0	1	50	30	40.13	–

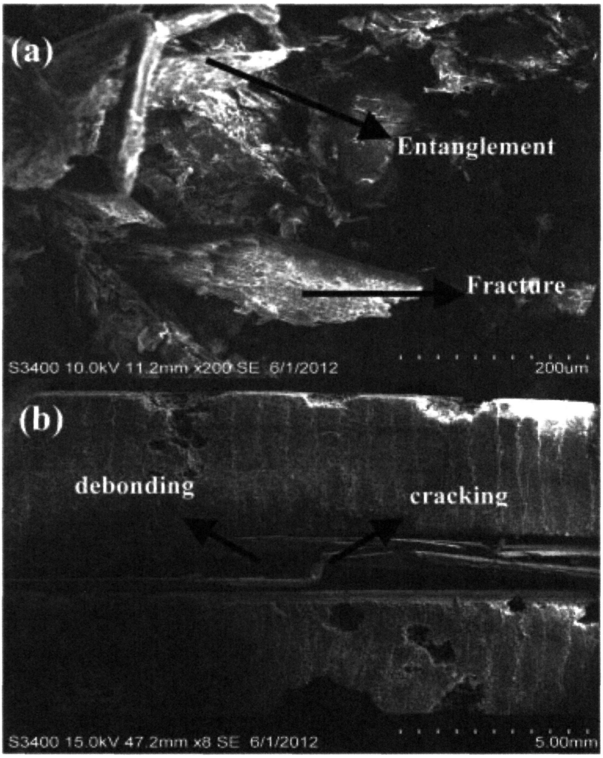

Figure 4: SEM observation of bio-fibre (paddy straw) (a) showing fracture and entanglement while polypropylene elongated and stretched (b) de-bonding and cracking with parts of polypropylene shows some porosity after abrasion

Wear mechanisms observed for of bio-fibre (paddy straw) as in Figure 4(a) showing fracture and entanglement while polypropylene elongated and stretched and after abrasion in Figure 4(b) de-bonding and cracking dominates while parts of polypropylene are being exposed with some porosity after abrasion. For powdered bio-shell reinforced polypropylene in Figure 5(a) before abrasion showing physical contact and embedded particulates (b) after abrasion showing detachment and loose contact of embedded particulates and pure polypropylene scratching occurred. Figure 6 shows scratching on pure polypropylene.

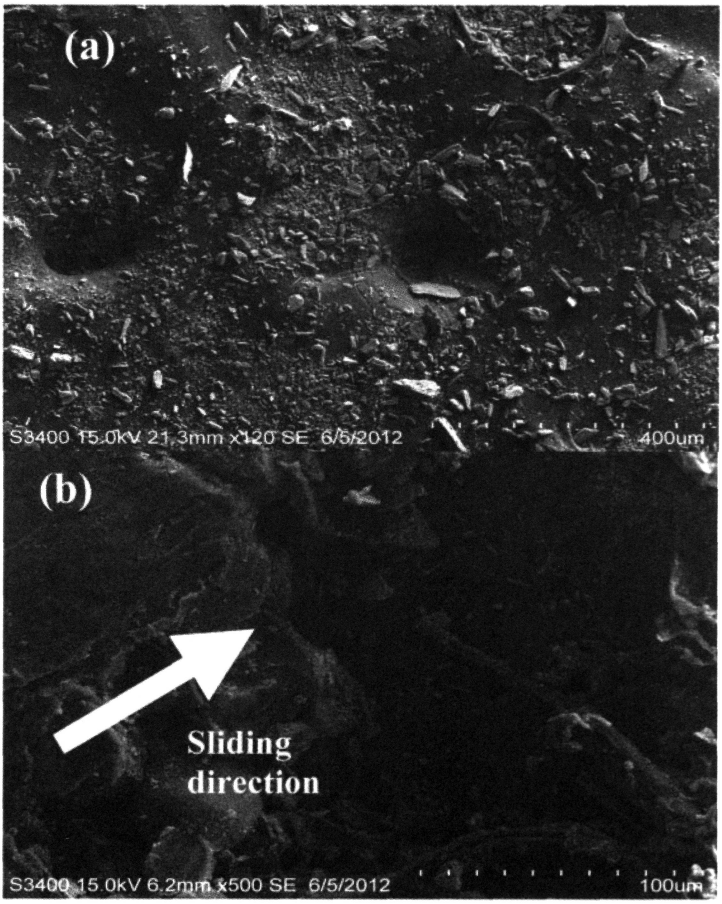

Figure 5: Optical SEM observation of powdered bio-shell reinforced polypropylene (a) before abrasion showing physical contact and embedded particulates (b) after abrasion showing detachment and loose contact of embedded particulates

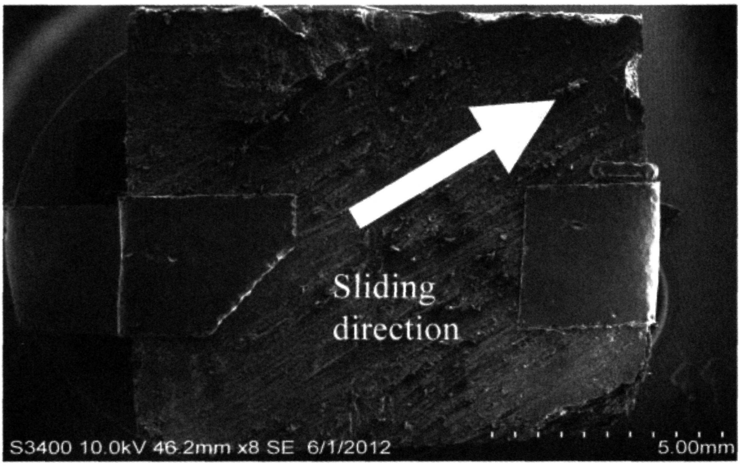

Figure 6: Optical SEM observation of pure polypropylene exposing some scratching after abrasion

Conclusions

Polypropylene has the highest wear rate with 40.13 mgs^{-1} followed by bio-fibre composite with 26.93 mgs^{-1} and bio-shell composite with 0.53 mgs^{-1} with parameters of the wear test being 200 rpm of rotating disc, 1 kg load and 50 mm of sliding distance. This shows that with the addition of bio-fibre or bio-shell, it reduces the wear rate of the polymer itself by at least two folds. The presence of lubricant in the research shows a reduction of the amount frictional forces needed to conduct the wear test. However, the reduction of the frictional forces until negative shows that there is a layer of liquid in between the testing specimen and the rotating disc. The coefficient of friction (COF) for polypropylene is the highest with 0.60 followed by bio-fibre composite with COF being 0.54 and bio-shell composite with COF being 0.50. This shows that more force is needed to move polypropylene continuously to push the composite to slide when in contact with another surface due to three-body abrasive in wear process.

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JOURNAL OF MECHANICAL ENGINEERING (JMechE)

Aims & Scope

Journal of Mechanical Engineering (formerly known as Journal of Faculty of Mechanical Engineering) or JMechE, is an international journal which provides a forum for researchers and academicians worldwide to publish the research findings and the educational methods they are engaged in. This Journal acts as a vital link for the mechanical engineering community for rapid dissemination of their academic pursuits.

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[2] H. Coelho and L. M. Pereira, "Automated reasoning in geometry theorem proving with Prolog," J. Automated Reasoning 2 (3), 329-390 (1986).
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