

## **PHYSICAL AND WEAR RESISTANCE PROPERTIES OF COMPOSITES MADE FROM FIRE CLAY AND RECYCLED POLYSTYRENE**

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### **ABSTRACT**

Environment faced many challenges during COVID19 pandemic, recycling the used polymer is considered as one of these challenges. Using natural and low-cost materials to produce polymer composite fabricated by recycled foam and reinforced it with fire clay particles will use as a promising solution to this issue. The results of wear rate and hardness of the polymer composite samples showed a significant increase in both the wear resistant and in the hardness values. The results reveal that fire clay polymer composites can be used in the industry to produce parts resist the friction force. Also, maximum values of wear rate were found in the mixture of ultrafine and micro sizes filler samples mixed with 100 rpm and reinforced with 5 wt. % On the other hand the results reveal that fire clay particles in both sizes (micro, ultrafine) were completely distributed inside the polymer matrix. Finally wear rate decreases with decreasing in applied load from 15 to 10 N.

### **KEYWORDS**

Wear Resistance, fire clay, polymer composites.

### **INTRODUCTION**

Global Warming have a high impact on the manufacturing sector, especially after the great industrialized countries signed the Climate Agreement in Paris in 2016. Over the last decade, researchers from all over the world have been trying to discover new environmentally friendly materials. Polymer composites are one of these materials because they are recyclable materials; they can be produced at a lower temperature. Thus, it can be considered as one of the promising materials in this field now. Nowadays, polymer composites are used in many renewable industries such as using a polymer as bipolar plate components in fuel cells manufacturing, [1 – 3]. Hence, many studies aim to improve the electrical performance of polymer composites to extend their applications. These studies were made by testing the effect of different types of fillers, and different manufacturing techniques on the electrical performance of the polymer. However, these studies could not determine the ideal technique of manufacturing, quantity, or appropriate specification for fillers to obtain superior performance polymer composites, [4 – 6]. This is mainly due to fillers have unique construction and characteristics, each filler has a different size and shape which leads to producing different electrical conductivity networks [7 – 9]. Therefore, fillers selection is crucial. all fillers even the small size and different shapes fillers should have a function within

the polymer matrix [4, 10]. To form a network with high electrical conductivity while maintaining good mechanical properties.

Polymer composites have gained considerable estimation in the materials engineering field, [11]. Products of Polymer Composites are produced to serve in many industrial applications such as components of sports gear and aerospace and medical pieces of equipment, [12]. Improving the mechanical properties of polymer composites is one of the big challenges in this field, due to the varieties of available reinforcements and varieties of available polymer, making selecting the suitable choice is too hard, [13, 14]. Improvement in wear resistance was observed in these polymers composite, but these achievement costs were too high, which restricted expansion in using this type of reinforcements, [15]. On the other hand, using scraps of metals or low-cost natural material may be justified as a suitable choice for manufacturing polymer composites, [16, 17].

Polyurethane is an organic polymer that is made by a chemical reaction between alcohol and polymeric isocyanate with the presence of suitable catalysts, [8]. It is suitable to many applications such as coating against chemical-resistant, water and in packaging process, [18]. Reinforced materials such as Silicon carbide (SiC), nitrides of titanium Ti(C, N), and aluminum oxide ( $Al_2O_3$ ) have been used with polymer in the production of automotive, aircraft and electronic parts [19, 20]. Many publications on polymer composite with similar microstructures have been reported. These publications have shown that shape [21], concentration, [22] and particle size, [23 – 26], characteristic of the reinforcement materials can affect mechanical properties. For epoxy (Epon 828/Z) filled with  $Al_2O_3$ , decreasing the size of particle and increasing the concentration of particle is found to increase the stress corresponding to 4% plastic strain, [27]. On the other hand, the small amount of filler of aluminum particles (approx. 5 vol. %) causes an increase in compressive yield stress for epoxy (DGEBA/MTHPA), [28]. Nevertheless, the yield stress and fracture toughness of the material have been increased with the increasing in the volume fraction of glass bead for epoxy (DOW DER 331/bisphenol-A), [29, 30]. In another researches on a similar material, decreasing the size of aluminum particle from micro to nano yielded to increase the cross-link density of epoxy and subsequently increased both dynamic and static strength, [23]. Effect of reinforcing particle on the strength has been reported, [31]. Authors referred that quality of adhesion between the reinforcement and the polymer matrix affects the overall composite toughness and strength.

According to the United States environmental protection Agency, Fire clay defines as a mineral substance consisting of a hydrous silicate of aluminum ( $Al_2O_3, 2SiO_2, 2H_2O$ ) with or without free silica, [32]. Fire clay differs from other clays significantly, [33]. It is highly rich in silica and alumina, with minimal amounts of trace impurities. It is highly malleable and can be molded or extruded, [34]. There are many additives that can add in to make fire clay more coarse, scraps for the fire clay can also be reused, as long as they are not subjected to fire. Also, the fire clay shrinks after it has been shaped in a mold and during the firing process, [35]. Fire clay is used in many industries such as refractories, white ware, Portland cement and heavy clay products, [36 - 38].

Many researchers referred that kaolinite-rich clay material is refractory with a high glazing range, low plasticity, and low drying and firing shrinkage, [37, 38]. Using clay as a filler can be useful to modify the properties of polymer, with remarkable effects on toughness, heat distortion, stiffness and hardness, [39]. Using clay as a filler cause an increase in weight, but this increase can be neglected under the improvement in the mechanical properties, [40]. Clay may introduce in polymer by blending process, [41]. Authors used nano clay as reinforcing HDPE to manufacture wood-plastic composites, where experimental results revealed that the mechanical properties of polymer composites could be improved with a suitable combination of the coupling nano clay type and agent content in the composites. Molin et al., [40] reported that Young's modulus and tensile strength of epoxy/5 wt.% of nano clay samples increased up to 34 % and 25 % respectively , as compared with unreinforcement samples. In addition, using clay as filler with natural fibers was examined. Hakamy et al., [42] investigate effect of using hemp fabrics and calcined nano clay as a filler, the results indicated an enhanced in thermal, mechanical and physical properties due to the addition of calcined nano clay into the cement matrix.

In this study, clay polymer composites were manufactured by a mechanical stirring process. By using a recycled foam with 1, 3, and 5 wt. % of fire clay. The effect of the weight percentages and clay particle size and mixing speed on mechanical properties and wear resistance were investigated to evaluate the suitability of using recycled polymer in the manufacturing of products for industrial applications.

## **EXPERIMENTAL**

### **Materials**

The polymer used is a scrap of foam supplied from local supplier and crushed by hand to small pieces. Foam was chemically recycled by using an organic solvent, in this process the foam dissolves in pure acetone with a purity of 99%. The fillers used were fire clay powder supplied from local supplier and crushed by ball milling to obtain micro and ultrafine size particles. Properties investigated in the laboratory table 1 shows the chemical analyses of the used sample in weight %. Its particle size is less than 30  $\mu\text{m}$  and the ultrafine particles are less than 95 nm. Figure 2 illustrates the shows a description of the techniques used in the investigation to obtain the samples.

### **Method**

Polymer composite samples were produced by a mechanical stirring means. Figure 1 illustrates preparation steps, first step, was using organic solvent (acetone) to melting the expanded polystyrene foams inside glass container (Figure 1), about 100  $\text{cm}^3$  is the required amount of acetone to dissolve 1000 g of expanded polystyrene foam. Second step was adding the predefined amount and size of fire clay. Third step was using the mechanical stirrer to mix polymer and clay matrix. The final step was heating the semisolid polymer to 85 C by an electrical heater for 2 min to remove air bubbles generated during mixing then poured the mixture in the metal mold coated with wax to facilitate the sample exit. Statistical software Design-Expert was used to design the experiments of different parameters, Table 2 shows range of independent variables and levels of experiment design. While table 3 shows the obtained values of each parameter in the study according to full factorial design  $n^k$  . All

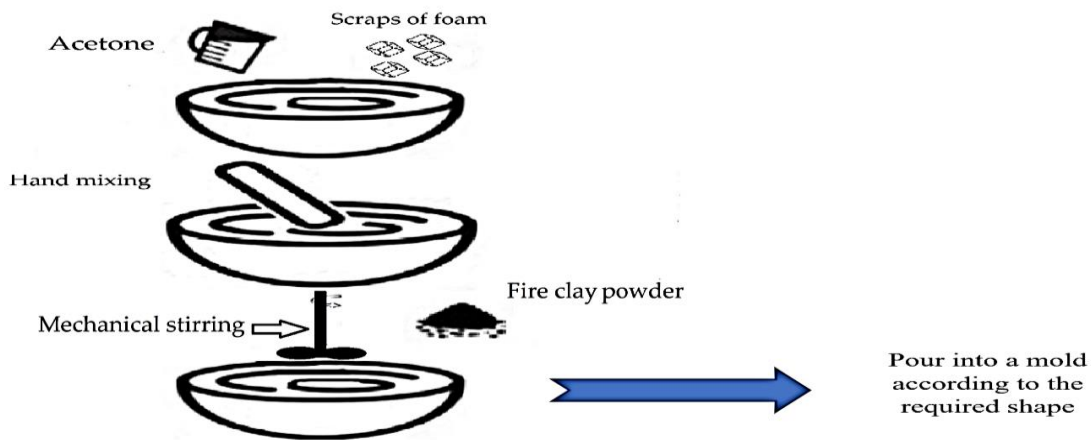
mixing processes were made at room temperature for 60 s. samples left to dry under cold pressed for 8 h, at room temperature and the pressure of the cold press was 100 kg/m<sup>2</sup>.

**Table 2. Levels of experiment design and range of independent variables.**

Experimental Parameters	Actual value (Coded value)		
wt% of clay	1(-1)	3(0)	5(1)
Size of clay particles	Micro size (-1)	Ultrafine size (0)	mixture of ultrafine and micro sizes (1)
Mixing speed	100 rpm (-1)	200 rpm (0)	300 rpm (1)

**Table 3. Experimental design matrix of different compositions.**

Sample no	Coded Factors			Actual factors		
	wt% of clay	Size of clay particles	Mixing speed rpm	wt% of clay	Size of clay particles	Mixing speed rpm
1	-1	1	-1	1	Mixture of ultrafine and micro sizes	100
2	1	-1	-1	5	Micro size	100
3	0	0	-1	3	Ultrafine size	100
4	-1	1	1	1	Mixture of ultrafine and micro sizes	300
5	1	1	-1	5	Mixture of ultrafine and micro sizes	100
6	1	-1	1	5	Micro size	300
7	1	1	1	5	Mixture of ultrafine and micro sizes	300
8	1	0	1	5	Ultrafine size	300
9	1	-1	0	5	Micro size	200
10	0	-1	1	3	Micro size	300
11	0	1	0	3	Mixture of ultrafine and micro sizes	200
12	-1	-1	0	1	Micro size	200



**Table 1 Chemical analyses of the used sample in weight %**

Element	Weight %
Al <sub>2</sub> O <sub>3</sub>	7.49
SiO <sub>2</sub>	22.12
TiO <sub>2</sub>	2.57
Fe <sub>2</sub> O <sub>3</sub>	0.87
MgO	0.76
CaO	17.23
SO <sub>3</sub>	4.56
LOI	41.32
P <sub>2</sub> O <sub>5</sub>	3.08



**Fig. 1 Dissolved polystyrene foams.**

### Mechanical properties

The effects of weight percentage and size of fire clay particles in addition to mixing speed were investigated. The hardness (Shore D type) measurement was performed according to the standard CSN EN ISO 868. Wear resistance of the polymer composites samples was measured using pin-on-disc testing apparatus under various conditions (rotating speed, time, and load) at room temperature. Wear resistance was measured by calculating the weight of the sample before conducting the test and after it. Then the rate of wear will calculate by the following equation [43].

$$\text{Wear rate} = (W_1 - W_2) * t / W_1 \quad (1)$$

Where:  $W_1$ = sample weight before test.

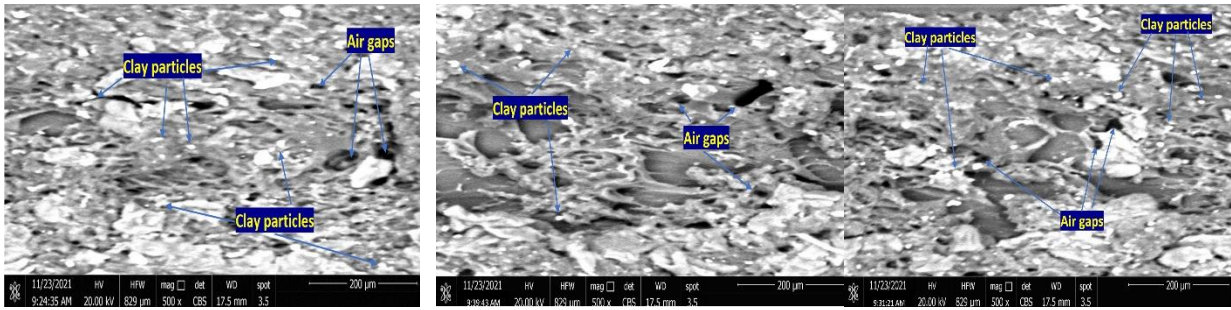
$W_2$ = sample weight after test

t= test durations (180, 360, and 540s)

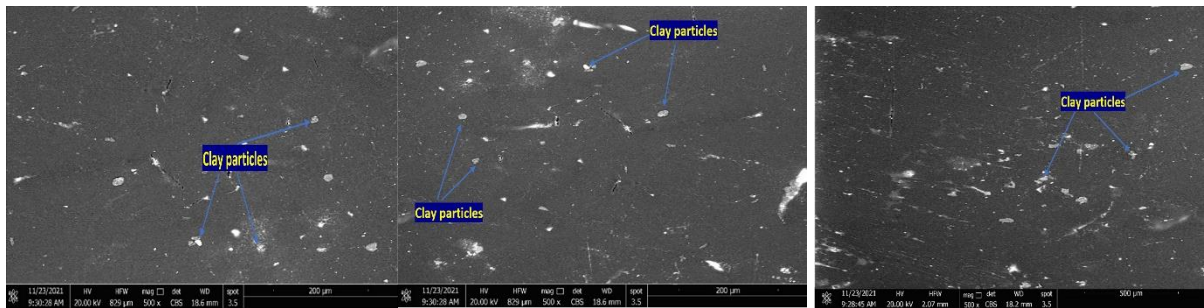
## RESULTS AND DISCUSSION

### Microstructure

SEM images were used to assure that reinforcement clay particles were dispersed in polymer matrix. Figures 2 and 3 show the microstructure photomicrographs and the particle size distributions for the section side and top views and at different particle sizes.



**Fig. 2 SEM images for section side of the fabricated polymer composite samples showing the distribution of clay particles in Polyurethane (3 wt. % and 300 rpm) at different size : (a) micro size, (b) ultrafine sizes and (c) A mixture of ultrafine and micro sizes.**



**Fig. 3 SEM images for top view of the fabricated polymer composite samples showing the distribution of clay particles in Polyurethane (5 wt. % and 200 rpm) at different size: (a) micro size, (b) ultrafine sizes and (c) A mixture of ultrafine and micro sizes.**

It is clear from the figures that the clay particles in both sizes the ultrafine and the micro are completely dispersed inside the Polyurethane, and it can be observed that clay particles were made an excellent link with Polyurethane due to the excellent adhesive and low viscosity of the recycled foam in the semisolid state, [44]. Due to the dispersion of particles improved and become easy on low viscos material, [45]. The other major observation in the SEM photomicrographs is the presence of a high amount of ultrafine size clay particles without any agglomeration at the top surface (Fig. 3 (c)). This is maybe due to using a low wt. % of particles. The appearance of air gaps in the samples has been happened due to using a mechanical stirring to max particles in polymer.

### Hardness measurement

Hardness measurement was obtained at different wt. % and sizes of clay, figure 4 shows hardness values. The largest values of hardness have appeared in the ultrafine size samples. The results show that the hardness increases with increasing weight fraction of clay particles, from 1 wt. % to 5 wt. %. On the other hand, the clay size shows a low effect on the hardness value. However, mixing speed showed a remarkable effect on the hardness value. At 1 wt. % fire clay and 300 rpm, the hardness. However, mixing speed showed a remarkable effect on the hardness value. At 5 wt. % and micro size of fire clay particles the hardness value increase from 79 to 88 when the mixing decreased from 300 rpm to 100 rpm. Maximum value of hardness was 7.2 found in the mixture of ultrafine and micro sizes and in mixing speed 100 rpm. For the same size of particle and same mixing speed the hardness enhancement of 6 %, 20 % and 31.6 % was recorded with 1 wt. %, 3 wt. %, and 5 wt. % clay particles respectively, as compared to unreinforced polymer.

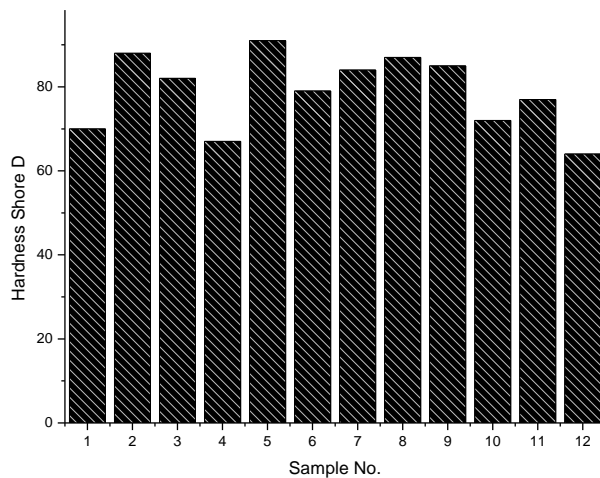
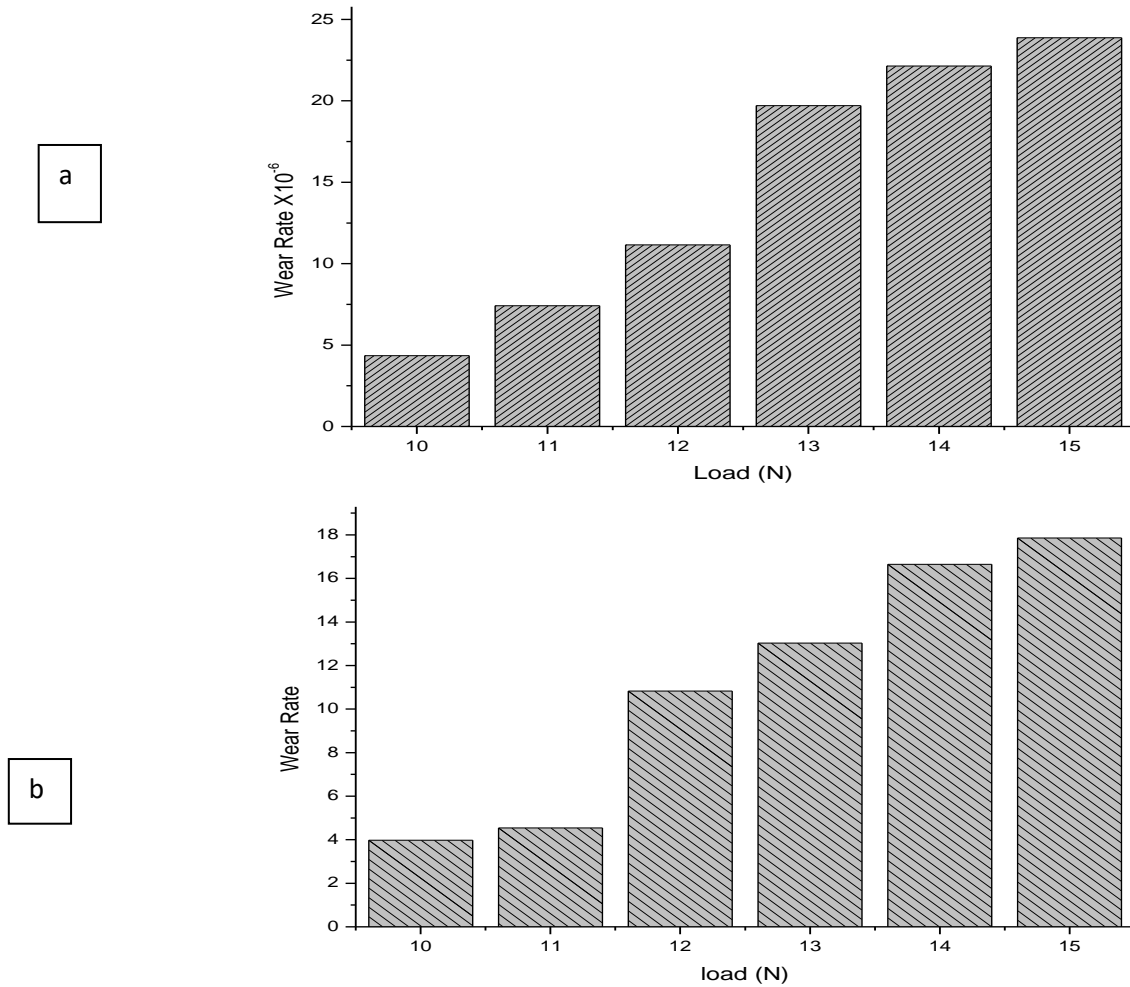


Fig. 4 Hardness of samples composite.

### Wear rate

Figures 7 - 10 show the results of wear rate at different conditions. It has been found a significant improvement in the wear resistance by reinforcing the recycled polymer with clay particles. For example, the wear rate of the sample with 1 wt. % of clay particles was  $11.43 \times 10^{-3}$  (g) decreased to  $3.76 \times 10^{-3}$  (g) for the sample with 1 wt. % of clay particles at same fabrication conditions (10 N and mixed speed 100 rpm). This enhancement is due to the protection of clay particles for the soft polymer surface. While the polymer can be removed under the friction force the clay particles resist the wear by creating hard protection to the surface. Results reveal also, the effect of mixing speed on the wear resistance improvement of the polymer composites. When the mixing speed increases, the possibility of air entry to the sample increases, which leads to an increase in the rate of wear due to air gaps that did not resist the friction force. Many papers had shown the role of weight percentage on the wear resistance of the composites, [46 – 49]. This research proved the positive effect of the filler reinforcement on increasing the wear resistance with the increasing of the weight % of the reinforcements. Maximum values of wear rate were found in the mixture of ultrafine and micro sizes filler samples mixed with 100 rpm and reinforced with 5% wt. of clay particles. In other words, there is an enhancement in the wear resistance of polymer composites back

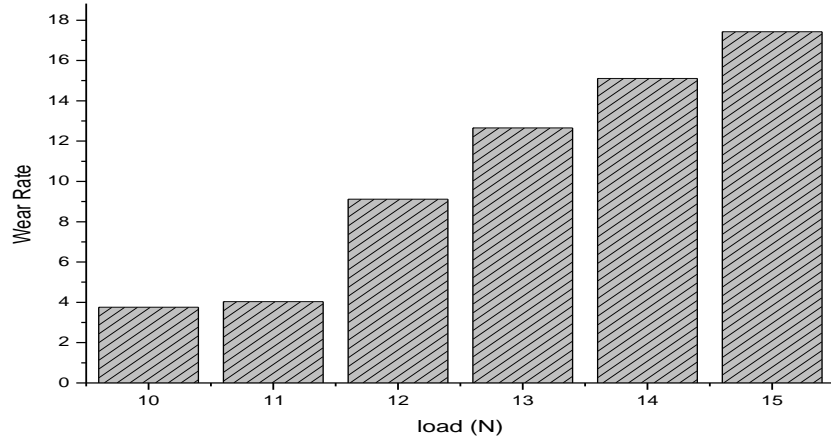
to the good dispersion of clay particles in the recycled foam. It is possible to highlight that wear rate increases with increasing in load applied to the samples. For example, the wear rate of the sample with 5 wt.% and mixed speed 100 rpm was  $3.76 \times 10^{-3}$  (g) at applied load 10 N increased to  $17.43 \times 10^{-3}$  (g) at applied load 15 N. This increase in the wear rate is due to an increase in the contact area due to the increase in the applied pressure, [50].



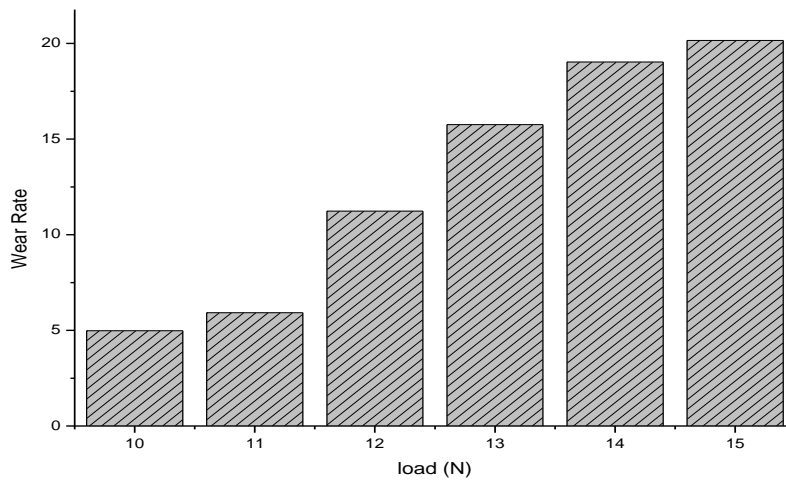
**Fig. 5 Effect of load on wear rate for ultrafine size at mixing speed: (a) 100 rpm / 3 wt. % (b) 300 rpm / 5 wt. %.**



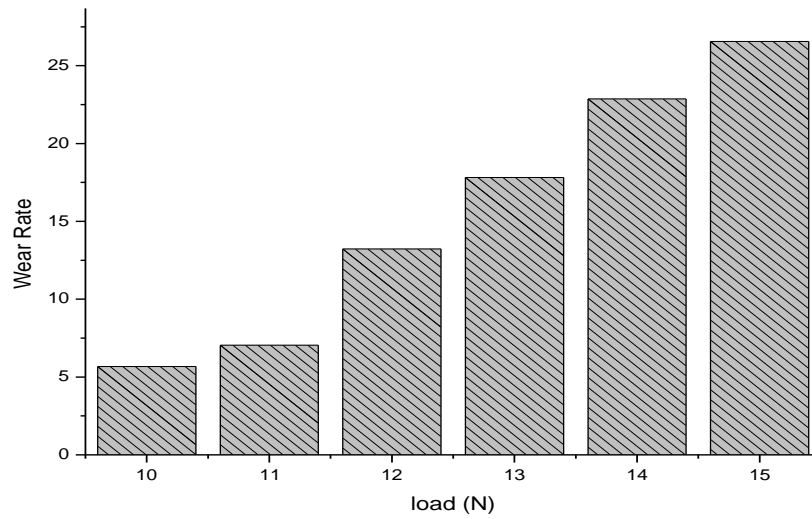
a



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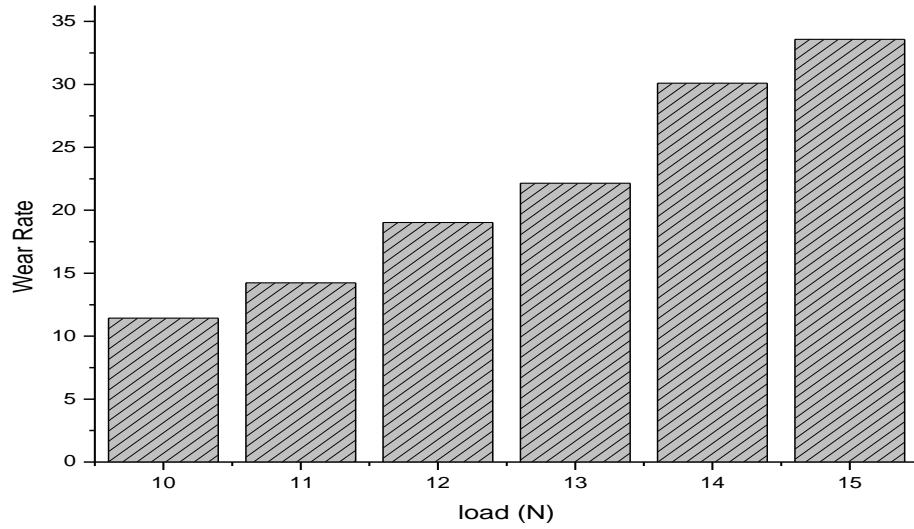


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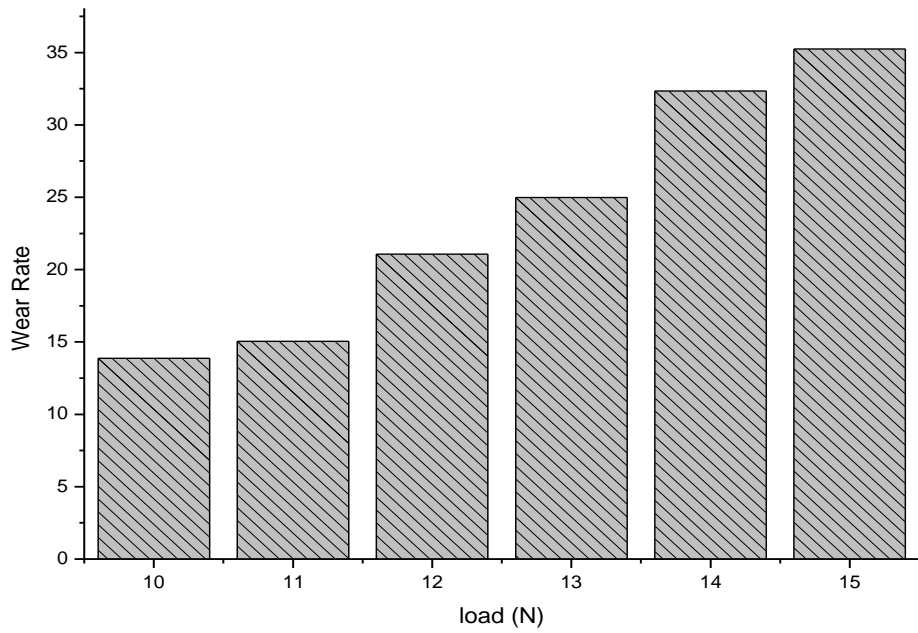


**Fig. 6 Effect of load on wear rate for Micro size at mixing speed: (a) 100 rpm / 5 wt. % (b) 200 rpm / 5 wt. %, (c) 300 rpm / 5 wt. %.**

a

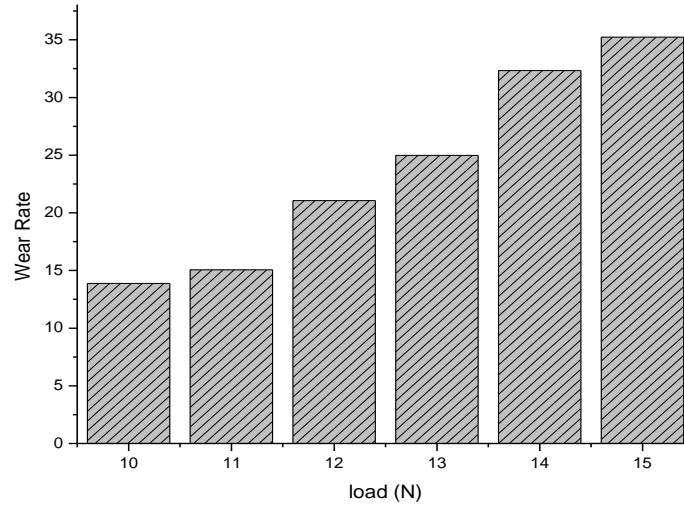


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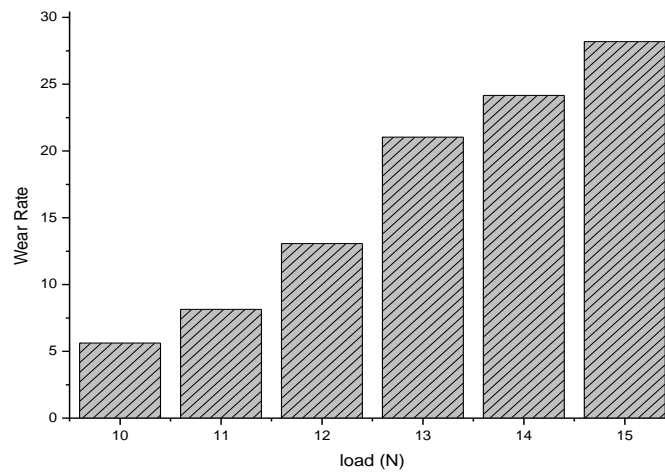


**Fig. 7 Effect of load on wear rate for Mixture size at mixing speed: (a) 100 rpm / 1 wt. % (b) 300 rpm / 1 wt. %.**

a



b



**Fig. 8 Effect of load on wear rate for Mixture size at mixing speed:  
(a) 100 rpm / 5 wt. %, (b) 300 rpm / 5 wt. %.**

## CONCLUSIONS

Polymer composite samples with different wt. % and size of fire clay were successfully prepared by a mechanical stirrer and at different mixing speeds. Analysis of their microstructure and mechanical properties have led to the following conclusions:

1. Microstructure study shows that the fire clay particles with all sizes are completely dispersion in the recycled polymer at all selected mixing speeds.
2. Fire clay particles in both sizes (micro, ultrafine) were completely distributed inside the polymer matrix.
3. Hardness increases with 31.6 % with the increasing in weight fraction of ceramic from 1 to 5 wt. %.
4. Hardness increases with 9% with the decreasing in mixing speed from 300 to 100 rpm.
5. Wear rate decreases with decreasing in applied load from 15 to 10 N.

6. Maximum values of wear rate were found in the mixture of ultrafine and micro sizes filler samples mixed with 100 rpm and reinforced with 5 wt. %

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