Erosive Wear Behavior of Jute Fiber / Polyester resin with Biowaste Materials

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Abstract:
The improvement of the mechanical and physical properties of hybrid composite materials plays a huge role in many different engineering applications. In this article, the hybrid composites were prepared using the hand lay up method from polyester resin with 4% wt. jute fibers and reinforcement with different weight fractions of (3%, 6%, 9%, and 11% wt. egg shells powder / rice husk powder) to investigate the resistance of these hybrid polymeric composites to the test erosive wear. The median particle size of the eggshell and rice husk powder used in this research was (15.2 µm, 53.7 µm) respectively. The parameters that were studied during the erosion test (weight fractions of the fillers, impingement angle (30º, 60º, 90º), size silica sand (450, 600, 750µm) at the time constant (15 hours). Erosive wear behavior results for all samples hybrid composites were analyzed and discussed by using the experimental design of Taguchi (L9) (MINITAB 16). We note from the results that the samples (polyester + 4 wt%. Jute fibers + 11% wt. Eggshell powder) and (polyester + 4 wt%. Jute fibers + 11 wt%. rice husk powder) give the best erosive rate (0.00010g, 0.00027 g) respectively at variables (angle 60º, size silica sand 450 µm). Through the results of the ANOVA analysis, it was found that all variables (filler content, angle impingement, and silica sand size) had a significant effect on the erosive test.

Terminology:

| Symbols | Definition |
|---------|------------|
| E.R     | Erosive wear rate |
| Δ Wc    | Weight difference |
| Ws      | Specimen weight before the test |
| S/N     | Signal to noise |
| n       | Number of observations |
| y       | Erosion wear rate |
| o       | Angle impingement |
| µm      | Size silica sand |

1. Introduction
A natural material is any product or physical matter that comes from animals, plants, or the ground, natural materials are receiving increasing attention today due to their availability [1]. Some natural fibers like (rice husk or eggshell) contain the good amount of silica and calcium oxide, that can be used in many industrial applications, therefore the addition of such bio-waste, particularly, especially the size of fine particles to the polymeric resin lead to improving some mechanical and physical properties [2,3]. There are various polymers can be used as a matrix for composite materials like (thermoset and thermoplastics). The most usually used thermoset polymers are epoxy resin,
unsaturated polyester resins, and vinyl ester. A thermoset is a hard and interrelated material that loses mechanical and chemical properties and is non-modifiable when exposed to heat [4]. Unsaturated polyester resin is a type of thermosetting polymer that is formed by reacting with an unsaturated monomer or pre-polymer by having a carbon-to-carbon bond in its polymer chain and has a good mechanical and physical property so it is suitable for applications requiring high resistance, corrosion resistance, moisture resistance, thermal insulation and good electrical properties [5]. Solid particle erosive is a gradual loss of original surface substance due to mechanical interaction between surface material and the solid particle. In general, the variables effect on erosive wear of polymer composite material is mechanical properties polymeric composite, filler, fiber, directional fiber, impingement angle, eroding the particle size and velocity [6]. Also, this type of wear occurs in many parts such as pipes, energy conversion system, helicopter rotor blade, jet engines, and in coal mine plants, therefore the importance studying this kind of wear is increasing [7]. There are many studies that have investigated the erosive behavior and attempted to find any of the most influential factors on the values of erosive resistances. Mohana. N et.al.[8] have examined the erosive behavior of epoxy reins / glass fiber filled with 4% wt. WC particles. Erosive wear rate were measured under effect factors (impact velocities 40 & 80 m/Sec, rodent size 150 & 280μm and angle impact 30°, 60° and 90°).

Results show the erosive rate improved with incorporation tungsten carbide in glass fiber-epoxy. Khandelwal1. A. et.al.[9] in their work, studied the effect (5% to 30% weight fraction) short glass and banana fiber reinforced with epoxy resin matrix on solid particle erosive, tensile strength, flexural strength and impact strength. From the results, it was found the specimen (epoxy-banana fiber) has maximum values micro-hardness and tensile strength than specimens reinforced with short glass fiber, while the specimen (epoxy-glass fiber) has maximum values flexural strength and impact strength than specimens reinforced with banana fiber. From Taguchi (L27) and analysis (ANOVA) results show the impingement angle; stand-off distance, impact velocity, temperature, and erodent size are the factors most significance on the erosive behavior rate of banana fiber in epoxy resin composites.

Reem. A. et.al. [10] investigate the influence of (2% to 8% volume fraction) Al2O3 reinforced with 4% volume fraction carbon fiber in a polyester resin matrix on solid particle erosive. From the results, it was found the specimen (polyester +4% C.F +8% Al2O3) has maximum erosion resistance. Taguchi (L9) and analysis (ANOVA) results show the filler content is the factor most significance on the erosive behavior than angles and particle size of erodent. Reem. A. [11] studied the effect of (1%, 2%, 3%, 4%, 5% & 6%) weight fraction nano TiO2 particles strengthened with 5% weight fraction carbon fiber into unsaturated polyester resin on impact properties, hardness shore D and erosive wear. Results show the (6% wt.) nano TiO2 has maximum value hardness shore D and impact properties. From Taguchi (L9) and analysis (ANOVA) turns out the (6% wt.) nano TiO2 has the best erosive rate resistance, also the angle and weight fraction of filler are more factors effect on erosive wear. The purpose of this research includes; study the influence of weight fraction jute fiber, reinforced with (eggshell and rice husk powder) into unsaturated polyester on erosive wear. Used Taguchi’s experimental design (L9) and ANOVA analysis in order to investigate the effect of factors (filler content, size silica sand and angles impingement) on erosive wear resistance. Improved the resistance unsaturated polyester resins by adding jute fiber with small amounts from biowaste material eggshell and rich husk powder to resist the conditions for erosive behavior.

2. Experimental

2.1 Materials
The type of unsaturated polyester resin used as a matrix in this work is (PETROL 111), equipped by the (PERFECT POLYMERS FZ-LLC) Company. Table 1 shows the some physical and mechanical properties of polyester resin [12]. Table 2 represents the mechanical properties of jute fibers used in the current work [13]. Rice husk consists of 20% silica, 30-40% cellulose, 25-30% lignin and 10-15% ash, 5-10% Humidity [14]. Initially, washed the eggshell and rice husk with distilled water to remove any membranes and dust materials, dried in the air at room temperature and then grinding for 3 hours until obtained the fine powder. The XRF (Ministry of Science and Technology) examination was performed to show the ratio of the elements present in the egg shell powder and the rice husk powder...
after milling, as shown in Table 3. The Average particle size of the eggshell and the rice husk powder is shown in Figure 1 and 2, where the examination was carried out at the Ministry of Science and Technology using a device (MASTERSIZER). The average particle size of eggshell powder and rice husk powder was (15.2µm), (53.7µm) respectively.

**Table 1.** Physical and mechanical properties of polyester resin [12].

| Properties                  | Values         |
|-----------------------------|----------------|
| Tensile Strength            | 55-65 MPa      |
| Tensile Modulus             | 3600-2800 MPa  |
| Flexural Strength           | 182-192 MPa    |
| Elongation at Break         | 1.9-2.3 %      |
| Heat Deflection Temperature | 63-71 °C       |
| Water Absorption after 24 hrs at 23°C | 15-19 mg      |
| Density                     | 1.10-1.11 gm/cm³ |

**Table 2.** Mechanical Properties of jute fiber[13].

| Properties                  | Values         |
|-----------------------------|----------------|
| Tensile Strength            | 400-800 MPa    |
| Young Modulus               | 10-30 GPa      |
| Elongation at break         | 1.8%           |
| Density                     | 1.46 gm/cm³    |

**Table 3.** Chemical composition of eggshell and rice husk by using (X-Ray Fluorescence Spectrometer)

| Component | Ratio% of the elements | Component | Ratio% |
|-----------|------------------------|-----------|--------|
| CaO       | 50.25                  | CaO       | 0.44   |
| SiO₂      | 0.020                  | SiO₂      | 25.33  |
| Al₂O₃     | 0.022                  | Al₂O₃     | 0.075  |
| MgO       | 0.055                  | MgO       | 0.038  |
| Fe₂O₃     | 0.044                  | Fe₂O₃     | 0.98   |
| Na₂O      | 0.55                   | Na₂O      | 0.25   |
| P₂O₅      | 0.045                  | P₂O₅      | 0.033  |
| SrO       | 0.033                  | SrO       | 0.0035 |
| NiO       | 0.0020                 | NiO       | 0.0083 |
| SO₃       | 0.64                   | SO₃       | 0.045  |
| Cl        | 0.029                  | Cl        | 0.071  |
| K₂O       | 0.080                  | K₂O       | 0.47   |
| MnO       | 0.030                  | MnO       | 0.022  |
| TiO₂      | 0.0043                 | TiO₂      | 0.0010 |
| CuO       | 0.0088                 | CuO       | 0.075  |
| V₂O₅      | 0.0014                 | V₂O₅      | 0.00060|
| Cr₂O₃     | 0.0028                 | Cr₂O₃     | 0.0037 |
| ZnO       | 0.0027                 | ZnO       | 0.0093 |
| Te        | 0.0013                 | Te        | 0.0011 |
| I         | 0.0020                 | I         | 0.0023 |
| BaO       | 0.0038                 | BaO       | 0.0036 |
2.2 Preparation of Test Specimens
Specimens polymer composite were prepared from three steps by hand lay-up method. The first step, preparing a mold from the glass with a dimension of \((200 \times 200 \times 5 \text{ mm}^3)\) and must be covered with a layer of nylon until prevents adherence between specimens and mold. Second step, the jute fibers is cut according to mold dimensions and calculate the weight fraction of filler materials depending on the role of the mixture [2]. Third step, the unsaturated polyester resins is mixed with weight fraction eggshell and rice husk (3%, 6%, 9%, and 11%) by using a glass rod until homogenous mixing is obtained, then adds the hardener to the mixture and continue the mixing process for 15 minutes in order to avoid bubbles [15]. Pouring part of the mixture into the mold and put layer jute fiber (4% weight fraction) and pour the remaining amount of mixture and leave for 24 hours at room temperature. After removing the specimens from the mold, place them in the oven at 55 temperatures for 1 hour in order to remove the remaining stresses and get better bonding [16-17]. The specimens slicing according to ASTM (erosive G 76) tests. Table 4 shows the detailed configuration of the specimen prepared.
Table 4. Detail Composition of the specimens

| Specimens | Composition        |
|-----------|--------------------|
| E0        | UP                 |
| E1        | UP+4% J.F          |
| E2        | UP+4% J.F +3% E.S  |
| E3        | UP+4% J.F +6% E.S  |
| E4        | UP+4% J.F +9% E.S  |
| E5        | UP+4% J.F +11% E.S |
| E6        | UP+4% J.F +3% R.H  |
| E7        | UP+4% J.F +6% R.H  |
| E8        | UP+4% J.F +9% R.H  |
| E9        | UP+4% J.F +11% R.H |

### 2.3 Erosive Wear Test

Solid particle erosive wear test was carried according to (an air jet) type. The erosive wear device consists motor with a constant flow rate 45 L/min, pump (40 mm diameter), the nozzle (5mm diameter) and tank "Perspex glass" with dimensions 50 cm long, 25 cm height and 25 cm width, as shown in Figure 3. The specimen dimensions in this test were (30 mm length, 5 thicknesses) according to ASTM (G76) [18]. The erosive wear rate can be determined from the following relation [19].

\[
E.R = \frac{\Delta W_c}{W_s}
\]  \hspace{1cm} (1)

Where:
- E.R: Erosive wear rate (g)
- \(\Delta W_c\): Weight difference (Specimen weight before – Specimen weight after the test)(g)
- \(W_s\): Specimen weight before the test (g)

![Figure 3. Erosion wear device](image)

### 2.4 Taguchi Experimental Design

In this research, three parameters specifically filler content, angle impingement, and size silica sand were examined in order to investigate the rate of erosive wear response for specimens composite. The operating requirements for any test were shown in Table 5. The test results were converted into a signal-to-noise (S/N) ratio. There are different S/N ratios enduring depending on the type of character; that is, less the better, normal the best, and greater the better. In this current work, used the lower is better, according to equation 2 [20-22].

\[
\frac{S}{N} = -10 \log \frac{1}{n} (\sum y^2)
\]  \hspace{1cm} (2)

Where:
- \(n\): Number of observations,
- \(y\): Erosive wear rate.
Table 5. Levels of variables utilized in the experiment of erosive behavior

| Variable                        | Level | Unit  |
|---------------------------------|-------|-------|
| Factor (A) Filler (Specimens)   | II    | E0    |
| (I)                             | II2   | E1    |
| (II)                            | II4   | E2    |
| W.F %                           |       |       |
| Factor (B) Angle impingement    | 30°   | E3    |
| (III)                           | 60°   | E4    |
| (IV)                            | 90°   | E5    |
| Degree                          |       |       |
| Factor (C) Size silica sand     | 450μm | E7    |
| (V)                             | 600μm | E8    |
| (VI)                            | 750μm | E9    |
| Micro                           |       |       |

3. Results and Discussion

3.1 Erosive Behavior

The results erosive rate for all experiments carried out according to the predetermined design on specimens composites are presented in Tables (6 and 7), also these tables present the experimental erosive wear rate along with the signal-to-noise ratio for each single test run. In Tables (6 and 7) the last column represents the ratio (S/N) of the erosive behavior test, where higher values (S/N) give minimum erosive rate, therefore the lowest erosive rate was found in the specimens (UP+4%jute fiber+11% eggshell and rice husk) (0.00010 gm/gm, 0.00027 gm/gm) respectively, compared with other specimens, because the fiber jute and filler materials gives a good interface with the resin matrix during the erosive wear conditions, this results agree with [23].

Figures 4 shows the main effects plot S/N ratios on erosive wear rate, clear from the main effects of the S/N measurements that the incorporation factor of (E2, E5, E6, E9, B1 and C1) gives a minimum erosive wear rate. It is clear through the Taguchi experimental that the minimum erosive wear rate can be obtained when the filler (A) is at the highest level, while the angle impingement (B) and size silica sand (C) are at the lowest level. These results indicated the change in erosive wear conditions has a direct effect on the erosive wear rate of the composite polymer specimens.

Figure 5 shows the relationship between the filler and erosive rate, where the erosive rate decreases with the increasing weight fraction of filler content (eggshell and rice husk) this can be explained by two reasons. The first reason is that the addition of such particles, improves the hardness of the specimens composite. The second reason, during erosive wear operation, the jute fiber and filler particles absorbs a good part of kinetic energy related to the erodent effect, this results in a limited amount of energy being prepared to be absorbed by the matrix resin material and the reinforcing fiber, these two factors lead to enhancement of erosion wear the resistance [24].

Figure 6 explains the effect variation of the impingement angle on the erosive wear rate for all specimens. In many studies, they have generally found in erosive wear behavior the angle impingement classification into two kinds (ductile and brittle). This classification depends on the variation of the erosive rate behavior with angle impingement. The ductile behavior occurs at a low impingement angle in the extent of (10-30°), while the brittle behavior is occurring at a higher impingement angle 90°, also there is polymeric composite material, reinforced with various filler shows the semi-ductile behavior at medium angles typically in the extent of (45-60°) [10, 25, 26].

Turns out from the figure the specimens (E5 and E9) give the maximum erosive wear rate at peak (90°) impingement angle, while giving the minimum erosive wearer at peak (60°) impingement angle. This obviously indicates that these polymeric composite materials manners behave (semi-ductile), these results agree with [27]. Figure 7 show the effect of size silica sand (450μm, 600μm, 750μm) on erosive wear rate. From this Figure it can be observed that with increasing size silica sand from (450μm to 750 μm) lead to increased erosive rate. The specimens (A6 and A10) give erosive wear resistance at size silica sand (450μm) than other specimens. The reason is that the presence of filler strengthening increases the bond between the resin matrix and reinforcing material, thus weight loss becomes less, this result agrees with [11 and 28].
### Table 6. Results erosive wear rate with the output results using L9 orthogonal array of specimens filled with eggshell powder

| Exp. | Filler (A) | Angle impingement (º) (B) | Size silica sand (µm) (C) | Wear Rate (g/g) | S/N  |
|------|------------|---------------------------|---------------------------|----------------|------|
| 1    | E0         | 30˚                       | 450                       | 0.0177         | 35.0405 |
| 2    | E0         | 60˚                       | 600                       | 0.0195         | 34.1993 |
| 3    | E0         | 90˚                       | 750                       | 0.0212         | 33.4733 |
| 4    | E1         | 30˚                       | 600                       | 0.0035         | 49.1186 |
| 5    | E1         | 60˚                       | 750                       | 0.0053         | 45.5145 |
| 6    | E1         | 90˚                       | 450                       | 0.0047         | 46.5580 |
| 7    | E2         | 30˚                       | 750                       | 0.0027         | 51.3727 |
| 8    | E2         | 60˚                       | 450                       | 0.0018         | 54.8945 |
| 9    | E2         | 90˚                       | 600                       | 0.0034         | 49.3704 |
| 10   | E3         | 30˚                       | 450                       | 0.0015         | 56.4782 |
| 11   | E3         | 60˚                       | 750                       | 0.0022         | 53.1515 |
| 12   | E3         | 90˚                       | 600                       | 0.0029         | 50.7520 |
| 13   | E4         | 30˚                       | 750                       | 0.00054        | 65.3521 |
| 14   | E4         | 60˚                       | 600                       | 0.00066        | 63.6091 |
| 15   | E4         | 90˚                       | 450                       | 0.00042        | 67.3550 |
| 16   | E5         | 30˚                       | 750                       | 0.00015        | 76.4782 |
| 17   | E5         | 60˚                       | 450                       | 0.00010        | 80.000  |
| 18   | E5         | 90˚                       | 600                       | 0.00019        | 74.4249 |

### Table 7. Results erosive wear rate with the output results using L9 orthogonal array of specimens filled with rice husk powder

| Exp. | Filler (A) | Angle impingement (º) (B) | Size silica sand (µm) (C) | Wear Rate (g/g) | S/N  |
|------|------------|---------------------------|---------------------------|----------------|------|
| 1    | E0         | 30˚                       | 450                       | 0.0177         | 35.0405 |
| 2    | E0         | 60˚                       | 600                       | 0.0195         | 34.1993 |
| 3    | E0         | 90˚                       | 750                       | 0.0212         | 33.4733 |
| 4    | E1         | 30˚                       | 600                       | 0.0035         | 49.1186 |
| 5    | E1         | 60˚                       | 750                       | 0.0053         | 45.5145 |
| 6    | E1         | 90˚                       | 450                       | 0.0047         | 46.5580 |
| 7    | E2         | 30˚                       | 750                       | 0.0027         | 51.3727 |
| 8    | E2         | 60˚                       | 450                       | 0.0018         | 54.8945 |
| 9    | E2         | 90˚                       | 600                       | 0.0034         | 49.3704 |
| 10   | E3         | 30˚                       | 450                       | 0.0015         | 56.4782 |
| 11   | E3         | 60˚                       | 750                       | 0.0022         | 53.1515 |
| 12   | E3         | 90˚                       | 600                       | 0.0029         | 50.7520 |
| 13   | E4         | 30˚                       | 750                       | 0.00054        | 65.3521 |
| 14   | E4         | 60˚                       | 600                       | 0.00066        | 63.6091 |
| 15   | E4         | 90˚                       | 450                       | 0.00042        | 67.3550 |
| 16   | E5         | 30˚                       | 750                       | 0.00015        | 76.4782 |
| 17   | E5         | 60˚                       | 450                       | 0.00010        | 80.000  |
| 18   | E5         | 90˚                       | 600                       | 0.00019        | 74.4249 |
UP, 4% J.f, 3% E.S

UP, 4% J.f, 6%, 9%, 11% E.S

(A)
Figure 4. Represent the main influence plot of S/N ratios on the erosive rate for (A) specimens filled with eggshell powder, (B) specimens filled with rice husk powder.
Figure 5. Represent effect filler on the erosive rate for (A) specimens filled with eggshell powder, (B) specimens filled with rice husk powder.
Figure 6. Represent effect angle impingement on the erosive rate for (A) specimens filled with eggshell powder, (B) specimens filled with rice husk powder.
Figure 7. Represent effect size silica sand on the erosive rate for for (A) specimens filled with eggshell powder, (B) specimens filled with rice husk powder

3.2 Analysis ANOVA for Erosive Rate Results
The analysis is used to understand the effect of the factors and their interaction on erosive rate, and allow determining the effect of each variable on the total variance of the results. The Tables (8 and 9) show the analysis, ANOVA results for specimens reinforced by eggshell and rice husk powder. In the tables, the last column represents the contribution percentage P for each variable and determines the percentage of the effect of the factors on the erosive rate, when P is less than 0.05, this factor has a more influence on the erosive wear rate. Table (8) shows that the P value of filler (A), angle
impingement (B) and silica sand (C) (0.0001, 0.011, 0.016) respectively, has a greater effect on erosive rate. Table (9) shows that the P value of filler (A), angle impingement (B) and silica sand (C) (0.001, 0.038, 0.035) respectively, has a greater effect on erosive rate. From these results can be noted the filler (A) followed the angle impingement (B) and followed the size silica sand (C) more effect on erosive rate for specimens filled with eggshell, while the filler (A) followed the size silica sand (C) and followed the angle impingement (B) more effect on erosive rate for specimens filled with rice husk.

Table 8. ANOVA analysis for specimens filled with eggshell powder

| Source                  | DF  | Seq SS    | Adj SS     | Adj MS        | F         | P          |
|-------------------------|-----|-----------|------------|---------------|-----------|------------|
| Filler (A)              | 5   | 0.0007990 | 0.0007989  | 0.0001598     | 451.61    | 0.0001     |
| Angle Impingement (B)   | 2   | 0.0000036 | 0.0000036  | 0.0000018     | 5.08      | 0.011      |
| Size Silica Sand (C)    | 2   | 0.0000037 | 0.0000037  | 0.0000019     | 5.27      | 0.016      |
| Error                   | 8   | 0.0000028 | 0.0000028  | 0.0000004     |           |            |
| Total                   | 17  | 0.0008092 |            |               |           |            |

Table 9. ANOVA analysis for specimens filled with rice husk powder

| Source                  | DF  | Seq SS    | Adj SS     | Adj MS        | F         | P          |
|-------------------------|-----|-----------|------------|---------------|-----------|------------|
| Filler (A)              | 5   | 0.0007646 | 0.0007646  | 0.0001529     | 576.66    | 0.001      |
| Angle Impingement (B)   | 2   | 0.0000044 | 0.0000044  | 0.0000022     | 8.28      | 0.038      |
| Size Silica Sand (C)    | 2   | 0.0000038 | 0.0000038  | 0.0000019     | 7.24      | 0.035      |
| Error                   | 8   | 0.0000021 | 0.0000021  | 0.0000003     |           |            |
| Total                   | 17  | 0.0007750 |            |               |           |            |

5. Conclusions

The incorporation of 11% wt. wastes eggshell and rice husk powder into unsaturated polyester resin with 4% weight fraction jute fiber can significantly reduce the erosive wear loss. The optimal erosive rate resistances characteristic. The specimens (UP +4% J.F +11% E.S) and (UP +4% J.F +11% R.H) give erosive rate resistance (0.00010 gm/gm) and (0.00027 gm/gm) respectively at angle impingement (60º) and size silica sand (450m), while the specimen (UP) give higher erosive rate (0.0212 gm/gm) at angle impingement (90º) and size silica sand (750m) with constant (15hours) time, and flow rate (45 L/min). All specimens behave semi-ductile, and peak erosive wear rate take place at 60º. ANOVA analysis showed that the variables filler, angle impingement and silica size sand have a pronounced effect during the erosion test.

References

[1] Rex J, Daniel A, Umar M 2018 Determination of The Thermal Properties of Groundnut Shell Particles Reinforced Polymer Composite IOSR Journal of Applied Physics 10(5), pp.51-57.
[2] Ruaa H, Reem A 2019 Experimental Investigation of Some Properties of Epoxy Reinforced by Egg Shell Particles International Journal of Mechanical Engineering and Technology 10(1), pp.152-163.
[3] Ahamed M, Reem A M, Jumaa R M 2019 Analysing Some Mechanical Properties of Cinnamon Powder Reinforced with Polymeric Materials Used in Dental Application Engineering and Technology Journal 37(3) Part A.
[4] Marwah S A, Reem A M and AL-Zubidi A B 2019 Flexural, compressive and thermal characterization of hybrid composite Materials AIP Publishing Conference Proceedings 2123, 020084-1–020084-12.
[5] Reem A M 2019 Tensile strength, impact strength and experimental analysis wear behavior of modified zinc nitrate filled polymer IOP Materials Research Express 6(12).
[6] Bijwe J, Rattan R, Fahim M., Tiwari S Erosive wear of carbon fabric reinforced polyetherimide composites Role of amount of fabric and processing technique Polymer composites 29 pp. 337–344.
[7] Finnie I 1960. Erosion of surfaces by solid particles Wear 3, pp. 87–103.
[8] Mohana N, Maheshaa C Rajaprakashb B., 2013, Erosive wear behaviour of WC filled glass epoxy...
composites Procedia Engineering Elsevier 68 pp. 694 - 702.
[9] Khandelwal A, Kumar M, Choube A Mechanical and Tribological Characterization of Short Fibers Reinforced Polymer Composites IOSR Journal of Mechanical and Civil Engineering 11(3), pp. 32-43.
[10] Reem A M, Rajaa K, Dalia M 2017 Study the Erosion Wear Behavior for Unsaturated Polyester Resin Composites Materials Reinforced by Carbon Fibers with Al2O3 Powder Using Taguchi Method Journal of Engineering and Sustainable Development 21(5), pp. 213-224.
[11] Reem A M 2018 Study of some Mechanical Properties and Erosive Behavior by Taguchi Method for Hybrid Nano Composites Engineering and Technology Journal 36(4) Part A.
[12] www.perfectpolymers.net.
[13] Mallick P 2008 Fiber Reinforced Composites Materials, Manufacturing and Design, (Third Edition book), Taylor and Francis.
[14] Aseel B, Emad S, Reem A M, 2015 Effect of Natural Materials Powders on Mechanical and Physical Properties of Glass Fiber / Epoxy Composite Eng. & Tech. Journal 33(1), Part (A), pp.175-197.
[15] Aseel B, Emad S, Marwa S A 2017 Mechanical and Physical Properties of Nano Carbon Tube with Carbon Fiber Reinforced with Polyester Resin Engineering and Technology Journal 35(5), Part A, pp.465-471.
[16] Reem A M 2016 Effect of Al2O3 Powder on Some Mechanical and Physical Properties for Unsaturated Polyester Resin Hybrid Composites Materials Reinforced by Carbon and Glass Fibers Engineering and Technology Journal 34(12), Part A, pp.2371-79.
[17] Aseel B, Emad S, Marwa S A 2018, Effect of Carbon Nano Tube on the Mechanical and Physical Properties of Composites Based on Resin Route Engineering and Technology Journal 36 (4), Part (A), pp.410-416.
[18] Annual Book of ASTM, 2013, Standard: Standard Test Methods for conducting erosion tests by solid particle impingement using gas jets G76- No. 13, DIO:10.1520/G0076-13.
[19] Mishra P. and Acharya S 2010 Solid particle erosion of Bagasse fiber reinforced epoxy Composite International Journal of Physical Sciences 5, pp.1-7.
[20] Patnaik A 2008 Implementation of Taguchi Design for Erosion of Fiber-Reinforced Polyester Composite Systems with SiC Filler Journal of Reinforced Plastics and Composites 27(10), pp. 1-19.
[21] Patnaik A, Satapathy A, Mahapatra S and Dash R 2008 A modeling approach for prediction of erosion behavior of glass fiber–polyester composites Journal of Polymer Research 15, pp. 147–160.
[22] Patnaik A 2008 A Taguchi Approach for Investigation of Erosion of Glass Fiber – Polyester Composites Journal of Reinforced Plastics and Composites 27(8), pp. 1-18.
[23] Aseel B, Emad S, Reem A Mohammed 2015 Influence of Coating with Some Natural Based Materials on the Erosion Wear Behavior of Glass Fiber Reinforced Epoxy Resin Al-Khwarizmi Engineering Journal 11(2), pp. 20-30.
[24] Patnaik A, Satapathy A, Chand N, Barkoula N, Biswas S 2010 Solid particle erosion wear characteristics of fiber and particulate filled polymer composites: A review Wear 268 pp. 249-263.
[25] Tewari U, Harsha A, Hager A, Friedrich K 2003 Solid particle erosion of carbon fibre- and glass fibre-epoxy composites Composites Science and Technology 63 pp.549-557.
[26] Anu G, Ajit K, Amar P, Sandhyaranji B 2012 Effect of Filler Content and Alkalization on Mechanical and Erosion Wear Behavior of CBPD Filled Bamboo Fiber Composites Journal of Surface Engineered Materials and Advanced Technology 2 pp.149-157.
[27] Aseel B, Emad S, Reem A M 2015 Erosion Wear Behavior of Industrial Material Reinforced Epoxy Resin Composites and its Coating with Natural Based Material Eng. & Tech. Journal 33 (4), Part (A), pp.902-918.
[28] Aseel B, Emad S, Marwa S A 2018 Effect of Carbon Nano Tubes on Erosion Wear of Carbon Fiber, Glass Fiber & Kevlar Fiber Reinforced Unsaturated Polyester Composites journal of engineering and sustainable development 22(4), pp.74-89.