Experimental study of food waste powder FWP influence on compressive and wear behaviour of polyester composite

Zaynab N. Rasheed1, a and Samah M. Hussein 1

1Applied Sciences Department, University of Technology, Baghdad, Iraq.

a) Corresponding author: 100123@uotechnology.edu.iq

Abstract: Composites reinforced by natural fillers approved to have good tribological properties which essentially required in industrial applications demand specific friction coefficient and wear resistance such as flooring materials and brake pads materials…etc. Food wastes powder (FWP) such as crusts are abundant and possess good mechanical properties, these materials evaluated to assess the possibility of using (Polyester/FWP) as a new engineering material with enhanced mechanical properties. In this research, (UPE/FWP) composites prepared by Hand lay-up molding. Compression and wear behavior of UPE composites reinforced with different types of food waste powder FWP have been investigated. Matrix polyester reinforced with four types of FWP (Coconuts Shells, Chestnuts shells, Egg shells, and Pistachio shells) proposed as new engineering materials with enhanced mechanical and frictional properties. The utilize particles size vary between (713.9, 1094.7, 1060.4 and 543.7) nm respectively. Mixing concentration ratio utilize were (2 and 4 wt %) for all. The results showed that all four types of FWP have improved the mechanical and tribological behavior of UPE composites with mild variation. Both, coconuts and chestnuts particles have the significant effect on the compression strength (C.S.), 4wt% ratio present the higher (C.S) value measured for all (FWP) used and the performance increase gradually as filler contain increased. Also, the value of Young’s Modulus observed to be increased as the (FWP) increases and the best value observe at 4wt% (UPE/coconuts shell and UPE/chestnuts shell) composites. Wear rate (W.R.) results present a noticeable reduction during the increase of additive concentration with mild variation. FWP acts as a good reinforcement with polyester composite so the wear resistances consequently increase.

Keywords: Polyester Composites, Food waste powder (FWP), UPE/FWP, Coconuts powder, Chestnuts powder, Eggs powder, Pistachio powder, Natural fillers.

1. Introduction

Composite materials are known as essential parts of modern industry especially with polymer matrix due to their superlatives properties such as high specific stiffness and strength, lightweight, cost-effectiveness and ease of processing. Generally, Polymer composite used in a broad area of structural applications like motor vehicles, aerospace, furniture and construction industries [1-3]. In the recent decades, research effort increased in the process of using natural fillers as polymer composites
reinforcement to improve the mechanical and tribological applications [4, 5]. Natural fillers have many characteristics such maintain good environmental properties, abundantly available, biodegradable, economical and ease of manufacturing comparing with artificial fillers, all these and more made it a universal tendency to be used in a wide range [6].

Numerous endeavors have been previously made to use natural fillers in several types to produce polymer composite with improved characteristics. Natural fibers reinforced polymer composites were used in order to increase both physical and mechanical properties [7-10]. Different types of food waste [11-14] and agriculture wastes [15 and 16] have been used as natural powder additives to improve the performance of polymers. A hybrid composite materials using Cashew Husk nut, Wood Powder and Groundnut were studied and exhibited good properties [17]. Also, nanoparticles comes from natural resources were incorporated into the polymer to obtain a nanocomposite [18-20]. In industrial applications, polyester composite is widely utilize with natural fillers [3, 6, 21 and 22], as they possess many advantages compared to other polymers such as room temperature cure capability, good mechanical properties and transparency. Polyester reinforced by natural filler is still in the field of research and development to conduct more advance practical studies and discussions.

In this study an attempt to further improve some mechanical and tribological properties of polyester composites like (compression strength and wear behavior). The main focus was to use four types of FWP (Coconuts Shells, Chestnuts shells, Egg shells, Pistachio shells) as composite filler with USP (matrix polymer). FWP used after several process to get the final shape of particles required. The added particles used in two ratio (2 and 4wt %). Using waste materials to fabricate polymer composites was mainly due to environmental and economic apprehensions. So, that why it is necessary to evaluate their behaviour under different working conditions.

2. Materials and preparation:

2.1 polyester preparation.

The prepared composite used polyester resin (SIRRESIN, SABIC KSA) as a polymeric matrix.

2.2 Technique of food waste powder FWP preparation.

Fig. 1 represents the collected food waste for four different food waste shells (Coconuts shells, Chestnuts shells, Egg shells and Pistachio shells) respectively from local households before and after grinding process. First, all the selected shells washed with water to remove unwanted objects and to get rid of the thin outer membrane, then left to dry in the sun. All four different shells treated with 6 gm of NaoH solution (1 liter) which immersed in a laboratory beaker which left for 3 hours and removed after
that to be dried inside special furnace at (60)°C for another 3 hours. This chemical treatment performed to enhance the bonding compatibility between the polymer matrix and added fillers.

To obtain the final required powder shape first of all manual grinding applied to all shells respectively then sequentially all these shells placed inside grain miller to obtain final fine powder. Final step was using sieving device to separate the different particle size inside the prepared powder. The final category used from the prepared powder represents the finest particles from the sieving process which were finally put a side for particles sizing process. Particle size distributions (PSD) for all prepared FWPs were carried out using laser diffraction particle size analyzer (Brookhaven Nano-Brook 90 plus USA device). The results of particle size analyzer showed in Fig.2 for all FWP used in this research. The mean particles diameter were (713.9, 1094.7, 1060.4 and 543.7) nm respectively for FWPs coconut shells, chestnut shells, egg shells and pistachio shells.

**Figure 1:** Food wastes powder FWP before and after preparation (a) coconut shells and powder (b) chestnut shells and powder (c) Eggshells and powder (d) pistachio shells and powder.
**Figure 2:** Particle size distribution (PSD) analysis: (a) coconuts shell powder (b) chestnuts shell powder (c) Eggshells shell powder (d) pistachio shell powder respectively.
2.3 Technique of polyester composite preparation.

Using hand layup method all previously mentioned polymer composite samples were done. At room temperature all samples prepared by mixing polyester resin polymer with the different type of food waste powder (FWP) additive. Initially, Chestnut shells, Coconuts Shells, Egg shells, and Pistachio shells were prepared and ready to mix with the polyester matrix. As showed in Table 1 demonstrate all samples with the weight ratio including the matrix and additives. A glass mold used which contain a thick glass cover used to get the required smooth surface and to prevent area bubble entry the dough during the curing. After measuring the selected additive weight ratio for each sample as in table 1, mixing process between the polyester and different additive powder were accomplish using a mechanical stirrer until homogenous shape obtained. Later on the polyester hardener poured in the specific amount for each case to the baker contain the mixture with continuous mixing for 5 min. lastly, the prepared mixture poured into the glass mould and let to dry. Then, samples must set in special oven at 60° for 1 hour in order to remove any remained stresses and to get better bonding. These samples, then been cut into the standard dimension of the selected tested in this study.

Table 1 composition of samples (Polyester / FWP) composite.

| Sample code | Composition                      | Weight of Polyester (g) | Weight proportion of additive (g) |
|-------------|----------------------------------|--------------------------|----------------------------------|
| p           | 100% Polyester                   | 86.71                    | -                                |
| a           | 98% Polyester +2% Coconuts shell powder | 84.97                   | 1.73                             |
| b           | 96% Polyester +4% Coconuts shell powder | 81.57                   | 3.46                             |
| c           | 98% Polyester +2% Chestnut shell powder | 84.97                   | 1.73                             |
| d           | 96% Polyester +4% Chestnut shell powder | 81.57                   | 3.46                             |
| e           | 98% Polyester +2% Eggs shell powder   | 84.97                   | 1.73                             |
| f           | 96% Polyester +4% Eggs shell powder   | 81.57                   | 3.46                             |
| g           | 98% Polyester +2% Pistachio shell powder | 84.97                   | 1.73                             |
| h           | 96% Polyester +4% Pistachio shell powder | 81.57                   | 3.46                             |
3. Testing procedure.

3.1 Compression test.

With the use of a hydraulic piston device (ley Bold Harris, No. 36110) compression test was applied on all the prepared samples. Compression strength (C.S.) is the value that represents the maximum stress that the material sample possesses before the final failure. Also, it is the magnitude of maximum stress for a rigid material under longitudinal compression. All samples must be cut according to (ASTM-D695) standard [23]. C.S. value for each sample measured mathematically:

\[
\text{C.S.} = \frac{\text{Maximum Stress}}{A} = \frac{F_{\text{max}}}{A}
\]

Where \((F_{\text{max}})\) is the maximum load applied (N) till the failure of the sample, \((A)\) is the cross section area \((\text{mm})^2\), Young's Modulus then could be measured using the following equation:

Young's Modulus \(\varepsilon\), where Strain \(\varepsilon\). The sample elongation represent by \(\Delta L\) and the original sample length represent by \(L\) (mm).

3.2 Wear Test.

The sliding wear test was carried using pin-on-disc technique which located in the applied science department, University of Technology. The wear rate W.R measured for samples before and after reinforcing with FWP at all ratio (as illustrated in table 1). A rotating iron disc attached to an electric motor used to measure the W.R. at room temperature, where all samples installed to a holder that connected to a flat metal arm. The iron disc hardness is 269 HB and the velocity is 500 rpm. The dimension of the samples were according to ASTM (G99-04) [24] standards for this test. To be noted that disc usually cleaned as well as polished to remove debris or remnants of transfer layer, etc. for each sample used for sliding test, also after wear sliding all the samples were cleaned before measuring the weight in order to remove any attached particles. For each sample the applied load were (10N), whereas the sliding time selected were (5, 10, 15 and 20min) consequently for each sample. The following equation measure wear rate (W.R.) [25]:

\[
\text{W.R.: wear rate (gm/mm), } \Delta m: \text{ difference in weight (gm), S.D.: sliding distance which calculated by: } \frac{S\times T}{60}, \text{ where S: Speed of sliding (mm/min) and T: Time (min)}
\]

4. Result and discussion:

4.1 Compression test evaluation.

For this study nine varied nano-composite samples were fabricated from mixture of (polyester as matrix) and four different types of FWP within ratio of (2wt% and 4wt%) respectively. All samples tested at same circumstances (room temperature 25\(^\circ\)). Fig.(3) represent the measured magnitude of C.S. for all polyester composite samples. From the results it is clear that a noticeable enhancement appear in
all samples after reinforcement comparing to the neat polyester resin, the determined C.S. value for the neat polyester was (55.2MPa). Interestingly, it observed that the best results in C.S. values after the reinforcement with 2wt% appears for both (UPE/coconuts shell and UPE/chestnuts shell) composites. So, the performance for both cases significantly increase until reach highest value about (76.49 MPa and 77.53 MPa) respectively. This behavior explained due to the better compression resistance the used additives possess compared to the polymer base material, also the advantage of additives presents which leads to a reduced vacancy within the matrix material through penetrating the polymer chains and increase the compressive strength [26],[27].

Moreover, as the additive ratio increase to 4wt% the C.S. value slightly increase compared to previous variation. All the results after the addition of FWP appear to be better than the neat polyester result (see fig.3). Best performance achieved by both (UPE/coconuts shell and UPE/chestnuts shell) composites (79.13 MPa),(79.9 MPa) respectively. On the other hand, because of the additive nature (less from the other types) the corporation of both (egg shells powder and pistachio shells powder) at 4wt% slightly enhanced the value of C.S about (60.58MPa) and (60.3MPa) respectively compared to neat polyester. As mentioned before, due to the applied stress transfers from the polymer to the stiff additive used which consequently change the material nature to stiffer and harder, these particles work to prohibit crack propagation [6, 13].

**Figure 3:** Comparison of the C.S. value for all samples.

Furthermore, table 2 presented Young’s Modulus (Y) value for (neat polyester) and the other composite (UPE/FWP) in both concentration ratio (2 wt% and 4 wt%). Young’s modulus represent an indication to the material stiffness which can be measured from the tangential slope of (stress-strain) curve that obtained from compression test. So, due to the reinforcement with different FWP the measured Young’s Modulus (Y) increased significantly and continue increasing steadily as the additive ratio increase until reach maximum value at 4 wt% for both composites (UPE/coconuts shell and UPE/chestnuts shell) composites as in table 2. The addition of FWP (which described as tough particles) leads to make the sample elongation reduced before material failure (break) and thus increase (Y). Consequently, the higher the stiffness of used additive in the composite the higher the (Y) for the same polymer matrix.

**Table 2** Mean value of Young’s Modulus for all samples.
4.2 Wear Rate W.R. evaluation.

The wear rate W.R. of neat polyester resin and four different composite prepared using FWP in two ratio (2 and 4 wt %) been calculated against the sliding time. In this work W.R. evaluated according to: (1) the increase in the sliding time for all samples compared to neat polyester value, (2) the increase of concentration ratio of FWP. The selected time for each sample measurement were (5, 10,15 and 20) min. Basically, from the results it is clear that the neat polyester present the highest W.R. value at all-time and increased consequently through time increase (poorest performance). Noticeable, The biggest W.R. variation increase in the neat polyester located after 20 min of wear sliding over (pin on disc device), this could be due to temperature that raised during the rotation which happened as a result of friction between (sample and disc) which lead to decrease the mechanical properties [28], neat polyester W.R. variation percentage illustrated in table 3.

All other composite samples for both concentration ratio presented a less W.R. comparing to neat polyester at the same sliding time, then the value nearly stabilized with the time. Over all, increasing the specific W.R. under the applied load through the time refer to sensitivity of loads on wear loss which occur due to material deterioration caused by thermal-mechanical deformations above the elastic limit of the materials [3].

| W.R. variation% | W.R. variation% | W.R. variation% |
|-----------------|-----------------|-----------------|
| (5-10)min       | (10-15)min      | (15-20)min      |
| 38%             | 32%             | 48%             |

Furthermore, from Figs (4, 5, 6 and 7) all results indicate a slight increase in the W.R. as the time of sliding increase except the neat polyester resin as mentioned before (W.R. were huge). Variations in the W.R. depend essentially on the FWP type used for each composite. W.R. of both (UPE/coconuts shell and UPE/chestnuts shell) composites presented the best wear performance. The samples (a, b, c and d) exhibit the lowest value for W.R. among the group. W.R. in neat polyester after 20 min was (15.9gm/mm) while
at 4 wt% for both (UPE/coconuts shell and UPE/chestnuts shell) composites the value reduced till (2.6gm/mm), (1.5gm/mm) respectively for the same sliding time. The enhancement percentage for using these two type of FWP were the best around (84%), (90%) respectively as illustrated in table 4.

It was clear that the wear resistance of these composites were higher than the other two types (UPE/eggshell and UPE/pistachio shell) at 4 wt % which indicates W.R. value after 20 min (3.4 gm/mm), (3.8 gm/mm) respectively. The enhancement percentage for the last two composites compared to neat polyester at the same sliding time illustrated in table 4. This could be explain as wear mechanism was dominated by FWP type and percentage. That means (a) the stiffness nature of FWP (i.e. the high hardness which lead to decrease the contact touching surface)[29] and (b) the high concentration of the reinforcement added, all these lead to a better wear performance compared to neat polyester. Overall, all composite samples (UPE/FWP) with 4wt % presented improved performance to reduce W.R. value (the value varied depending on FWP type) .The increase in wear resistance was due to many reasons: the FWP dispersed uniformly inside the matrix polymer, and forming a thick, protective friction layer lead to enhance the friction surface strength [30].

Figure 4: Plots between W.R. and sliding time of neat polyester resin and (UPE/Coconuts shell) composite at (2 and 4 wt%) respectively.

Figure 5: Plots between W.R. and sliding time of neat polyester resin and (UPE/Chestnuts shell) composite at (2 and 4 wt%) respectively.
Figure 6: Plots between W.R. and sliding time of neat polyester resin and (UPE/Eggs shell) composite at (2 and 4 wt%) respectively.

Figure 7: Plots between W.R. and sliding time of neat polyester resin and (UPE/Pistachio shell) composite at (2 and 4 wt%) respectively.

Table 4 the improvement in W.R. of polyester/FWP compared to neat polyester

| Sample code | a  | b  | c  | d  | e  | f  | g  | h  |
|-------------|----|----|----|----|----|----|----|----|
| Improvement%| 69 | 84 | 76 | 90 | 72 | 79 | 64 | 76 |

5. Conclusion
This study concludes the following:
- Incorporation of FWP in polyester resin enhanced C.S. and this raise steadily as the concentration of additive increase.
- Both (coconuts and chestnuts) shells powders had significantly increased the ultimate compressive strength value among all types of FWP from 55.2 MPa to 79.13MPa and 79.7 MPa respectively.
• Young’s modulus value increase as FWP concentration increase in polyester composite compared to neat polyester.
• Young’s modulus for both (coconuts and chestnuts) shells powder at 4 wt% indicate the highest value among the group (4495.2 MPa) and (4039.1MPa) respectively.
• As sliding time increases W.R. increased significantly especially for the neat polyester. Yet, a slight change in this value found within polyester/FWP composite.
• The weight loss and W.R. during wear test decreases with the increase of FWP concentration ratio depending on the powders type.
• Best wear resistance found in 4wt% using both (coconuts and chestnuts) shells powders as additives after 20 min sliding, W.R. improved for both (84% and 90%) respectively.
• All types of FWP reinforcement used in this study reduced W.R and introduced significant enhancement for wear performance.

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