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Physico-Mechanical Properties of Composites Produced from Thermoplastic Polymers Filled with Egg Shell

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

The aim of this research is to develop environmentally friendly, lightweight composites using egg shell, as filler in some thermoplastic polymer matrices Polypropylene (PP), High Density Polyethylene (HDPE), Acrylonitrile-Butadiene-Styrene (ABS) and Polystyrene (PS) polymer; to determine the physico-mechanical properties of the egg shell agro-residue polymer composite, to find if there is any new improvement over the properties of the starting thermoplastic polymer composites.This research work studied the reinforcement potential of egg shell in thermoplastic polymers (HDPE, PS, PP and ABS). Egg shell was collected from the surroundings of Ekwulumili in Nnewi-South L.G.A of Anambra State, Eastern Nigeria where they have been dumped after usage. The research was carried-out at JUNENG NIG LIMITED Enugu, Civil Engineering Department Laboratory University of Nigeria and Chemical Engineering Department Laboratory Ahmadu Bello University (ABU), Nigeria; between May 2016 and August 2018. The agro-wastes were grand into power and incorporated into the virgin thermoplastic polymers as filler at varied levels of 3%, 6%, 9%, 12% and 15%. The virgin thermoplastic polymers were used as the Control in the study. The mechanical properties of the composites produced were determined using American standard for Testing and Materials (ASTM), Standard Testing Methods. The results generally showed significant improvements in the physico-mechanical properties of the egg shell filler composites which were largely influence by the amount of filler in the composites. However, the water absorption capacities of the composites were found to be higher than those of the virgin thermoplastic polymers; an

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indication that egg shell reinforced at different percentage values are not compactable with polymer matrices due to the hydrophilic nature of natural fibers. HDPE at 15% (8.95%), 3% (4.28%), 9% (3.11%), 12% (0.88%) and 6% (0.85%) and Control (0.00%). PS, at 3% (8.24%), 6% (7.49%), 12% (2.18%), 9% (1.13%), 15% (0.49%) and Control (0.12%). PP, 9% (5.02%), 12% (3.99%), 3% (3.06%), 6% (0.78%) and 15% (0.67%) and Control (0.13%). ABS at 6% (5.52%), 12% (5.03%), 15% (1.50%), 3% (1.02%) and 9% (0.83%) respectively also had very high-water absorption than the Control (0.11%).

Brinell hardness property of egg shell/polymer matrix composites had better values than the virgin polymer; HDPE value at 6% (39.48 N/mm^2) > 3% (39.46 N/mm^2) > 9% = 12% (39.40 N/mm^2) > 15% (39.39 N/mm^2) and Control (36.44 N/mm^2). PS at 3% (39.60 N/mm^2) > 6% (39.56 N/mm^2) > 9% (39.54 N/mm^2) > 12% (39.12 N/mm^2) > 15% (38.85 N/mm^2) respectively had higher brinell hardness above the Control (37.04 N/mm^2). PP had value only at 3% (29.28 N/mm^2) that showed lower brinell hardness; 6% (39.35 N/mm^2) > 15% (37.55 N/mm^2) > 9% (37.36 N/mm^2) and > 12% (36.93 N/mm^2) respectively showed higher brinell hardness than the Control (36.32N/mm^2). ABS; 12% (39.54 N/mm^2) > 6% (39.40 Nmm^2) > 3% equal to 9% (39.39 N/mm^2) and > 15% (39.35 N/mm^2) respectively had better brinell hardness than the pure polymer. Abrasion results of all egg shell/polymer matrix composites used (exception of PS) showed poor abrasion values than the Control; For HDPE the value at 3% (29.47 g/s), 9% (25.03 g/s), 12% (23.54 g/s), 15% (23.13 g/s) and 6% (22.36 g/s) and Control (14.57 g/s). PS, at 12% (12.16 g/s), 3% (10.79 g/s), 6% (8.35 g/s),15% (6.69 g/s) and 9% (5.59 g/s) and Control (16.20 g/s). PP had at 12% (55.47 g/s), 6% (47.90 g/s), 3% (40.16 g/s), 9% (32.80 g/s) and 15% (22.11 g/s) and Control (18.02 g/s). ABS at 3% (15.05 g/s), 15% (87.52 g/s), 6% (24.10 g/s), 12% (22.08 g/s), 9% (21.07 g/s) and Control (17.39 g/s).

The impact strengths absorbed higher amount of energy than the Control in PP, HDPE, ABS, 3%, 6%, 9% of PS, 3%, and 6% of PP in egg shell composites. HDPE at 12% (3.12 J/mm^2) > 3% (2.95 J/mm^2) > 6% (2.88 J/mm^2) > 9% (2.35 J/mm^2) > 15% (1.63 J/mm^2) and Control (1.84 J/mm^2). In PS, 3% (4.03 J/mm^2) > 6% (2.86 J/mm^2) > 9% (2.67 J/mm^2) >12% (1.48 J/mm^2) > 15% (1.25 J/mm^2) and Control (1.98 J/mm^2). PP at 6% (2.16 J/mm^2) and 3% (1.63 J/mm^2) showed higher impact strength while 15% (1.23 J/mm^2) > 9% (1.08 J/mm^2) > 12% (0.91 J/mm^2) respectively showed lower impact strength than the Control. In ABS 15% (1.14 J/mm^2) absorb lower energy while 9% (1.17 J/mm^2) had equal value with control (1.17 J/mm^2); at 12% (3.18 J/mm^2), 6% (2.16 J/mm^2), and 3% (1.38 J/mm^2) respectively absorb higher energy than the Control. This study has provided different combinations of agro-waste/agro-residue thermoplastic polymer composites which has potential application in the automobile and building construction industry.

Keywords: Egg shell; polymer matrices; composites; hardness; abrasion; water adoption; impact percentages (3%, 6%, 9%, 12% and 15%).

1. INTRODUCTION

The trends in present days of environmentally friendly materials design and fabrication has triggered towards green composite due to challenges of global environmental concerns such as follows: rising average global temperatures, rising sea level and decreasing polar ice cap etc [1,2].

In developed and under-developing countries, agro-waste products are produced in large quantities and cause environmental degradation, such as being burnt off or dumped in water bodies thereby causing environmental pollution [3-5]. The utilization of agro-waste products would help solve the problem of environmental pollution which they constitute. It will also serve as a means of turning waste to wealth by utilizing agro-waste products in developing a low-cost polymer composite to serve a number of interesting applications. The abundant presence of natural fibre/filler and any other available agro-waste has been also responsible for latest development in research towards eco-friendly composite materials [6-8]. Having discovered from practical works that particulate fillers or fibres are very good in reinforcing and enhancing the properties of polymer matrices, it is imperative to utilize waste from agricultural products and extracts obtained for material development and applications. Blending or fabricating of agro-waste and plastic (virgin or recycled) to obtain a material of superior properties to the single material for multi-functional applications could formed a good composite. Agro-waste as filler and its reinforcement in thermoplastics are popular when compared to inorganic materials such as glass filler, carbon filler, clay etc. [9]. Thus, these inorganics most likely produce residues with toxic by-products during manufacturing process. The studies of natural-filler-based packing materials possess various benefits and excellent properties over synthetic packaging materials such as improved mechanical strength, dimensional stability, wear resistance, low cost, low specific gravity, availability, non-abrasiveness and recyclability etc. [10]. Polymer matrix composites consist of polymer (e.g., epoxy, polyester, urethane), reinforced by thin diameter fibres (e.g., agro-waste, graphite, aramids, boron). Generally, the mechanical properties of polymers are insufficient for many structural determinations. In particular, their strength and stiffness are low compared to metals and ceramics. These complications are overcome by reinforcing polymers with other materials. The equipment essential for manufacturing polymer matrix composites are simpler. Due to this reason, polymer matrix composites are developing rapidly and would soon become popular for structural applications [11,12]. Current literature shown a studied-on utilization of the bio-fibre based reinforced polymer composites. In their work banana, bamboo and pineapple fibres were used to formulate the composite [13,14]. The amalgamation of all three fibres (bamboo/banana/pineapple) gave rise to the reinforced hybrid composites. The maximum weight of reinforcing element used in composite is 30% and the other is matrix material. The developed samples were subjected to mechanical tests as per American Society for Testing Materials (ASTM) standards and best arrangement is recommended for the manufacturing of automobile applications (7).

The aim of this research is to develop environmentally friendly, lightweight composites using cow horn, as filler in some thermoplastic polymer matrices Polypropylene (PP), High Density Polyethylene (HDPE), Acrylonitrile-Butadiene-Styrene (ABS) and Polystyrene (PS) polymer; to determine the mechanical properties of the agro-residue polymer composite, to find if there is any new improvement over the properties of the starting thermoplastic polymer composites.

2. METHODOLOGY

Egg shell was collected from the surroundings of Ekwulumili in Nnewi-South L.G.A of Anambra State, Eastern Nigeria where they have been dumped after usage. Commercial virgin polymer matrices were purchased from one of the Petrochemicals company, Nigeria. The polymeric matrices used in this research are pellets of Polypropylene (PP), High Density Polyethylene (HDPE), Acrylonitrile-Butadiene- Styrene (ABS) and Polystyrene (PS) polymer. The equipment used were Monsanto Tensiometer, weighing balance, ventilated oven, 0.2 μm mechanical sieve, and Universal Testing Machine (UTM) 5569A (JJ Lloyd, London, United Kingdom, capacity 1-20KN) in accordance with ASTM D570 for water absorption, Izod impact strength ASTM D256, hardness ASTM D785 methods. Zinc Stearate was used as a protective incorporated.

Egg shell was washed with clean running water, sun dried and then was broken into pieces with mechanical grinding mill machine. The broken pieces were then ground produce fibre powder and then they were separated with 0.2 μm mechanical sieve to get the particle form. Inside a beaker 1g NaOH was added into 99ml of distilled water to make solution. After adequate drying of the fibres for 2 to 3 hours, the fibres were soaked in the prepared NaOH solution. Soaking was carried out at different time intervals depending upon the strength of fillers/fibre required. The fibres were then taken for compression moulding and the particle sized of the filler used were 3 g, 6 g, 9 g, 12 g and 15 g of coconut shell fillers. The composites were prepared using the following blending formulation:

2.1 Egg Shell/Polymer Composite Formulation

One hundred grams (100 g) each of polymer matrices were used as a starting material (Control) before reinforcement of various percentages such as 3%, 6%, 9%, 12% and 15% of egg shell fillers were added into the different polymer matrices used. Polymer matrices blended with particle size of the agro-wastes fillers were measured into a compression mould, for example 97 g of acrylonitrile butadiene styrene matrix blended with 3 g of egg shell filler was measured before subjecting the mixtures to compression moulding to produce the composites. Zinc stearate was used as protective incorporated coated into polymer matrix composite to prevent adhesion to the plastic surface and it was mixed into resin for compression moulding. Polymer matrix.

Chart 1. Comparative view of Polymer matrices and Agro-Wastes Filler

Weight of Polymer matrices (g)	Weight of Agro-Wastes Filler in Composites (g)
100	0.0
97	3.0
94	6.0
91	9.0
88	12.0
85	15.0

composite was placed between them and then the mould was closed; heat and pressure were applied to obtain a homogeneous composite. A preheating time of about 1 hour at 120°C was needed for moulding and 30 minutes for cooling to get the solid moulding. Rapid cooling (quenching) was applied at the end of holding time. After processing, specimens were cut into the desired size and shape before the characterization of the samples. Each of the experiment was carried out severally in order to obtain accurate data.

2.2 Mechanical Properties

All the tests were carried out using International Standards such as American Society for Testing Materials (ASTM) standards. Universal Testing Machine (UTM) 5569A was suitable for many mechanical tests of polymer matrix composites. The composites containing 3%, 6%, 9%, 12%, 15% w/w filler each were prepared and the mechanical properties examined. The parameters determined were brinnel hardness, abrasion, water absorption, Izod impact.

1) Brinnel Hardness Test

Hardness test is a mechanical property of the material that can be described as the resistance of the material to localized deformation or measurement of toughness. For this test, ASTM D785 method and monsanto Tensiometer equipment with sample size of 20 × 20 × 3.2 mm dimension were employed for measuring the hardness.

Procedure:

i. On the Universal testing machine, six of the brinnel buld (Indenter pin) were placed and appropriately pinned.
ii. The test piece facing the direction of the indenter in a horizontal direction was inserted. (Ensure that the surface area of the test piece was well polished)
iii. Constant load applicable to the entire samples were chosen. (Note that it was a comparative test). The load to reach the chosen value was applied and then stopped, and the sample removed.
iv. The depth of penetration on the test piece was measured and recorded as (d) while D is the indenter diameter.
v. The Brinnel Hardness Number (HBN) was thus calculated using the expression;

Where,

P= constant chosen load (N)
D= Brinnel buld diameter (indenter diameter)
d= depth of indentation (mm)
HBN=Brinnel hardness Number (N/mm^2)

2) Abrasion Test (Tabar Abrasion Test)

Abrasion test is a measurement of wear resistance under constant scratching. Abrasion tester (Tabar) equipment and sample size of 100 × 20 ×4 mm dimension was employed for measuring the abrasion.

Procedure:

i. The test piece was fixed into the abradant pin such that they faced each other.
ii. The range of load was selected which caused the failure of the test piece (relating to its tensile strength).
iii. The Knob button was switched on; this caused the test piece to start to rib round the abradant pin. As the motion continued, the number of cycles to failure was recorded and the amount of mass worn out before the material's failure was also recorded.
iv. The wear index of the material was calculated using the following formula:

$$\text{Wear index} = \frac{\mathrm{L} \times 1000}{\mathrm{c}}$$

This was measured in g/s or g/cycle

Where,

L = Mass Lost
C = Number of cycles

3) Water Absorption (WA) Test

Water Absorption test is a physical property of material for measuring the ability of material to withstand moisture when exposed. The effect of water absorption is important in case the material that has been developed when used for applications comes in contact with water or a measurement of material's ability to withstand moisture when exposed. The test was carried out according to ASTM D570 to find out the moisture content of specimen. The apparatus used were a sensitive weighing balance, ventilated oven and sample size of 100 × 20 × 3.2 mm (L × B × T) dimension.

Procedure:

i. The specimen was dried in a ventilated oven at a temperature of 105°C to 115°C till it attained substantially constant mass.
ii. The specimen was cooled at room temperature and its mass (W_1) obtained; the specimen that is too warm to touch should not be used for the purpose.
iii. Dried specimen was immersed completely in clean water at a temperature of 27°C for 24 hours.
iv. The specimen was removed and any traces of water wiped out with damp cloth and then weighed after it has been removed from water (W_2).

Water absorption measured in percentage (%) is given as:

$$\text{WA\%} = \frac{W_2\,W_1}{W_1} \times \frac{100}{1}$$

Where: W_1 is dry mass and W_2 is wet mass.

4) Izod Impact Test

Impact is the measurement of materials to withstand rumpling or folding when hit with a big force. Impact test was used to evaluate the fracture characteristics of polymer matrix composites, by using standard technique of Izod Impact testing. This method was used to measure the impact energy of polymers. The apparatus used was Impact Testing Machine according to ASTM Standard D256 and weight of Hammer of 6.031 kg; the precision was 0.01 Ft – Lb, maximum temperature was 25°C and maximum tonnage was 180 and size of 100 × 20 × 3.2 mm dimension.

Procedure:

i. The specimens were clamped into the pendulum Impact Test fixture with the notched side facing the stricken edge of the pendulum.
ii. The pendulum was released and allowed to strike through the specimen.
iii. The energy absorbed during the impact was recorded in the unit of Ft – Lb.
iv. The energy in Ft- Lb (pounds) was converted to S.I. unit of J→1Ft – Lb = 1.356 J
v. The impact strength was calculated as follows:

$$\text{Impact Strength} = \frac{\text{Energy absorbed}}{\text{Thickness of the sample (J/mm)}}$$

3. RESULTS AND DISCUSSION

❖ Brinell Hardness (N/mm^2)

Table on Brinell hardness values for agro-waste/polymer matrix composite at 3%, 6%, 9%, 12% and 15% agro-waste levels

❖ Abrasion Test (g/s)

Table on Abrasion values for agro-waste/polymer matrix composite at 3%, 6%, 9%, 12% and 15% agro-waste levels.

❖ Water Absorption (%)

Table on Water absorption values for agro-waste/polymer matrix composite at 3%, 6%, 9%, 12% and 15% agro-waste levels.

❖ Impact Strength Test (J/mm^2)

Table on Impact strength values for agro-waste/polymer matrix composite at 3%, 6%, 9%, 12% and 15% agro-waste levels.

Table 1. Brinell hardness values for agro-waste/polymer matrix composite

			Different percenteges fillers loading				
Agro-waste	**Polymar matrices**	**Control**	**3%**	**6%**	**9%**	**12%**	**15%**
Egg shell	HDPE	14.57	29.47	22.36	25.03.	23.54	23.13
	PS	16.20	10.79	8.35	5.59	12.16	6.69
	PP	18.02	40.16	47.90	32.80	55.47	22.11
	ABS	17.39	15.05	24.10	21.07	22.08	87.52

Table 2. Abrasion values for agro-waste/polymer matrix composite

			Different percenteges fillers loading				
Agro-waste	**Polymar matrices**	**Control**	**3%**	**6%**	**9%**	**12%**	**15%**
Egg shell	HDPE	14.57	29.47	22.36	25.03.	23.54	23.13
	PS	16.20	10.79	8.35	5.59	12.16	6.69
	PP	18.02	40.16	47.90	32.80	55.47	22.11
	ABS	17.39	15.05	24.10	21.07	22.08	87.52

Table 3. Water absorption values for agro-waste/polymer matrix composite

			Different percenteges fillers loading				
Agro-waste	**Polymar matrices**	**Control**	**3%**	**6%**	**9%**	**12%**	**15%**
Egg shell	HDPE	0.00	4.28	0.85	3.11	0.88	8.95
	PS	0.12	8.24	7.49	1.13	2.18	0.49
	PP	0.13	3.06	0.78	5.02	3.99	0.67
	ABS	0.11	1.02	5.52	0.83	5.03	1.50

Table 4. Impact strength values for agro-waste/polymer matrix composite

			Different percenteges fillers loading				
Agro-waste	**Polymar matrices**	**Control**	**3%**	**6%**	**9%**	**12%**	**15%**
Egg shell	HDPE	1.84	2.95	2.88	2.35	3.12	1.63
	PS	1.98	4.03	2.86	2.67	1.48	1.25
	PP	1.28	1.63	2.16	1.08	0.91	1.23
	ABS	1.17	1.38	2.16	1.17	3.18	1.14

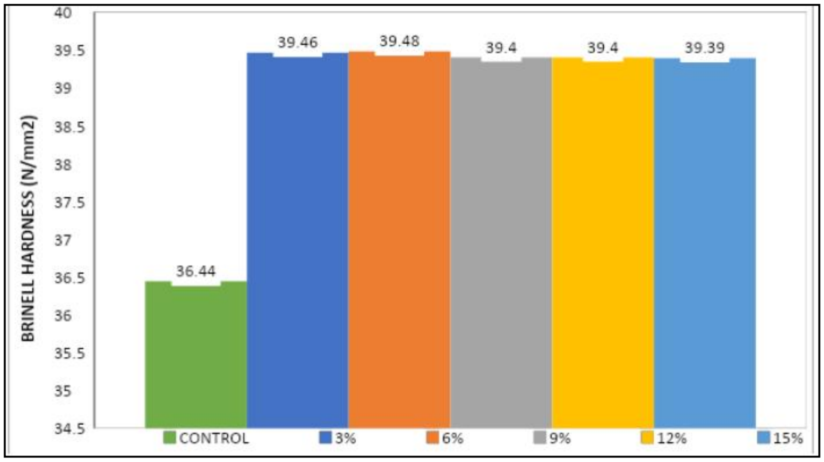

Fig. 1a. Brinell hardness values of the control (HDPE) and HDPE- egg shell composites at 3%-15% filler levels

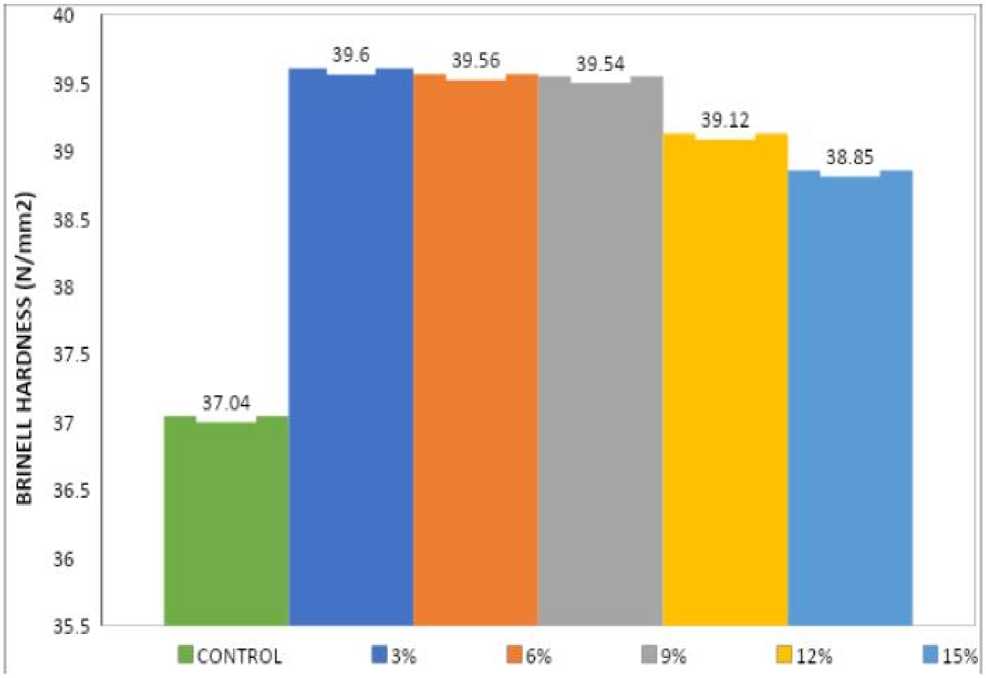

Fig. 1b. Brinell hardness values of the control (PS) and PS- egg shell composites at 3%-15% filler levels

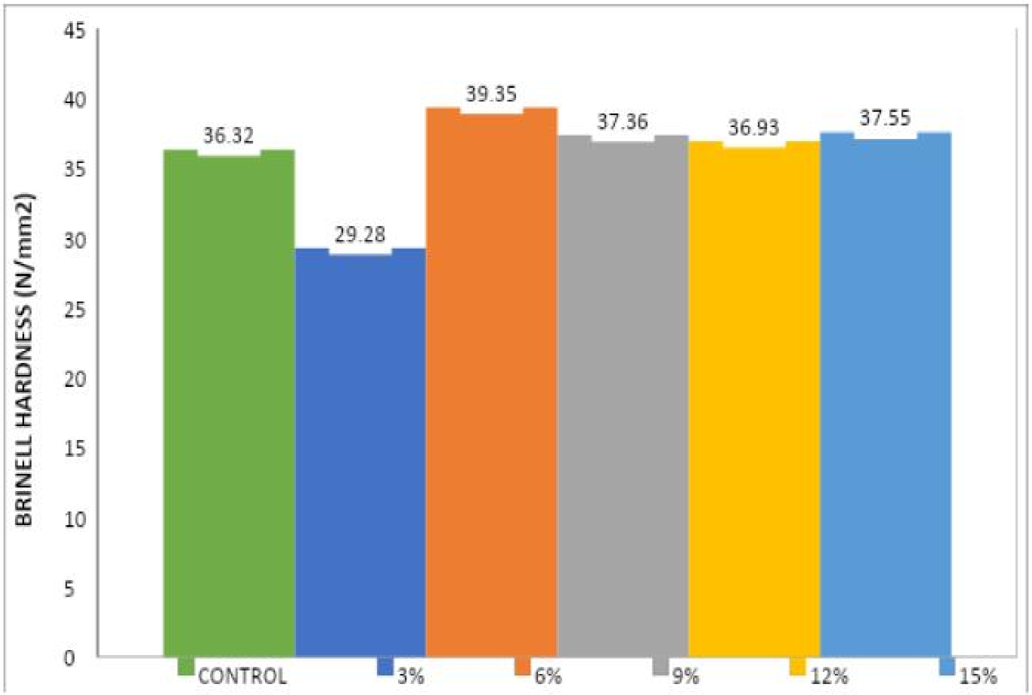

Fig. 1c. Brinell hardness values of the control (pp) and pp- egg shell composites at 3%-15% filler levels

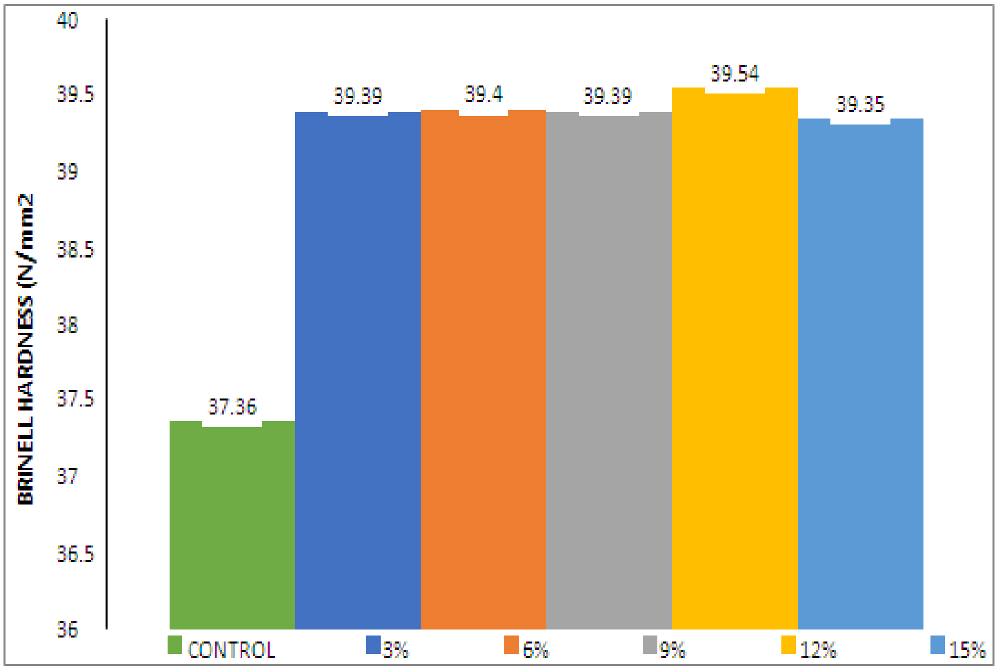

Fig. 1d. Brinell hardness values of the control (abs) and Abs- egg shell composites at 3%-15% filler levels

Pictogram on Abrasion of Egg Shell/Polymer Composite:

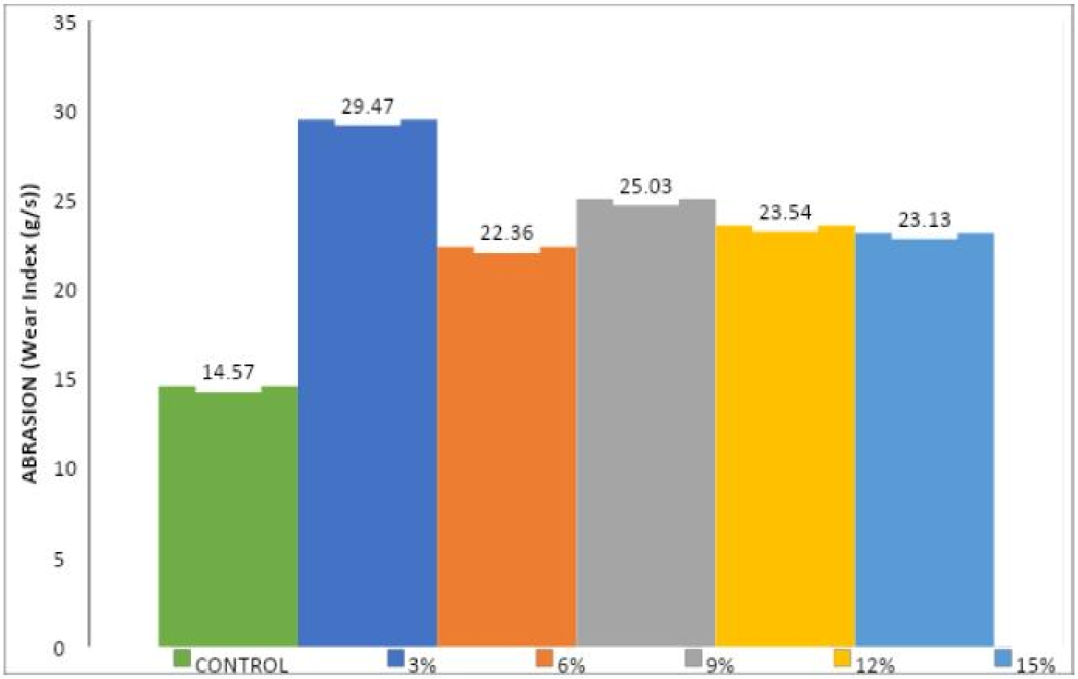

Fig. 2a. Abrasion (Wear Index) values of the control (HDPE) and HDPE- egg shell composites at 3%-15% filler levels

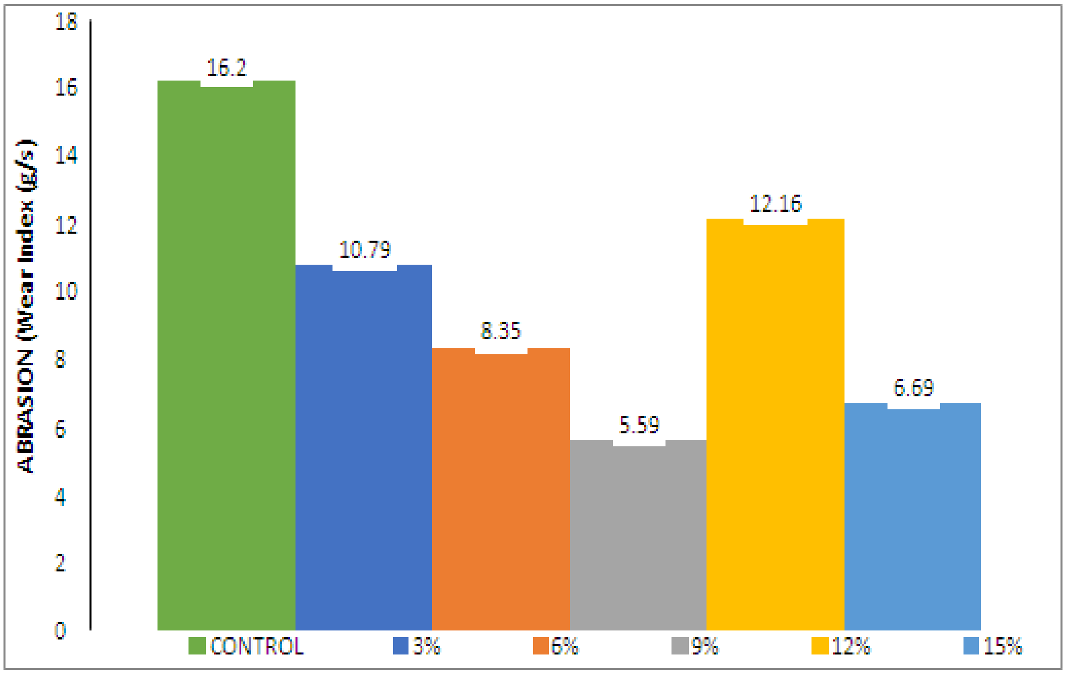

Fig. 2b. Abrasion (Wear Index) values of the control (PS) and PS- egg shell composites at 3%-15% filler levels

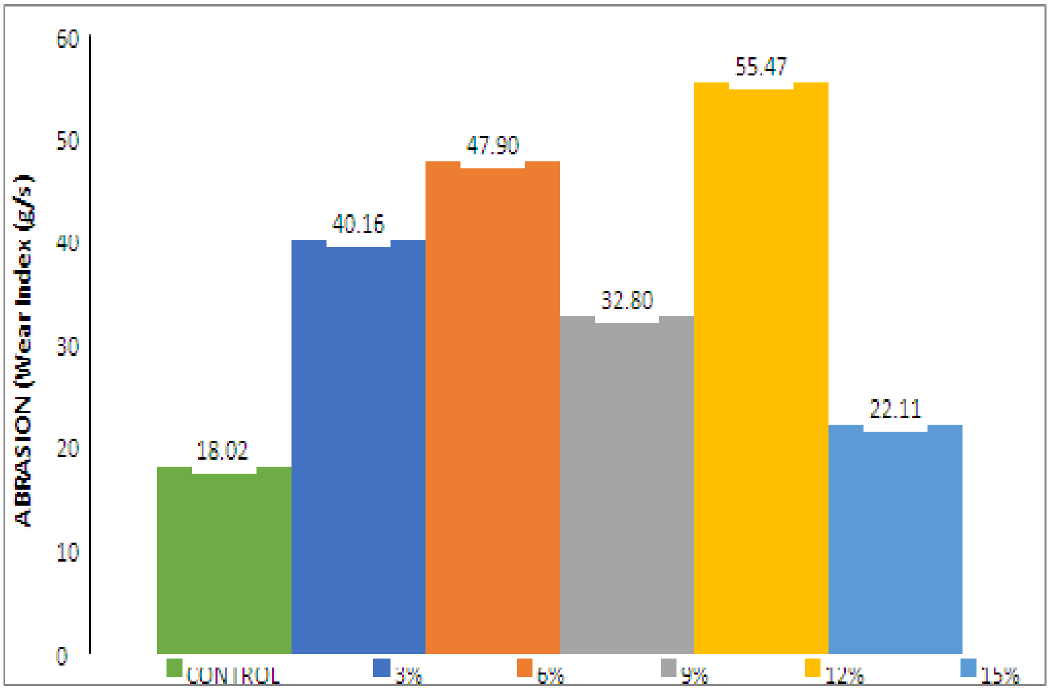

Fig. 2c. Abrasion (Wear Index) values of the control (PP) and PP- egg shell composites at 3%-15% filler levels

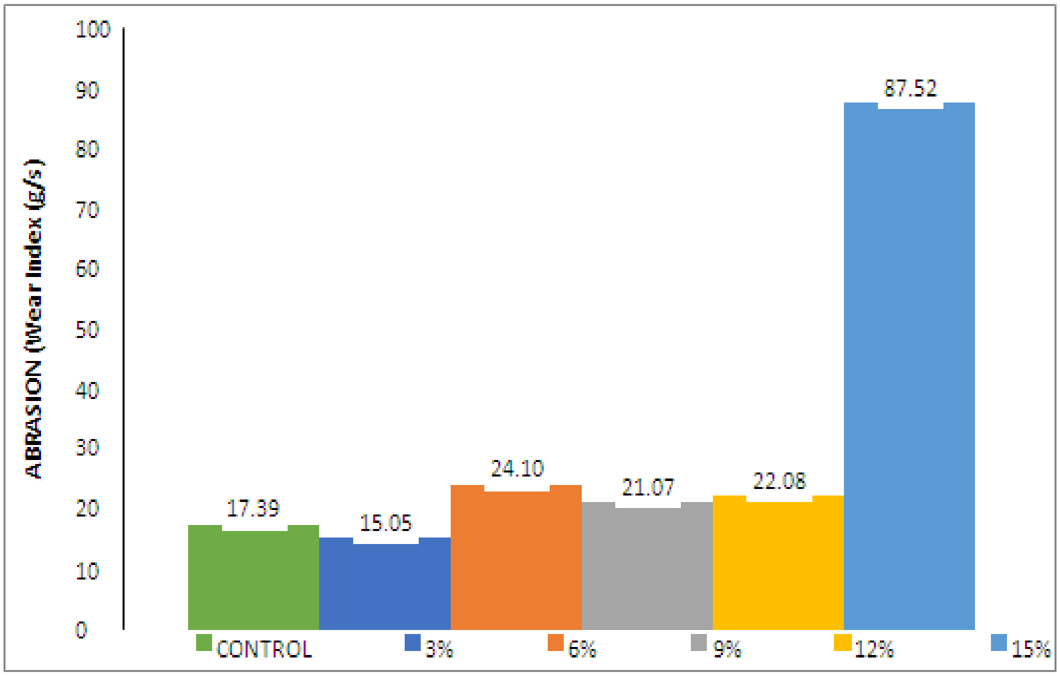

Fig. 2d. Abrasion (Wear Index) values of the control (ABS) and ABS- egg shell composites at 3%-15% filler levels

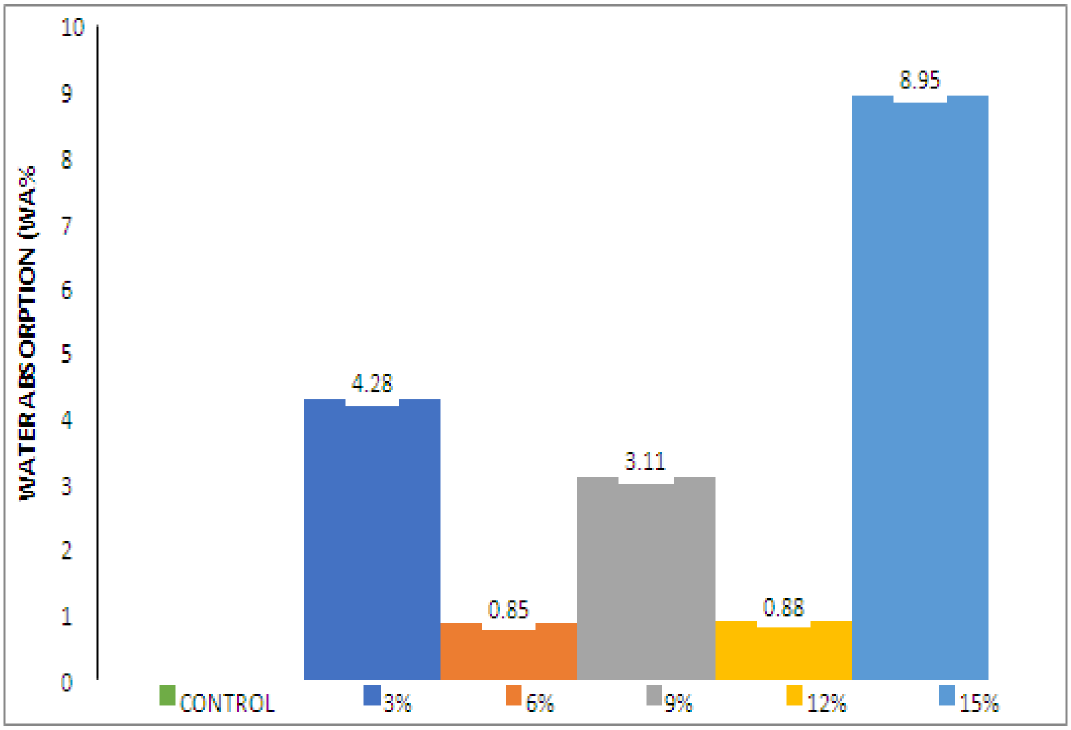

Fig. 3a. Water Absorption (%) values of the control (HDPE) and HDPE-egg shell composites at 3%-15% filler levels

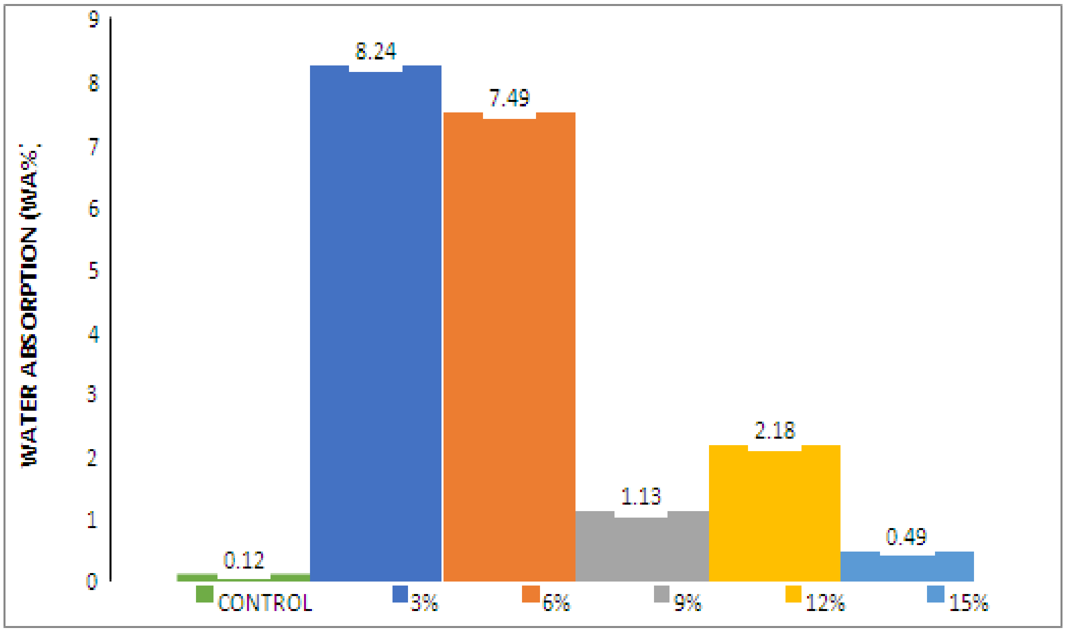

Fig. 3b. Water Absorption (%) values of the control (PS) and PS-egg shell composites at 3%-15% filler levels

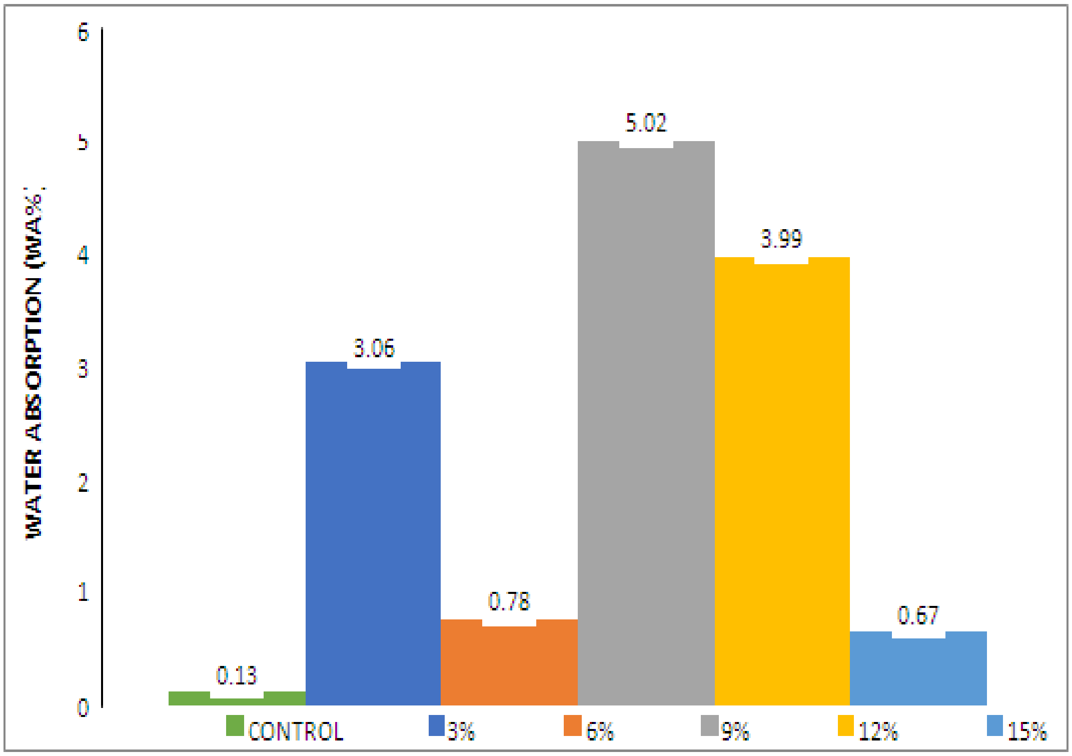

Fig. 3c. Water Absorption (%) values of the control (PP) and PP-egg shell composites at 3%-15% filler levels

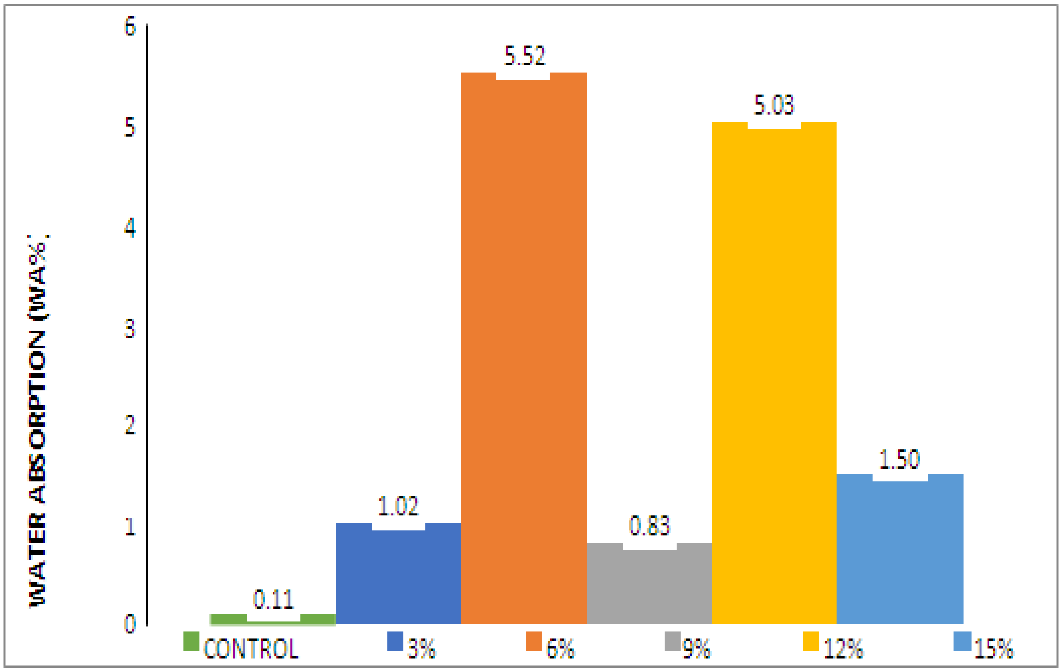

Fig. 3d. Water Absorption (%) Values of the Control (ABS) and ABS-Egg Shell composites at 3%-15% filler levels

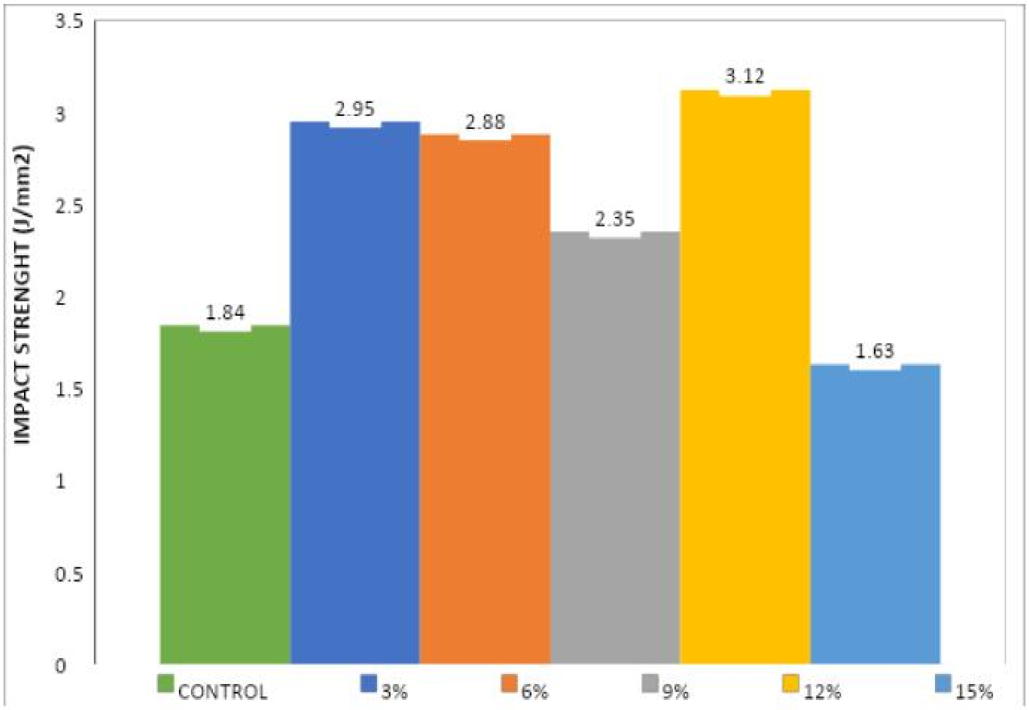

Fig. 4a. Impact Strength Values of the Control (HDPE) and HDPE-Egg Shell composites at 3%-15% filler levels

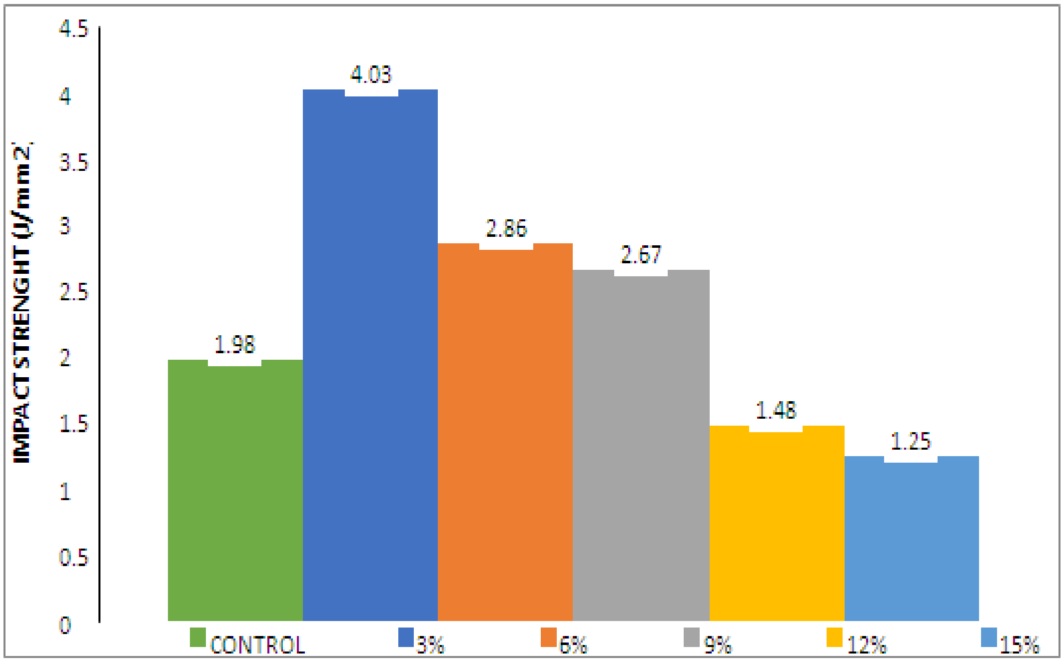

Fig. 4b. Impact Strength Values of the Control (PS) and PS-Egg Shell composites at 3%-15% filler levels

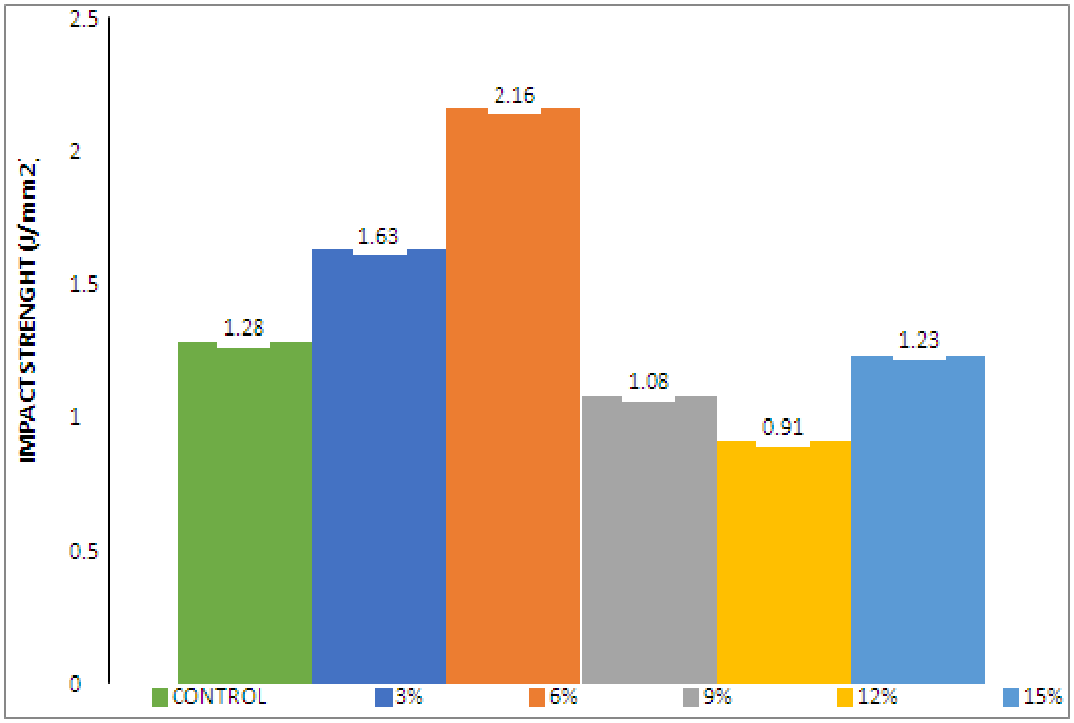

Fig. 4c. Impact Strength Values of the Control (PP) and PP-Egg Shell composites at 3%-15% filler levels

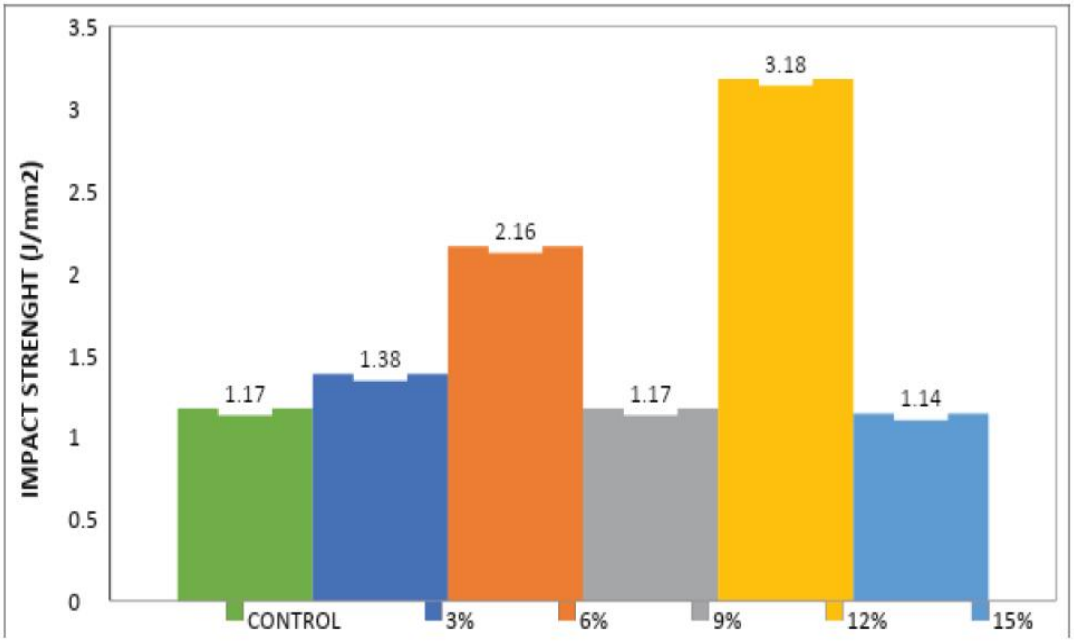

Fig. 4d. Impact Strength Values of the Control (ABS) and ABS-Egg Shell composites at 3%-15% filler levels

3.1 Brinell Hardness

Surface hardness of the composites is considered as one of the important factors that govern the wear resistance of the composites. The effects at different percentages of egg shell filler on the brinell hardness of the polymer composite (HDPE, PS, PP and ABS) are shown in Table 1 and Figs. 1(a-d).

3.1.1 HDPE matrix

HDPE value at 6% (39.48 N/mm^2) > 3% (39.46 N/mm^2) > 9% = 12% (39.40 N/mm^2) > 15% (39.39 N/mm^2) respectively. They all had higher brinell hardness than the Control (36.44 N/mm^2).

3.1.2 PS matrix

PS all the percentage filler loadings of egg shell used, namely 3% (39.60 N/mm^2) > 6% (39.56 N/mm^2) >9% (39.54 N/mm^2) > 12% (39.12 N/mm^2) > 15% (38.85 N/mm^2) respectively had higher brinell hardness above the Control (37.04 N/mm^2).

3.1.3 PP matrix

PP had value only at 3% (29.28 N/mm^2) that showed lower brinell hardness, whereas others, viz 6% (39.35 N/mm^2) > 15% (37.55 N/mm^2) > 9% (37.36 N/mm^2) and > 12% (36.93 N/mm^2) respectively showed higher brinell hardness than the Control (36.32 N/mm^2).

3.1.4 ABS matrix

All the percentage filler loadings of egg shell of ABS used at 12% (39.54 N/mm^2) > 6% (39.40 Nmm^2) > 3% equal to 9% (39.39 N/mm^2) and > 15% (39.35 N/mm^2) respectively had better brinell hardness than the pure polymer.

From these results, it can be concluded that all the reinforced polymer matrix composites formed at different percentage fillers showed better or higher toughness compared to the Controls with the exception of PP loaded with 3% egg shell (29.28N/mm^2). These results are in agreement with the findings in literature [15].

Abrasion: Abrasion resistance is the ability of a material to resist mechanical action such as rubbing, scraping, or erosion that tends progressively to remove material from its surface. When a product has abrasion resistance, it will resist erosion caused by scraping, rubbing, scratching etc. under a specified set of conditions. The lesser the values, the better abrasion of agro-waste polymeric composites, which means it would give a better wear resistance or withstand mechanical action under constant scratching or rubbing etc.

The effects at different percentages of egg shell filler with HDPE, PS, PP and ABS on the abrasion of the composites are shown in Table 2 and Figs. 2(a-d).

3.1.5 HDPE matrix

For HDPE the value at 3% (29.47 g/s), 9% (25.03 g/s), 12% (23.54 g/s), 15% (23.13 g/s) and 6% (22.36 g/s) respectively showed higher abrasion values than the Control (14.57 g/s).

3.1.6 PS matrix

In PS, all the percentage filler loadings of egg shell used at 12% (12.16 g/s), 3% (10.79 g/s), 6% (8.35 g/s),15% (6.69 g/s) and 9% (5.59 g/s) respectively had better abrasion property than the Control (16.20 g/s). There was decrease in abrasion thereby making egg shell/ PS matrix composite better wear resistance under constant scratching.

3.1.7 PP matrix

PP had at 12% (55.47 g/s), 6% (47.90 g/s), 3% (40.16 g/s), 9% (32.80 g/s) and 15% (22.11 g/s) respectively showed higher abrasion values than the Control (18.02 g/s).

3.1.8 ABS matrix

ABS at 3% (15.05 g/s) had better abrasion property compared to the Control (17.39 g/s) while others at 15% (87.52 g/s), 6% (24.10 g/s), 12% (22.08 g/s) and 9% (21.07 g/s) respectively showed higher abrasion values and poor abrasion property than the Control (17.39 g/s).

A low specific wear rate was found only in PS composite of egg shell reinforced at different percentages. It is evident that only egg shell/PS composite showed the minimum specific wear when compared to other polymer matrix composites prepared which implies that there are fewer natural types of filler to support the matrix. Similar results with different reinforced materials were reported in previous researches [16].

3.3 Water Absorption

Water Absorption is a physical property of material for measuring the ability of material to withstand moisture when exposed; the lesser the value of this parameter, the better the composite can withstand moisture when exposed. The effect of water absorption is important in the case of the polymer composite that has been developed for special when used for applications.

The effects at different percentages of egg shell filler with studied polymer matrices on the physical water absorption of the composites are shown in Table 3 and Figs. 3(a-d).

3.3.1 HDPE matrix

HDPE can be seen to have all the percentage filler loadings of egg shell at 15% (8.95%), 3% (4.28%), 9% (3.11%), 12% (0.88%) and 6% (0.85%) respectively. All showed higher water absorption than the Control (0.00%).

3.3.2 PS matrix

In PS, it could be seen that all the percentage filler loadings of egg shell used at 3% (8.24%), 6% (7.49%), 12% (2.18%), 9% (1.13%) and 15% (0.49%) respectively showed higher water absorption than the Control (0.12%).

3.3.3 PP matrix

PP, all the percentage filler loadings of egg shell used at 9% (5.02%), 12% (3.99%), 3% (3.06%), 6% (0.78%) and 15% (0.67%) respectively also showed higher water absorption than the Control (0.13%).

3.3.4 ABS matrix

ABS at 6% (5.52%), 12% (5.03%), 15% (1.50%), 3% (1.02%) and 9% (0.83%) respectively also had very high-water absorption than the Control (0.11%).

The entire polymer composite used loaded with egg shell filler showed higher water absorptions than the Control; they tend to absorb and retain water than the Control. This observation is due to the hydrophilic nature of natural filler which is responsible for the water absorption in the composites and by virtue of the presence of abundant hydroxyl groups (8). However, treatment with NaOH does reduce water uptake, by contracting the particle cellulose walls (2).

3.4 Izod Impact Strength

Impact strength is a measurement of the amount of energy that a material can absorb before fracturing under a high rate of deformation. The higher the value of this parameter, the better the composite can absorb energy.

The impact strength was determined on the egg shell reinforced polymer composites of HDPE, PS, PP and ABS and the results are presented in Table 4 and Figs. 4(a-d).

3.4.1 HDPE matrix

HDPE at 15% (1.63 J/mm^2) showed lower impact strength compared to the Control (1.84 J/mm^2) and at 12% (3.12 J/mm^2) > 3% (2.95 J/mm^2) > 6% (2.88 J/mm^2) and > 9% (2.35 J/mm^2) respectively all showed higher impact strength than the Control (1.84 J/mm^2).

3.4.2 PS matrix

In PS, 3% (4.03 J/mm^2) > 6% (2.86 J/mm^2) > 9% (2.67 J/mm^2) respectively showed higher impact strength than the Control (1.98 J/mm^2) but at 12% (1.48 J/mm^2) and 15% (1.25 J/mm^2), there was decrease in impact strength.

3.4.3 PP matrix

PP at 6% (2.16 J/mm^2) and 3% (1.63 J/mm^2) showed higher impact strength while 15% (1.23 J/mm^2) > 9% (1.08 J/mm^2) > 12% (0.91 J/mm^2) respectively showed lower impact strength than the Control.

3.4.4 ABS matrix

In ABS 15% (1.14 J/mm^2) absorb lower energy while 9% (1.17 J/mm^2) had equal value with control (1.17 J/mm^2); at 12% (3.18 J/mm^2), 6% (2.16 J/mm^2), and 3% (1.38 J/mm^2) respectively absorb higher energy than the Control (1.17 J/mm^2).

The loss of energy is the energy absorbed by the specimen during impact. It was observed that above 12% to 15% of egg shell/polymer matrix impact strength decreased with filler content. The decrease in impact strength observed in 12% egg shell filler of PS, PP matrix and 15% egg shell filler of HDPE,PS, PP and ABS matrix loadings may be due to improper mixing of the polymer and egg shell particles which led to weak interfacial bonding between the particles, resulting to poor adhesion of the egg shell filler on the polymer matrix. Similar trends were observed by other researchers when other natural fillers were used [17,18].

4. CONCLUSIONS

There was a significant improvement in Brinell hardness and izod impact in egg shell filler composites which were influenced by the amount of filler in the composites. HDPE value at 6% (39.48 N/mm^2) > 3% (39.46 N/mm^2) > 9% = 12% (39.40 N/mm^2) > 15% (39.39 N/mm^2) and Control (36.44 N/mm^2). PS at 3%) (39.60 N/mm^2) > 6% (39.56 N/mm^2) > 9% (39.54 N/mm^2) > 12% (39.12 N/mm^2) > 15% (38.85 N/mm^2) respectively had higher brinell hardness above the Control (37.04 N/mm^2). PP had value only at 3% (29.28 N/mm^2) that showed lower brinell hardness; 6% (39.35 N/mm^2) > 15% (37.55 N/mm^2) > 9% (37.36 N/mm^2) and > 12% (36.93 N/mm^2) respectively showed higher brinell hardness than the Control (36.32 N/mm^2). ABS; 12% (39.54 N/mm^2) > 6% (39.40 Nmm^2) > 3% equal to 9% (39.39 N/mm^2) and > 15% (39.35 N/mm^2) respectively had better brinell hardness than the pure polymer. The impact strengths absorbed higher amount of energy than the Control in PP, HDPE, ABS, 3%, 6%, 9% of PS, 3%, and 6% of PP in egg shell composites. HDPE at 12% (3.12 J/mm^2) > 3% (2.95 J/mm^2) > 6% (2.88 J/mm^2) > 9% (2.35 J/mm^2) > 15% (1.63 J/mm^2) and Control (1.84 J/mm^2). In PS, 3% (4.03 J/mm^2) > 6% (2.86 J/mm^2) > 9% (2.67 J/mm^2) >12% (1.48 J/mm^2) > 15% (1.25 J/mm^2) and Control (1.98 J/mm^2). PP at 6% (2.16 J/mm^2) and 3% (1.63 J/mm^2) showed higher impact strength while 15% (1.23 J/mm^2) > 9% (1.08 J/mm^2) > 12% (0.91 J/mm^2) respectively showed lower impact strength than the Control. In ABS 15% (1.14 J/mm^2) absorb lower energy while 9% (1.17 J/mm^2) had equal value with control (1.17 J/mm^2); at 12% (3.18 J/mm^2), 6% (2.16 J/mm^2), and 3% (1.38 J/mm^2) respectively absorb higher energy than the Control. The impact strength on polymer matrices especially in HDPE, PP and ABS composites reinforced at different percentages of agro-waste filler loadings used showed the amount of energy that a material would absorb before fracturing under a high rate of deformation. While abrasion results of all egg shell/polymer matrix composites used (exception ofPS)showedpoorabrasionvaluesthantheControl; For HDPE the value at 3% (29.47 g/s), 9% (25.03 g/s),12%(23.54 g/s),15%(23.13 g/s)and6%(22.36 g/s) and Control (14.57 g/s). PS, at 12% (12.16 g/s), 3% (10.79 g/s), 6% (8.35 g/s),15% (6.69 g/s) and 9% (5.59 g/s) and Control (16.20 g/s). PP had at 12% (55.47 g/s), 6% (47.90 g/s), 3% (40.16 g/s), 9% (32.80 g/s) and 15% (22.11 g/s) and Control (18.02 g/s). ABS at 3% (15.05 g/s), 15% (87.52 g/s), 6% (24.10 g/s), 12% (22.08 g/s), 9% (21.07g/s) and Control (17.39g/s). It could be concluded that in most of the composites, the filler had good degree of interaction with the polymer as indicated by the test data obtained from the egg shell agro-waste thermoplastic polymer composites. It was observed that agro-wastes reinforced polymer matrix composites of brinell hardness property showed better or higher toughness compared to the virgin polymers. Abrasion results of all agro-waste/polymer matrix composites used (exception of PS) showed higher abrasion values than the Control. These indicate their thermoplastic polymers filled egg shell agro-wastes could withstand less mechanical action such as rubbing, scratching or scraping etc. than the virgin polymers used. The composites showed higher amount of water absorption than the Control under specified conditions; HDPEat15%(8.95%),3%(4.28%),9%(3.11%),12% (0.88%)and6%(0.85%)and Control(0.00%).PS,at 3% (8.24%), 6% (7.49%), 12% (2.18%), 9% (1.13%),15%(0.49%)and Control (0.12%).PP,9% (5.02%),12%(3.99%),3%(3.06%),6%(0.78%)and 15% (0.67%) and Control (0.13%). ABS at 6% (5.52%), 12% (5.03%), 15% (1.50%), 3% (1.02%) and 9% (0.83%) respectively also had very high-water absorption than the Control (0.11%). This indicates that agro-waste reinforced polymer matrices are not compactable with polymers. This was expected since natural particle fillers are hydrophilic in nature, they tend to absorb and retain water. However, the amount of NaOH used for treatment should be increased in order to reduce water uptake (hydrophilicity) of agro-waste fillers/fibres, by contracting the particle filler cellulose walls. The utilization of agro-waste products in Nigeria would serve as a means of turning waste to wealth by utilizing agro-waste products in developing low cost polymer composites to serve a number of interesting applications and solve the problem of environmental pollution threat.

SUMMARY

- The study has provided several combinations of matrix/natural fillers that promote formation of new classes of composites and products with lower cost, light weight, high specific strength, toughness, eco-friendly nature and availability.
- Stiffness and strength are provided by natural fibres to the composites. They are easily recyclable; moreover, bio-fibres will not be fractured when processing over sharp curvatures, unlike brittle fibres, such as glass.
- This study has provided different combinations of agro-waste/agro-residue thermoplastic polymer composites which has potential application in the automobile and building construction industry.
- The research has opened a new area of agro-wastes management for sustainable economy, creating job opportunities in industries and wealth creation.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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