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RESEARCH ARTICLE

FLEXURAL AND QUASI-STATIC COMPRESSIVE BEHAVIOR OF INJECTION-MOLDED WALNUT SHELL (WS)/HDPE COMPOSITES

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ABSTRACT

The present study focuses on flexural and quasi-static compression behavior of high-density polyethylene (HDPE)/walnut shell (WS) composites. Flexural and quasi-static compression specimens by 20, 40 and 60 wt. % of WS are synthesized by polymer injection (PI) molding. The flexural modulus and strength are observed to increase with increase in the wt.% of WS. Compared to pure HDPE, the flexural modulus and strength increased in the range of 205-403% and 49-58% respectively. Further quasi-static compression tests are carried at 0.001, 0.01, 0.1 s-1 strain rates. Compressive modulus of HDPE/WS specimens is lower as compared to pure HDPE samples for all the strain rates. Compressive yield strength of HDPE/WS specimens shows increasing trend with increase in the strain rates. Scanning electron microscopy (SEM) is employed to study the fractography of the samples.

KEYWORDS

Polymer Injection, Quasi-static compression, HDPE, Flexural, Walnut shell.

1. INTRODUCTION

Composites are multifunctional materials having unique mechanical and physical properties which can be tailored to meet the requirements of specific applications [1]. Presently there is worldwide interest in manufacturing composites with industrial and agricultural materials that focus on reduction in polymer consumption and thrust on using naturally available materials. Thermoset and thermoplastic are the two types of polymeric resins that are widely being explored for variety of applications [2-4]. Thermoplastic polymers are reusable and demoldable into different shapes on heating. Reinforcing these polymers provides great strength and stiffness [5]. Viscoelastic nature of thermoplastic polymers is found to be higher when compared to thermosetting polymers and also it is anticipated to have better strain rate sensitivity [6-8]. Thermoplastics composites with natural and engineered reinforcements are synthesized using injection molding, compression molding and until recently 3D printing [9-11]. One such naturally available reinforcement is walnut shell powder which can be used as effective reinforcement in composites. WS flour is compounded with PP and HDPE in a single screw extruder and the samples were prepared with press moulding process [12]. WS flour greatly enhanced the water resistance of the panels, however flexural properties and internal bonding strength decreased with the increasing filler loading [13, 14]. Melting and crystallization enthalpy of palm kernel nutshell/HDPE were largely reduced by the alkaline treatment of the shell [15]. The tensile and flexural properties improved by polymerization of natural oil-based resins strengthened with natural fillers [16]. Compressive modulus decreases with WS filler content [17]. Polypropylene/WS composites are prepared with injection molding [18]. Most promising process method across all the available processing routes is, injection molding due to its lower cycle time.

The present work is focused on utilization of polymer injection molding technique with optimized process parameters to prepare HDPE/WS composites and study the flexural and quasi-static compression properties [19].

2. MATERIALS AND SAMPLE PREPARATION

2.1 Blend Material

HDPE is selected as matrix constituent of grade HD50MA150 having 97,500 g/mol molecular weight. The resin is in pallet form having average diameter of 3 mm obtained from Reliance Industries Ltd., Mumbai, India. Properties of HDPE are listed in Table 1.

Table 1: Properties of HDPE grade HD50MA150.

Properties	Test Method	Value	Unit
Density at 23°C	ASTM D1505	950	kg/m^3
Melt flow index	ASTM D1238	20	g/10 min
Tensile yield strength	ASTM D638	22	MPa
Elongation at yield	ASTM D638	12	%
Flexural Modulus	ASTM D790	750	MPa
Hardness	ASTM D2240	55	Shore D

*As supplied by Reliance Industries Ltd., Mumbai, India.

WS particles in the form of residue being generated by agro industries grinding the walnut shell, it is light brown color powder, renewable and unutilized agriculture material supplied by Palli Plaster Industries, Kashmir is used as filler having particle size in the range of 0.149-0.177 mm.

2.2 Sample preparation

Blend of WS/HDPE is prepared using barbender mixture at 210 0C by. This blend is fed to injection molding machine with optimized process parameters [19] to fabricate flexural samples (ASTM D790-10) and quasi-static compression samples having dimensions of 127 × 12.7 × 3.2 mm and 10 × 10 × 3.2 mm [6, 20, 21] respectively. Three compositions of composite samples prepared with 20, 40, and 60 wt %. of WS particles. Samples are coded as per XYY (X – HDPE, YY – WS wt. %) convention. Figure 1 presents sample preparation flow chart.

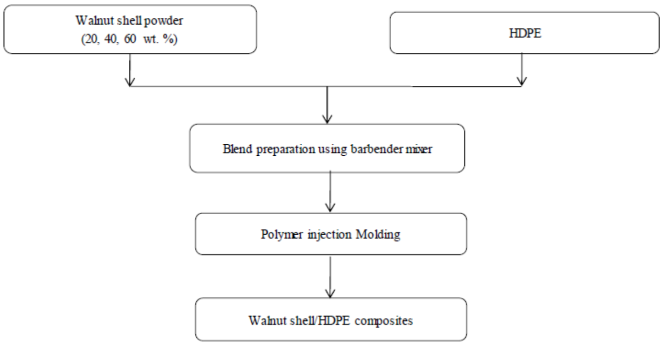

Figure 1: Processing route of Walnut shell/ HDPE composites.

2.3 Flexural Quasi-static compressive test

The flexural tests are performed using a Zwick (Zwick Roell Z020, ZHU) computer controlled universal test system having load cell capacity of 20 kN. This test is carried out in three-point bend configuration, with an initial load of 0.1 MPa and crosshead displacement of 1.45 mm/min. Five replicates of each wt. % samples are tested and average value is reported. Quasi-static compressive tests are conducted at an initial strain rates of 0.001 s-1, 0.01 s-1 and 0.1 s-1 corresponding to velocities of crosshead displacement 0.001 mm/s, 0.01 mm/s and 0.1 mm/s respectively. The test is stopped at 20 kN load. Using in-house developed MATLAB code, the data was analyzed to estimate yield strength and modulus for all the specimens. At least five specimens of each wt. % were tested and average value is reported.

2.4 Imaging

Microstructure observation of samples is performed using Scanning Electron Microscopy (SEM) JSM 6380LA (JEOL, Japan). All the specimens are sputter coated using JFC-1600 auto fine coater**.**

3. RESULT AND DISCUSSION

3.1 Flexural behavior

Figure 2 presents the flexural stress-strain responses of HDPE/WS specimens prepared with different wt. % (20, 40 and 60 %) of WS. Under flexural testing the prepared specimens did not fractured even after 10 % strain and there was no visible sign of specimen failure. A similar pattern of stress-strain behavior is observed for all specimens with initial linear elastic region and remaining part of the curves is observed to be non-linear elastic and plastic. It is observed that strength of WS/HDPE composites increases with WS content. The modulus is observed to increase with increase in wt. % of WS (Figure 3a). Higher stiffness of composites is obtained by using higher stiffer walnut shell particle. Related to the modulus of pure HDPE, 204.7 MPa [22], H20, H40 and H60 composites specimens have 295, 308.4 and 403.1 % higher modulus respectively. Similarly, flexural strength (Figure 3b) is also found to increase with wt. % of WS. H20, H40 and H60 composite specimens show 49.1, 51.6 and 58.8 % higher strength as compared to neat HDPE (12.4 MPa) [22] owing to uniform dispersion of WS in HDPE and rigorous barbender mixing method adopted [22].

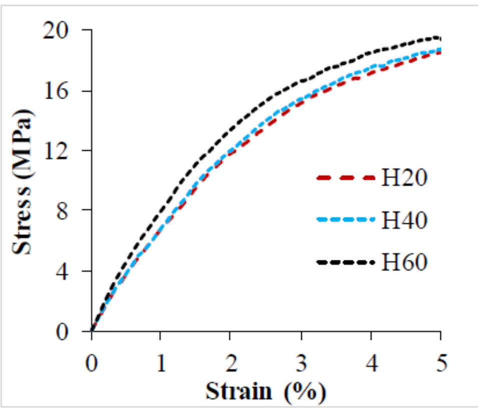

Figure 2: Flexural stress-strain behavior of a HDPE/WS composites

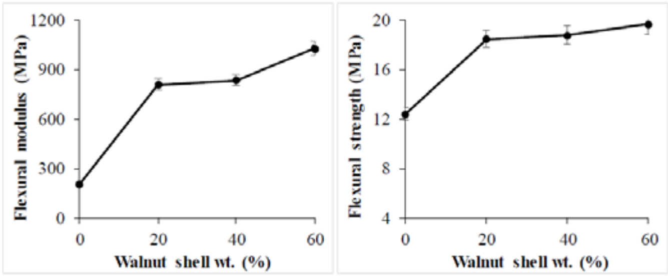

Figure 3: Experimentally measured flexural (a) modulus and (b) strength of composites at different wt. % of WS

The typical SEM images of the HDPE/WS (60 and 40 wt. %) is presented in Figure 4. These micrographs show walnut particles are uniformly dispersed in HDPE matrix (Figure 4a and Figure 4b). Flexural modulus and strength strongly depend on reinforcing members state of stress which in turn depends upon particles survival. A higher magnification of H60 and H40 (Figure 4c and Figure 4d) shows that the walnut particles are surrounded by matrix. WS particles are seen to be intact post loading condition and act as an effective reinforcement in HDPE matrix.

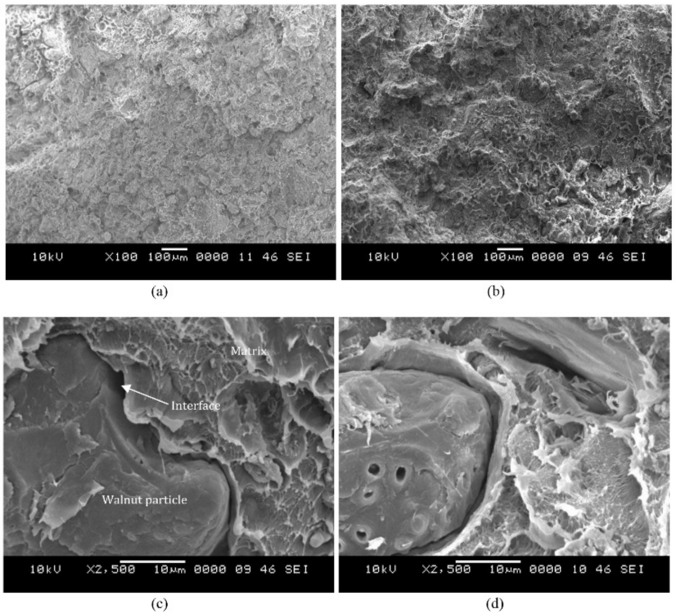

Figure 4: (a) and (b) Flexural fractured microstructure of H60 and H40 HDPE/WS specimens showing uniform distribution of walnut particles in HDPE. Figure (c) and (d) H60 and H40 shows interface between the matrix and walnut particles.

3.2 Quasi-static compression behavior

Stress-strain curves of all HDPE/WS specimens at various strain rates are presented in Figure 5. Stress-strain behavior is different from that observed from epoxy syntactic foam composites [2]. Figure 5 indicates that the strength and modulus of H20, H40 and H60 specimens increases with strain rate.

The measured mechanical properties of HDPE/WS composites by quasi-static strain rate test are presented in Table 2. Average compressive elastic modulus and yield strength are observed to increase with increasing the strain rate for all HDPE/WS specimens. H20 shows the highest yield strength at 0.1/s strain rate compared to all the specimens. Highest modulus of 343 MPa is observed for H40 at 0.1/s strain rate. Compared to modulus of pure HDPE [18], modulus of all HDPE/WS for all strain rates are found to be lower. Yield strength of all specimens are observed to higher. The higher strain resistance and energy absorption result in higher modulus. Yield strain and energy absorption at 50 % strain for specimens increases with increasing the strain rate.

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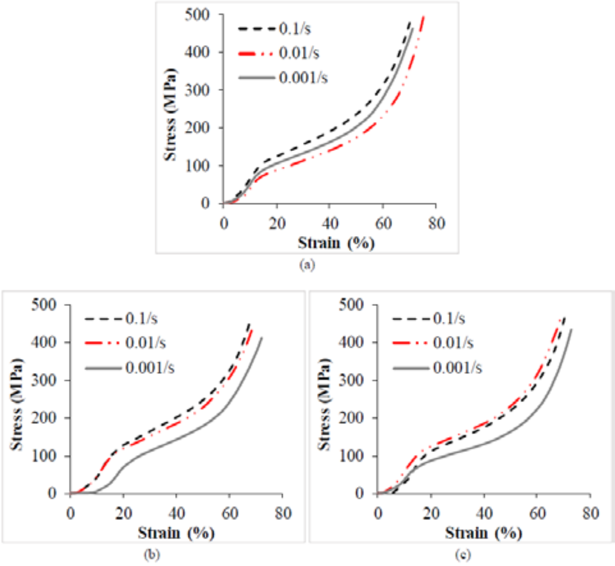

Figure 5: Comparison of quasi-static compression stress-strain curves of samples for different strain rates (a) H20 (b) H40 and (c) H60.

Table 2: Mechanical properties for HDPE/WS composites.

Material	Strain rate (s^{-1})	Elastic Modulus (MPa)	Yield Strength (MPa)	Yield strain (%)	Energy absorbed to 50% strain (MJ/m^3)	Densification stress (MPa)	Densification strain (%)
H20	0.001	246 ± 38	22 ± 6	7.1 ± 1.7	19 ± 2.1	460 ± 3.4	70 ± 1.2
	0.01	275 ± 5	25 ± 5	7.4 ± 0.4	18 ± 2.7	474 ± 4.6	74 ± 1.4
	0.1	332 ± 32	29 ± 2	7.8 ±1.8	24 ±2.8	480 ±8.8	70 ±2.1
H40	0.001	233 ± 19	21 ± 4	7.5 ± 0.2	16 ± 0.5	413 ± 5.2	72 ± 0.3
	0.01	239 ± 11	25 ±0.6	8 ±0.1	19 ±0.2	440 ±3.8	69 ±1.8
	0.1	343 ± 6	28 ± 0.9	14 ± 0.6	24 ± 0.1	445 ± 6.3	69 ± 0.6
H60	0.001	233 ±15	17 ± 0.6	6.2 ± 2.8	15 ± 0.3	432 ± 8.5	73 ± 0.3
	0.01	287 ± 7	23 ± 2	7.1 ± 0.2	21 ± 0.9	474 ± 7.3	69 ± 0.4
	0.1	334 ± 28	25 ± 1.9	9.4 ± 0.3	21 ± 0.2	478 ± 3.1	71 ± 0.2

Micrographs of the post compressed H60 specimen at 0.001/s rate are presented in Figure 6. It can be observed that at lower magnification (Figure 6a), walnut particles are surrounded by matrix. Figure 6b shows that some walnut particles are intact in the sample even after densification strain is reached. This similarity is observed in the specimens of HDPE/cenosphere as well [6]. The micrographs show extensive deformation of the matrix and the fractured particle is visible in Figure 6c.

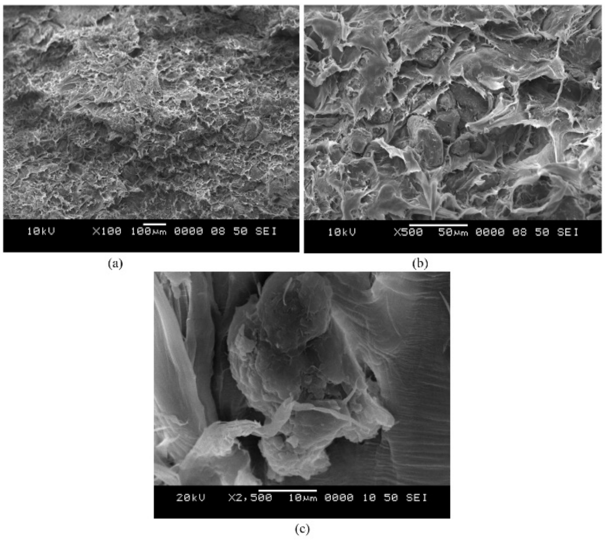

Figure 6: Micrographs of compressed H60 composite (a) Dispersion of particles at 0.001/s rate, (b) Intact of walnut particles are found in the matrix and (c) Debris of fractured particle.

4. CONCLUSION

The present work focused on developing naturally available walnut (WS) shell particle reinforced with thermoplastic polymer (HDPE) composites using plastic injection molding process. HDPE/WS containing 20, 40 and 60 wt.% walnut shell (WS) particle are fabricated. Flexural and quasi-static compression tests are conducted on samples. The results are summarized as:

1. Microstructure observations reveal uniform distribution of WS particles and poor interfacial bonding between the walnut shell (WS) and matrix (HDPE).

2. Flexural modulus and strength of HDPE/WS specimens are found to increase with WS wt. %.

3. HDPE containing 60 wt.% WS particles resulted in the highest flexural modulus and strength of 1034 and 19.34 MPa respectively.

4. Compressive modulus and yield strength properties of HDPE/WS specimens result in rise with increase in strain rate.

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