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Fabrication and Characterization on Physico-Mechanical and Structural Properties of Sawdust Reinforced Acrylonitrile Butadiene Styrene (ABS) Composites

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Abstract

The sawdust reinforced Acrylonitrile Butadiene Styrene (ABS) composites were prepared by using hot press molding machine for five different wt% (0%, 5%, 10%, 15% and 20%) at 180˚C temperature and 50 KN load. Sawdust was collected from local saw mill of Savar, Dhaka, Bangladesh and ABS polymer was collected from local market of Dhaka, Bangladesh. In this study, different properties of composites like physical (bulk density and water absorption), mechanical (tensile properties and hardness) and structural (Fourier Transform Infrared Spectroscopy) properties were studied. The bulk density of composites was not altered consistently and it gave greater value for 5% and 20% composites. The water absorption enhanced for all composites with the accumulation of fiber content and soaking time. The reduction of tensile strength and Leeb's rebound hardness of the composites were observed with the increase of the fiber content in all compositions. Maximum (%) of elongation was found for 5% composite, and then it gradually decreased; however, elastic modulus increased with the increased of fiber content in composites. Fourier Transform Infrared (FTIR) spectroscopy study was done for structural characterization. It was found that there was a new bond (C≡C) stretching formed for 20% composite; moreover, C-H rocking for 0% composite was broken for all other composites after the addition of sawdust in ABS polymer matrix.

Keywords

Sawdust-ABS Composite, Hot Press Molding Machine, Tensile Strength,

Leeb's Rebound Hardness, FTIR Spectroscopy

1. Introduction

Manufacturing industries like automotive, construction and packaging company are searching new materials which can replace conventional non-renewable reinforcing materials such as glass fiber due to pressure of new environmental legislation and consumer demand [1] [2] [3] [4]. The production of bio-composites in different industries is increasing day by day on account of their unrivaled properties, for example, good thermal and mechanical behavior, biodegradability, low cost, low density and renewability. In addition, environmental constraints have also pushed industries and researchers to exploit natural resources such as banana, clay, wood, rattan, kenaf, palm, coconut, bamboo, jute, coir, sisal, and pineapple to substitute manufactured glass fillers for creating composites. Consequently, much work was led to abuse these normal fillers and those investigations set up that the natural fillers were comparable with synthetic glass [5]. Moreover, the lightweight, simple accessibility, and biodegradability of common fiber composites bear the cost of an assortment of employments of these materials for the development of aero planes, vessels, structures, extensions and transportation [6].

These cellulosic fibers in their natural condition as well as several waste cellulosic products such as shell flour, wood flour and pulp have been used as reinforcing agents in diverse thermosetting and thermoplastic resin such as PVC, PP, ABS, nylon, epoxy resins, polyester resins and polyurethane [7]-[12].

Wood is a fibrous composite where cellulose filaments are embedded in lignin matrix. Cellulose fibers are exceptionally flexible (*i.e.* low stiffness) and have high tensile strength. Bone is a natural composite by which the weight of various members of the body is supported [13] [14]. The combinations of two materials are usually known composite. One of the materials is called the reinforcing phase which is in the form of fibers, sheets, or particles and another is called matrix. Fibers are inserted in the matrix phase. They can be metal, ceramic, or polymer. Normally reinforcing materials have low densities but strong and the matrix is material which is usually ductile or tough [15] [16] [17]. If the composite is designed and fabricated correctly, the strength of the reinforcement is combined with toughness of the matrix to accomplish a combination of desirable properties which is not available in any single conventional material [18]. Among various kinds of fibers, sawdust fiber is one of particular interest, because sawdust is a little cost fiber which is a surplus product of saw mills in Bangladesh and all over the world. The properties of natural filaments to a great extent rely upon the fiber's chemical composition. Sawdust fiber comprises of 35% - 50% cellulose, 23% - 32% hemicellulose, 15% - 25% lignin, 0% - 1% pectin and 19% - 28% moisture content [19]. ABS is a thermoplastic polymer which com-

prises of an amorphous, heterophasic polymer with very good mechanical properties, especially high impact resistance [20]. ABS is made by polymerizing styrene and acrylonitrile within the presence of polybutadiene. The extents of substance in ABS can differ from 15% to 35% acrylonitrile, 5% to 30% butadiene and 40% to 60% styrene. The nitrile groups from neighboring chains, being polar, attract each other and bind the chains together, making ABS stronger than pure polystyrene. The styrene gives the plastic a sparkling, impenetrable surface. The butadiene which is a rubbery substance, gives flexibility even at low temperatures. For the majority of applications, ABS can be used between −20˚C and 80˚C as its mechanical properties vary with temperature [21]. The properties are created by rubber toughening, where fine particles of elastomeric are distributed throughout the rigid matrix. These polymers are of ease and give fantastic mechanical properties [22]. Then again, the ABS restrictions are: poor flame and chemical resistance, and low thermal stability [23].

An enormous number of investigations have been done with natural fiber reinforced polymeric composites by different research groups all over the world. L. Chotirat *et al.* investigated the ABS/wood sawdust composite by FTIR technique and mechanical testing in 2007 and observed that the enhancement of wood sawdust content could raise the modulus and reduce the strength of the composites [24]. M. Kaseem *et al.* investigated Rheological Property of Sawdust/ABS Composites by using a capillary rheometer in 2015 and found that the viscosity of the composites increased with the increase of wood particles [25]. Similar property was studied by P. Threepopnatkul and his co-workers and they found very good properties of the composite [26]. Various mechanical, thermal, and morphological properties of ABS/textile fiber composites were investigated by Johnny N. Martins *et al.* and they observed that the fiber content increased the stiffness of the composite [27]. Mohammad, N. N. B. *et al.* [28] carried out research on the morphological study of Kenaf fiber reinforced rPET/ABS composites. The distribution effects between rPET/ABS and kenaf were studied through morphological characterization by using SEM. The result showed that there was rising of the brittleness of composites when higher percentage of fiber was introduced and kenaf was fully interpenetrated into the composite. Thermal properties palm fiber-reinforced ABS composite was studied by our research group in 2016 and very good thermal stability was observed [12].

Sawdust fiber would be a good reinforcing agent in ABS and will be a good area of research. With the addition of sawdust fiber in ABS, polymeric matrix could change the physical, mechanical and structural properties of the composites. Therefore, the physical (bulk density and water absorption), mechanical (tensile properties and hardness) and structural (FTIR Spectroscopy) properties were measured in the sawdust fiber reinforced ABS composites in this study. The intention of this research work is to investigate a composite with high physical, mechanical and structural properties using sawdust fiber as reinforcement with ABS as a polymer matrix.

2. Materials and Methods

2.1. Raw Materials Collection

The raw materials used for the sawdust-ABS sample preparation are sawdust as fiber, acrylonitrile butadiene styrene (ABS) as polymer and sodium hydroxide (NaOH) for treatment of fiber. Sawdust was collected from the local sawmill of savar, Dhaka, Bangladesh. ABS and NaOH were collected from scientific materials market of old Dhaka, Bangladesh.

2.2. Methods for Preparation of Composites

2.2.1. Treatment of Fibers with NaOH

Raw sawdust was treated with NaOH solution to extract impurities from sawdust, such as hemicellulose, lignin, aromatic acids, esters, etc. which might weaken the adhesion between fiber and matrix. At first, raw sawdust was sieved with a sieve. Then fiber was washed several times with distilled water and dried in oven up to 12 hours at 60˚C. Then the sawdust fiber was immersed in 5% NaOH solution only for removing the cementing agents (hemicellulose, lignin, pectin, etc.). The treatment was done for 1 hour at room temperature as it was reported that over treatment of natural fibers using NaOH could have a negative effect on the base fiber properties [29]. Finally, fiber was washed several times with distilled water to neutralize the NaOH solution and dried at 60˚C for 24 hours. NaOH treated sawdust was ground to form sawdust powder by the ball mill. The fiber was ground for 2 hours and the grinding speed of the jar was 500 rpm. After that the fiber was kept in a dry container. The bonding strength between fiber and polymer matrix in the composite is considered a major factor in order to get superior fiber reinforcement composites properties. Because of pendant hydroxyl and polar groups in fiber, this leads to extremely high moisture absorption of fiber, resulting in weak interfacial bonding between the fiber and the hydrophobic matrix polymer. To develop composites with good mechanical properties, chemical modification of fiber carried out to reduce the hydrophilic behavior of fiber and the absorption of moisture [30] [31].

2.2.2. Fabrication of the Sawdust-ABS Composites

After collecting the raw materials and pretreatment of the fiber, pure ABS sheet were made with the help of hot press molding machine (PO-40W, Weber Pressen, Germany). For making pure ABS sheet, 30 gm ABS polymer was poured in the mold and heated at 180˚C, then hold for 20 minutes at the load 50 KN in the hot press molding machine. When the temperature was fallen down, the sheet was released from the mold having size of 150 mm × 150 mm area. After that, ABS sheet and sawdust fiber were layered by sandwiching the layers in the mold, then the composite was fabricated at the same load, time and temperature that was used for pure ABS sheets. By using the same process composites with 5 wt%, 10 wt%, 15 wt%. 20 wt% sawdust reinforced ABS were prepared as shown in **Figure 1**. Research works were done by our research group with palm fiber and ABS polymer by using injection

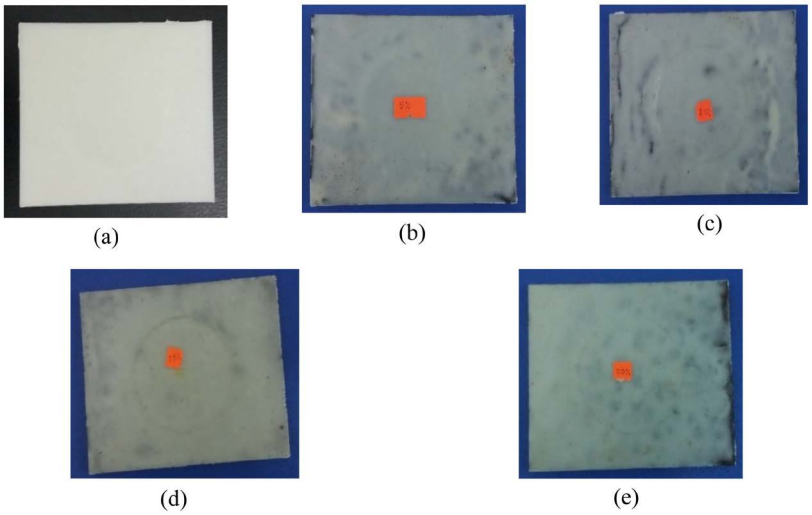

Figure 1. Composites with different wt% of sawdust in ABS polymer (a): 0 wt%, (b): 5 wt%, (c): 10 wt%, (d): 15 wt%, and (e): 20 wt%.

moulding machine. In these research works, three sets of composites samples were prepared with 5%, 10% and 20% fiber content to carry out these research [12] [23].

2.3. Characterization of Sawdust-ABS Composites

2.3.1. Physical Properties of Sawdust-ABS Composites

1) Bulk Density: The bulk density of composites was determined according to ASTM C-134-76 [32]. The samples were first dried into oven at 60˚C for 24 hours before measuring the density. Bulk density of sawdust-ABS composites was taken using five samples from their average length, width, thickness and weight by using the following Equation (1),

$$\text{Bulk density, } D = \frac{W_s}{V} = \frac{W_s}{L \times W \times H} \tag{1}$$

where, W_s is the weight, L is the length, W is the width and H is the height of the sample, respectively.

2) Water Absorption: Water absorption test was carried out according to ASTM D570-98 [33]. The average dimension of the test specimen was 31.86 mm × 16 mm × 4.75 mm. Samples were dried in the oven at 60˚C for 24 hours. Then cooled in a desiccator and immediately weighted every sample. After that sample was immersed in distilled water in beaker at room temperature. And after 1, 2, 24, 48, 72, 168, 192, 216, 240, 264, 288 and 312 hours, samples were taken out from water and wiped gently by using tissue papers and then measured weight immediately. The water uptake was measured by subtraction of initial weight from final weight. The percentage of water absorption was determined by using the following Equation (2),

$$W_g = \frac{W - W_o}{W_o} \times 100 \tag{2}$$

where W and W_o are the weight of the sample after and before soaking in water.

2.3.2. Mechanical Properties of Sawdust-ABS Composites

1) Tensile Property of the Composites: Tensile test of composites was carried out according to ASTM D 3039/D 3039 M-00 [34]. At first, the samples were dried into oven at 60˚C for 24 hours to remove moisture then the test specimen was kept in a desiccator. The dimension of the test specimen was approximately 105 mm in length and 7.5 mm in width and 4.5 mm in thickness as shown in **Figure 2**. Gauge length of UTM was 50 mm and cross-head speed was 2 mm/min. Then the test specimen was gripped into the jaws of Universal Testing Machine (H10KS, Hounsfield, UK) with a 10 KN load cell. The test was monitored with a computer through Q-mat professional (*Tinius Olsen, UK*) software. The overall average tensile properties (TS, % of elongation and elastic modulus) were obtained by averaging data obtained from three samples.

2) Hardness: The Leeb hardness test of the composites was carried out with an H1000 portable hardness tester (HARTIP-1000, QUALITEST, Canada) according to ASTM A956-06 [35]. The hardness test sample dimension was 109 mm in length 9 mm in width and 4 mm in thickness, approximately as shown in **Figure 3**. After cutting the samples, they were dried into oven at 60˚C for 24 hours to remove moisture. The composite sample was placed over a cemented table using glycerin. By pressing the button, samples were hammered by carbide ball of Leeb's tester. The ball bounced back from the samples. The electronic sensor recorded the rebound velocity. The hardness was measured at 6 - 10 different locations over both surfaces of the sample. Average data was considered as the Leeb's rebound hardness of the sample.

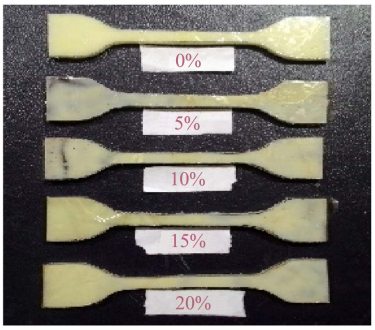

Figure 2. Tensile test samples.

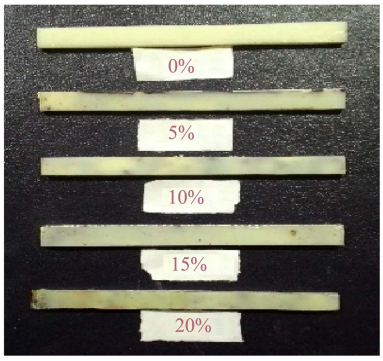

Figure 3. Hardness test sample.

2.3.3. Structural Property of Sawdust-ABS of Composites

Fourier Transform Infrared (FTIR) spectroscopy: Fourier Transform Infrared (FTIR) spectroscopy spectra of the samples were recorded at room temperature by using a double beam IR spectrometer (SHIMADZU, FTIR-8900 spectrometer, Japan) in the wave number range of 625 - 4000 cm^{-1}. For this measurement the composite samples were made in tablet form by using a pressure gauge. At first the composite and potassium bromide (KBr) were ground very well manually with the help of mortar and pestle. Then by applying 80 KN pressure for three minutes in the pressure gauge the sample was made in the form of a transparent pellet as shown in Figure 4. By keeping the tablet specimen in a measuring cell for the measurement of the FTIR spectra the beam of light passed through the sample and it became less intense due to the absorption of certain frequencies. The FTIR spectra of the composites were recorded in transmittance (%) mode. The absorbance of the sample at a particular frequency can be calculated as

$$A = \log \frac{I_0}{I} \tag{3}$$

$$\text{Transmittance,} \quad T = \frac{I}{I_0} \tag{4}$$

where, I_0 and I are the intensity of beam before and after interaction.

3. Results and Discussion

3.1. Physical Properties of Sawdust-ABS Composites

3.1.1. Bulk Density of Composites

Effect of fiber loading on bulk density in the sawdust-ABS composites as shown in Figure 5. The figure indicates that bulk density varied in the range of 0.998 - 1.038 gm/cc. No significant effect is obtained by the sawdust addition. Bulk density of sawdust-ABS composites increased a little first for 5% sawdust-ABS composite; then it started to decrease with the addition of 10% and 15% fiber content. Again bulk density increased for 20% sawdust-ABS composite. Highest bulk density was found for 20% sawdust-ABS composite. Bulk density increased means the composite became denser.

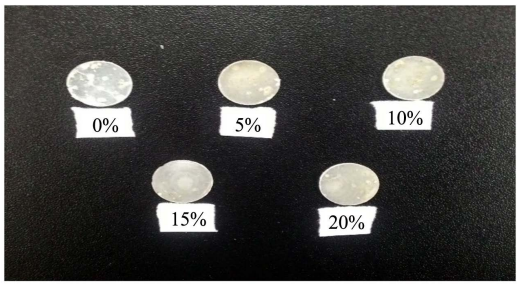

Figure 4. Sawdust-ABS composite samples for FTIR spectra measurements with different wt% of fiber content.

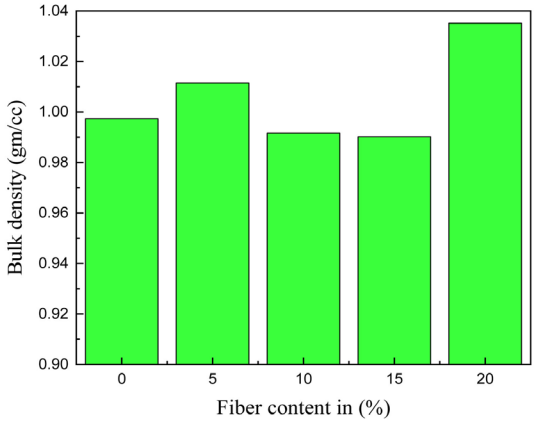

Figure 5. Bulk density vs different wt (%) of fiber content in sawdust-ABS composites.

3.1.2. Water Absorption Property of Composites

Effect of sawdust fiber addition in sawdust-ABS composites in their water absorption ability was as shown in **Figure 6**. The water absorption of the composites was found to increase with the addition of the fiber content in composites and with soaking time. However, there was no uniformity in water absorption by sawdust-ABS composites as in the case of bulk density and maximum water absorbed by 10% sawdust-ABS composite then 20%, 15% and 5% composites. The percentage of water absorption was very close for 0% and 5% composites. In 5% sawdust-ABS composite may be the fiber content was too little to absorb water and the absorption was similar as 0% composite. Moreover, at first water absorbed very quickly for both 0% and 5% compositions but after 48 hours the water absorption was in saturated condition.

Naturally, polymer likes ABS and polylactic acid are hydrophobic and sawdust is hydrophilic. The sawdust-ABS composites absorbed more water due to the hydrophilic nature of sawdust fiber (due to presence of polar group).Water may penetrate into the composite through the cutting/interfacial side of the sample [36] that allowed hydrogen bonding to occur between the free hydroxyl group of the cellulosic molecules with water molecule. As 5% sawdust-ABS composite contain very little amount of fiber it absorbed less water as same as 0% composite. At higher fiber content composites, however, there were more hydroxyl group to interact and absorbed more water compound in comparison with lower fiber content composites.

3.2. Mechanical Properties of Sawdust-ABS Composites

3.2.1. Tensile Property of Composites

Figure 7 shows the tensile strength of sawdust-ABS composites for different wt% of fiber loading. This figure indicates that the tensile strength of the sawdust-ABS composites decreased drastically with the addition of fiber content in composites. Tensile strength decreased sharply for 5% and 10% composites, however, after 10% composition tensile strength increased slightly for 15% composition then the value decreased again for further addition of fiber content (for 20% sawdust-ABS Composites).

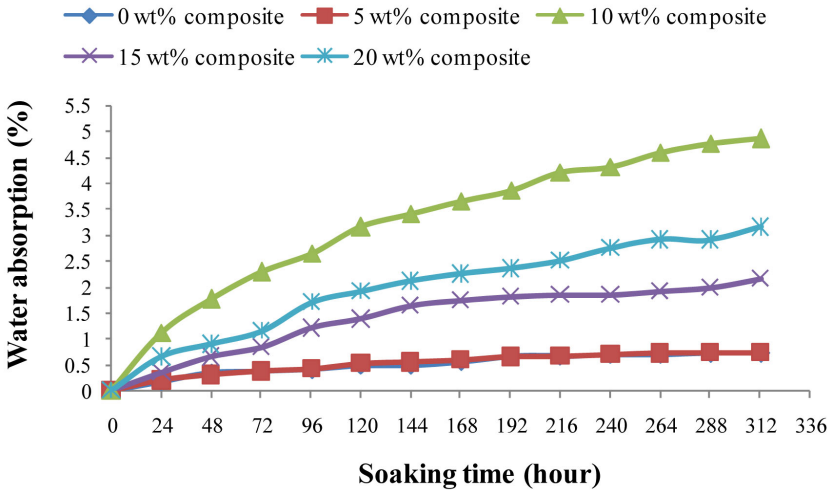

Figure 6. Water absorption vs soaking time in hours for different wt% of fiber content in sawdust-ABS composites.

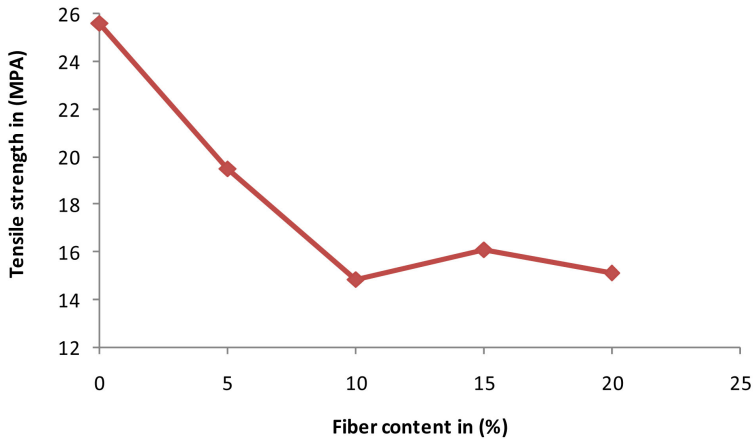

Figure 7. Tensile strength of sawdust-ABS composites for different wt% fiber content.

Tensile strength depends on number of factors-fiber loading, matrix strength, fiber adhesion between fiber and matrix, orientation of fiber, etc. Moreover, for short fiber, the interfacial bonding is also important. Neher *et al.* showed that the tensile strength decreased with the increase of the fiber content up to 5% and then it started to increased (upto 10%). After 10% it again decreased up to 20% compositions [37]. Seung-Hwang *et al.* [38] showed that the tensile strength gradually decreased with the increase of fiber content. Mohammad, N. N. B. *et al.* [28] carried out research on the mechanical properties of kenaf fiber reinforced rPET/ABS composites. They observed that there was a slightly decrement in mechanical properties with addition of kenaf fiber. Rafia Akter *et al.* [39] observed that the tensile strength decreased with the increase of talc content in the composites. This may be due to poor interfacial adhesion between polymer matrix and fiber. This is general phenomenon in incompatible composites with different characteristics, such as hydrophobicity of the polymer matrix and hydrophilicity of the filler.

Percentage (%) of elongation for different wt% of fiber content in composites as shown in Figure 8. With the addition of fiber in composites the percentage of elongation increased firstly for 5% composites, moreover, the maximum percentage of elongation was given by 5% composites. After that it decreased rapidly with higher addition of fiber contents. However, after 15% composition the value again increased slightly for 20% composites. The value of elongation at break showed a significant decreasing order with increasing fiber loading which indicates hindrance by fiber to molecular mobility or deformability of polyester matrix. It is also derived that elongation at break decreased with increasing fiber content in all composites accept 5% sawdust-ABS composite. This may be due to the increase in the discontinuity of the polymer matrix with the increase in the dispersed phase [38] [40]. Natural fiber and their composites are environmental friendly and renewable, however they have several bottlenecks. They have poor wet ability, incompatibility with some polymeric matrices and high moisture absorption. Due to high moisture absorption properties, there are formations of void in the composites which can reduce the mechanical properties of composite [37] [41].

The effect of sawdust fiber addition in sawdust-ABS composites for their elastic modulus as shown in Figure 9. This figure shows that the elastic modulus increased with the increase of fiber content in all composites. Moreover, after 5% composites elastic modulus increased sharply for 10% and 15% composites then

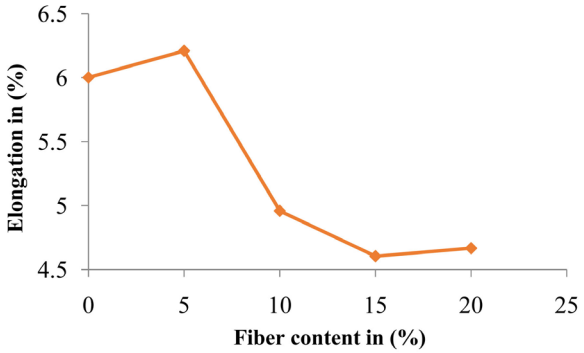

Figure 8. Percentage (%) of elongation in sawdust-ABS composites for different wt% of sawdust fiber.

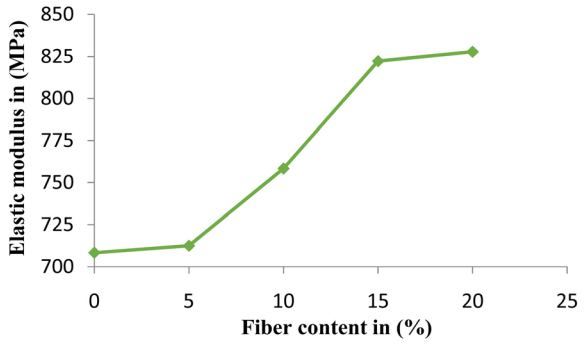

Figure 9. Elastic modulus in sawdust-ABS composites for different wt% of sawdust fiber.

the value is in saturated condition for 20% composite. The maximum value of elastic modulus is 827.88 MPa which is for 20% sawdust-ABS composites. Mohammad, N. N. B. *et al.* [28] showed that stiffness and stress transfer in composites increased with an increased or excessive addition of fiber which provided a better loss modulus and also a better storage modulus. The loss modulus is also considered to be increased with fiber addition up to 756 MPa at 50 phr fiber loading compared to the loss modulus of gum that is 415 MPa.

3.2.2. Hardness

Leeb's rebound hardness for different wt% of fiber loading in sawdust-ABS composites as shown in **Figure 10**. With the addition of sawdust fiber in sawdust-ABS composites the hardness of the composites decreased abruptly. However, after 5% combination with the increase of the fiber loading Leeb's rebound hardness for other combinations was more or less in unchanged condition. As the stiffness of the ABS polymer is higher than that of the sawdust fiber, the sawdust-ABS composites are softer then the pure one and Leeb's rebound hardness decreased with the addition of fiber contents. Before performing each of the experiment, all the samples were dried at 60˚C in dryer for 24 hours, however, the composites may contain some moisture content. C. Tan *et al.* [42] showed that due to high moisture absorption properties, there are formations of void in the composites which can reduce the mechanical properties of composite such as hardness. Bhuiyan, A. H. *et al.* [43] showed that with the inclusion of TiO2, the hardness of the composites decreased. This conclude that the composite materials were somewhat soften by the addition of filler. Furthermore, in this experiment, 5% NaOH used for treatment which may reduce mechanical properties. Venkateshwaran *et al.* [44] studied the effect of alkali (NaOH) treatments of various concentrations (0.5%, 1%, 2%, 5%, 10%, 15%, and 20%) on the mechanical properties of banana/epoxy composite. The results reported that as compared to other treated and untreated fiber composites, 1% NaOH treated fiber reinforced composites have a better property. The alkali concentration on the fiber surfaces results in better mechanical properties of the resulted composite. However, the rising of alkali concentration maybe causes fiber surface damage, leading to a decrease of mechanical properties.

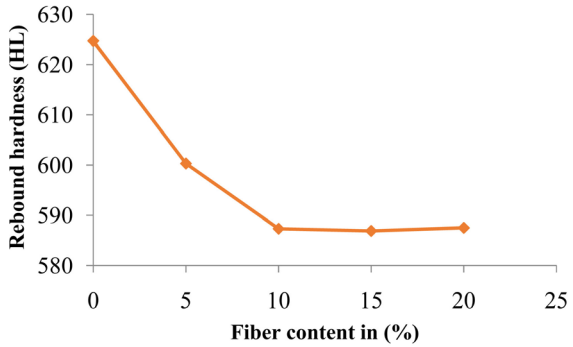

Figure 10. Leeb's rebound hardness in sawdust-ABS composites for different wt% of fiber loading.

3.3. Structural Property

Fourier Transform Infrared (FTIR) Spectroscopy.

The FTIR spectrum in the frequency range (650 - 4000 cm^{-1}) for different wt% of fiber loading in sawdust-ABS composites shown in Figure 11. Figure shows that the major peaks for sawdust reinforced ABS polymer composites at about 664, 770, 911, 1035, 1449, 1637, 2236, 2363, 2924 and 3447 is due to C–H out of plane, =C–H out of plane bending, C–H rocking, C–O–C stretching, asymmetry C-H bending, C=C stretching, C≡N stretching, C≡C stretching, symmetric C–H stretching and O–H stretching. A new bond probably C≡C stretching was formed for 20% composite. Moreover, C–H rocking of 0% composite at 911 was broken after addition of sawdust fiber in all other composites [42] [43].

4. Conclusion

In present work, physical, mechanical and structural behaviors of sawdust-ABS composites were studied. This study showed that maximum bulk density was found for 20% composites. Water absorption test showed that with the increase of fiber content and soaking time, percentage of water absorption increased. Maximum amount of water absorption was given by 10% sawdust-ABS composite. The tensile strength and hardness of the composites both decreased with the increase of the fiber content. Percentage of elongation was maximum for 5% composite, and then it decreased with the increase of the fiber loading in sawdust-ABS composites. However, elastic modulus increased gradually with the increase of the fiber loading. Research showed that treatment of sawdust fiber in ABS matrix did not bring regular and considerable change in the mechanical properties of the composites. FTIR spectrum showed that there was a new bond C≡C stretching formed for 20% composite and C-H rocking for 0% was broken after the addition of sawdust in ABS polymer matrix.

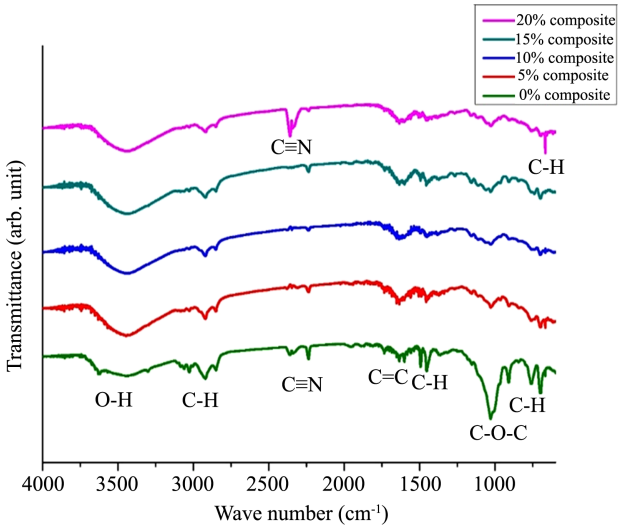

Figure 11. FTIR spectrum of sawdust-ABS composites for different wt% fiber content in composites.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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