Assessment of the physical properties of banana pseudo stem/ ABS composites

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Abstract. The physical properties of Banana Pseudo Stem (BPS) reinforced Acrylonitrile Butadiene Styrene (ABS) composites with different fiber weight percentages were studied. BPS fibers were pretreated by using Sodium hydroxide solution with 5% concentration for 24 hours. ABS/BPS composites were prepared with 0, 10, 20 and 30 wt. % fibers. The Moisture Content (MC %) and Water Absorption (WA %) for BPS fiber were studied. The water absorption (WA %) and Thickness Swelling (TS %) of the composites were investigated. The scanning electron microscope (SEM) observation for fracture surfaces was also studied. The Thermogravimetric analysis (TGA) and Differential Scanning Calorimetry (DSC) analyses were used to measure the thermal stability and glass transition temperature (Tg) of BPS/ABS composites. Moreover, the melt flow index (MFI) and dimensional stability tests for the composites were studied.

1. Introduction
Polymeric matrix composites play an important role in our life. Composites share in manufacturing of many applications such as aerospace, transportation, wind energy, construction, automotive and marine applications [1]. The global composite materials market is expected to reach an estimated $40.2 billion by 2024 and it is forecast to grow at a CAGR of 3.3% from 2019 to 2024 [2]. The major motives for growth in composites market are increasing demand for lightweight materials in the aerospace, defense and automotive industry corrosion and chemical resistance materials demand in construction and pipe & tank industry [2].

ABS is one of the important copolymers which consists of Acrylonitrile, butadiene and styrene. It is used in many applications such as polymeric wood composites. It has a good physical property when compared with other plastics, ABS is the most widely used material in fused deposition modelling (FDM) applications such as 3D- Printing technology [3]. The global market size of ABS was USD 20.22 billion in 2014. Its market share is expected to be USD 34.88 billion by 2022. This is due to rising the use of the product in numerous applications including automotive ancillaries, consumer goods, and construction materials [1]. Importance of light weight automobiles on account for a better fuel efficiency is expected to increase products application scope. Recent developments in the Corporate Average Fuel Economy (CAFE) have forced automobile manufacturers to seek new ways to reduce fuel consumption which will have a strong impact on the industry over the forecast period [4].

Due to environmental pollution and increase of harmful emissions, that comes from using non-natural compounds in the industry field and causes many different health and environmental problems.
Natural fibers became good candidates to invade the field of industry as an alternative to synthetic fibers. Due to low cost, low density and good properties compared with synthetic fibers [5]. Nowadays, the utilization of agriculture wastes (AGW) is combined between past tradition and present technology. By using them as composting, biogas, electricity and animal foods. They are also a big source of natural fibers to be used as filler or reinforce in polymeric matrix composites (PMCs) [5]. The amount of (AGW) in Egypt were reached 35 million tons / year (23 million tons of vegetarian wastes and 12 million tons of animal wastes per year). Almost 21 million tons/year of AGW haven’t been utilized till now [6]. During last years, different industries tried to decrease usage of composites from petroleum due to harmful impact on environment. So natural fiber composites (NFCs) can be considered as replacement for petroleum ones. The price and manufacturing consumed energy of natural fibers are low when compared with synthetic fibers [6].

The estimated amount of Banana wastes reached 1.7 million tons /year. Banana residues can be used as a source of banana fiber (BF). The production of banana fruit over 130 countries is nearly 120-150 million tons (as the second major production of fruit) with nearly 16% of total global production of fruit, only 12% of the weight of banana tree is represented as banana fruit and the others (leaves and pseudo stems, etc.) aren’t used as food but used in fiber production [7]. BF can be obtained from many parts of banana plant such as leaves, rachis and stems. Many industries such as paper, mats, textiles and composites are improved by BF. Pseudo stems are considered as a cluster of leaf stalk which aggregated together in cylindrical shape. They have many applications in industry like cardboards with high quality, ropes for marine field, currency paper and fabric materials. Banana pseudo stem (BPS) fibers are better than rachis and leaf fibers due to its high mechanical strength [8]. BPS fibers are considered as Bast plant fibers with complex structure of cellulose, hemicellulose and lignin. BPS have high mechanical properties due to high cellulose percentage compared with others [8].

The aim of this paper is to study the physical and thermal properties of BPS/ABS composites through using BPS (fibrils extracted from banana tree wastes) with the ABS material as a thermoplastic composite material. ABS is used as a basic matrix and BPS fibers are used as a reinforcing material with different wt. % of (0-10-20-30%).

2. Methodology

2.1. Materials
Banana Pseudo Stem (BPS) fibers were supplied by Banana Kingdom Co. The chemical analysis and density of banana fibres are shown in table 1 [9]. The banana fiber length and diameter were measured by using FEROX PL Microscope, the average fiber length, diameter, and aspect ratio are listed in table 2.

| Table 1. Chemical composition of BPS fibers [9]. |
|-----------------------------------------------|
| Cellulose [wt.%] | Hemicellulose [wt.%] | Lignin [wt.%] | Others [wt.%] |
| 63 | 12 | 5 | 20 |

| Table 2. Physical Properties of BPS fibers [9]. |
|-----------------------------------------------|
| Density (kg/m³) | Average fiber length | Average fiber diameter | Average fiber aspect ratio |
| 721 | 4 ± 0.5 (mm) | 163.64 ± 20 (µm) | 25 ± 3 |

Samsung ABS code SD-0150, UN-reinforced General-Purpose ABS granules were used in this research.

2.2. Pre-treatment of BPS fibers
BPS fibers were chemically treated by using (5%) NaOH Solution at room temperature (25°C) for 24 hrs [8]. The treated fibers were washed by running water and immersed into hydrochloric acid HCl.
solution of (1%) concentration at room temperature (25°C) for 10 minutes [9]. This was followed by washing in running water. Consequently, the fibers were dried in open air under the sun light for 24-48 hrs., then placed in the oven for drying at 80°C for 48 hrs. [9].

2.3. BPS/ABS Composite preparation
BPS/ABS Composites were prepared by placing the ABS granules in thermal mixer machine at 180°C for 15 minutes [10]. Then BPS fibers were added with different weight percentage (0-10-20-30) wt. %. The recommended mixing time is 10 minutes to achieve homogeneous mixing results [10]. These composites were consequently crushed into granules and then injected using injection machine type METAL MECCANICA (65/90 SR).

2.4. Physical and thermal tests
2.4.1. Moisture content test. The moisture content (MC) test was performed for untreated and treated BPS fiber according to DIN EN 322 by using ADAM balance NBL 623e.

2.4.2. Water absorption (WA%) and thickness swelling (TS%) test. The WA% and TS% tests were carried out for pure ABS and BPS/ABS composites at different fiber wt. % according to ASTM D570 b using ADAM balance NBL 623e.

2.4.3. Melt flow index (MFI) test. The melt flow index (MFI) tests were carried out through a Melt Flow Index Tester DW5450D for both pure ABS and BPS/ABS composites at different fiber wt.% according to ASTM D1238-04.

2.4.4. SEM observation. The microstructure analysis was made for BPS/ ABS at different wt.% using scanning electron microscope Quanta FEG-250 microscopy.

2.4.5. TGA test. TGA test was done using Thermo gravimetric device with model TA instrument Q500 according to ASTM D 6370.

2.4.6. DSC analysis. DSC analysis was performed by using TA instrument Q2000, according to ASTM D 3417.

2.4.7. Dimensional stability test. The dimensional stability test was performed using Q400 TA Universal according to ASTM D1204.

3. Results and discussion
3.1. Moisture content of untreated & treated BPS fibers
The moisture content of untreated and treated BPS fibres in an ambient with room temperature of 25 oC and humidity of 50%. The moisture content for treated fibres was 14.52 % while, for untreated fibres was 8%. Due to alkaline treatment for BPS fibres, the moisture content increases from 8% to 14% (with an increase of 75%). Therefore, the BPS fibres should be dried in oven for 24-48 hrs. before processing.

3.2. Effect of fibers weight percentage in water absorption (WA%) of BPS/ABS composite
The water absorption percentage of BPS/ABS composite as a function of time at different fiber wt.% and time is presented in figure 1. The WA% of BPS/ABS composites after immersion time of 288 hrs. were 1.21, 1.85, 2.42, and 2.27 % at 0, 10, 20, and 30 % BPS fiber weight percentage.
Figure 1. Water absorption as a function of time for BPS/ABS composites.

The results show that the WA% increases with increments of fiber weight percentage wt. %. BPS/ABS composite samples absorb moisture more than ABS matrix sample. This is due to hydrophilic nature of BPS fiber which is responsible for water absorption of composite. However, the increase of voids at fiber - matrix interface influences increasing the water absorption of composites.

3.3. Effect of fiber weight percentage in thickness swelling (TS%) of BPS/ABS composite

Figure 2. Thickness swelling as function of time for BPS/ABS composites.

Figure 3. Relationships between water absorption and thickness swelling. Figure 2 shows the percentage thickness swelling of the TS% of BPS/ABS composite as a function of
time at different fibres wt. %. The TS% of BPS/ABS composites after immersion time of 288 hrs., were 1.17, 2.12, 3.04, and 3.25 at 0, 10, 20, and 30% BPS fiber weight percentage. The TS% of BPS/ABS composites increase as the water absorption increases as shown in figure 3. ABS with wt. % of 30% BPS fibers exhibit maximum water absorption and thickness swelling during the whole duration of immersion. Water absorption leads to a build-up of moisture in the fiber cell walls, which then results in fiber swelling. Increasing fiber weight percentage wt. % increases hydrophilic sites which are available for water absorption [11].

3.4. Effect of fiber weight percentage in MFI of BPS/ABS composite
The melt flow index of pure ABS under investigation recorded 20.5 gm/ 10 min, which is concordant with standard MFI of ABS. The effect of fiber weight percentage wt.% on MFI of BPS/ABS composite is presented in figure 4. The MFI of BPS/ABS was 18.5, 17, and 15 gm/10 min at 10, 20, and 30% fiber content. The results show decreasing MFI with increasing BPS fiber wt.%. This may be due to BPS fiber misalignment which affects the viscoelasticity dynamics of BPS/ABS melts. Also, the mobility of molecular chains of polymers have been hindered by BPS fibers.

![Figure 4. Effect of fiber wt. % on melt flow index MFI of BPS/ABS composite.](image)

3.5. SEM study
SEM micrographs of tensile test fracture surfaces for (BPS/ABS) composites containing 10% fibers weight percentage show uniform fiber distribution and decrease of cavities and voids comparing to 20% and 30% fibers content in figure 5(a). However, as the fiber weight percentage increased to 20% and 30%, voids appeared at the fiber/matrix interface as shown in figures 5(b) and 5(c).

(a)  
(b)
3.6. Effect of fiber weight percentage on thermal stability of BPS/ABS composite

The previous researches indicated that as the total weight residue increases, the thermal stability also increases [9]. Thus, increasing the fiber weight percentage, the total weight residue at 500°C increases dramatically from 2.72% at 0% BPS to 4.1%, 7.2% and 7.29% at 10%, 20% and 30% BPS fiber weight percentage respectively (see figure 6). Corresponding, the thermal stability of BPS/ABS composites increased.

3.7. Effect of fiber weight percentage on Tg of BPS/ABS composite

Figure 7 Shows the effect of fiber weight percentage on Glass transition temperature of BPS/ABS composite. The Tg of pure ABS matrix was 94.8°C. It is observed that glass transition temperature increases with addition of BPS fiber in ABS matrix, also related with decrease in mobility of polymer with the addition of fiber, so Tg is considered as an indicator for interfacial interaction between fiber and matrix. This is an agreement with the loadings of other molecules. Thus, the addition of BPS fiber to ABS matrix increases the Tg of composite to 102.85°C and 103.43°C at 10 and 20% BPS fiber wt.% respectively. The DSC thermogram showed that the glass transition temperature of composites above 20% fiber weight percentage decreased 102°C at 30% fiber weight percentage.
3.8. Effect of fiber weight percentage on dimensional stability of BPS/ABS composite

The coefficient of shrinkage -due to heating at 100°C (24 hrs) in oven- for parallel and transverse directions of injection molding are shown in figures 8(a) and 8(b) respectively. It is noticed that the coefficient of shrinkage (parallel direction of process) were 12.72, 10.399, 9.286, and 7.306% for 0, 10, 20, and 30% fiber weight percentage wt. % respectively. While the coefficient of shrinkage (transverse direction of process) were 23.61%, 20.46%, 19.27%, and 15.54% respectively. Specimens with higher fiber weight percentage wt.% exhibited lower shrinkage. During the injection molding of BPS/ABS composites, most BPS fibers were suspended in molten ABS matrix with its long axis parallel to liquid surface which led to BPS fiber orientation parallel to the finished composite surface. Thus the shrinkage coefficients in parallel direction were less than the others in the transverse direction (fiber orientation). This is an agreement with the work of Shinoj et al [11].

The equivalent shrinkage coefficient of BPS/ABS composite was calculated as an average of linear shrinkage coefficient in both directions and shown in figure 9. As the expansion or shrinkage coefficient decreases, the dimensional stability increases. The addition of BPS fibers in ABS matrix enhances the dimensional stability of ABS composite.
4. Conclusion
The following conclusions can be drawn from this work.

- The moisture content for treated BPS fibers of 14.52\% while the moisture content of untreated was 8\%.
- The MFI of BPS/ABS composite decreased as the fiber wt.% increase, thus the viscosity increased.
- The water absorption WA\% and thickness swelling TS\% of BPS/ABS composite increased with increasing fiber content from 10\% to 30\%.
- The addition of BPS fiber in ABS matrix enhances the dimensional stability of ABS composite.
- The thermal stability of BPS/ABS composite increase as the fiber weight percentage increases.
- The dimensional stability increases with the addition of BPS fibers in ABS matrix.

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