Development of FRP composites using natural fibres for food packaging

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Abstract. Packaging helps to protect and preserves the quality of the goods available for storage and transport purposes. Many businesses have begun to look for new techniques and tactics for better design in order to sell their products, which has boosted the need for change packaging materials. This market segmentation is expected to change significantly by the end of 2018 as Asia is projected to reach for more than 40% of global demand. Many of the popular packaging were plastic materials in form of boxes, cans, bags, bottles, wrappers, envelopes and containers. Those plastic-packaging materials performs well but it becomes non-degradable waste that causes unnecessary landfills and harmful to environment. To overcome such drawbacks, the recent researches reported that the renewable and biodegradable materials have drawn much attention in the packaging domain due to their eco-friendly nature. In this research, the biodegradable composite material has introduced for packaging applications using natural fibres. The different material of natural fibres such as Aloe Vera, Jute and Coir have used as reinforcement to make composite material. The mechanical behavior of Tensile, Compression, Flexural strength and Impact for different composition have studied experimentally and conducted the SEM analysis to determine casting failures. Comparatively, the obtained results show that the Jute material behaves better than others to replace packaging material do.

1 Introduction

Products used to organize, conceal, handle, supply, and display commodities from makers to consumers from raw materials to completed items are referred to as packaging. Usually, it is divided into groups according to the primary raw materials, which include ceramic, paper, cardboard, metal, glass, polymer, wood, and fiber. Global packaging is actually a very important industry division and continues to grow. Products like polypropylene, polyethylene (PE) and other synthetic polymers have become very common in food packaging. Moreover, their low biodegradability is the greatest drawback of conventional polymers. Biodegradable polymers, including starch, cellulose, polyhydroxyalkanoate, chitosan, polylactic acid (PLA), are alternative products; however, they tend to have some drawbacks, such as PLA's quite high prices. Natural fibers are very promising fabrics, which can be used to production of biodegradable materials to lower or non-biodegrade prices, thereby making them more eco-friendly. Even promising are non-woven based on natural lignocellulose fibers.

The Purpose of this research is therefore to determine the current knowledge on composite natural fibers, particularly on the use of new composite materials based on fiber in food packaging. The natural fibers of aloe-vera, coir and jute are chosen as proposed raw material to make biodegradable composite material for packaging. This new material proves suitable alternate for packing food by experimental investigation. Verma et al [1] has reviewed about the coir fiber reinforcement in polymer composites and its application. Coir fiber ability for surface chemical alteration has been extensively utilized in a wide range of applications, e.g., packaging, furniture etc. Ajith Gopinath et al [2] has examined

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the mechanical properties of jute fiber reinforced composites. The jute-epoxy & jute-polyester composite tensile strength was 12.46 $N.^{-mm2}$ and 9.23 $N.^{-mm2}$ respectively. The 5-percentage sodium hydroxide-treated jute fiber enhanced composites tended to have a higher tensile strength than 10 percentage sodium hydroxide-treated fiber enhanced epoxy composite by 18.67% and an improvement of 16.67 percentage for polyester composites. Mohammed Khalifa and Santosh Chappar [3] has experimented the Banana Reinforced Epoxy Composites. The results of the study showed that banana fibers have a considerable influence on the tensile strength of composite materials, with greater fiber diameter translating into higher strength and lower modulus. Other characteristics that were examined were strain elongation and tensile strength and modulus. Sankar and Chandramohan [4] have studied the mechanical behavior of (NFRC) using different fibers. Superior strength is achieved by using a polymer-reinforced composite with a 50%–75% ratio and hybrid Sansevieria Trifacta–jute fiber, a blend of two natural fibers. It can be used as an alternative to synthetic fibers made of E-glass in a variety of applications, according to specimens examined under a scanning electron microscope. Kumaresan et al [5] has investigated the effect of fiber orientation on the reinforced epoxy composites being treat with sisal fiber leads to the following conclusion. Sisal fibers typically possess strong absorbing properties of effects. Mohamed and Pushpaganeshan [6] were experimented the mechanical characteristics of flax fiber reinforced composites. Because flax fibers are less expensive and have unique mechanical qualities, they might eventually take the place of glass fibers in composite materials. Lingo cellulosic materials' mechanical qualities may be effectively altered by enhancing their dimensional stability and environmental stability. The hybrid composite material, which required for aerospace and automobile industries, has studied by Manjunath Pattan et al [7]. Jute and Aramid hybrid laminated composites show remarkable flexural strength; they do not shatter even after 900 bends under a 0.24 KN stress. Sivakumar et al. [8] investigated how fiber loading affected the mechanical, physical, and water absorption characteristics of epoxy-based hybrid composites reinforced with glass, nylon, and jute fiber. According to the produced composite morphology, SEM photos reveal less fiber pull-outs and deboning in composite glass (11% + 26% + jute 35% + epoxy 20%). The sisal fiber-reinforced polypropylene (PP/SF) composites by melt mixing with different fiber length have studied by Suchhanda et al [9]. The SEM analysis has conducted for proposed composite to found the suitable material orientation of composite. Ayyappa Atmakuri's [10] study looked at the mechanical and moisture characteristics of hybrid epoxy resin composites reinforced with sisal and caryota fibers. The study discovered that hybrid composites have better mechanical characteristics than single fiber composites by scanning electron microscopy examination. Tamilarasan and Inbanaathan suggested the natural fibers mixed with carbon fiber to make degradable composites [11]. The study highlights how adding carbon fiber in equal amounts might change the mechanical characteristics of composites made of natural fibers. Jesus Vicente [12] analyzed the composite material using fibers through scanning electron microscopy experiment. The composite line shows locations where reinforcing material is consistently linked mechanically, and thus offers great prospects for future growth.

1.1 Summary

Natural fiber reinforced composites (NFRCs) made of plants have superior qualities than synthetic materials made of petroleum, such as biodegradability, biocompatibility, and renewability. The mechanical characteristics, difficulties, and possible uses of cellulosic fibers and polymeric matrices for NFRC manufacturing are covered in this paper along with their attributes. Plant fibers do have certain disadvantages, such as a greater tendency to retain moisture, but these may be addressed by chemical and physical changes. It is difficult to produce 100% green bio composites from natural and renewable resources, nevertheless. The commercial development of pure green bio composites needs to receive greater attention in order to improve sustainability. For the purpose of creating polymer matrices and reinforcing materials, new sources of natural biopolymers and fibers are required. Furthermore, studies want to investigate the utilization of short and non-spinnable natural fiber wastes as polymer matrices or reinforcing components in entirely green bio composites that are manufactured.

2 Method and Material

FRP composites are the material which made by matrix resin and reinforcement of fibre materials. The use of natural fibre as reinforcement in polymeric composites founded on environmental concerns and the high cost of synthetic fibres leads to replace natural fibres [13, 15]. The primary goal of this study is to develop biodegradable packaging materials that use natural fibres to give increased stiffness and strength, decrease weight, and reduce costs by lowering polymer content. The methods of this experimental investigation have listed as follows:

- To experiment the composite material using different composition of natural fibres.
- To conduct the structural tests of tensile, compression, impact and flexural test in ASTM standards.
- To validate the results of different composition of natural composites.

2.1 Material selection

The selection of materials is a crucial phase in the designing process. It is critical for a design engineer to use the right materials for a design that they created so that the product performs optimally [14]. The raw materials for the proposed packaging material are fibres of Aloe Vera, Coir and Jute that belong to natural fibres. These fibres have intrinsic properties such as low weight, low cost, high specific strength, and better physical characters [17]. So, the different combination these 3 fibres have been used to made composite. Epoxy resin is used as the binding material to fabricate the proposed fibre reinforced polymer material. The fibre material graphically represented in Figure 1 whereas the physical properties are representing in Table 1.

Table 1. Fibre material property

Properties	Units	Aloe Vera	Coir	Jute	Epoxy Resin
Density	Kg/m^3	1200	1400	1500	1000 - 1050
Young's Modulus	GPa	35	16 - 26	10 - 20	1.85±0.21
Poisson Ratio	-	0.3	0.3	0.36	0.33

A *B* *C*

Fig. 1. Aloe Vera fibre (a), coir fibre (b), and jute fibre (c)

3 Specimen preparation

Hand layup technique (Figure 2) have used to the manufacturing these FRP composites. Investigates the creation of composite material plates with a thickness of (300 x 300 x 3 mm) by combining resin that is applied by rollers with fibers that are chopped and molded into mats [20]. High flexibility, process efficiency, and inexpensive tooling are among the advantages. Nevertheless, disadvantages include labor-intensiveness, minimal automation potential, and lengthy development times. The specimen details classified into six compositions shown in the Table 2 and Figure 3 represents material testing samples of different composites.

Fig. 2. Composite preparation

Fig. 3. Test samples on ASTM standard

Table 2. Specimen identification details

Specimen ID	Materials	Mixed Ratio (%)
A	Coir	100
B	Jute	100
C	Aloe Vera	100
D	Aloe Vera & Coir	50/50
E	Coir & Jute	50/50
F	Aloe Vera & Jute	50/50

4 Experiment results

The suggested FRP materials' tensile, compression, flexural, and impact characteristics were tested and discussed below [16]. The surface and composition states were ascertained by SEM analysis. Every specimen was examined for manufacturing flaws and material imperfections, and if required, was thrown away. Before moving on to the next specimen, the outcomes and causes of failure were confirmed.

4.1 Compressive strength

The Compression test was conducted to the all six compositions which specimen standard of ASTM D3410 using UTM Machine. Table 3 provides the calculated mechanical parameters, including ultimate breaking load displacement at maximum force. Comparatively, jute fibre composite (B) attains maximum load of 1954.47 N than other materials. The compressive strength of jute fibre composite is 22.938 MPa.

Table 3. Compression test result for specimens

Specimen ID	CS Area (mm^2)	Peak Load (N)	Compressive Strength (MPa)
A	75	923.735	11.439
B	75	1954.470	22.938
C	75	1105.987	13.695
D	75	461.466	6.023
E	75	165.159	2.933
F	75	1783.098	20.104

Tensile, compression, flexural, and impact tests were performed on the suggested FRP materials. To ascertain the surface and composition condition, SEM analysis was employed. Every specimen was examined for manufacturing and material flaws and, if required, disposed of. Before moving on to the following specimen, the outcomes and failure mechanisms were confirmed.

4.2 Tensile strength

The jute fibre composite (B) performs maximum tensile characteristics while compared to the other fibre composites; it’s numerically characterized to the Table 4. The tensile strength of sample B is 38.837 MPa for obtained load of 1675.517 N. This tensile result of jute fibre 3 times better than results by Ajith Gopinath et al (2) i.e., jute-epoxy tensile strength is 12 MPa obtained for 748 N load. According to survey (9), the tensile strength results 1.7 times better than existing for load ranges to 1990 N.

Table 4. Tensile test result for specimens

Specimen ID	CS Area (mm^2)	Peak Load (N)	% Elongation	Tensile Strength (MPa)
A	45	987.108	5.150	21.161
B	45	1675.517	3.900	38.837
C	45	1049.08	5.870	23.309
D	45	567.544	10.620	17.812
E	45	632.303	2.470	11.342
F	45	1070.919	5.220	21.396

4.3 Impact energy

The impact response of various fiber composites was tested in the study using a Charpy impact test apparatus. The composite material made of jute fiber (sample B) had the highest impact strength and most energy obtained when compared to other composites, according to the results. The impact energy for sample B is 0.47 joules.

Table 5. Impact test result for specimens

Specimen ID	Impact Value (J)
A	0.31
B	0.47
C	1.05
D	0.14
E	0.31
F	0.52

4.4 Flexural strength

Similarly, the flexural test also conducted for prepared samples A to F through UTM machine. The obtained results flexural test has been tabulated in table 6. The maximum flexural strength of 17.224 MPa attains for jute fibre composite (sample B) whereas its flexural modulus is 338.284 GPa.

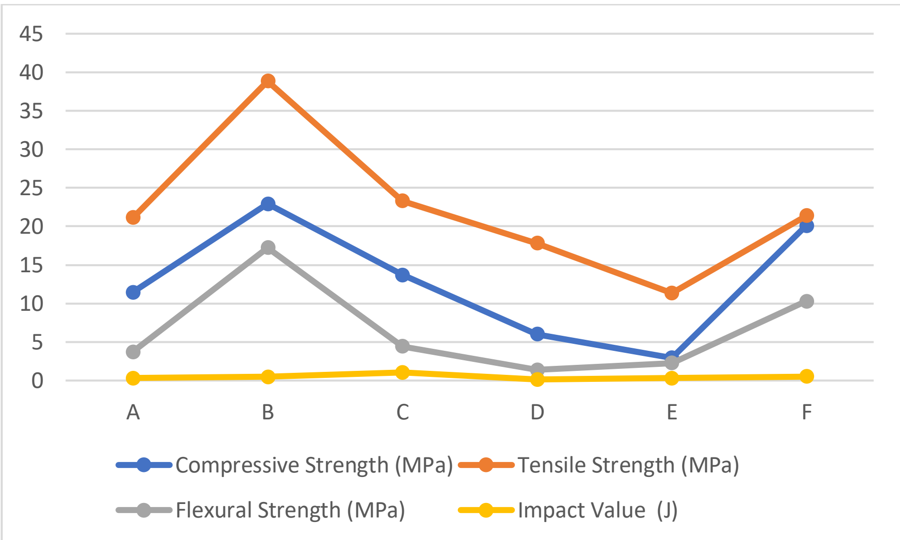


Fig. 4. Comparison of experiment results

Comparatively, mechanical characteristics of tensile strength, compressive strength, impact energy and flexural strength were achieved maximum in jute fibre (100%) composition because of its stiffness nature. Also, Figure 4 representing the comparison of all results.

Table 6. Flexural Test Results

Specimen ID	CS Area (mm^2)	Peak Load (N)	Flexural Strength (MPa)	Flexural Modulus (GPa)
A	169	105.977	3.703	182.183
B	169	343.056	17.224	338.284
C	169	77.077	4.421	57.757
D	169	53.867	1.391	42.173
E	169	28.125	2.248	22.243
F	169	254.864	10.311	1.060

4.5 SEM analysis

Scanning electron microscopy (SEM) has been shown to be a useful tool for the direct study of surface morphology of given material. Here, the microstructure analysis of proposed composite material has conducted and drawn the imaging of casting failures [18,19]. Figure 5 shows the obtained results of SEM analysis for the specimen 23-A (100% coir material). The specimen has tested on various magnification ranges from 350 X to 5 kX for working distance of 12 mm and occurred electrons high on 5kV (EHT – 5kV). The grain size for each magnification had different sizes i.e., 100µm for 350 X, 20µm for 500 X, 20µm for 1kX, 10 µm for 2.5KX and 2 µm for 5KX range. The material crater formed over surface because of coir physical properties. These results clear that if the optical magnification increased then the grain size observation become less.

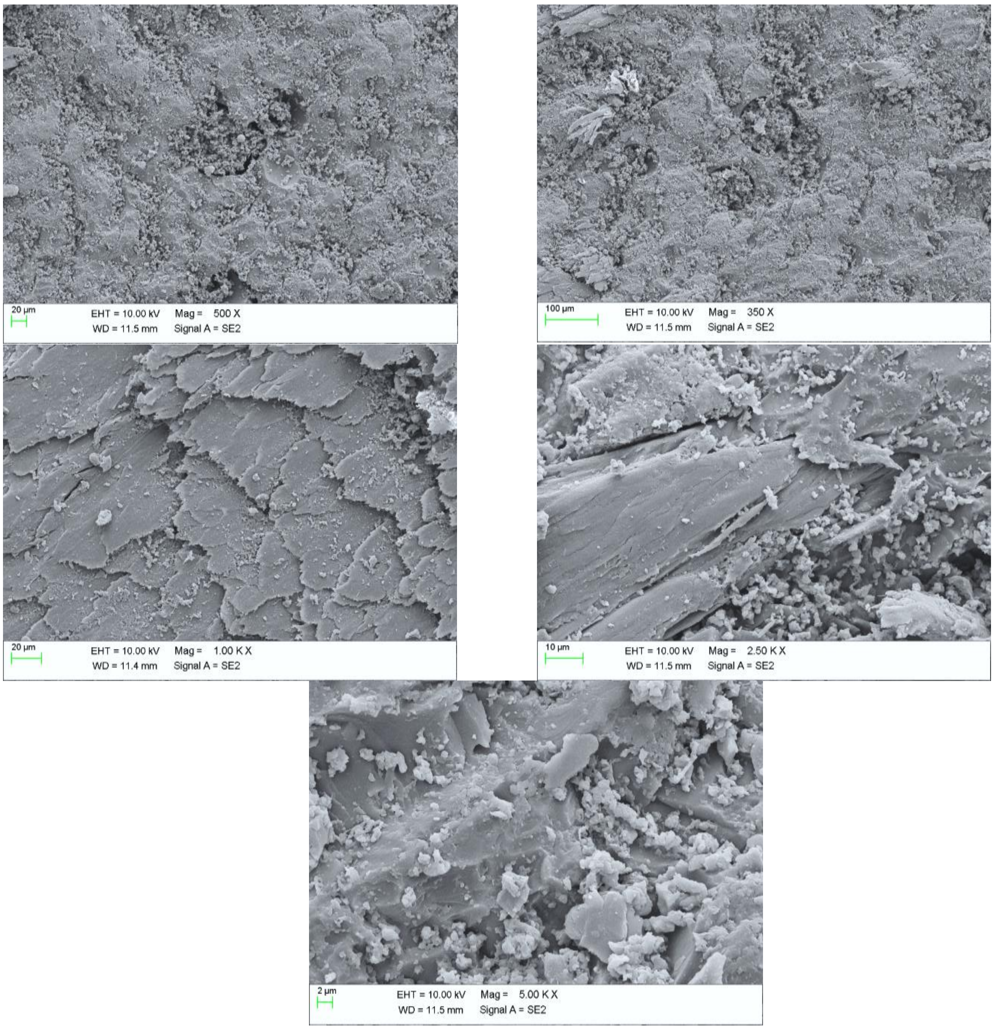


Fig. 5. Micrograph imaging of specimen 23-A

Figure 6 indicates the SEM results of specimen 23-B i.e., 100% jute fibre material. Here, the image magnification ranges from 350 X to 5KX and occurred EHT of 10kV for the working distance of 11.5mm. In specimen 23-B, the less grain size has observed for the magnification of 5kX is 2µm. Comparatively, this specimen 23-B occurred more electron tension than specimen 23-A.

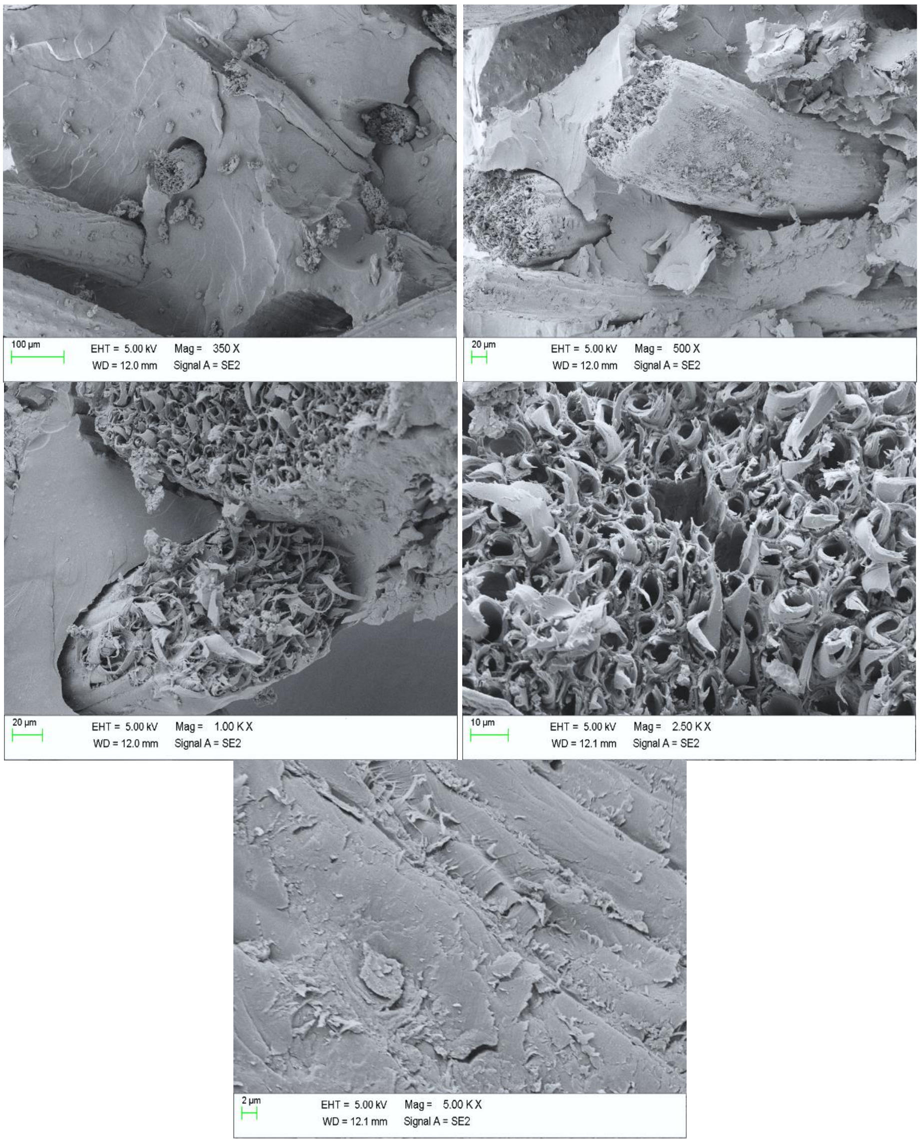


Fig. 6. Micrograph imaging of specimen 23-B

Similarly, the SEM results for specimen 23-C (100% Aloe Vera fibre) has shown in Figure 7. Here the working distance of imaging is 11.4 mm for 350 X mag, 11.1 mm for 500 X to 2.5kX and 11mm for 5kX range. The minimum grain size observed for 5kX and maximum size for 350X. A crater has observed in this specimen 23-C compare to 23-A & 23-B. It causes development of crack over material surface.

The same condition material structure has observed on the specimen 23-D (Aloe Vera + Coir) where the SEM results shown in Figure 8. Here, the electron high tension reduced upto 5kV for the working distance of 12.3mm, 12.4mm and 12.5mm. The less grain size of 2µm observed for 5.00kX magnification.

Next, the SEM results of specimen 23-E (Coir & Jute fibres) shown in Figure 9. Here, the electron occurred upto 5kV for the working distance 11.8mm for 350 X magnification whereas 11.3mm for 5.00kX range. Comparatively, maximum level of material craters and shrinkage has observed on image drawn on microscope than other specimens which shown from the range of 350 X and 500 X but Very less granules formed over surface for 5.0kX magnification.

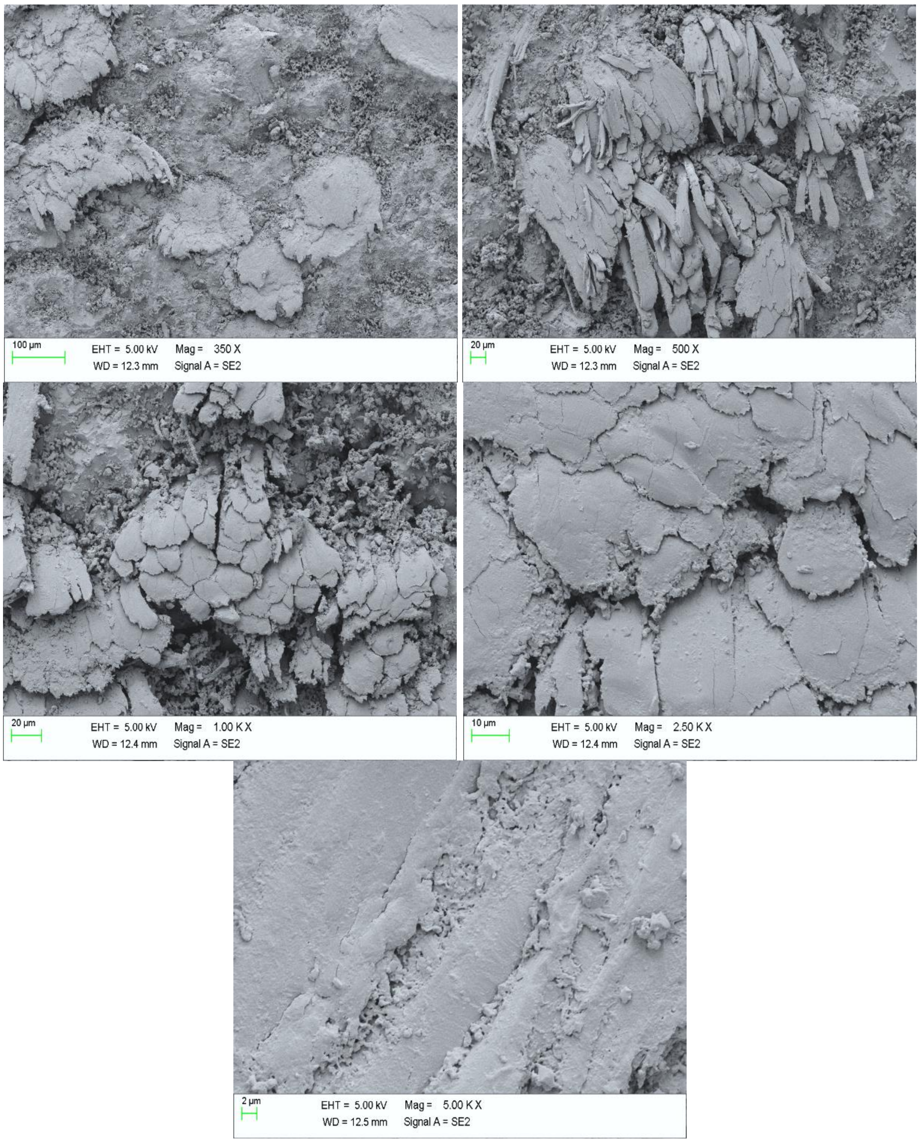
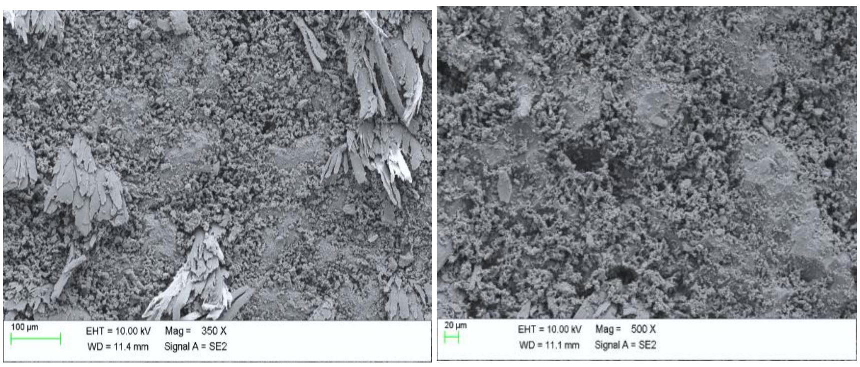


Fig. 7. Micrograph imaging of specimen 23-C



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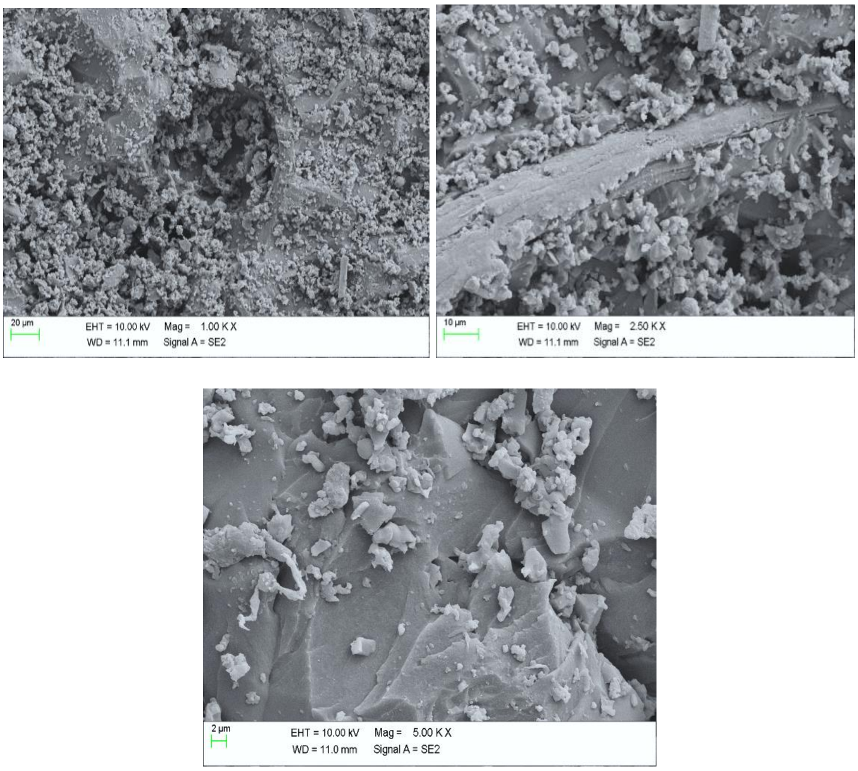
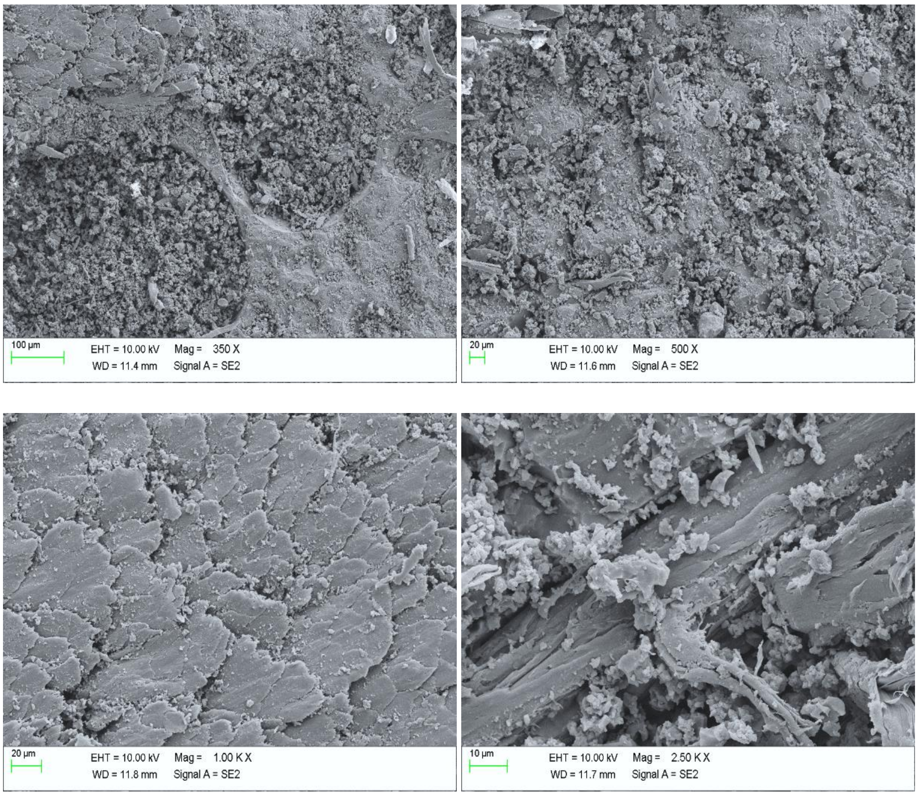


Fig. 8. Micrograph imaging of specimen 23-D



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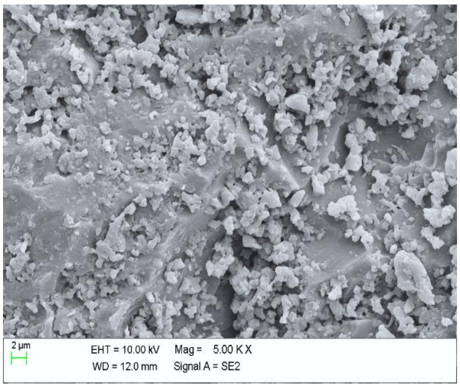

Fig. 9. Micrograph imaging of specimen 23-E

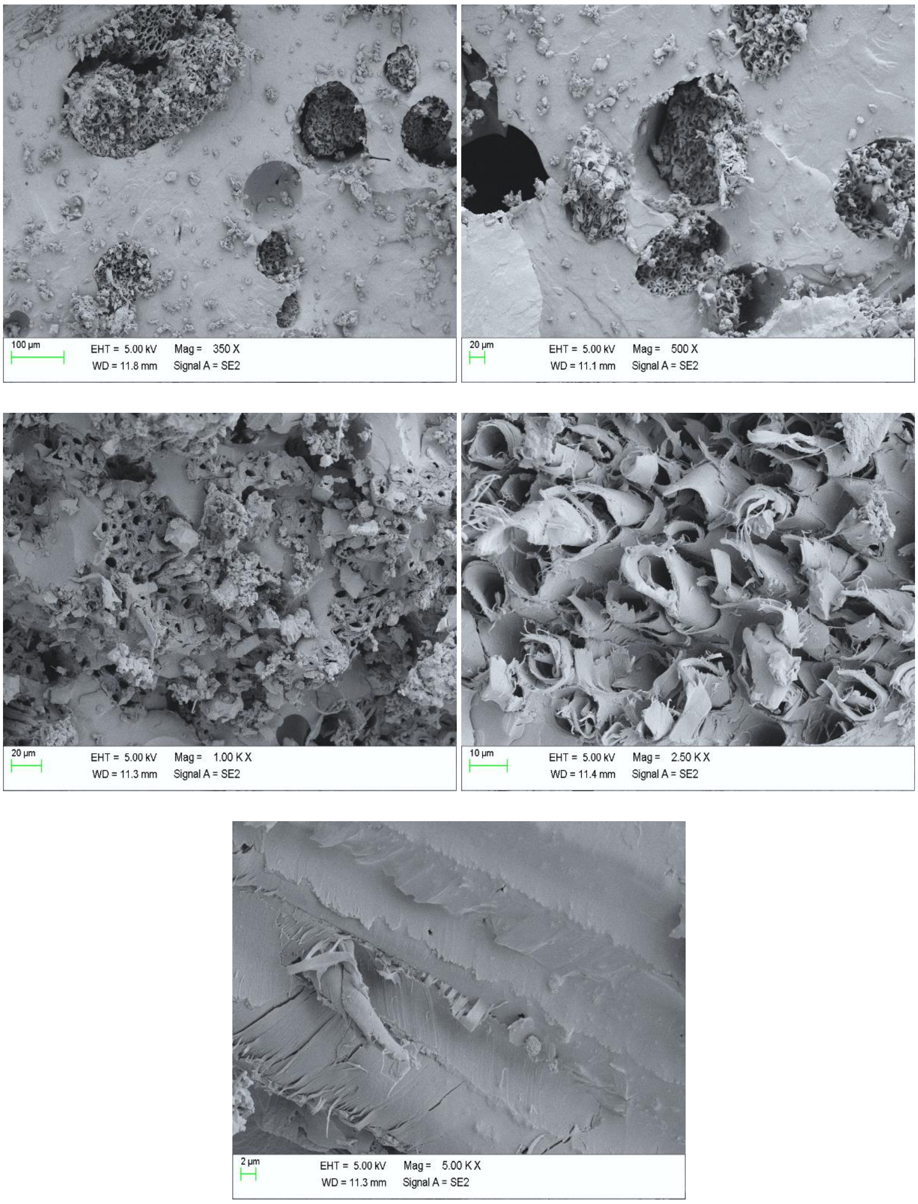

Fig. 10. Micrograph imaging of specimen 23-F

Finally, the specimen 23-F (Aloe vera & Jute fibres) have tested which shown in Figure 10. This specimen occurred 10.00kV of EHT for WD of 11.4mm for 350 X, 11.6mm for 500 X, 11.8mm for 1.0kX, 11.7mm for 2.5kX and 12 mm for 5.0 KX of magnification range. The material crater and shrinkages has observed over surface but lesser than specimen 23-E. At last, the specimen 23-B material shows better results than others in SEM analysis.

5 Conclusion

The development of composite materials has opened up a number of options for packaging lighter items. In general, the choice of packing materials is essential to achieving its intended function. In this study, the polymer matrix composite has proposed to replace existing polymer goods. Implementation of natural fibres to make composite material results degradable character while disposal. So, the natural resources of Aloe Vera, Jute and Coir fibres were used in this experiment. Six different material combination of composite material have experimented to conclude the suitable proposed material. By observing the experimented results, the Jute fibre composite (specimen B) achieves better results than other composites. The following results of specimen B has obtained from experiment:

- The compressive strength of 22.938 MPa attained for the peak load of 1954.470 N.
- The tensile strength of sample B is 38.837 MPa for obtained load of 1675.517 N.
- The impact energy attains for specimen is 0.47 joules but less than specimen F (0.52 joules).
- The maximum flexural strength of 17.224 MPa attains for jute fibre composite (sample B) whereas its flexural modulus is 338.284 GPa.
- SEM results of specimen B shows less material failure than others such as less craters and shrinkages over surface.

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