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Effect of the Quantity of Bio Resins on the Tensile Strength of Agro Waste Enset Woven Fabric Reinforced Composite

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Abstract: The growths of ecological concerns and regulations, most of the researchers and industries have been focused on natural fiber based reinforcing green composite materials. Enset fiber was abundantly available, light weight, moderate moisture content and biodegradable un-utilized fiber under Ensete Ventricosum family. This research work focused on the mechanical properties of enset woven fabric reinforced composite structures. Natural gums (acacia and boswellia) were used as bio resin obtained from plants. Biodegradable composite structures were manufactured by hand layup assisted resin mechanism. SHIMADZU Strength tester was used for analyzed of tensile strength. The influences of grammage of enset fabrics and bio resin on tensile strengths were studied. The test result indicated that, bio resins had a significant effect on tensile strength of composite structure which was reinforced with enset fabrics having the same number of warp yarns. Increasing the grammage (quantity) of bio resin was restored energy and improves the performance of tensile strength by reduced deformation of composite structure.

Keywords: Bio resin; Ecofriendly; Enset Fabric; Green Composite; Tensile Strength

1. Introduction

The discovery of metal materials nearly 5000 year B.C. was the most preferable materials in most engineering applications.[1] However in the past few years, the endlessly growing demand for novel materials having low cost, abundantly available and high strength to weight ratio were attract the researcher to found out a new alternative materials by combining two or more materials, the so called composite.[1-3] Recently most of the large families of textile fiber, yarn, and multi-dimensional fabrics manufactured from agro waste fibers had become most interesting field of research area in biodegradable composite industry.[1-4] Natural fibers used for composite application were obtained from seed, bast, leaf as well as fruit parts of the plant. [1-5] Rural economics and reducing petroleum based products were becoming more responsible for the development of biodegradable materials, which are decomposed or composted by themselves.[3-5] Researches were tried to revisiting natural fibers as reinforcement and gums obtained from plants as bio materials for decreasing of world's global warming.[3-5]

The mechanical and physical properties of green composite materials were influenced by several factors such as fiber length, orientation, distribution, volume of fiber fraction and all mechanical performances of matrix material.[5] The performance of the composite structure also affected by the adhesion and concentration between the fiber and matrix.[5-8] Manufacturing techniques of composite has a significant effect on physic-mechanical properties of green composite structure.[5,6] From the structural point of view, natural fibers are multicellular lignocelluloses having a number of continues layered with different shape, size and arrangement [9]. These natural gifted characters were played important role in the performance of the reinforcing materials.[9-14] The pore and amorphous region of the natural fibers were a key factor that influence the physic-mechanical performance of the composite material, makes them very important properties for interior and exterior application.[15-17] Use of synthetic fiber for a long period of time will bring environmental hazard and health problems.

Enset is the name used by the Amharic language for Enset plant which scientifically called Ensete Ventricosum under Musa family. [18-20] Enset is often known as Abyssinia banana or false banana due to its physical resemblance to a banana plant. [18, 20] Enset plant was grow in all geographical locations and every season with tolerate drought better than most cereal crops.[19,20] It gives a lot of advantage for the farmer as coffee plant shelter, traditional packaging materials and ropes. [20] The fibers were obtained from the agricultural waste material after mechanically extraction as well as decortication of the food contents from the fiber.[20] It has an average equivalent diameter of 194-206 μm, 1.2 g/cm^3 of density and a length of 0.5 to 4.5 m.[20] These technical fibers are generally characterized by hard, stiff and coarse in texture. Moreover, the fibers are low cost; naturally exist as composite structure and good mechanical strength. [20] Introducing a new and unutilized agro waste fiber, like enset fiber, for green composite manufacturing industries

Fig. 1. (a) Enset Plant (b) Enset Fiber

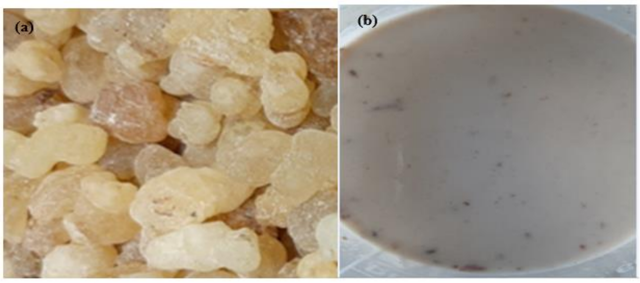

Fig. 2. (a) Granules of Acacia and Boswellia Gums (b) Lab-made Acacia and Boswellia Gum's Bio-Resin.

will reduced industrial harmful waste as well as gives benefit of human healthy. [21] It was observed from the previous studies, there was a limitation of using vegetable oil like soya, sun flower and linseed used as bio resin applications.[21-27] Plant secret gums like acacia under Vachellia Tortilis family and freakiness under Boswellia Papyrifera gins were among the oldest naturally existing gums used as sticker and gelling ingredients in Ethiopia.[25-27] For this study enset fabric as reinforcement and two type of plant secreted bio resins, acacia and boswellia gums were used. Biodegradable composite structure were manufactured by hand layup assisted resin mechanism. The aim of this research work was focused on investigating, characterization and preparing of bio resin and manufacturing of bio degradable composite materials by using low cost, abundant natural resources and simple manufacturing techniques of enset fiber and plant gums for light weight structural elements. Moreover, the studies were try to show alternative fiber and matrices to solve global warming which was drastically increased due to non-bio degradable as well as non-compostable matrices and fibers were used. Also, the influences of grammage on mechanical behavior were studied.

2. MATERIALS LAND METHODS

2.1. Materials

2.1.1. Enset fiber as Reinforcement Materials

Enset is the name used by the Amharic language for Enset plant which scientifically called Ensete Ventricosum under Musaceae. Enset plant is the most abundantly available pseudo stem plant in Ethiopia shown in Fig.1a. The variety of the enset plant distribution is characterized by a lot of factors related to climatic condition, Culture and geographical location. The fibers are obtained from the agricultural waste material by mechanically decortication and manual extraction of the food content from the plants as shown Fig.1b. The fibers are characterized by low cost (less than 0.25 USD/Kg), light weight, and naturally exist as composite fiber and good mechanical strength (seen in Table 1). The physical and mechanical properties of the fibers were easily enhance by treating the fibers with caustic soda for advanced application in green composite, construction, geotextile and packaging industry.

2.2. Methods

2.2.1. Preparation of Bio Matrices from Natural Gums

Acacia and boswellia natural gums were collected, cleaned and mixed for the preparation of bio-matrix at lab. The bio resin used for the fabrication of enset fabric reinforced green composite was prepared from acacia and boswellia Papyruses gums in laboratory with as shown in Fig. 2a. The bio matrices were prepared with 1:20 material to liquor ratio of natural gums to liquid (water) at a temperature of 70±2^{0}C for 1Hour. The solution was continuously agitated for 5 minutes by SCILOGEX-0S40-S mixer with an interval of 20 minutes. Finally cooled for 15 minute to time for formation of gel and sticky resins as shown in Fig. 2b.

2.3. Green Composite Structures Manufacturing and Specimen Preparation

Green composite structures were manufactured by using bio resin gum and enset fabric with fiber weight percentage of 70:30 wt. %. Hand lay-up composite manufacturing technique was used to manufacture the composite. Then the samples were dried in oven for one hour (Rapid Oven) at a temperature of 115 ± 2 0C before cooling at room temperature. The samples were prepared according to ASTM-D638-10 standards for air permeability and sound absorption tests respectively (as shown in Fig. 3 a-c). SHIMADZU Strength tester (a force of 5kN and speed of 6mm/minute) was used for analysis the tensile strength of both the fabric, single faced and double faced green composite structures having the same number of total warps (8 warps per sample) in 5 cm wide and 20 cm effective length of samples. The thickness of the fabric was around 2mm and 2.5 mm for single faced and 4.5 double faced composite. The tensile strength measurements were carried out from 5 different samples and conducted in warp direction.

Table 1. Physical properties of the enset fibers

Fiber	Dia(µm)	Length (m)	Aspect Ratio (l/d)	Bulk Density (kg/m^3)	Tensile strength (MPa)	Max. Elongation (mm)	Max. Time Fiber breakage(Sec)
Enset fiber	150 -206	1.5-3.5	170	1099 -1200	450-600	4-12	1.68

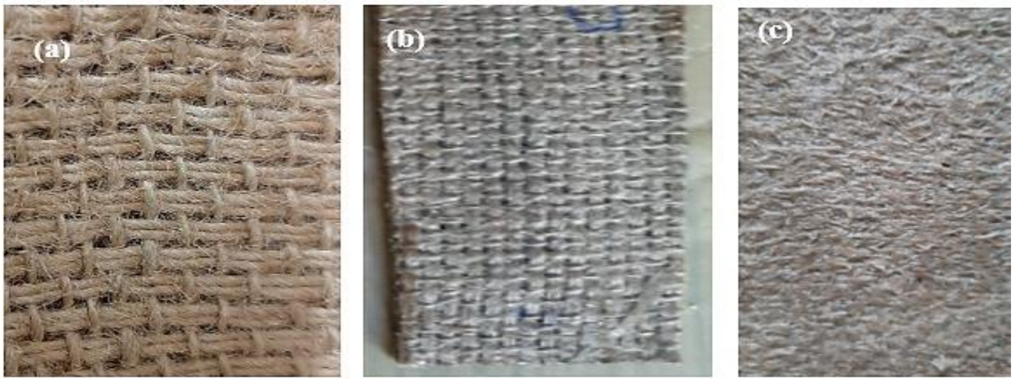

Fig. 3. (a) Enset Fabric (b) Fabricated Single layar Bio Composite(c) Fabricated double layared Bio Composite.

Table 2. General Properties of Acacia-Boswellia Gum's Bio Resin

Property	Acacia - Boswellia gum
Moisture (%)	8.6-14.2
Ash (%)	0.7- 0.734
Viscosity (cP)	1236.6-1450.4
Molecular Weight	153,000-157,400
Solubility (%)	46.75/32.3 @ 60 Mint (Cold water)
	94.7/56.5 @ 60 Mint (Hot water)

3. Results and Discussions

3.1. Characterization of Bio resin for Tensile Strength Test

Acacia-boswellia gum based bio resin material was prepared for the manufacturing of enset fabric reinforced composite materials. The general properties of both acacia-boswellia gum's bio resin was summarized by Table 2. This bio resin was directly used as bio matrix material without using hardener like as thermoset resin materials as well as no need of using thermal energy like thermoplastic matrix materials. So, this lab made bio resin has a cost and time advantage as compared with most commonly used synthetic type of resin materials. The composite structure materials made by using this bio resin has lower mechanical performance as compared with commercial used petrochemical based matrices materials.it has environmental and health advantage of during manufacturing, usage and waste disposal of composite materials made from this bio resin materials.

3.2. Tensile Strength of Enset Fabric and its Bio-Composite

Enset fibers had high lignocellulose content and its immature cellulose materials create a barrier in the internal polymer chains of enset fiber and made it dissociated from its structure. This naturally gift property provides the enset fiber to had good tensile strength (500MPa) and better elongation than most commercial known natural fiber like sisal (400 MPa), bamboo (140-230 MPa) and coir (106 -15 MPa) fibers.[27] Table 3 described that the elongation at break of the fiber was near to flax (2.7-3.2), banana (5.9) and jute (3-10) fiber. [27] These promising properties made effectively un-utilized enset fiber would be used in light weight composite industries and play a significant role by reducing the dependence of petrochemical fibers.

Table 3. Mechanical properties of same natural fibers

Type of Fiber	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Reference
Enset	450-600	10-22.4	-
Sisal	400-700	9-20	[6,11]
Jute	550-900	17-26	[6,11]
Banana	529-914	1.56-1.86	[6-115]
Bamboo	140-230	7.7-32	[6,11]
Hemp	690	35.5	[6,11-19]
Cair	106-270	3-6	[6,11]
Flax	1100	100	[10,11]
Cotton	264-654	4.98-10.92	[12-20]
Ramie	348-816	53.4	[12-15]

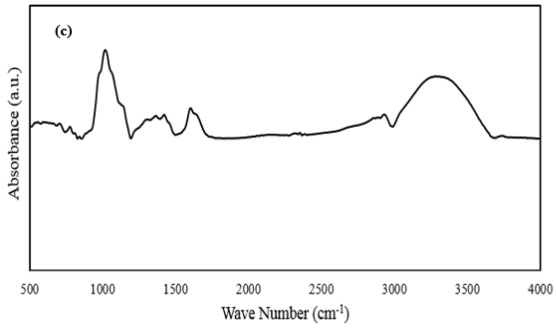

Fig. 4. FTIR Analysis of Bio resin.

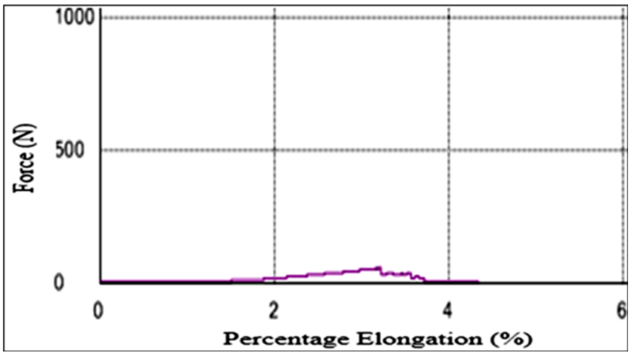

Fig. 5. Tensile Strength of single Enset yarn (warp)

From Table 4, Fig. 5 and Fig. 6, it was observed that the mechanical properties of most natural fibers like enset did not give the same test values, due to variation of its chemical constituent's and cultivation factors. The tensile strength and percentage of elongation of enset yarn had 53.23 N and 3.04 % respectively. Also, it was observed that, enset fabric (8 number of yarn in its effective length) had tensile strength and percentage of elongation of 528.83 N and 5.70 % respectively. Based on the experimental values of a

Table 4. Enset yarn and fabric Tensile Strength for 20 cm effective length of sample

Sample No.	Enset Yarn		Enset Fabric (20cm X 5cm)	
	Max. Force(N)	Max. Percentage Elongation (%)	Max. Force(N)	Max. Percentage Elongation (%)
1	46.26	2.55	545.26	5.52
2	53.00	3.24	454.60	6.86
3	43.98	4.12	537.56	6.09
4	70.63	3.23	601.65	6.00
5	52.26	2.054	505.05	4.02
Average	53.23	3.04	528.83	5.70

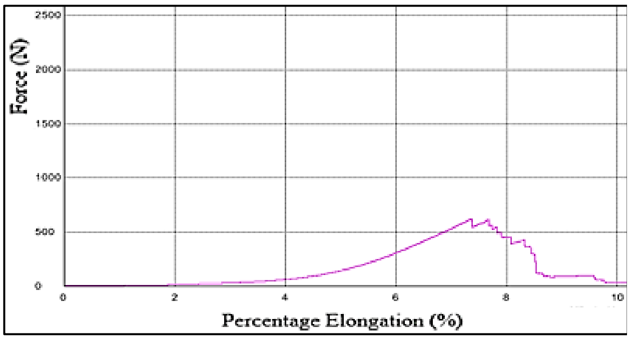

Fig. 6. Tensile Strength of Enset Fabric having 8 Number of warps in its structure.

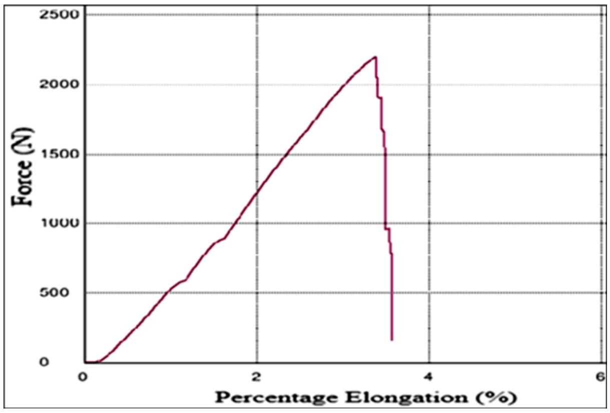

Fig. 7. Effect of grammage on tensile strength of single layer Enset Fabric composite is having 8 numbers of warps in its structure.

single enset yarn obtained from this test, the tensile strength of enset fabric having 8 number of yarns in the fabric would has 425.84 N. But the test result indicated that, woven enset fabric's tensile strength was 528.83 N. This was due to the interaction between the yarns were affect the tensile strength and percentage of elongation of enset fabric.

It was known that the fabric's tensile strength (from 425.84N to 528.83 N) was increased due to interlacing of warp and wefts that can develop inter and intra yarn and fiber frictions with in the fabric. In the same manner, the free movement developed with in the warp and weft yarns will increase the elongation (5.70%) of enset fabric (fig. 2.).

The interaction between the yarns and the bio resin not only affect the tensile strength of the fabric, it also affects the overall mechanical performance of the fabrics. Fig. 7 and Fig. 8 show, the tensile strength of single faced and double encrusted ecofriendly composite materials respectively. In case of Fig. 4, the reinforcing materials (fabric) was not broken during testing for double encrusted structure rather the bio matrix was failed and separates the layers without transferring the applied load into the reinforcing materials. These situations indicate that used bio-resin materials had given better strength to the green composite structure and theses bio resin had a promising future with minor modifications to enhance its load transmission characteristics. All the discussion was considered as based on these phenomena.

According to Table 5, Fig. 7 and Fig. 8, having the same number of warps in composites materials, the tensile strength of the fabric was drastically changed from 528.83 N for single layered to 2074.15 N and 3479.69 N for double layered composites. This indicates that the agro based bio resin materials had a significant effect on the mechanical performance of composite structure. The tensile strength of the structure was enhanced by 340% (2074.15 N) for a single layer green composite material (As seen in Fig. 2 and Fig. 3). Likewise, fabrics having double layer composite structure of enset fabric materials (As seen in Fig. 4), the tensile strength was drastically changed due to the dual effect of bio-resin and the intra friction developed within the yarns (3479.69 N). From the above discussion, it was generalized that, agro base resin like Etan and Girar gum had a very significant effect on the mechanical performance of composite materials. So it will have a promising future to use as industrial bio resin in light weight structure manufacturer with same minor modification. Generally these bio resins had dual advantage, firstly: the matrix was enhanced the tensile strength of the composite in light weight application with very low cost of manufacturing techniques produced at home (time and cost effect bio-resin). Moreover, this lab made bio resin did not need any hardener like petrochemical based resin materials. Secondly, they will play a significant role and put their finger print on the reduction of global warming and ecological problems by substituting petrochemical resins.

3.3. Effect of grammage on Physical properties of enset composite structure

Grammage is the weight of fabrics per unit areas. The mechanical properties of enset fabric reinforced composite structure were significantly affected by grammage. Thickness and mechanical strength of enset composite materials was controlled by the grammage of enset fabrics and bio resin. Increasing the grammage was restored energy and tensile performance by reduced deformation of composite structure.

From table 5, Fig. 7 and Fig. 8, it was observed that the average tensile strength of the composite materials increased with respect to grammage for the same areas and number of yarn (2074.15 N and 3479.96 N). Moreover, the tear strength of the single layered enset composite material was increased with respect grammage. The average tensile strength and mass of single layer enset composite

Table 5. Single and Double layer Enset fiber fabric reinforced Green Composite Tensile Strength

Sample No.	Single layer Enset fabric reinforced Green Composite(8 Number of warps)		Double faced Enset fabric reinforced Green Composite(8 Number of warps)	
	Area= 100 cm^2/ Mass= 60 gm.		Area= 100 cm^2/ Mass=120 gm.	
	Max. Force(N)	Max. Percentage Elongation (%)	Max. Force(N)	Max. Percentage Elongation (%)
1	2200.75	3.38	3708.59	6.79
2	1821.33	2.79	3577.09	5.60
3	2355.43	3.05	3679.27	5.41
4	1792.50	3.07	3187.05	7.17
5	2200.75	3.38	3246.46	4.79
Average	**2074.15**	**3.14**	**3479.69**	**5.95**

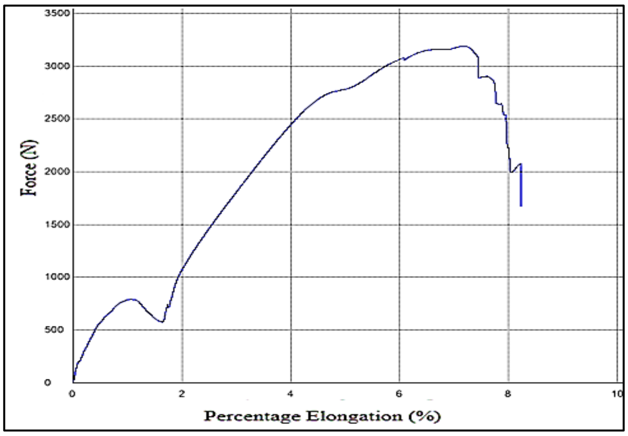

Fig. 8. Effect of grammage on tensile strength of double layer Enset Fabric composite is having 16 numbers of warps in its structure.

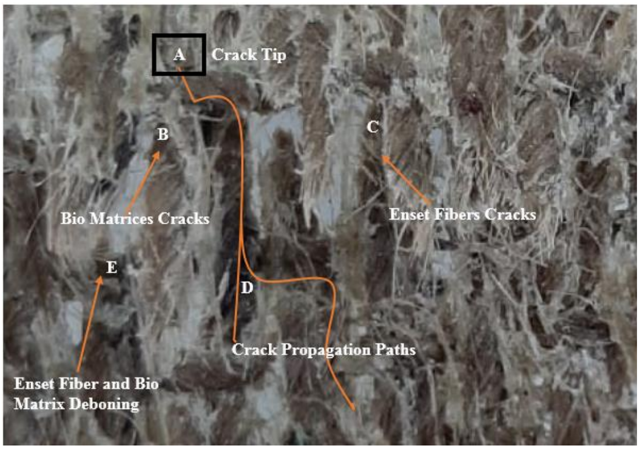

Fig. 9. Crack Propagations Analysis of Enset Fabric Reinforced Composite Structures by Optical Microscope.

had 2074 N and 60 gm respectively. But the percentage of elongation was decreased (from 5.70 % to 3.14 %) due to the restriction of yarn movement within the fabric by bio resin. If the grammage of the enset fabric was doubled (i.e 120gm), both the average tensile strength and percentage of elongation of enset composite was drastically changed, 3479.69 N and 5.96 % respectively. Double layered green composite structure had better elongation than single layer composite materials due to the variation in the quantity of bio resin. The elongation of double layer enset composite was increased by the effect of Girar rand Etan gum (Fig. 4).

3.4. Tear Strength Analysis of Enset Fabric Reinforced Green composite

The observation made from Fig. 9 shown that the image of surface fracture and cracking propagation of enset fabric reinforced composite structures were seen and analyzed by using optical microscope after the applied different type of loads or strength tests. The optical microscopic view confirmed that, the propagation of the crack through enset fabric reinforced material in to bio resin interface of the samples for different types of tests as shown in Fig. 9 A,B, and C. This situations were confirmed and used as an evidence for crack propagation of the composite structures were started and the deboning of enset fabrics from the bio resins(acacia-boswellia) would happened through the crack path. Moreover, the morphological analysis of enset fabric reinforced composite structures were indicated that, there are a lot of smooth grooves (porosity) in the green composite structures and the cracks were stared and would be propagated to enset fabrics- bio resins deboning at these grooves as shown in Fig. 9 D and E Also, the bio matrix was started to crack and the majority of enset yarn in the woven fabrics were broken in the warps direction. All the above phenomena have been a significant effect on the overall mechanical performance of enset fabric reinforced composite materials. So, good mechanical properties of enset fabric reinforced composite was obtained by rescuing the percentage of void ratio and using the optimum amount of reinforcing materials,i.e.,70:30% of bio resin to enset fabric ratio.

4. Conclusions

Enset fabrics were lignocellulose abundant, low cost, light weight and having good specific mechanical strength. Since enset fiber was obtained from both bast and leaf part of the plant, it had superior tensile strength, modulus of elasticity and superior impact resistance. Due to these, the tensile strength and modulus of elasticity of enset fiber was better than fibers obtained from only bast as well as leaf part of the plant. The tensile strength of enset fabric reinforced structure was enhanced with respect to grammage (quantity of bio resin used). Increasing the grammage of enset fabric, such as single layer and double layered composites structures having the same number yarns would show a great difference in their tensile strength (up to 3479.69 N), tear strength and elongation at break (for 120gm mass of composite is 5.95 %). The elongation of the composite materials was depend on the interaction between the enset fabrics and bio resin, in case of single layered composite structure, the elongation of the materials was decreased due to the restriction of the movement of yarns in the enset woven fabric by bio resin in its structure. Utilization of agro waste enset fabrics and natural gum based bio resin play a significant role on the decreasing of global warming by substitute petrochemical base fibers reinforcing materials in composite application without affecting the desired mechanical properties like tensile strength and tearing strength in light weight structural applications.

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Conflicts of Interest

The Authors declare no conflict of interest.

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