

Characterization of Fabricated FG Pipe with Natural Fiber-Flyash-Epoxy using Centrifugal Casting



Sarmila Singh, Sarada Prasad Parida, Premananda Ekka, Pankaj Charan Jena

Abstract: This research presents the design of fabrication technique for hollow pipe made up of functionally graded materials and its characterization. In the first part, a horizontal centrifugal casting model is designed and developed using CATIA package. After getting an optimized design the fabrication work is performed in workshop. Different powder materials (Banana stem fiber, Jute fiber and Fly ash) are prepared by considering different chemical treatment and physical process. Different powder sizes (300 μ , 150 μ , 75 μ , 53 μ , 45 μ) are considered to fabricate current functionally graded cylindrical pipe by altering their weight percentage. The different weight percentages (5%, 7.5%, 10%, 12.5%, 15% of Banana stem and 2.5%, 5%, 7.5%, 10%, 12.5% of Fly Ash) of constituents are considered for fabricating FGM cylindrical pipe. By altering the constituent of FGM material composition, twelve numbers of various functionally graded materials (FGMs) pipes are fabricated. In the second part, the material characterization is performed using different testing machines in Laboratories. Mechanical properties (Compression test and Micro hardness test) and physical properties (Density test, Water absorption test and thermal conductivity test) are investigated. Furthermore, the microstructures of the fabricated FGNF pipes are examined using Scanning Electron Microscope (SEM).

Keywords: FGM; centrifugal casting; Pipe; Characterization; Microstructure.

I. INTRODUCTION

Selection of suitable material is an important aspect in product design for which product to be sustainable under different loads. The mechanical property of newly designed material plays an important role. However, both physical and mechanical properties of products play additional attributes for design aspect. The selections of material also have a great effect on any design to bring off low cost. By looking into the present industry demand and keeping knowledge of environmental effect, the suitable product's material along with its reliability has currently very important for an engineering product design. A number of works had been conducted in literatures mentioned with an emphasis to develop new kind of material from the industrial wastes and natural fibers as well.

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Cherradi et al. 1994 [1] have presented a study on FGM in structural application by designing from its microstructure level. Kieback et al. 2003 [2] have outlined the different preparing technologies of functionally graded materials (FGM). They have considered processing of powder and approaches concerning the processing of metal melts and graded polymers and their dependency gradient extension and the geometry of the components. They have also discussed microstructure gradients. Watari et al. 2004 [3] have fabricated some titanium/hydroxyapatite (Ti/HAP) FGM specimen for bio-medical implantation purpose. Mukhopadhyay et al. 2008 [4]; have studied the properties of natural fiber and its advantages. They have considered Banana fiber and characterised it as per fiber diameter and corresponding variation of mechanical properties. Kumar 2010 [5] has combined the stainless steel with Al and Cu foils using ultrasonic consolidation to join the different metallic foils together. Chumanov et al. 2011 [6] have described a process for introducing a diffuse powder into a metal melt to manufacture FGM. Mahamood et al. 2012 [7] have fabricated functionally graded material and they have focused on best production technique i.e. solid free form (SFF). Wu et al. 2013 [8] have developed the unified formula of the virtual displacement principle (PVD) and the finite cylindrical layer method (FCLMs). They have “performed three-dimensional linear buckling analysis of the FGM hollow cylinder under axial compression and external pressure.” Udupa et al. 2014 [9] have described the overviews of the functionally graded composite material (FGCM) as fundamental approach, their classifications, properties and their preparation procedure. They have considered a case study as CNT-reinforced Al functionally graded materials. They have used powder metallurgy methodology for the fabrication of FGCM. Through case studies, they have observed the effects of layered CNT enhancement, which changed physical properties due to uneven microstructure and spatial changes. Biermann et al. 2015 [10] “have investigated turning machining of FGM steel using finite element simulation and they have compared simulation results with experimental results. Jamian et al., 2016 [11] have fabricated functional graded composite using slurry in centrifugal casting technique. Zhang and Wang 2017 [12] have proposed thermal bonding lamination method for producing a polymer FGMs having a closed cell and an open cell under the enforced compressive load, controlled heating and suitable holding time. Galy et al. 2017 [13] have investigated the horizontal centrifugal casting using SiCp+Al concept of FGM to produce multifunctional components of metal matrix composites. Fabrication of “functionally graded metal matrix composites.

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They have considered dissimilar mass fractions (0%, 2.5%, 5%, 7.5%, 10% and 15%) of SiCp having element size 16 μm , 23 μm and 500 μm and three rotational speed 800 rpm, 900 rpm and 1000 rpm. They have found that the SiCp element deposit decreases from outer to inner layer. Yu et al. 2017 [14] have stated the functionally graded material manufacturing via heat treatment or material consolidation. They have applied heat treatment including solid solution (T4) and aging treatment (T6). They have examined the creep growth using creep testing machine. They have also investigated distribution of metal composition using electron probe analysis. They have studied creep crack paths and fracture morphology by scanning electron microscope. After heat treatment, they have found that the circulation of copper FGM became thicker, and the thickness of the transition zone of the Cu FGM sample in this region increased, and the crack rate decreased.

Saheb and Jog 1999 [15] have investigated the properties of natural fiber reinforced composites. They have observed these are of low density; low cost, high specific properties of ecological and non-abrasive nature. These composites offer particular superior property compared to traditional fiber composites. The ease of fabrication technique, low production cost it has replaced many conventional metals/materials for different uses. Azwa and Yousif 2013



present work, the centrifugal casting technique is designed and functionally graded hollow pipe are fabricated. The mechanical property and physical property of the fabricated pipe are examined. Microstructure analysis of fabricated FGM is carried out to learn the reinforcement distribution.

II. MODELLING OF EXPERIMENTAL SET-UP

The test samples were manufactured by horizontal centrifugal settling method. For the purpose a hollow steel cylindrical mould was designed and assembled. The detailed designed specification of the centrifugal settling unit and its parts is presented in table 1. The prepared polymeric FGM mixture is poured through a hollow pouring rod mounted axially to the mould from the pouring basin. A stabilizer is used to regulate the input voltage so as to control the speed of motor to control the speed of the cylindrical mould. For smooth functioning of the setup subordinate attachments are fitted to it.

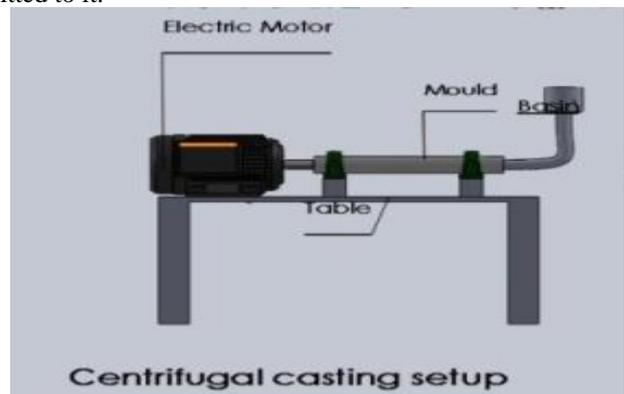


Figure 1: presents Isometric view of the hollow cylinder used in centrifugal casting

Table 1: Specification of mold.

Part Name		Specifications
cylinder	Internal diameter of mould	20mm
	External diameter of mould	50mm
	Mould length	150mm
Bearings	Internal Diameter	20mm
	Outer Diameter	30mm
	Width	5mm
collar		
Motor.	Speed	Max 1500 rpm
	Supply	240 V, 50 Hz
	Range of Power	0.5 -5.0 HP
	Rated Output	300W
	Rated torque	0.994 N-m
	Input Voltage	AC 220.

[16] have studied the properties of natural fiber, treated with an alkalization process and exposed to high temperatures. They have investigated thermal decomposition behaviour of the treated and untreated kenaf/epoxy composites and their components. They have examined the surface morphology of the composite by using SEM. They have observed that untreated kenaf fiber have a higher moisture content than the treated fiber. Al-Oqla & Sapuan, 2014 [17] have reported the possibility of industrial utilization of the natural fiber composite (NFC). Garcia-Espinel et al. 2015 [18] have identified an excellent composite i.e. glass-fiber reinforced composites for marine civil engineering use. They have studied the effects of a number of factors on their mechanical properties which have considerable roles in structural design like tensile and flexural strength. Jena 2017 [19] investigated mechanical properties and vibration response of short bamboo fibre polymer composite beam structures.

There are many types of researches conducted on the improvement of functionally graded material using natural fiber and epoxy. There are also various ways have been found to use fly ash (industrial waste) but few researches have been done in the direction of integrating fly ash in fabricating FGM structure like natural fiber/epoxy using centrifugal casting method. In current research industrial waste fly ash is considered an ingredient along with natural fiber for reinforcement. The different weight fraction of ingredients like fly ash and banana fiber are considered. The

The detailed steps followed used for the fabrication of FGM composite by the help of horizontal centrifugal casting is shown figure 2.

The epoxy resin L 12(LY 556), Hardener K6 (HY 951) is used to prepare the mixture of reinforcement and filler properly. Wooden wax is applied on the mold before fabrication for easier removal of casted specimen. Banana stem powder with particle sizes 300 μ , 150 μ , 75 μ , 53 μ , 45 μ after sieving analysis are taken into consideration for the present fabrication as reinforcement as presented in Figure 3. fly ash with different particle sizes i.e. 300 μ , 150 μ , 75 μ , 53 μ and 45 μ as presented through Figure 4 is used as filler Silicon Spray is a release agent and applied during the removal of the material. Total twelve no. of specimen with two samples for each composition as presented in table-II were prepared as shown in fig.5.

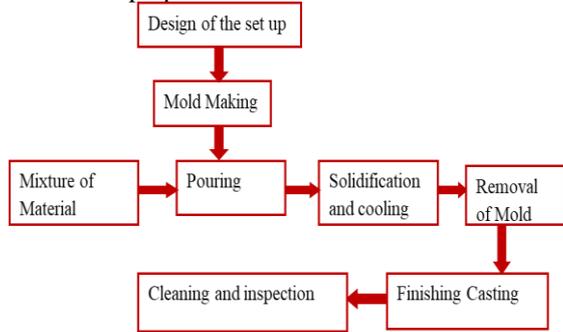


Fig.2: Flow chart of casting process for FGM hollow cylinder.

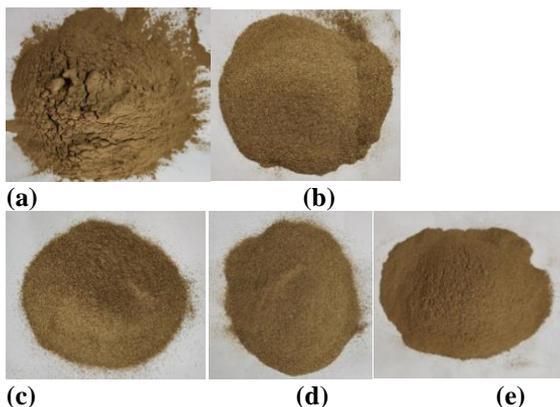


Fig. 3: Different size of banana fibres: (a) 75 μ ; (b) 45 μ ; (c) 150 μ ; (d) 53 μ ; (e) 300 μ .

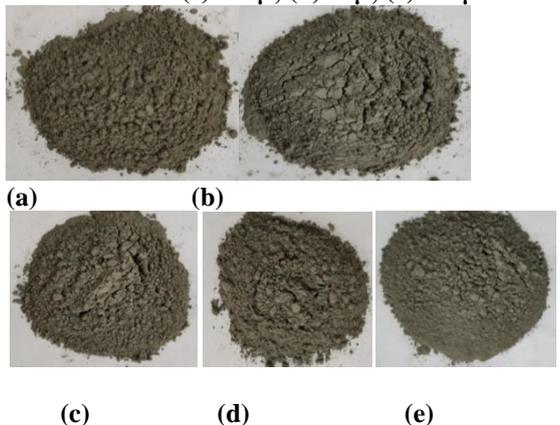


Fig.4: Different grade size of Fly ash: (a) 75 μ ; (b) 45 μ ; (c) 150 μ ; (d) 53 μ ; (e) 300 μ .



Fig.5: Image of Fabricated FGM.

Table -II: Material composition.

Specimen	Bananas stem %	Fly ash%	Epoxy%
A	2.5	2.5	92.5
B	7.5	5	87.5
C	10	7.5	82.5
D	12.5	10	77.5
E	15	12.5	72.5
F	-----	-----	100

III. CHARACTERIZATION OF PROPERTIES

The mechanical properties like micro hardness, compressive strength, density, water absorptivity, thermal conductivity and SEM study of cured FGM hollow pipe samples were carried out.

Micro Hardness: Hardness reflects that a characteristic of the material which defines the indentation resistance and measured by the intensity of indentation. Harder a material small will be the depth of indentation. For this test Micro Vickers hardness test method is used. For this Hardness test Micro Vickers hardness tester is used to find out the Hardness of FGM hollow cylinder. Indentations were taken per sample in a dwell time of 15 seconds. Then the readings were taken and hardness value was calculated. Figure 6 shows the Micro hardness tester with test specimens required for the hardness test.

Compressive strength: It is a testing method that is used to establish crushing resistance of the specimen and the ability of the material to recover after a specified compressive force is applied over a certain period of time. For compressive strength UTM is used according to the ASTM standard.

Density Test: Density testing methods are used here to find out the density of the material, as described in ASTM Standard D792-91. This technique is used to resolve the density of the FGM and its components shown in Figure 8

Water Absorption Test: "It is used to find out the quantity of water absorbed by FGM under certain conditions. General Factors that affect water absorption include: plastic type, additives used, temperature and exposure time. For the water absorption test (Figure 9), the sample was dried in an oven for a specified time and temperature and then placed in a desiccator for cooling. The sample was weighed immediately after cooling. The material then appears in the water under agreed conditions; typically, at 23 ° C for 24 hours or at equilibrium. The sample was taken out, patted dry with a cloth, and weighed. Water absorption is expressed as an increase in weight percentage."

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$$\text{Water absorption} = \left[\frac{(\text{wet weight} - \text{dry weight})}{\text{dry weight}} \right] \times 100.$$

Thermal conductivity test: It is used to determine thermal conductivity of a bad conductor using Lees Apparatus as shown in Figure 10. Where the working formula is

$$k = \frac{m \cdot c \cdot (dT / dt) \cdot d}{A \cdot (T_1 - T_2)} \quad (3)$$

Where k = Thermal conductivity of the bad conductor in W/m-K

A = area of the bad conductor (m²), "T₁ and T₂ = Temperature in K,"d= Distance which the heat travels in meters, m = sample mass in kilograms, c = specific heat of a given material in J/ kg-K (dT/dt) = Rate of cooling in Kelvin / second,

SEM Analysis of FGNF: A scanning electron microscope (SEM) testing is performed to study the composition of the surface shown in Figure 12 and Figure 13.

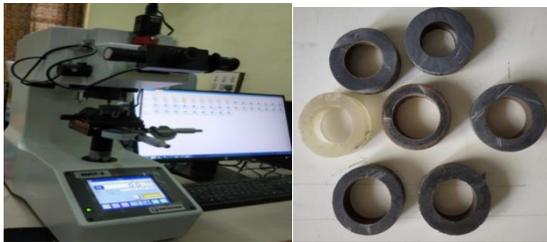


Fig.7: Micro Vickers Hardness tester Machine



Fig.8: test specimen after compression test.



Fig.9: Density test rig.



Fig.10: Test specimen in water absorption test.



Fig.11: Thermal conductivity test rig (Lees Apparatus).



Fig. 12: Image of SEM machine and specimens for SEM analysis.

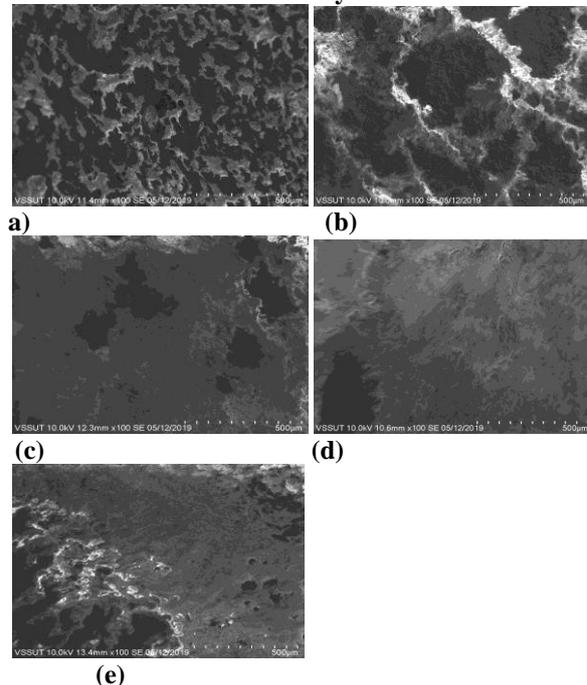


Fig. 13: SEM of (a) 300μ; (b) 150μ; (c) 53μ; (d) 45μ; (e) 75μ samples.

IV. RESULTS AND DISCUSSION

Micro Hardness Test Result: The micro hardness test results of FGNF samples are presented in Figure 14 to Figure 15. It has been found that the hardness value increases with increase in fiber content in the mixture. The Hardness value test specimen varies from 80.02 to 190HV at different loads. At 1000GF the hardness value of epoxy (not including mixture of fiber) is 161HV and at 500GF the value is 82.2HV. From the above table it has been shown that the Hardness Vickers no of the specimen 6 which contain Banana stem (5wt %) and fly Ash (2.5wt %) have higher hardness value than other FGNF specimens at an applied force of 1000gf. In case of 500 gf, the hardness Vickers value of the specimen 4 which contain banana stem (7.5wt %) and Fly Ash (5wt %) have higher hardness value than other FGNF specimens.



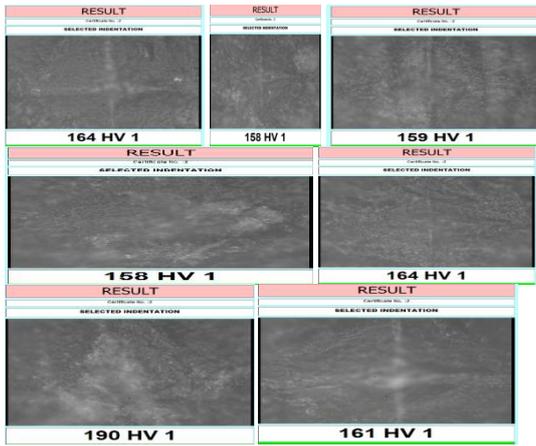


Fig. 14 Hardness Result of FGNF Samples at 1000gf.

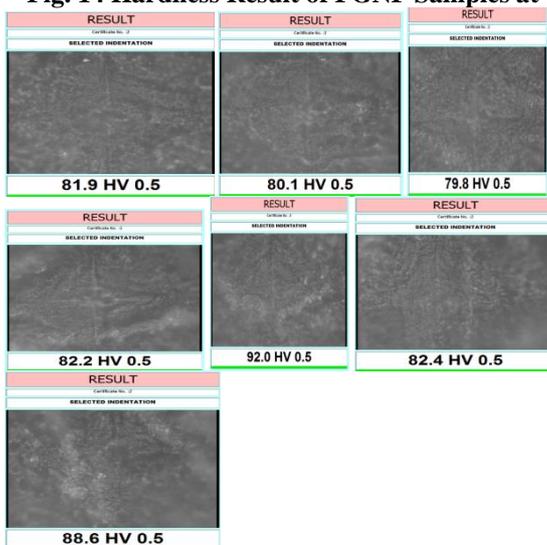


Fig. 15: Hardness Result of FGNF Samples at 500gmf.

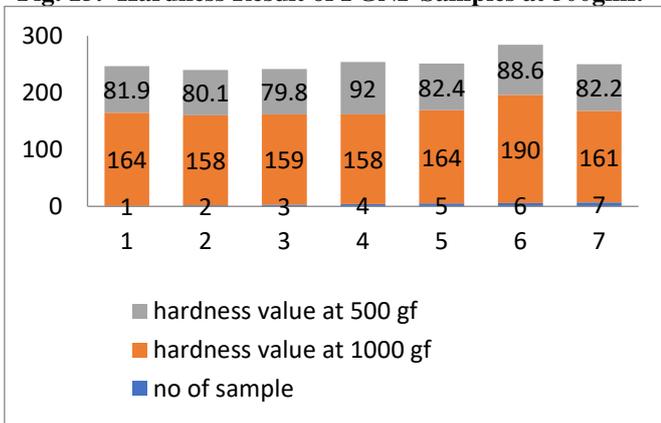


Fig. 16: shows micro hardness no at both 1000gf and 500gf applied load.

Compression test result: Fig.17 show the stress strain curve of FGNF cylinder. It can be seen from the stress strain graph described above that the FGM sample having a larger percentage by weight of fly ash has certain brittleness. From the figure it can be found that the FGM sample 5 with 5wt% banana stem fiber and 2.5wt% filler fly ash was recorded as the highest compressive strength of 59.339MPa and FGM specimen 4 which contain only epoxy has the lowest compressive strength of 8.765MPa.

Table-III: Compressive strength test result of FGNF specimen.

	wt % of Banana fiber	wt % of fly ash	particle size	Maximum force applied (KN)	Compressive strength (Mpa)	Young's modulus (Kn/m ²)
1	7.5	5	150 μ	14.4	13.026	0.0131
2	12.5	10		26.25	24.51	0.0251
3	12.5	—	300μ.	11.68	13.10	0.0131
4	0	0	epoxy	9.450	8.765	0.0188
5	5	2.5	300μ.	48.66	59.33	0.0596
6	10	7.5	75μ	20.81	18.29	0.0183
7	10	10	150 μ	14.00	14.35	0.0143
8	15	12.5	45 μ	20.61	19.45	0.0230
9	15	15	150 μ	9.850	8.965	0.0191
10	—	12	300μ	11.21	12.06	0.0120
11		12	150 μ	16.91	18.16	0.0181

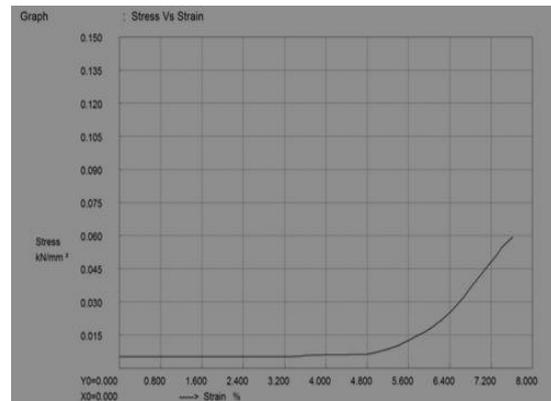


Figure 17: The stress-strain relation of sample 5 is shown.

Density Test Results: The density value of the measured FGNF 'cylinders recorded have densities ranging from 1.184 to 1.284 g/ cm³.' At the same time the specimen containing only the epoxy resin had a density value of 1.232 g/cm³. 'The presence of bubbles reduces the density of the FGM column and also weakens the bond between the matrix and the fibers. From table 4 it can be verifying that FGM specimen having banana stem 15wt% and fly ash as filler 12.5 wt% have high density value than other FGNFs.'

Water Absorption Test Result: The water absorption test shows that sample with 15wt % of banana absorbs higher percentage of water.

Thermal conductivity test result: Table6 represents the thermal conductivity along with the composition and particle size of the specimen. It is observed that increase in particle size decreases the thermal conductivity. As it affects heat conduction by reducing the contact area. Figure18 shows that the specimen containing 15wt% banana and 12.5wt% fly ash has the higher thermal conductivity (0.074 W/cm.c) and specimen containing 5wt% banana and 2.5 wt % fly ash has the lowest thermal conductivity (0.045 W/cm.c).



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Table-IV: Density of FGNF achieved from density test

Specimen	Wt before Absorption (gm)	Wt after Absorption (gm)	Density (g/cm ³)	Rotating speed in rpm
1	13.55	11.05	1.226	1367
2	15.04	12.20	1.232	1400
3	16.77	13.77	1.217	1419
4	17.45	14.40	1.211	1438
5	17.30	14.60	1.184	1442
6	14.06	11.80	1.191	1444
7	15.56	12.40	1.254	1479
8	13.13	10.22	1.284	1485
9	16.72	13.16	1.27	1486
10	20.14	16.12	1.249	1487
11	18.63	14.81	1.257	1499
12	21.15	17.20	1.229	1684

Table-V: water absorption result of FGNF (15wt % of banana)

Specimen	Wt before Absorption (gm)	Wt after Absorption (gm)	Water absorption n (%)	Absorption in Hour
1	17.30	17.35	2.8	12
2	17.28	17.67	2.25	24
3	15.40	15.90	3.18	36
4	13.13	13.15	0.152	48
5	15.04	15.16	0.79	60
6	20.14	20.40	1.27	72
7	13.55	13.71	1.16	84
8	16.78	17.00	1.311	96
9	21.15	21.36	0.99	108
10	17.30	17.35	0.028	120
11	13.55	15.90	1.74	132
12	15.04	15.67	4.18	144

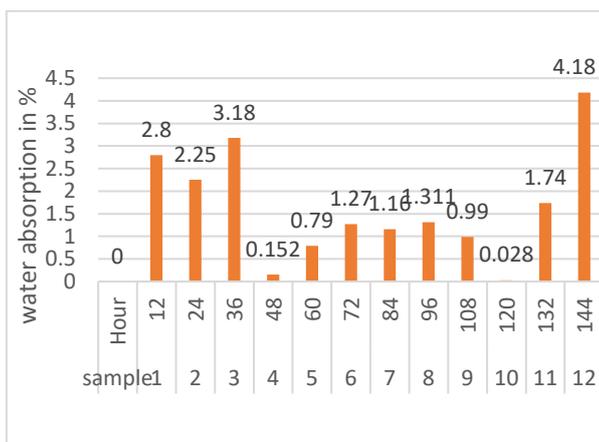


Fig.18: Shows graph for water absorption test

SEM Result: Figure 20 (a) to (f) study the effect of functionally graded natural fibres on surface morphology. Scanning electron microscopy (SEM) micrographs show that the fibres are detached from the resin surface due to poor interfacial adhesion. It has also been found that there

are some voids in the surface of the material. In Figure 6.21(c), for FGN samples containing 5% by weight of banana stem fiber and 2.5% by weight of fly ash and having a particle size of 300 μ , the drawn fibres were clearly visible. On the other hand, the FGM sample containing 15wt% of banana fiber and 12wt% of filler is shown good adhesion quality between the matrix and the reinforcing material.

Table VI: Thermal conductivity of the FGNF specimen

No. of specimen	Particle size in μ	wt % of Banana fiber	wt % of fly ash	wt % Epoxy	Thermal conductivity (W/m.K)
1	53 μ	12.5	10	77.5	0.063
2	45	15	12.5	45	0.074
3	75	10	7.5	82.5	0.055
4	150	15	12.5	72.5	0.051
5	300	5	2.5	92.5	0.045

Energy Dispersive X-ray Analysis

The EDS spectrum of the FGNF sample gives chemical composition data as shown in Figures 39 to 43. As can be seen from EDS, the samples are composed of the same materials, namely carbon, oxygen, magnesium, barium, chlorine, potassium and calcium. Sample 1, Sample 2, Sample 3, Sample 4 and Sample 5 had the highest carbon contents of 67.12%, 60.60%, 69.87%, 68.31% and 71.69%, respectively. Table 13 shows the EDX data for the test results for all functionally graded natural fibres Sample.

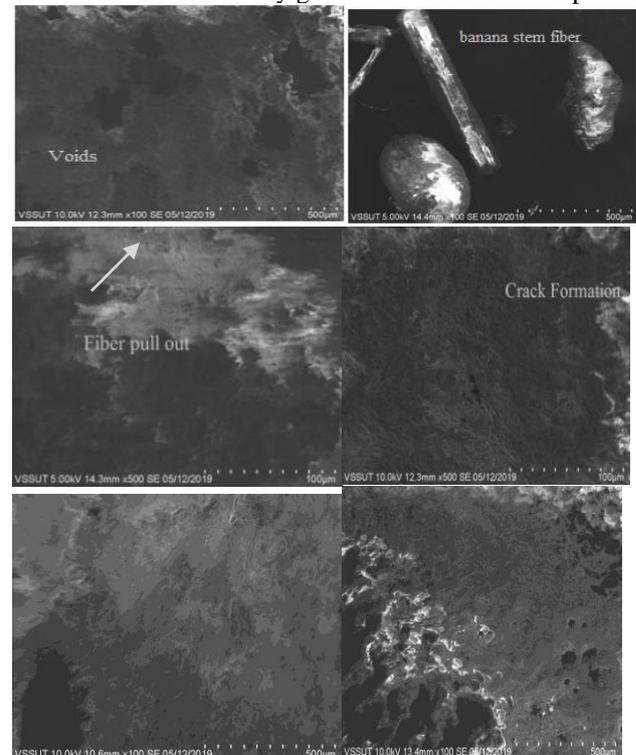


Fig.20: SEM micrographs of FGM samples after compression test show a) voids on the surface of the FGM sample b) banana stem fibres c) fiber pull-out images d) crack formation on the surface e) good interfacial adhesion f) interface Poor adhesion.

Table 13: EDX data of All FGNF specimen

fiber and 2.5 wt% fly ash having a 300μ particle size, the drawn fiber was evident.

Elements	Weight %					Atomic %				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
C	67.12	60.60	69.87	68.31	71.69	73.40	68.18	75.77	75.10	77.70
O	31.71	35.15	29.23	28.08	26.36	26.04	29.69	23.80	23.17	21.45
Na	0.36	1.23	0.30	0.76	0.31	0.21	0.72	0.17	0.44	0.18
Al	0.18	.....	0.17	0.82	.....	0.09	.....	0.08	0.40	0.16
Si	0.37	2.50	0.22	1.46	0.42	0.17	1.20	0.10	0.69	0.19
Cl	0.18	0.52	0.14	0.34	0.38	0.07	0.20	0.05	0.13	0.14
K	0.07	.....	0.06	0.12	0.33	0.02	.....	0.02	0.04	0.11
Ca	.....	.....	.....	0.12	0.22	.....	.....	.....	0.04	0.07
Mg	.....	.....	.....	.....	0.30	.....	.....	.....	.....	.....

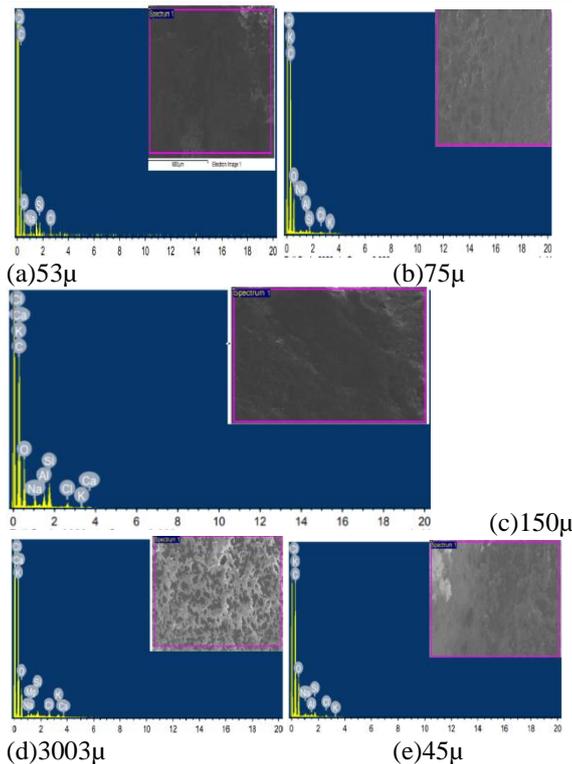


Fig. 21: EDS of FGNF samples.

V.CONCLUSION

It is observed that FGM specimen having Banana stem 5wt% and fly ash 2.5 wt% as filler have higher hardness value than other FGMs at 1000gf load and FGM having Banana stem fiber 7.5wt% and filler 5wt% have higher hardness value at applied load of 500gf. The compressive strength is higher in FGNF having Banana stem 5wt% and Fly ash as a filler material 2.5wt%. The FGM specimen is having Fiber (banana stem) 15 wt% and filler (fly ash) 12.5 wt% have higher density value than other fabricated FGMs. From the result of water absorption test it is found that the FGM specimen (fabricated using particle size 150μ) having 7.5wt% of banana stem and 5wt% of filler fly ash has more water absorption value which was dipped in water for 144hours. the thermal conductivity test shows that the specimen containing 15wt% banana stem and 12.5wt% of fly ash has the higher thermal conductivity (0.074 W/cm.c) and the specimen containing 5wt% banana stem and 2.5 wt % of fly ash has the lowest thermal conductivity (0.045 W/cm.c).For FGNF samples containing 5 wt% banana stem

On the other hand, the FGNF sample containing 15 wt% of banana fiber and 12.5 wt% of filler showed good adhesion quality between the matrix and the reinforcing material. Energy dispersive X-ray analysis shows the chemical composition of the FGM sample. EDS analysis exposed the highest carbon content of sample 1, sample 2, sesimen3, sample 4 and sample 5 were 67.12%, 60.60%, 69.87%, 68.31% and 71.69%, respectively.

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