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TENSILE BEHAVIOUR OF SUGARCANE FIBRE / FLY ASH / CARBON NANO TUBES REINFORCED EPOXY COMPOSITES

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Increase in production capacity of industries in every field results into generation of huge amount of waste materials. These wastes can be utilized in an effective manner; one of those ways is fabricating a green composite which uses natural fibres and biodegradable materials in place of synthetic fibres as reinforcements. This is the main drive behind selecting sugarcane fibre and fly ash as our reinforcement materials for making epoxy polymer matrix composite. For further improvement in mechanical properties, carbon nano tube (CNT) is also used as reinforcement material in the composite. It is intended to investigate tensile behaviour of the composite by varying the wt. % of CNT / sugarcane fibre / fly ash in epoxy polymer matrix. Experimental specimens are made using Central Composite Design (CCD) of Response Surface Methodology (RSM), one of the Design of Experiments (DOE) approaches. Determining the influence of CNT / sugarcane fibre / fly ash reinforcements on the tensile behaviour of epoxy composite is achieved by using ANOVA. Results reveal the positive effect of sugarcane on yield strength and Young's modulus of the composite and that of fly ash and CNT on ultimate tensile strength. Optimized parameters are obtained to achieve improved tensile behaviour and the same is confirmed by confirmation experiment.

Keywords: Tensile properties, Sugarcane fibre, Design of Experiment, Central Composite Design

1. Introduction

Holbery and Houston [1] presented that due to light weight and high strength, composite materials are extensively used in recent times predominantly in making door panels, dashboards, headliner, and interior parts in automobile industry. Prasad [2] mentioned that Glass-fiber reinforced plastic composites are contemporarily used in vehicle manufacturing. Nonetheless, Mantia and Morreale [3, 4] mentioned that these synthetic composites have numerous health hazards and poor degradability. Hence, it is exceedingly necessary to find sustainable solution

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to this problem. As a result, research on green fiber reinforced composite has picked up the momentum. Various biodegradable materials like cotton, jute, saw dust, sugarcane are used as reinforcements in recent researches on composites as they are inexpensive as well as completely or partially recyclable. More often than not, biodegradable material reinforced polymer matrix based composite materials has lower stiffness and toughness. Cerqueira and Baptista [5] studied the effect of reinforcing sugarcane fiber in polypropylene composite and concluded that the addition of sugarcane fiber is fairly positive on the mechanical properties of polypropylene composite. Oladele [6] studied the effect of untreated sugarcane fiber reinforcement on Young's modulus of polyester matrix composite. The author inferred that the effect on Young's Modulus of composite by reinforcing untreated sugarcane fiber being reasonably positive.

Along with biodegradable reinforcements, fly ash is one of the more attractive fillers used due to its excessive abundance and easy availability. Singla and Chawla [7] examined the effect of fly ash reinforcement in compression strength of the composite. They deduced that the compressive strength of the composite increases with the increment in the percentage proportion of fly ash reinforcement. Sim et al. [8] studied the effects of various volumes of fly ash on the mechanical properties of the epoxy composite. They concluded that the tensile strength of the composite increased up to a certain threshold of volume percentage of fly ash and then it decreases with increasing amount of fly ash.

Venkatachalam et al. [9] investigated the effects of fly ash and banana fiber reinforcements on tensile and flexural properties of the epoxy polymer composites. They deduced that the effect of fly ash on the ultimate tensile strength of composite is not significant. In general, Carbon Nano Tube (CNT) is added as filler / reinforcement in composites to achieve the desired mechanical properties. Montazeri and Javadpour [10] conducted experiments and concluded that with addition of Multi-walled CNT (MWCNT), Young's modulus and tensile strength are increased. Al-Hamdani et al. [11] tested the epoxy polymer matrix composites having MWCNT as reinforcements. They concluded that the MWCNT reinforcement has a positive impact on Young's modulus and tensile strength. However, the dispersibility, the orientation of fibers and optimum amount of CNT plays vital role in achieving ultimate mechanical properties for polymer matrix. Dai and Sun [12] concluded this after conducting various experiments. Sivakumar et al. [13] studied shear strength of epoxy polymer composite reinforced with CNT / coir fibre / fly ash and reported the influences of reinforcements on shear strength of composite using statistical techniques.

From the literature, it can be observed that limited / no attempts have been made to find the effects of sugarcane fibre, fly ash, and MWCNT reinforcements on tensile properties of epoxy polymer matrix composite. The same is ventured in this paper. Central Composite Design (CCD), a model available in Response

Surface Methodology (RSM) is used in finding various combinations in sample preparation. RSM is one of the Design of Experiment (DOE) approaches. To find the level of influences of reinforcements on tensile behavior of composite, analysis of variance (ANOVA) is utilized.

2. Experimental Procedure

2.1. Materials

Epoxy is used as a matrix in polymer matrix composite. As fly ash is one of the abundant and easily available materials, it is used as one of the fillers / reinforcements. For the purpose of making epoxy polymer matrix composite, fly ash with grain diameter of 50 μm is acquired. Sugarcane fiber is mainly used in composite matrix due to its bio-degradability. For reinforcement in epoxy polymer matrix composite, dried sugarcane is obtained and pulverized in a pulverizer. After pulverizing, sugarcane fiber is sieved in the sieve with mesh dimension of 150 μm. Thus, the sugarcane fiber used for epoxy polymer matrix composite has the grain diameter of 150 μm. Carbon Nano Tube (CNT) is a material which contributes highly to the tensile strength of the epoxy polymer matrix composite if added as filler / reinforcement. Multi-walled CNT (MWCNT), acquired from Sisco Research Laboratories Pvt. Ltd., is to be used as another filler / reinforcement in the epoxy polymer matrix. Specifications of CNT acquired are Multi-walled CNT type 3; Outer Diameter (OD) of 10-20nm; Length of 10-30μm.

2.2.Methodology

The CCD (Central Composite Design), one of Response Surface Methodology (RSM) models, is used as DOE at 5 different levels of wt. % for fly ash, sugarcane fibre and MWCNT. The wt. % values for fly ash and sugarcane fibre are in range of 0 to 2. Similarly, wt. % values for MWCNT are in range of 0 to 1. Table 1 shows the coded values and actual percentage values.

Table 1

wt. % of fly ash, sugarcane, MWCNT at different levels

Parameters	Levels				
	-2	-1	0	1	2
Wt. % of fly ash	0	0.5	1	1.5	2
Wt. % of sugarcane	0	0.5	1	1.5	2
Wt. % of CNT	0	0.25	0.5	0.75	1

Table 2 shows 20 different combinations of fly ash / sugarcane fibre / MWCNT in wt. % which are to be reinforced into epoxy resin matrix for sample preparation. These combinations are obtained using CCD of RSM. These samples are prepared in accordance with ASTM D3039 standard for tensile testing. Triplicate samples are prepared for each combination. Triplicate samples of pure epoxy composites are also manufactured for comparison. Figure 1 shows the samples prepared for tensile testing. In this work, a SHIMADZU AG-X plus 50 kN universal testing machine is used for tensile testing as shown in figure 2. The strain rate is kept during the testing is 2mm/min.

Table 2

Different combinations samples meant for tensile testing

Sample No	Fly ash (%)		Sugarcane (%)		CNT (%)	
	Coded	Actual	Coded	Actual	Coded	Actual
1	2	2	0	1	0	0.5
2	-2	0	0	1	0	0.5
3	0	1	2	2	0	0.5
4	0	1	-2	0	0	0.5
5	0	1	0	1	2	1
6	0	1	0	1	-2	0
7	1	1.5	1	1.5	1	0.75
8	-1	0.5	1	1.5	1	0.75
9	1	1.5	-1	0.5	1	0.75
10	1	1.5	1	1.5	-1	0.25
11	-1	0.5	-1	0.5	1	0.75
12	-1	0.5	1	1.5	-1	0.25
13	1	1.5	-1	0.5	-1	0.25
14	-1	0.5	-1	0.5	-1	0.25
15	0	1	0	1	0	0.5
16	0	1	0	1	0	0.5
17	0	1	0	1	0	0.5
18	0	1	0	1	0	0.5
19	0	1	0	1	0	0.5
20	0	1	0	1	0	0.5

3. Results and Discussions

3.1. Tensile Properties

Table 3 shows the results of tensile behaviour such as yield strength, ultimate tensile strength (UTS) and Young’s Modulus for 20 samples prepared according to Table 2. Triplicate samples for each combination are tested in INSTRON machine and mean values are tabulated in Table 3. Pure epoxy samples are also tested and the mean value is added in Table 3 for comparison. From the values shown in Table 3, it is evident that sample 3 exhibits high yield stress and Young’s modulus whereas sample 11 exhibits highest ultimate tensile strength value.

Table 3

Ultimate Tensile Strength and Young's Modulus from tensile test

Sample No	Yield Strength (MPa)	UTS (MPa)	Young's Modulus (MPa)
1	3.35	9.68	569.9
2	3.9	14.85	680.6
3	5.3	10.39	935
4	2.42	12.90	416.5
5	1.1	16.75	155.5
6	1.12	9.77	174.8
7	2.39	9.48	408.95
8	2.91	16.19	480.6
9	2.32	9.76	402.4
10	2.3	11.35	396.7
11	1.37	20.14	253.1
12	3.2	7.11	545.5
13	1.79	11.04	304.96
14	1.45	9.09	275.1
15	1.43	8.84	262.2
16	1.52	7.73	272.1
17	1.5	7.88	265.2
18	1.55	9.42	279.9
19	1.53	8.75	278.4
20	1.42	7.96	234.8
Pure epoxy	1.35	8.54	210.8

Fig. 1. Tensile samples prepared according to ASTM D3039

Fig. 2. Tensile test using SHIMAZZU – UTM

3.2. Regression Equation

Influences of wt. % of fly ash, sugarcane and CNT on tensile behaviours are studied using analysis of variance (ANOVA). The values obtained from the tensile test are fed to the MINITAB software to carry out ANOVA. The regression equations are obtained which show the influences of wt. % of fly ash, sugarcane, and CNT on tensile behaviours of composite. Equations 1, 2 and 3 show the regression equation for yield stress, UTS and Young's modulus, respectively. From the regression equation, yield stress, UTS and Young's modulus values for all 20 samples are calculated by substituting the corresponding wt. % of fly ash / sugarcane fibre / CNT in the equations 1, 2 and 3. The values obtained from regression equation are tabulated and error between experimental and regression equation values are presented in table 4. Except few, errors are generally less than 10% which show the veracity of the regression equations.

$$\begin{aligned} Yield\ strength\ (MPa) &= 2.962 - 3.338\ Flyash - 1.631\ Sugarcane + 1.68CNT \\ &+ 2.022Flyash \times Flyash + 2.257Sugarcane \times Sugarcane \\ &- 1.971CNT \times CNT - 1.355Flyash \times Sugarcane \\ &+ 0.990Flyash \times CNT - 0.650Sugarcane \times CNT \end{aligned} \tag{1}$$

$$\begin{aligned} UTS\ (MPa) &= 10.99 - 1.93\ Flyash - 9.76\ Sugarcane + 13.72CNT \\ &+ 3.969Flyash \times Flyash + 3.346Sugarcane \times Sugarcane \\ &+ 19.86CNT \times CNT + 2.980Flyash \times Sugarcane \\ &- 23.29Flyash \times CNT - 2.56Sugarcane \times CNT \end{aligned} \tag{2}$$

$$\begin{aligned} Young's\ Modulus\ (MPa) &= 537 - 615\ Flyash - 317Sugarcane + 401CNT \\ &+ 341.8Flyash \times Flyash + 392.3Sugarcane \times Sugarcane \\ &- 473CNT \times CNT - 200Flyash \times Sugarcane \\ &+ 196Flyash \times CNT - 128Sugarcane \times CNT \end{aligned} \tag{3}$$

3.3. Surface Plots

Fig. 3 (a) shows the surface plot of effect of sugarcane fiber % and fly ash % on yield strength of composites by keeping CNT percentage as zero. The surface plot shows the combined effect of fly ash and sugarcane on the yield strength of composites. The yield strength is low in fly ash at 1% and sugarcane at 1% ratio combination and it is very much higher when fly ash at 0% and sugarcane at 2% combination. Fig. 3 (b) shows the combined effect of sugarcane % and CNT % on yield strength of composites by keeping fly ash at 0%. The surface plot shows minimum value of yield strength at sugarcane of 0.5% and CNT of 1% combination and maximum value of yield strength at sugarcane at 2% and CNT at 0.25%. Figure 3 (c) shows the surface plot of combined effect of fly ash and CNT on yield strength by keeping sugarcane at 0%. The plot shows minimum value at fly ash of 1% and CNT of 0% combination and maximum value at fly ash of 2% and CNT of 1% combination.

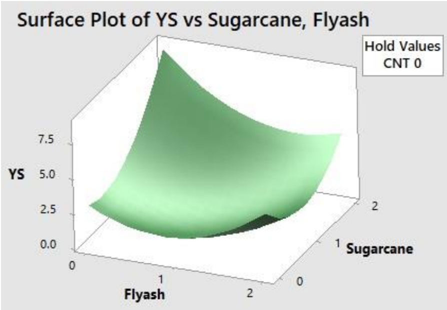
Fig. 4 (a) shows the surface plot of combined effect of sugarcane % and fly ash % on ultimate tensile strength (UTS) of composite by keeping CNT at 0%. The surface plot records minimum value of UTS at fly ash of 0% and sugarcane of 1.5% and records maximum value of UTS at fly ash of 2% and sugarcane of 2% combination composites. Fig. 4 (b) shows the surface plot combined effect of sugarcane % and CNT % on UTS of composite by keeping fly ash as 0%. The composite shows lower value of UTS at sugarcane of 2% and CNT of 0%, whereas higher value of UTS at sugarcane of 0% and CNT of 1% composition. Fig. 4 (c) shows the surface plot of combined effect of fly ash % and CNT % on UTS. The plot record least value of UTS at fly ash of 2% and CNT of 0.8% and plot record higher value of UTS at fly ash of 0% and CNT of 1%.

Table 4

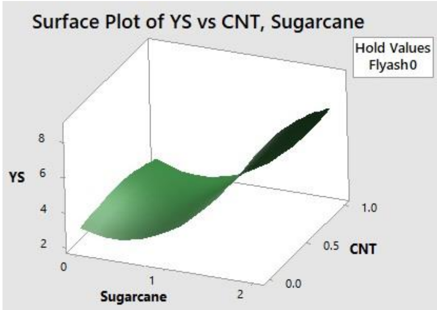
Comparison between Experimental and Regression values for YS, UTS and YM

Sample No	Yield Strength (MPa)			Ultimate Tensile Strength			Young's modulus (MPa)		
	Experiment	Regression	Error %	Experiment	Regression	Error	Experiment	Regression	Error %
1	3.35	3.30	1.43	9.68	9.81	1.3	569.9	566.3	0.64
2	3.9	3.61	7.44	14.85	15.12	1.8	680.6	633.1	6.99
3	5.3	4.89	7.66	10.39	10.47	0.8	935	856.3	8.42
4	2.42	2.49	2.81	12.90	13.21	2.4	416.5	444.1	6.61
5	1.1	0.97	12.1	16.75	17.33	3.4	155.5	140.1	9.9
6	1.12	0.92	18.1	9.77	9.60	1.7	174.8	139.1	20.4
7	2.39	2.62	9.67	9.48	9.00	5.0	408.95	457.5	11.8
8	2.91	3.21	10.1	16.19	15.99	1.2	480.6	541.9	12.7
9	2.32	2.26	2.67	9.76	9.52	2.4	402.4	382.2	5.02
10	2.3	2.51	9.22	11.35	11.60	2.1	396.7	438.8	10.6
11	1.37	1.49	8.54	20.14	19.49	3.2	253.1	266.6	5.33
12	3.2	3.59	12.2	7.11	6.94	2.3	545.5	621.2	13.8
13	1.79	1.82	1.9	11.04	10.83	1.9	304.96	301.9	0.99
14	1.45	1.55	6.76	9.09	9.16	0.7	275.1	284.3	3.36
15	1.43	1.43	0.28	8.84	8.50	3.9	262.2	257.9	1.66
16	1.52	1.43	5.66	7.73	8.50	9.8	272.1	257.9	5.24
17	1.5	1.43	4.4	7.88	8.50	7.7	265.2	257.9	2.77
18	1.55	1.43	7.48	9.42	8.50	9.8	279.9	257.9	7.88
19	1.53	1.43	6.27	8.75	8.50	2.9	278.4	257.9	7.38
20	1.42	1.43	0.99	7.96	8.50	6.7	234.8	257.9	9.82

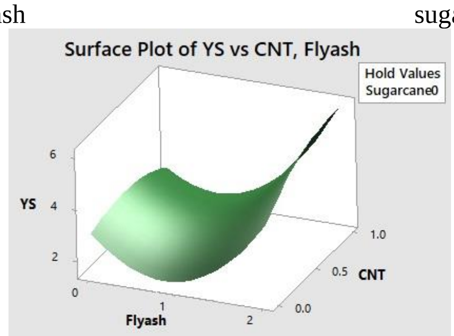
Where YS – Yeild Stress, UTS – Ultimate Tensile Stress, YM – Young's Modulus



(a) YS versus percentage of sugarcane fibre and fly ash

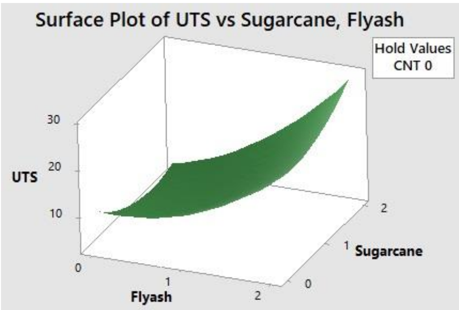


(b) YS versus percentage of CNT and sugarcane fibre

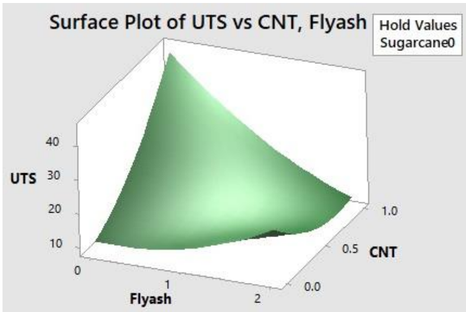


(c) YS versus percentage of CNT and fly ash

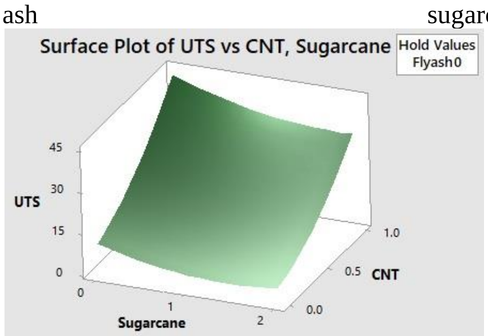
Fig. 3. Surface plot of yield strength (YS) – interaction between two parameters



(a) UTS versus percentage of sugarcane fibre and fly ash

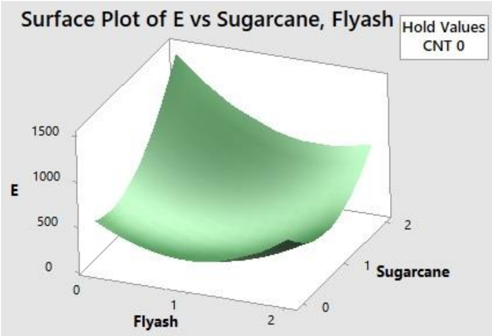


(b) UTS versus percentage of CNT and sugarcane fibre

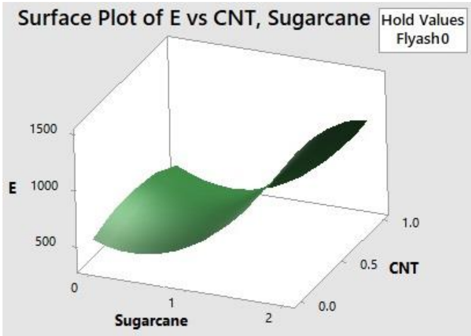


(c) UTS versus percentage of CNT and fly ash

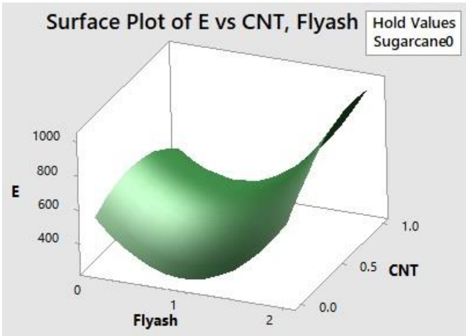
Fig. 4. Surface plot of ultimate tensile strength (UTS) – interaction between two parameters



(a) Young's modulus versus percentage of sugarcane fibre and fly ash



(b) Young's modulus versus percentage of CNT and sugarcane fibre



(c) Young's modulus versus percentage of CNT and fly ash

Fig. 5. Surface plot of Young's modulus (E) – interaction between two parameters

Fig. 5 (a) shows the combined effect of fly ash % and sugarcane % on Young's modulus of composited by keeping CNT at 0%. The surface plot shows minimum value of Young's modulus at fly ash of 1% and sugarcane of 0.5%, maximum value at fly ash of 0% and sugarcane of 2% combination composite. Figure 5 (b) shows the combined effect of sugarcane % and CNT % on Young's modulus of composite by keeping fly ash at 0%. The minimum value of Young's modulus of composite records at sugarcane of 0.5% and CNT of 1% and maximum value of Young's modulus at sugarcane of 2% and CNT of 0% combination. Figure 5 (c) shows the surface plot of combined effect of fly ash % and CNT % on the Young's modulus of composites by keeping sugarcane at 0%. The composites exhibits lower Young's modulus at fly ash of 1% and CNT of 0.3% combination and higher Young's modulus values at fly ash of 2% and CNT of 1% combination.

3.4. Optimization of parameters to achieve maximum response

Table 5

Optimized parameters exhibiting maximum responses

Fly ash % (w/w)	sugarcane fibre % (w/w)	CNT % (w/w)	Yield strength (MPa)	Ultimate Tensile Stress (MPa)	Young's modulus (MPa)
0.5	2	0.85	5.53	19.62	914.96

Using RSM optimizer tool available in MINITAB, optimized parameters are found out to achieve maximum responses. From the table 5, it is understood that more than 95 % of the maximum responses i.e. yield strength of 5.53 MPa, UTS of 19.62 MPa and Young's modulus of 914.96 MPa are achieved using the combination of 0.5 wt. % of fly ash, 2 wt. % of sugarcane fibre and 0.85 wt. % of CNT. Confirmation experiment is conducted to test the legitimacy of optimum parameters meant for maximum responses. Optimized combination of parameters obtained using RSM optimizer is in good agreement with confirmation experiment which is evident from table 6.

Table 6

Comparison of optimization and experimental results for maximum responses

Yield strength (MPa)		
Optimization	Experiment	Error %
5.53	5.2	6.35
Ultimate Tensile Stress (MPa)		
Optimization	Experiment	Error %
19.62	18.88	3.92
Young's modulus (MPa)		
Optimization	Experiment	Error %
914.96	847.97	7.9

4. Conclusion

Sugarcane fiber reinforced epoxy polymer composites are fabricated with fly ash and CNT as fillers. Investigations are carried out to expose the influences of input parameters such as wt. % of fly ash, sugarcane fiber and CNT on tensile behavior of the composite. Central composite design of response surface methodology is used to decide the different combinations of samples based on wt. % of fly ash, sugarcane fiber and CNT. After conducting tensile test, the influences of different input parameters on tensile behavior are investigated using ANOVA. Contour plots and regression equations reveal the level of influences of input parameters. Following inferences are obtained from the ANOVA results.

- Wt. % of fly ash and CNT have positive influence on UTS while wt. % of sugarcane has positive influence on yield strength and Young's modulus.
- Increasing wt. % of fly ash in the composite increases UTS but decreases yield strength and Young's modulus.
- Increasing wt. % of sugarcane fiber in the composite increases yield strength and Young's modulus but decreases UTS.
- Increasing wt. % of CNT in the composite increases UTS but does not influence significantly on yield strength and Young's modulus.
- 'Sugarcane fiber and fly ash interaction', 'sugarcane fiber and CNT interaction' and 'fly ash and CNT interaction' are significant for 'yield strength and UTS', 'UTS' and 'yield stress and Young's modulus' respectively.
- Error analysis between experimental values and regression equation values shows the authenticity of all regression equations.
- Maximum response values i.e. yield strength (5.53 MPa), ultimate tensile strength (19.62 MPa) and Young's modulus (914.96 MPa) are obtained at 0.5 wt. % of fly ash, 2 wt. % of sugarcane fibre and 0.85 wt. % of CNT.
- These composites can be utilized for making switch gears, mobile phone holders and kitchen storage utensils.

REFERENCES

[1]. *J. Holbery and D. Houston*, "Natural-Fiber-Reinforced Polymer Composites in Automotive Applications", The Journal of The Minerals, Metals and Materials Society, **Vol. 58**, no. 3,11,Nov 2006, pp. 80-86.

[2]. *T. Siva Prasad*, "Characteristics of Glass Fiber reinforced Epoxy composites for automotive Engine Hood", International Journal of Science Technology and Management, **Vol. 4**, no. 11, Nov 2015, pp. 429-437.

[3]. *F.P. La Mantia and M. Morreale*, "Green composites: A brief review", Composites: Part A 42, **Vol 42**, no. 6, June 2011, pp.579-588.

[4]. *P. Prabaharan Grcaeraj and G. Venkatachalam*, "Investigation into Tensile Strength of Jute fiber reinforced hybrid polymer matrix composites", Engineering Review, **Vol. 35**, no. 3, Oct 2014 pp.275-281.

[5]. *E.F. Cerqueira and C.A.R.P. Baptista*, "Mechanical behaviour of polypropylene reinforced sugarcane bagasse fibers composites", Procedia Engineering, **Vol. 10**, Jan 2011, pp. 2046-2051.

[6]. *Isiaka Oluwole Oladele*, "Effect of Bagasse Fibre Reinforcement on the Mechanical Properties of Polyester Composites", The Journal of the Association of Professional Engineers of Trinidad and Tobago, **Vol 42**, No 1, Nov 13, pp. 12-15.

[7]. *M.Singla and V.Chawla*, "Mechanical Properties of Epoxy Resin-Fly Ash Composite", Journal of Minerals & Materials Characterization & Engineering, **Vol. 9**, no. 3, March 2010, pp. 199-210.

[8]. *Jeesoo Sim, Youngjeong Kang, Byung Ju Kim, Yong Ho Park, Young Cheol Lee*, "Preparation of Fly Ash/Epoxy composites and its effects on mechanical properties", Polymers, **Vol. 12**, no.1, Jan 2020.

[9]. *G.Venkatachalam, S.Kumar Sharma, Jangid, A.K., Vignesh. P, Nilesh, S.N. and Pandivelan.C*, “Investigations on Tensile and Flexural Characteristics of Flyash and Banana Fiber-Reinforced Epoxy Matrix Composites”, Engineering Transactions, **Vol 68**, 2020, pp. 89-101.

[10]. *A.Montazeri and J.Javadpour*, “Mechanical properties of multi-walled carbon nanotubes/epoxy composites”, Materials and Design, **Vol. 31**, April 2010, pp. 4202-4208.

[11]. *N.Abdulla Al-Hamdani, Tariq Suhail Najim, Fatima Ahmed Khalaf*,(2014), “Mechanical and thermal behaviour of Polymer Composite reinforced with functionalized Carbon Nanotubes”, IOSR Journal of applied Physics, **Vol. 6**, no. 4 Ver I, Aug 2014, pp. 50-53.

[12]. *Lixing Dai and Jun Sun*, “Mechanical Properties of Carbon Nanotubes-Polymer Composites. Carbon Nanotubes - Current Progress of Their Polymer Composites”, Intechopen, July 2016, pp. 155-194.

[13]. *M.Sivakumar, G.Venkatachalam, V.Hemanth, P.Vignesh, P.S.V.Prashanth and S.Vimalanand*, “Studies on Shear Strength of CNT/Coir Fibre/Fly Ash Reinforced Epoxy Polymer Composites”, Emerging Materials Research, **Vol. 9**, no. 1, March 2020, pp 78-88.