OPTIMIZATION AND MODELING THE MECHANICAL PROPERTIES OF BAGASSE AND LUFFER CYLINDRICA FIBER REINFORCED EPOXY POLYMER HYBRID COMPOSITE USING TAGUCHI DESIGN AND FUZZY LOGIC.

Chibueze, I. G.[1], Atuanya, C. U.[1], Nwobi-Okoye, C. C.[2], Obele, C. M.[3]
[1]Department of Metallurgical and Materials Engineering, Nnamdi Azikwe University, Awka, Anambra State.
[2]Department of Mechanical Engineering, Chukwuemeka Odumegu Ojukwu University, Uli, Anambra State.
[3]Department of Polymer and Textile Engineering, Nnamdi Azikwe University, Awka, Anambra State.

ABSTRACT
In this study, Taguchi robust design was used to design the experiment and optimize the mechanical properties of the hybrid composite while modeling and prediction of the mechanical properties was done using fuzzy logic. The hybrid composite was produced using bagasse (5%wt,10%wt and 20%wt) and luffer fiber (5%wt,10%wt and 20%) as reinforcement in epoxy resin based polymer matrix. The mechanical properties considered in this study are impact strength, hardness and flexural strength. Taguchi optimization evaluated and gave the expected optimum value for flexural strength as 103MPa, 22MPa for impact strength and 20HRfor hardness. The analysis also shows that %wt of bagasse is the most significant factor in the optimization of the hybrid composite in the case study. Fuzzy logic model predictions gave a correlation coefficient (R) value of 0.945577 for impact strength, 0.994524 for flexural strength and 0.996712 for hardness. The result show that fuzzy logic can be used to predict the flexural strength, hardness and impact strength of bagasse/luffer fiber reinforced epoxy hybrid composite.

Keywords: Bagasse Fiber, Luffer Cylindrica Fiber, Epoxy Resin, Taguchi Robust Design, Fuzzy Logic

Nomenclature: Percentage weight of bagasse (%wt Bg)
Percentage weight of luffer cylindrica (%wt luffer)

1.0 INTRODUCTION
It is known that the most feasible method of improving the mechanical properties of a biodegradable composite material is by reinforcing with a fiber which also help to reduce the cost of production (Shibata et al, 2004). Fibers are categorically divided into two, which are synthetic and natural fibers. Synthetic fibers are very costly and are not environmentally friendly, but posses' better mechanical properties than natural fibers (sabra et al 2011).

Natural fibers are fiber produced from plants, animal or through geological processes (Solomon nwigbo and Okoye lotanna 2018) and oksman et al 2001 research shows the advantage of natural fiber, which include low density, high strength to weight ratio, low cost, eco-friendly, biodegradable, recyclability, and good specific mechanical properties, no skin irritation. Due to the growing global environmental predicament and eco -friendly hazards, natural fibers have become an important part of research and because they are readily available, low cost in processing, natural fibers such as jute, sisal , bagasse luffer cylindrica, banana, rice husk have become researchers favorite as a substitute for synthetic fiber.(Nirbhay et al, 2015).

The bagasse fiber has fairly good mechanical properties; they are freely available and are by product of sugar cane. Bagasse fibers are sometimes combined with another natural or synthetic fiber o as to curtail some of the drawback such as their hygroscopic nature, poor wet ability and low thermal stability (Saw et al, 2011).

A hybrid composite is an amalgamation of two or more different types of fibers in which one type of fiber reduces the drawbacks of another fiber and hybridization aims at creating a new material that will preserve the benefits of its constituents but not their limitations (Prashant et al, 2018).
Luffa cylindrica is a subtropical vegetable which belongs to the family of Cucurbitaceae, which produces fruit containing fibrous vascular system. Luffer is a natural fiber extracted from the sponge-gourd plants.
prasad et al, (2011) Observed the tensile and flexural strengths of Glass-sisal polyester hybrid composite. Tensile strength and flexural strength value for the composite laminates were about 12.35 MPa and 53.46MPa.

Lassaad Ghali et al, (2011) discovered that the luffa fiber weight fraction is very significant on the flexural properties of polyester composites. The maximal values of strength and strain were reported at the optimum weight of fiber (10% weight fraction of fiber).

Boyand et al. (2003] investigated the effect of alkali treatment on sponge gourd (luffa cylindrica) fibers on the flexural properties of polyester matrix composites. Results show an increment of 14% on the flexural strength.

Agnivesh et al, 2020 investigated the fuzzy logic approach for modeling and prediction of mechanical properties of hybrid abaca-reinforced polymer composite. It was therefore observed from the model result that the developed model can be used to predict mechanical properties of hybrid composites with a maximum accuracy of 87%.

Naresh et.al (2014) studied the modeling and analysis of machining GFRP composites using fuzzy logic and ANOVA. The model prediction gave 94% co efficiency of correlation, which signifies that the model was good and there was a good correlation between the factors and responses.

From observation, it can be said that fuzzy logic has not been fully implored for the modeling and prediction of Natural fiber reinforced hybrid composite (kadi 2006). In this research, the mechanical properties (flexural strength, impact strength and hardness) of the natural fiber reinforced hybrid composite will be analyzed, optimized using taguchi and subsequently modeled via fuzzy logic. The developed fuzzy model will be capable to predict the hardness, flexural and impact strength of the hybrid composite.

2.0 MATERIALS AND METHOD

2.1 Materials

The raw materials used in the fabrication were epoxy resin LY 556, Luffa cylindrica Fiber, sugarcane bagasse, Hardener HY951, paraffin Wax, NaOH, methanol and a mould

2.2 Design of Experiment

Taguchi method was used to design the experiment which was developed by Dr Genichi Taguchi. These designs involve using orthogonal arrays to organize the parameters affecting the process and the level at which they should be varied. The Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments testing a pair of combinations which aid in the collection of the necessary data to determine which factor most affect the product quality with a minimum amount of experimentation, thus saving time and resources. In this research, two factors and three levels were used to conduct the experiment as shown in table 1.

Table 1: Processing Factors and levels Considered in Taguchi Robust Design of Experiment.

S/N	Processing factor	Levels		
1	wt of bagasse (%wt bg)	5	10	20
2	wt of luffer (%wt luffer)	5	10	20

Therefore, since two factors and three levels are considered, L9 orthogonal array was suitable and therefore selected as shown in Table 2.

Table 2: L9 orthogonal array for the two factors and three level experiments

S/N	%wt of Bg	%wt of luffer	Flexural strength (MPa)	Impact strength (MPa)	Hardness (HR)
1	5	5			
2	10	5			
3	20	5			
4	5	10			
5	10	10			
6	20	10			
7	5	20			

8	10	20			
9	20	20			

2.3 Experimental Procedures: Sample Preparation, fabrication and testing

i. Samples preparation

Samples were treated in alkaline solution (10% NaOH solution) for 24 hours so as to remove any greasy material, hemicelluloses and lignin from the surface and also to improve the fiber roughness and then subsequently sun dried before it was pulverized.

ii. Fabrication

Metal mould of 300mm × 300mm× 5mm was used to produce the samples. The composites were fabricated with 10%wt, 15%wt, 20%wt, 25%wt, 30% and 40% of fiber (bagasse + luffer). The treated fibers were measured in required weight fractions, mixed with the epoxy resin and hardener (2;1) before pouring the mixture into the mold. Afterward the composite samples were allowed to cure for at least two days before removing them from the mould. Then the Specimens were cut for testing as per ASTM standards.

iii. Mechanical Testing

The tests performed on the specimen were flexural strength, impact strength and hardness test.

Flexural testing

Flexural strength of the composites was determined from the three point bend technique. It was carried out in a modified UTM machine in accordance with ASTM D790-03. All the composite specimens were of rectangular shape having length 200mm × 20mm× 5mm. Experiments were conducted at a cross head speed of 0.5 mm/min. Then flexural strength was calculated using simple bending moment diagram of simply supported beam at central point load.

Impact Strength Test

The impact test was performed to understand the toughness of the composites using a Veekay instrument. The Charpy impact test was carried as per ASTME23 standard [vilay et al, 2008)] to measure the impact behavior of the composites. The standard sample size 100mm ×20mm ×5mm was taken, and a V-notch was made at an angle of 45^0 with a root depth of 2 mm

Hardness

The computerized Rockwell hardness tester (Model: VM50PC) machine with load accuracy 1% of the nominal load value was used to determine the hardness of the composites.

For making the sharp indentations on the specimens, a rigid precision diamond indenter (136^0pyramid) was used in this test with a 5 kgf load.

3.0 RESULTS AND DISCUSSION

The following results were obtained from the mechanical testing of the samples as shown in Table 3.

Table3: Mechanical properties test result.

S/N	%wt of Bg	%wt of luffer	Flexural strength (MPa)	Impact strength (MPa)	Hardness (HR)
1	5	5	90	19.00	17.9
2	10	5	103	20.58	18.2
3	20	5	110	22.00	18.4
4	5	10	90	22.54	18.6
5	10	10	85	21.56	20
6	20	10	80	22.00	17.9
7	5	20	98	19.60	41
8	10	20	65	21.56	39
9	20	20	55	19.00	49

3.1 Analysis of the Results

3.1.1: Impact strength

Effect of process parameter on impact strength

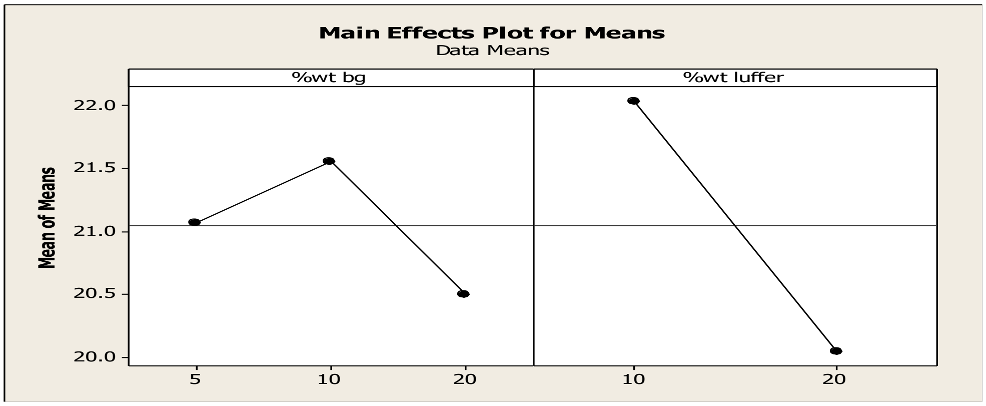

Fig1: Effect of process parameter on impact strength.

From the mean plot shown in fig1, it was observed that impact strength increases as the %wt bagasse increases, the impact strength attains a maximum value at 10%wt of bagasse before it begin to decrease as the %wt of bagasse increase. Furthermore, it was also observed that impact strength attain maximum value at 5% luffer before decreasing drastically as the %wt of luffer decreases.

Contour plot:

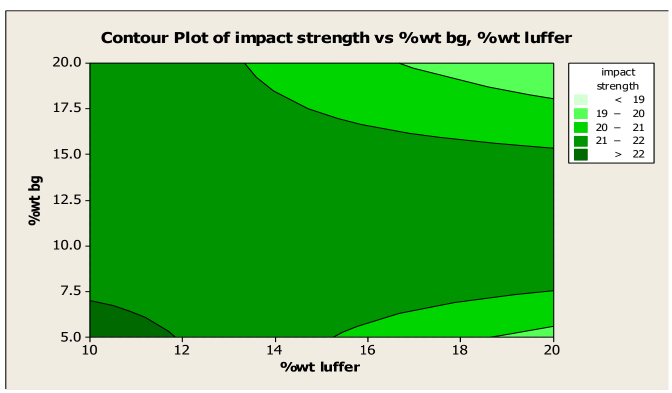

Fig2: Contour plots of impact strength Vs the process parameter.

Contour plots examine the relation between the response variable and two control variables by viewing discrete contours of the predicted response variables. Fig 2 shows that the maximum impact strength was achieved in the region between 10%wt – 12%wt of luffer and 5%wt – 7%wt of bagasse. While the least impact strength was in the region of 17.5%wt – 20%wt of bagasse.

Optimization of the impact strength of bagasse/luffer reinforced hybrid composite.

The optimum control factor for impact strength was obtained by applying Taguchi statistical design. The impact strength was optimized so as to estimate the possible optimum value and also predict the control factor that most influence the response. The result of the mean, SN ratio, analysis of variance of mean, response SN ratio table and the ranking for larger is better is explained from Table 4a – Table 4d.

Taguchi Analysis: Impact Strength versus %wt bg, %wt luffer.

Table 4a: Analysis of Variance for SN ratios

Analysis of Variance for SN ratios

Source	DF	Seq	SS Adj	SS Adj	MS	F	P
%wt bg	2	0.2128	0.2128	0.1064	0.41	0.708	
%wt luffer	1	1.0311	1.0311	1.0311	3.99	0.184	
Residual Error	2	0.5165	0.5165	0.2582			
Total	5	1.7604					

Table 4b: Analysis of Variance for Means

Analysis of Variance for Means

Source	DF	Seq	SS Adj	SS Adj	MS	F	P
%wt bg	2	1.126	1.126	0.5629	0.38	0.723	
%wt luffer	1	5.881	5.881	5.8806	4.00	0.184	
Residual Error	2	2.941	2.941	1.4706			
Total	5	9.948					

Table 4c: Table for signal to Noise Ratios (larger is better)

Response Table for Signal to Noise Ratios (Larger is better)

Level	%wt bg	%wt luffer
1	**28.45**	26.86
2	26.67	**27.03**
3	26.21	
Delta	0.46	0.83
Rank	2	1

Table 4d: Response table for means

Response Table for Means

Level	wt bg	%wt luffer
1	**22.07**	22.03
2	21.56	**23.05**
3	20.50	
Delta	1.06	1.98
Rank	2	1

Results obtained from Table 4a – Table 4d, the Taguchi statistical analysis of impact strength shows that luffer fiber display stronger effect for both SN ratio and mean value and are also ranked the best. Therefore luffer fiber is the most significant parameter in the optimization of impact strength of bagasse/luffer hybrid composite. The optimum factor settings that will give the optimum impact strength are 5%wt luffer, 10%wt luffer while the expected optimum impact strength is 22.5MPa.

Flexural strength

Fig 4 shows how the process parameters affect the flexural strength. It was observed that flexural strength is maximum at 5%wt bagasse before decreasing as the %wt bagasse increases, similarly as shown above, the flexural strength decreases as %wt luffer increases.

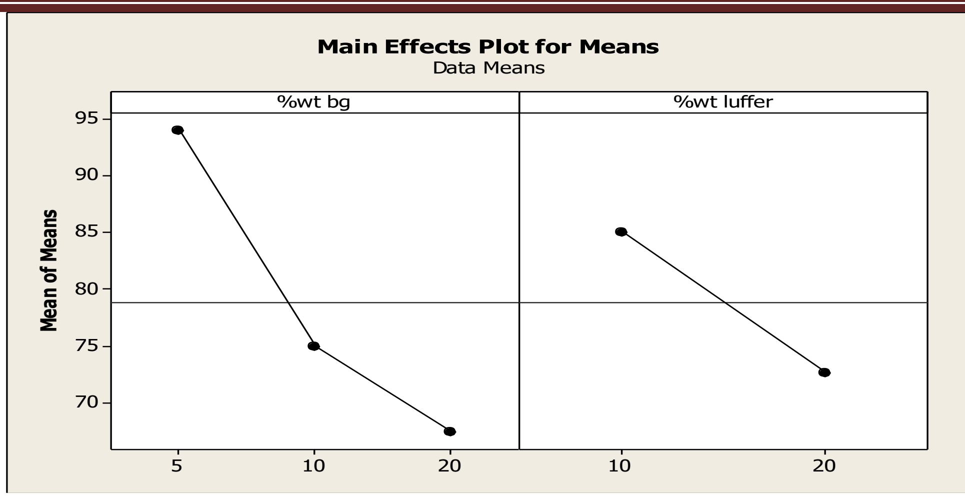

Fig 4: The main effect plots of flexural strength Vs the process parameter.

Contour plot:

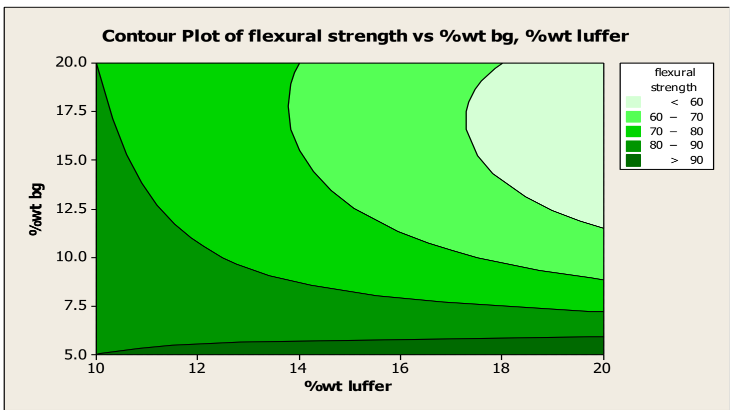

Fig 5: contour plot of flexural strength Vs %wt bg and %wt luffer

The contour plot as seen in fig 5 details the relationship between flexural strength and the processing factors, It was observed that the maxima flexural strength occur within the region of10%wt luffer to 20%wt luffer and at 5%wt Bg. While the minimum flexural strength is within 18%wt luffer to 20%wt luffer and 15%wt Bg to 20%wt Bg.

Optimization of the flexural strength of bagasse/luffer reinforced hybrid composite.

The optimum control factor for flexural strength was obtained by applying Taguchi statistical design. The flexural strength was optimized so as to estimate the possible optimum value and also predict the control factor that most influence the response. The result for the mean, SN ratio, analysis of variance for mean, response SN ratio table and the ranking for larger is better is shown from Table5a to Table5d.

Taguchi Analysis: flexural strength versus %wt bg, %wt luffer:

Table5a: Analysis of varience for SN ratios

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
%wt bg	2	9.484	9.484	4.742	2.17	0.316
%wt luffer	1	3.912	3.912	3.912	1.79	0.313
Residual Error	2	4.372	4.372	2.186		
Total	5	17.768				

Table5b: Analysis of Variance for Means

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
%wt bg	2	746.3	746.3	373.2	2.36	0.298
%wt luffer	1	228.2	228.2	228.2	1.44	0.353
Residual Error	2	316.3	316.3	158.2		
Total	5	1290.8				

Table5c: Response Table for Signal to Noise Ratios

Response Table for Signal to Noise Ratios(Larger is better)

Level	%wt bg	%wt luffer
1	37.45	38.58
2	39.42	36.96
3	36.43	
Delta	3.02	1.61
Rank	1	2

Table5d: Response Table for Means

Response Table for Means

Level	%wt bg	%wt luffer
1	73.00	85.00
2	94.00	72.67
3	67.50	
Delta	26.50	12.33
Rank	1	2

Results obtained from Table 5a to Table 5d, the optimization of flexural strength shows that bagasse fiber display stronger effect for both SN ratio and mean value and are also ranked the best. Therefore bagasse fiber is the most significant parameter in the optimization of flexural strength of bagasse/luffer hybrid composite. The optimum factor settings that will yield optimum flexural strength are 10%wt Bg, 5%wt luffer while the expected optimum flexural strength is 103MPa.

Hardness

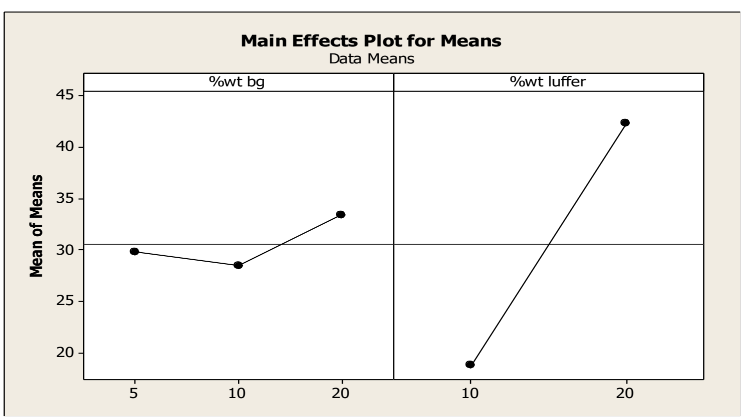

Fig7: Effect of processing factor on hardness

The main effect of hardness versus the processing factor is shown in fig 7. From fig7, it was observed that the hardness increases as the %wt of luffer increases and decreases as %wt of bagasse increases but later increases at 10%wt bagasse.

Contour plot:

The contour plot below (fig 8) details the relationship between hardness and the processing factor. It was seen that the maximum hardness occur at 20%wt of luffer and in the region of 17.5%wt to 20%wt of bagasse. Minimum hardness was also observed to be within 10%wt to 10.5%wt of luffer and 5%wt to 20%wt of bagasse

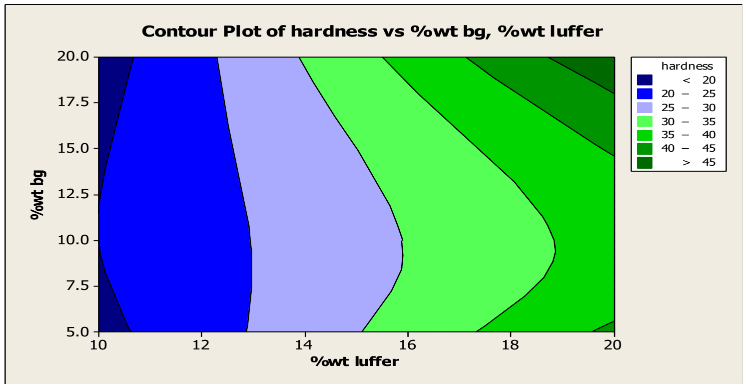

Fig 8: Contour plots of hardness vs the process parameter.

Optimization of hardness for bagasse/luffer reinforced hybrid composite.

Taguchi statistical design was used to obtain the optimum control factor for hardness. Hardness was optimized so as to estimate the possible optimum value and also predict the control factor that most influence the response. The result for the mean, SN ratio, analysis of variance for mean, response SN ratio table and the ranking for larger is better is shown from Table 6a to Table 6d

Taguchi Analysis: flexural strength versus %wt bg, %wt luffer:

Table 6a: Analysis of Variance for SN ratios

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
%wt bg	2	9.484	9.484	4.742	2.17	0.316
%wt luffer	1	3.912	3.912	3.912	1.79	0.313
Residual Error	2	4.372	4.372	2.186		
Total	5	17.768				

Table 6b: Analysis of Variance for Means

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
%wt bg	2	746.3	746.3	373.2	2.36	0.298
%wt luffer	1	228.2	228.2	228.2	1.44	0.353
Residual Error	2	316.3	316.3	158.2		
Total	5	1290.8				

Table 6c: Response Table for Signal to Noise Ratios

Response Table for Signal to Noise Ratios (Larger is better)

Level	%wt bg	%wt luffer
1	37.45	36.58
2	39.42	38.96
3	36.43	
Delta	3.02	1.61
Rank	1	2

Table 6d: Response Table for Means

Response Table for Means

Level	%wt bg	%wt luffer
1	72.00	72.00
2	94.00	85.67
3	67.50	
Delta	26.50	12.33
Rank	1	2

Results obtained from the optimization of hardness (table 6a – table 6d) shows that bagasse fiber display stronger effect for both SN ratio and mean value and are also ranked the best. Therefore bagasse fiber is the most significant parameter in the optimization of hardness of bagasse/luffer hybrid composite. The optimum factor settings that will yield optimum hardness are 10%wt Bg, 10%wt luffer while the expected optimum hardness is 20HR.

4.0 FUZZY LOGIC MODELING

Fuzzy logic is a simple rule based system modeling tool which is very versatile and can be used for prediction and decision making. Fuzzy models entail fuzzifying the given input data by converting the crisp quantity into a fuzzy quantity with the aid of a membership function consisting of linguistic variables and subsequently defuzzifying the output data which convert the output data into crisp data, which involve taking the centroid of the membership function. Fig 10 below shows the fuzzy logic system for predicting the mechanical properties of the hybrid composite. As shown in Figure 10 below, %wt of bagasse, %wt of sponge gourd(luffer) are inputs to the fuzzy logic system, while the flexural strength, impact strength and hardness derived from defuzzification are the output. The membership functions for %wt bagasse and %wt sponge gourd shown in Figure 11 and 12 respectively. The membership function for %wt bagasse and %wt sponge gourd as shown in Figure 11 and 12 consists of five (5) linguistic variables namely very low (VL), low (LW), Medim (M), High (H) and Very High(VH). Three fuzzy logic models were used in the prediction modeling. Model I have 13 linguistic variables for the output (hardness) as shown in Figure 13, model 2 have 15 linguistics for the output flexural strength (fig 14) and model 3 have 20 variables for impact strength (fig 15).

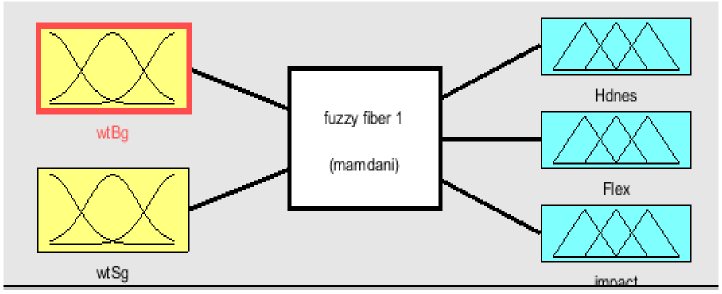

Fig 10: Fuzzy logic system for predicting the mechanical properties of the hybrid composite

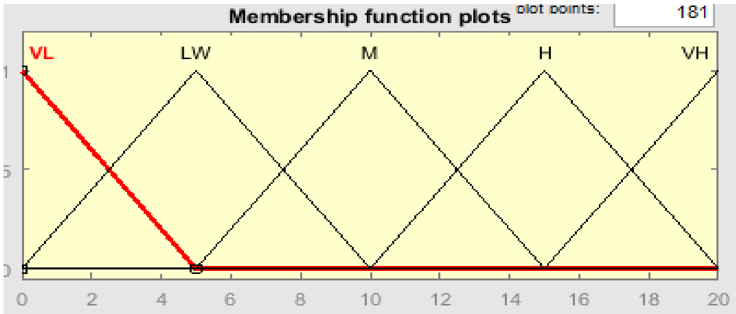

Fig11: Membership functions of %wt bagasse

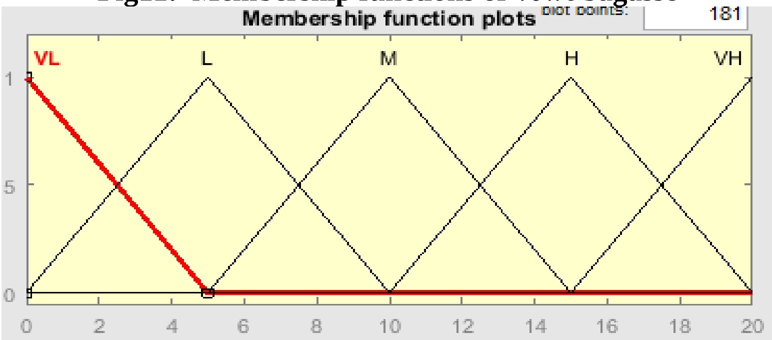

Fig 12: Membership functions for %wt luffer

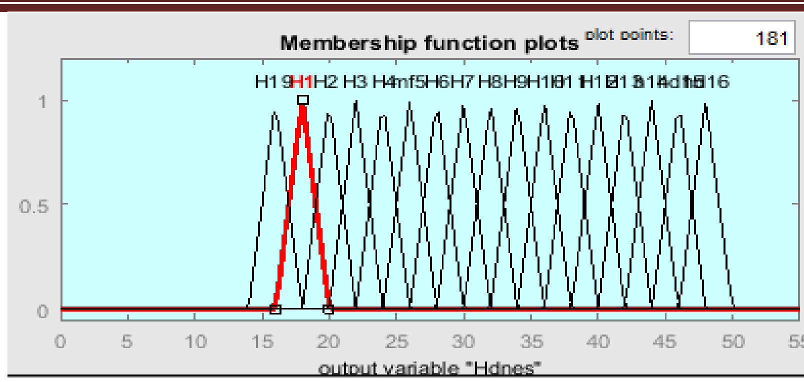

Fig 13: Membership functions for hardness

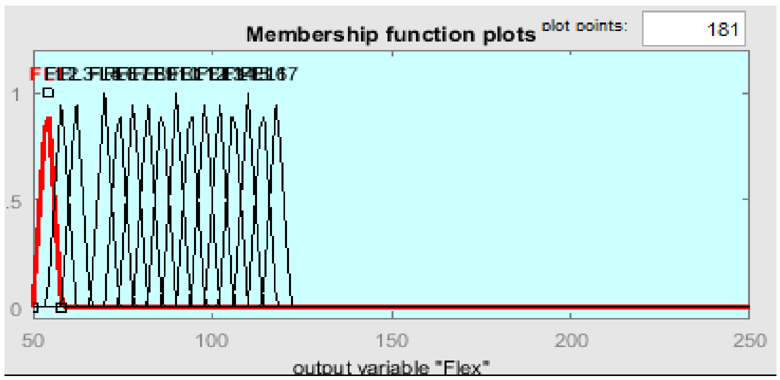

Fig 14: Membership functions for flexural strength

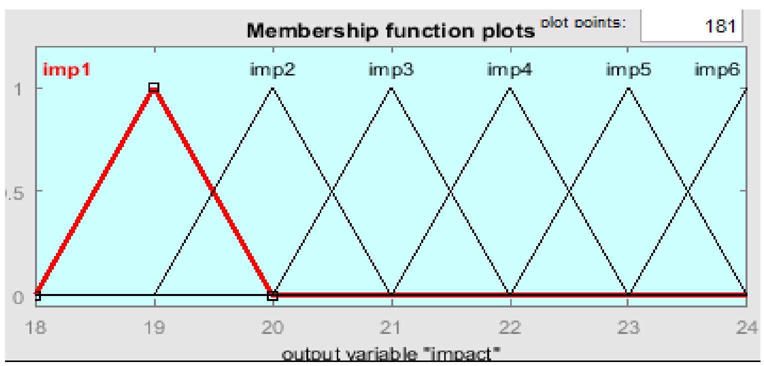

Fig15: Membership functions of impact strength.

The fuzzy logic model generates 9 different rules. The rules were used by the Mamdani fuzzy inference system to predict the mechanical properties (hardness, flexural strength and impact strength) after defuzzification using the centroid method. The coefficient of correlation and regression line for the fuzzy predictions are shown in the figures below.

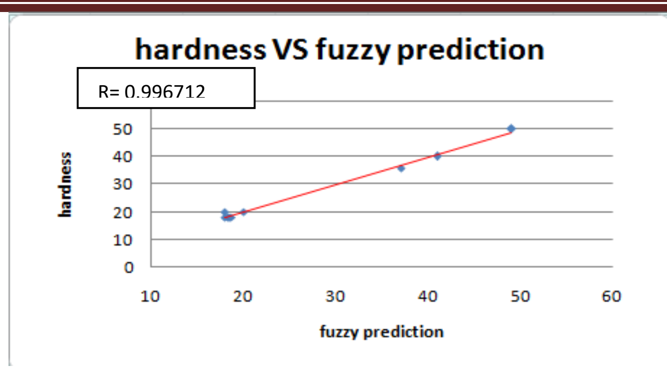

Fig 16: Hardness Vs fuzzy prediction

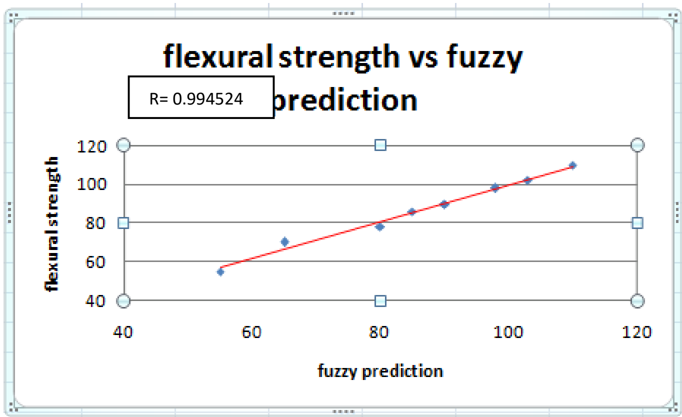

Fig 17: Flexural strength Vs fuzzy prediction

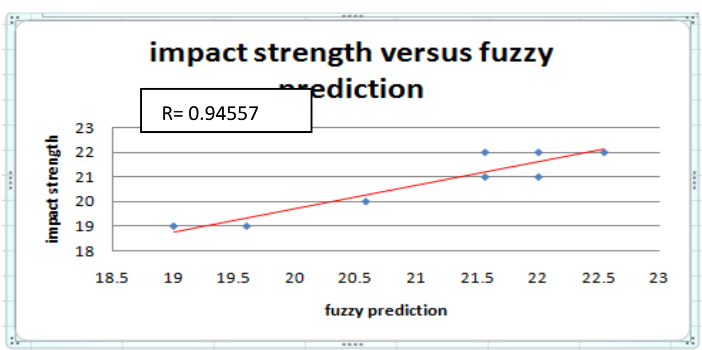

Fig 18: Impact strength Vs fuzzy prediction

The graphs in Figure above (fig 16 to 18) show the regression lines for the mechanical properties and fuzzy predictions. As shown in the graphs, the fuzzy logic prediction for hardness (fig 16) has a correlation coefficient of 0.996712, similarly for flexural strength (fig 17), the prediction correlation coefficient (R) gave 0.994524 and finally the correlation coefficient for impact strength (fig 18) is 0.945577.

From the figures (fig 16 to 18) shown below, it shows there is a very good agreement between the fuzzy logic predictions and experimental results. As observed from fig 16 – fig 18, the maximum correlation coefficient is 0.996712, while the minimum is 0.945577.

Hence, the fuzzy logic predictions are very good since there is a very good agreement with the fuzzy logic predictions and experimental results and based on the coefficient of correlation (R), it shows that the experimental data can be predicted successfully using fuzzy logic.

CONCLUSION

The optimization and modeling the mechanical properties of bagasse/luffer fiber reinforced epoxy resin hybrid composite using Taguchi robust design and fuzzy logic have been studied with the following observations

- Bagasse fiber is the most significant parameter in the optimization of hardness of bagasse/luffer hybrid composite and the optimum factor settings that yield the optimum hardness are 10%wt Bg, 10%wt luffer while the expected optimum hardness is 20HR.
- The optimum factor values of 5%wt bagasse with 10%wt of luffer fiber yields expected optimum impact strength of 22.5MPa. It also indicates that luffer fiber influences the impact strength of bagasse/luffer reinforced resin hybrid composite.
- Flexural strength of bagasse/luffer fiber reinforced resin hybrid composite is more affected by bagasse fiber and the optimum factor settings of 10%wt Bg and 5%wt luffer will yield an expected optimum flexural strength value of 103MPa.
- Fuzzy logic shows approximately 99.4% accuracy in predicting the flexural strength, 99.6% in predicting the hardness and 94.6% in predicting the impact strength of bagasse/luffer fiber reinforced resin hybrid composite.
- Regression analysis showed that error was very low and results were reliable.

REFERENCES

C. A. Boynard, S. N. Monteiro and J. R. M. D'Almeida, Aspects of Alkali Treatment of Sponge Gourd (Luffa Cylindrica) Fibers on the Flexural Properties of Polyester Matrix Composites, Journal of Applied Polymer Science, 87 (2003),1927-1932

El Kadi H (2006) Modeling the mechanical behavior of fiber reinforced polymeric composite materials using artificial neural networks—a review. Compos Struct 73:1–23.

Heijenrath R and Peijs T. Natural-fibre-mat-reinforced thermoplastic composites based on
flax fibres and polypropylene. Adv Compos Lett 1996; 5(3): 81–85.

Lassaad Ghali , Slah Msahli , Mondher Zidi , Faouzi Sakli,'Effects of Fiber Weight Ratio, Structure and Fibre Modification onto Flexural Properties of Luffa-Polyester Composites' Journal of Advances in Materials Physics and Chemistry, 1 (2011), 78-85.

Naresh, N, modeling and analysis of machining GRFP composites using fuzzy logic and ANOVA, The IUP journal of mechanical Engineering, Vol. VII, No. 4, November 2014, pp 26-36,

Nirbhay M, Misra RK, Dixit A (2015) Finite-Element Analysis of Jute- and Coir-Fiber-Reinforced Hybrid Composite Multipanel Plates. *Mech Compos Mater* 51: 505–520

Oksman K. High quality flax fiber composites manufactured by the resin transfer moulding process. J Reinf Plast Compos 2001; 20: 621–627.

Prashant Tripathi, Vivek Kumar Gupta, Anurag Dixit, Raghvendra Kumar Mishra and Satpal Sharma(2018), Development and characterization of low cost jute/bagasse and glass reinforced advanced hybrid epoxy composite. Aim material science 5(2) : 320 - 337

Saw SK, Sarkhel G, Choudhury A (2011) Dynamic Mechanical Analysis of Randomly Oriented Short Bagasse/Coir Hybrid Fibre-Reinforced Epoxy, Novolac Composite *Fiber Polym* 12: 506–513.

Shibata M, Takachiyo KI, Ozawa K, et al. Biodegradable polyester composites reinforced with short abaca fiber. J Appl Polym Sci 2002; 85(1): 129–138.

Shubhra QTH, Alam AKMM and Quaiyyum MA. Mechanical properties of polypropylene composites: a review. J Therm Compos Mater 2011; 26(3): 362–391.

Vilay, V.; Mariatti, M.; Taib, R.M.; Todo, M. E_ect of fiber surface treatment and fiber loading on the properties of bagasse fiber-reinforced unsaturated polyester composites. Compos. Sci. Technol. **2008**, 68, 631–638.

V. Naga prasad naidu, M.Ashok kumar, G.Ramachandra reddy, K.V.P.Chakradhar, Tensile & flexural properties of sisal/glass fibre reinforced hybrid composite, Journal of Macromolecular science, 22 (2011) 19- 22.