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Optimization of Notch Parameter on Fracture Toughness of Natural Fiber Reinforced Composites Using Taguchi Method

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Abstract

In recent decades, natural fiber-reinforced composites are getting much attention in structural applications, automobile industries and household applications. The present work describes the fracture behaviour of new polymer composites consisting of jute fabric reinforcement and epoxy resin for various notch sizes. The composites are characterized to analyse their fracture behaviour and their strength. Edge Notched tension (ENT) test was conducted as per ASTM E 1922 standards. The load bearing capacity increases with 3.8% width and 53.32% thickness contribution. And also it was observed that the load carrying capacity decreases with increase of 38.20% A/W ratio contribution.. The fracture toughness is increasing with65.02% A/W ratio and decreases with 7.50% width and 20.62% thickness contribution. Effect of A/W on load carrying capacity of composite is a very less but more influence is on toughness. The obtained results of experimental analysis are optimized using Taguchi method. For the purpose of observing the degree of influence of the process parameters, three factors at three levels each is considered. The fracture toughness values corresponding to each experiment were reported and analysed using Analysis of variance (ANOVA) and Response Surface Analysis (RSM) to estimate the influencing factor.

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Introduction

Fabric-reinforced composites have become necessary materials in various engineering applications such as aerospace, marine, and automobile engineering applications, because of their light weight, high strength, stiffness, and resistance to high temperature low weight, good integral performance, low thermal expansion and good corrosion resistance[1]. Still numerous materials are processed and fabricated, and thus flaws are often not completely preventable. The presence of flaws leads towards crack propagation and fracture of materials. Apart from that, brittle fracture, which causes sudden and catastrophic failures, may cause serious disasters. A significant number of published studies have been dedicated to mechanical and thermal properties. However, because a flaw-free material is extremely difficult to be produced and cracks may be introduced during service, understanding the crack resistance ability is thus essential. Good toughness and crack-stopping capability are particularly important[2].It has been mentioned that toughness of a brittle thermosetting polymer such as polyester and epoxy can be improved through natural fibre reinforcement. However, fracture toughness studies of bio composites have received relatively little attention from the scientific community until now. Due to increasing demand of bio composites in various applications, it is envisaged that the fracture toughness of bio composites will play a vital role over the coming years. It is known that bio fibres- or bio particles-reinforced epoxy based bio composites are prone to brittle fracture under mechanical loading. Compared with metals, the application of fracture mechanics concepts to polymers and composites is still in the primitive stage. In the polymer field, the fracture toughness test is meant for homogeneous materials are used to determine K[3].

The Taguchi method is very effective, because it is simple to carry on the experimental design. The main objective of the Taguchi method is to analyse the statistical data, which has been given as an input function to produce an optimal result[4]. The method developed for designing experiments to investigate how different parameters affect the mean and variance of a process[5]. Analysis of variance (ANOVA) on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic[7].

An investigation of mechanism of Translaminar fracture in glass/textile fabric polymer hybrid composite. The fracture toughness of glass/textile fabric reinforced epoxy hybrid composites has been experimentally determined under different notch size. And he concludes that the fracture toughness is increases with increasing the notch parameter (A/W) from 0.3 to 0.5[1]. The Fracture behaviour of glass fibre-reinforced polyester composite was investigated using linear elastic fracture mechanics approach (LEFM). The effect of fibre volume fraction of chopped strand mat glass fibres in the matrix on the composite properties was considered. He concluded that the dramatic increase in the values of fracture toughness with increasing fibre content. And he showed numerical results to agreement with experimental one[3]. The tensile strength of polyethylene material was examined by the application of Taguchi method. Obtained results from the experiment were statically analysed by the Taguchi method. The research was conducted in order to determine which factor and how much they affect the breakage of specimen. Apart from this we have also accounted the environmental aspects such as waste prevention, waste recycling (in preference to materials recycling) and waste management[8]

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In this study, the employed procedures are similar as described by ASTM E1922 standards. Very limited work are found in the literature regarding the mode-I fracture behaviour of natural fiber composite materials using Edge notched tension (ENT) specimens. In the present investigation mode-I fracture experiments were conducted on ENT specimen to determine the fracture toughness of a jute fabric reinforced epoxy polymer composite material. The effects of crack length, width and thickness on fracture toughness of jute fabric reinforced composites were investigated using the Taguchi experimental design method.

Experimental

The composite specimen of 60% jute fabric and 40% epoxy matrix was fabricated by hand lay-up technique. Ample precautions were taken to minimize voids in the material and maintain homogeneity. The Specimens were prepared for varied thickness and width that has been precracked [9]. Fracture toughness testing of ENT was cut from fabricated board in accordance with the dimension given by ASTM E1922 standards as shown in fig 1.

Selection of process parameter and orthagonal array

Table 1: Factors and levels considered.

Code	Control factors	Level 1	Level 2	Level 3
A	(a/w) ratio	0.3	0.4	0.5
B	Width in mm	20	25	30
C	Thickness in mm	7.5	10	12.5

Table 2: Experimental design using L9 OA

Trial	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The test procedure for edge notched tensile test (ENT) was according to standards. Loading fixtures are used to hold the single edge notched specimen in order to maintain the uniaxial tensile load at the crack tip. The loading fixture allows the specimen to rotate around the loading axis in order to reduce torsional effects. Tensile load was applied eccentrically to the specimen. During the test, failure load data was recorded for all the specimens under all the conditions [1].The propagations of the crack and failure surface of specimen is as shown in fig 2.

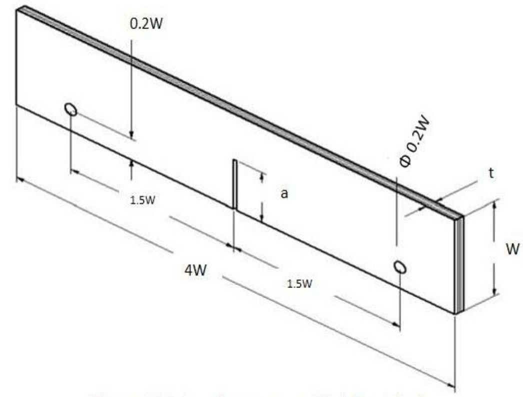

Figure 1: ENT specimen as per ASTM standard

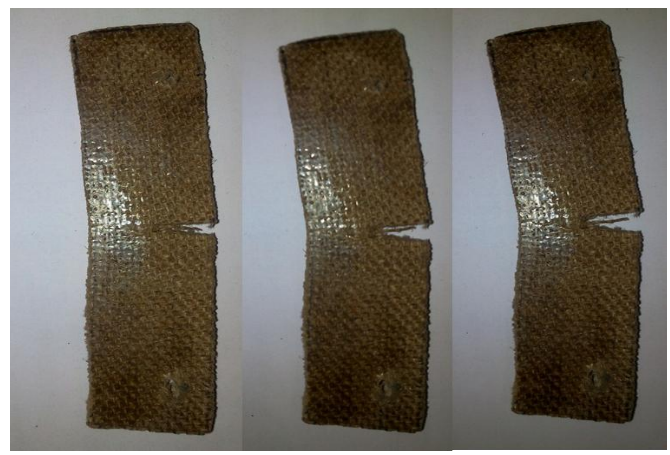

Figure 2: Fractured surface of specimens under ENT testing

Results and Discussion

Experiment have been carried out to characterize the fracture toughness of composite material under different specimen configurations, the analysis of the results and influence of process parameter on the properties are summarized in following section.

Table 3: Experimental plans based on Taguchi orthogonal array (L9)

Sl. no	A/W ratio	Width (mm)	Thickness (mm)	Failure load(N)	Fracture toughness MPa m½
1	0.3	20	7	350	62.83
2	0.3	25	10	500	56.21
3	0.3	30	12	600	51.31
4	0.4	20	10	500	81.37
5	0.4	25	12	530	64.30
6	0.4	30	7	400	75.94
7	0.5	20	12	400	72.01
8	0.5	25	7	300	82.80
9	0.5	30	10	380	68.78

Statistical analysis:

Analysis of variance (ANOVA):

ANOVA is done on MINITAB software. The main aim of the analysis is to estimate the percentage of the individual contribution of the process parameter on the load carrying capacity and fracture toughness, and also give accurately the combination of the process parameters. Individual optimal values for the process parameters and their specified performance characteristics can be obtained[11].

ANOVA for load carrying capacity:

Table 4: Analysis of variance for Load carrying capacity (N)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of confidence level
A/W ratio	2	28867	28867	14433	8.33	0.107	38.29
Width(mm)	2	2867	2867	1433	0.83	0.547	3.80
Thickness(mm)	2	40200	40200	20100	11.60	0.079	53.32
Error	2	3467	3467	1733			4.59
Total	8	75400					100

DF=Degrees of freedom, SS=sum of squares, MS=Mean Square, F=Variance & P= test statics.

The ANOVA (see Table4) of the experimental results gives the relative importance of all the variables. The main factors influencing the load carrying capacity are the Thickness (53.32%) and A/W ratio (38.29%) and width (3.8%) has very little influence on load carrying capacity. The ANOVA analysis showed that thickness has major effect on load carrying capacity this is because larger area of the specimen can take up the applied load before the failure and also table shows the error variation, reasons may be the wrong fabrication steps or defects or improper adhesion between the matrix and the reinforcement material.

ANOVA for fracture toughness:

Table 5: Analysis of variance for Load carrying capacity (N)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of confidence level
A/W ratio	2	607.51	607.51	303.75	9.43	0.096	65.02
Width(mm)	2	69.70	69.70	34.85	1.08	0.480	7.50
Thickness(mm)	2	192.72	192.72	96.36	2.99	0.250	20.62
Error	2	64.40	64.40	32.20			6.86
Total	8	934.32					100

DF=Degrees of freedom, SS=sum of squares, MS=Mean Square, F=Variance & P= test statics.

Observing above table Fracture toughness of the composite depends greatly on A/W (65%) ratio as compared over the Width (7.5%) and thickness (20.62%) factors. Higher the A/W radioed specimens obviously will have the more Toughness compared over width and thickness. Error shows the fabrication defect affecting on fracture toughness.

Main effect plots:

The main effect plots graphs the mean response for each factor level connected by a line. When the line horizontal, then there is no main effect present. Each level of the factor affects the response in the same way and response mean is the same across all factor levels. When the line is not horizontal, then there is a main effect present. Different levels of the factor affect the response differently. The steeper the slope of the line, the greater will be the magnitude of the main effect.

Main effect plot for the load carrying capacity:

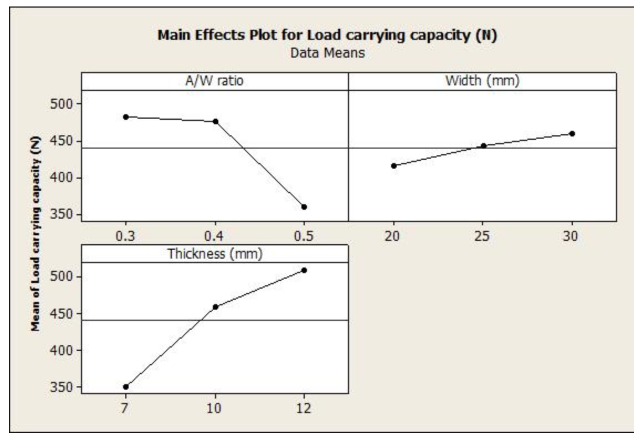

Figure 3: Main effect graph for mean load carrying capacity v/s A/W ratio. Width and Thickness.

The main effect plots provides the factors which influences significantly on the Load carrying capacity of the composite as shown in the fig3.the load carrying capacity decreases with increases A/W ratio and increases with both increasing width and thickness because of stress concentration factor will be the dominated by width and thickness[9]. The thickness as greater influence on load carrying capacity is clearly shown on the above plot.

Main effect plot for the Fracture toughness (MPa m½):

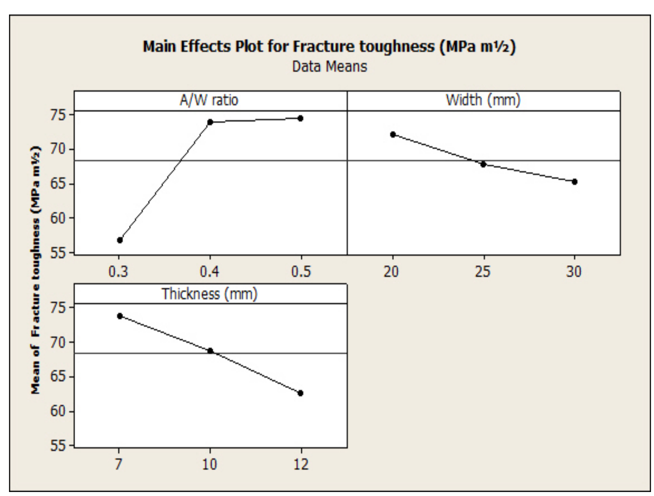

Figure 4: Main effect graph for mean Fracture toughness v/s A/W ratio. Width and Thickness.

Main effect plot of fracture toughness is presented fig.. The fracture toughness is Increases with increasing the A/W ratio .By increasing with and thickness the fracture toughness is reduces because of stress concentration will leads to failure of the composite[9]. This plot will shows that A/W ratio has greater influence on fracture toughness as compare to other two parameters.

Response surface plots:

The response surface plot can help in the prediction of the response at any zone of the experiment domain.

Surface Plots for Load Carrying Capacity (N):

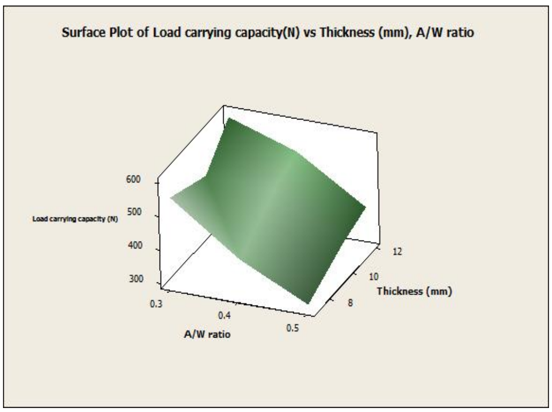

Figure 5: Surface plot of load carrying capacity v/s A/ W ratio and width.

Surface plot of Load carrying capacity vs. A/W ratio, Thickness and width is shown in fig 4.and fig 5. Figure clearly describing the increase of Load carrying capacity of with the increase of thickness and it will decreases for the A/W ratio. Fig 4 shows the highest value 600N found to be at 12mm thickness. It is observed from the fig 5. load carrying capacity increases with width has it revealing small influence of width factor on load.

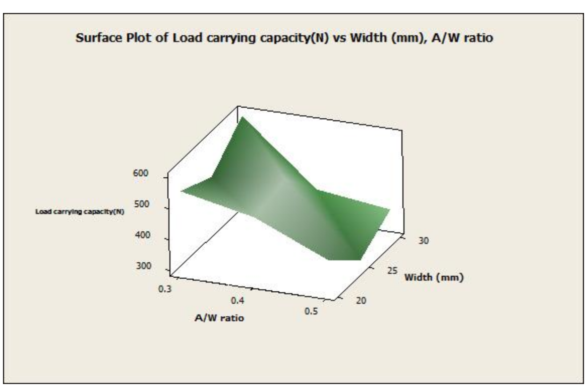

Figure 6: Surface plot of load carrying capacity v/s A/ W ratio and width.

Surface plot for Fracture Toughness (MPa m½):

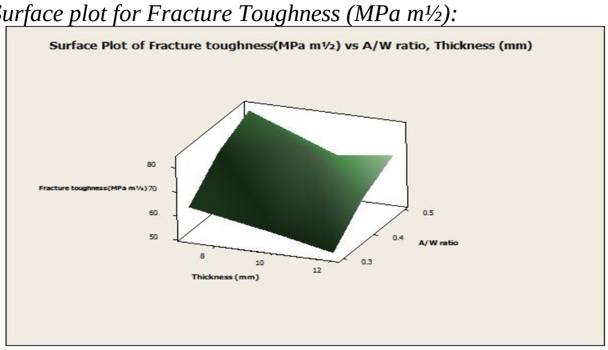

Figure 7: Surface plot for Fracture Toughness (MPa m½) v/s Thickness and A/W ratio.

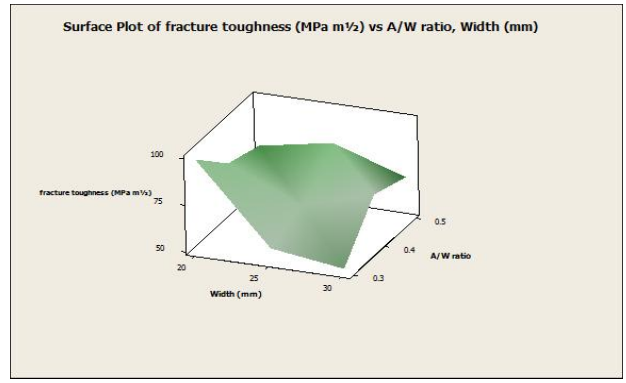

Figure 8: Surface plot for Fracture Toughness (MPa m½) v/s Width and A/W ratio.

Surface plot of fracture toughness v/s A/W ratio, thickness and width is shown in fig 6. and fig 7.its clearly observed that fracture toughness in decreases with thickness and increases on A/W ratio. Fig 6 shows the fracture toughness value 80 MPa m½ as maximum at A/W ratio 0.5 and 50 MPa as minimum value at thickness 12mm.and also fracture toughness decreases with width is clearly seen in the fig 7. From surface analysis, we conclude that fracture toughness of the composite is directly influence by factor A/W ratio.

Conclusions

The composite made of jute fabric reinforced epoxy polymer composite were studied under various factors such as A/W ratio, width and Thickness to know the load carrying capacity and fracture toughness of the composite.Taguchi method is used to investigate that parameter and its level of influence. The experimental results were statically analysed by analysis of variance (ANOVA) to know the percentage of contribution of parameters on fracture toughness and load carrying capacity.

For the conditions Tested here, following conclusions can be drawn:

1. The Edge Notched Tensile (ENT) is best suited specimen configuration for analysis of crack growth and fracture toughness.
2. This work shows that successful fabrication of a jute fabric reinforced in epoxy composites by simply hand layup technique.
3. The load carrying capacity increases with Thickness (53.32% contribution) and width (3.8%). Along with this load carrying capacity decreases with increasing the A/W (3.8% contribution) ratio.
4. The fracture toughness increases with A/W ratio (65.02% contribution) and decreases with thickness (20.62% contribution). Also width of 7.5% contribution on fracture toughness.
5. The overall effect of width on load carrying capacity and fracture toughness of the composite is negligible.

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