

# **Investigation of Fracture behavior of Fibre Reinforced Plastic Sheets during Impact Loading**

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**ABSTRACT:** The behavior of fiber reinforced plastic sheets varies with manufacturing process, material size, fiber orientations and chemical compositions. This project is mainly focuses on modeling and analyzing the fracture energy of the fibre reinforced plastic during impact load. This paper aim is to find safe fracture energy under various inputs namely thickness of sheet, material size, material composition, drop height and fiber orientation. This work describes response surface methodology to model safe Fracture energy of fibre reinforced plastic sheets. It is an attempt to identify important parameters which affects the response. The observations are recorded for the future reference to select the parameters which are optimum for the safe fracture energy is to be studied and to formulate safety index. From this experimental analysis the thickness of sheet, drop height, resin composition is directly proportional to the impact energy and material size is indirectly proportional to the impact energy.

**KEYWORDS:** Fracture energy, response surface methodology, safety index

## **I. INTRODUCTION**

Currently, the interest of fibre based polymer composite as primary structural material in various applications such as aerospace, marine, transportation and others have greatly increased. Fiber based polymer composites are an alternative material over metal based materials as it has advantages such as higher corrosion resistance to various corrosive metal mediums, light weight and capability of tailoring structure to applications. In order to enhance the material applications, the material behaviour or mechanical properties must be further understood and characterized. Fiber based polymer composite are utilizing the polymer resin as the matrix to bond the layer of fiber. Most of the polymer matrix are brittle and result in composite materials that are sensitive to impact damage. Hence the studies of composite material failure behaviour due to low or high velocity impact loading are stressed and concerned.

Impact testing is one of the important mechanical testing approaches for material performance characterization. In composite material, impact testing is applied for characterizing the material damage resistance to impact energy penetration. Hence, the impact loading behaviour of fiber reinforced polymer composites has been studied primarily to evaluate stress wave progression in these materials. Most of the researches have been performed on various fiber reinforced plastic materials for different parameters. This study is mainly to find out the optimum fracture energy for the particular parameters like thickness of sheet, drop height, material size, composition, fiber orientation and to analyze the material for safety aspects. The application of fiber reinforced plastic sheet is FRP boat which has the

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly Peer Reviewed Journal)

Vol. 5, Issue 2, February 2016

following benefits like Light weight, High strength, Corrosion resistance, Weather resistance, Non-magnetic, High impact strength, Low Thermal conductivity, Low maintenance, Long term durability, Design freedom, High levels of stiffness and Good electrical insulating properties.

## II. REVIEW OF LITERATURE

W.H. Choong, K.B. Yeo and M.T. Fadzlita, discussed the fundamental studies of low Velocity impact damage characteristics of woven GFRP composite has been carried out based on the testing standards. Degrees of damage mechanism that are linearly increasing due to the impactor drop height and impact energy.

Paramasivam M, explained importance and applications of fibre reinforced plastic material in boat manufacturing. The magic word in fisheries along the Coromandel coast today is FRP or fiberglass reinforced plastic. Kattumarams in FRP are fast-replacing the wooden versions which have dotted the coastline for centuries. By changing the chemical composition of the resins and by varying the reinforcements, one may change the properties of finished FRP to suit different applications.

H.N. Dhakal, Z.Y. Zhang, M.O.W. Richardson, O.A.Z. Errajhi, suggest that as the fibre volume fraction increases the contact time increases, which contribute to a higher peak load. The increase in fibre volume fraction results in an increased damage propagation phase thus increasing the impact resistance properties. At lower fibre volume fractions the impacted test specimens exhibit brittle fracture behaviour. At higher volume fractions the failure mode of the composites is more ductile with correspondingly higher energy absorption characteristics.

Russell V. Lenth studied for analysis of the resulting data, the package provides for estimating the response surface, testing its lack of fit, displaying an ensemble of contour plots of the fitted surface, and doing follow-up analyses such as steepest ascent, canonical analysis, and ridge analysis. It also implements a coded-data structure to aid in this essential aspect of the methodology.

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## III. MATERIAL SELECTION

Fiber reinforced plastic material was selected as a test specimen to evaluate impact strength and analyze safe fracture energy due to it has the following input parameters.

- I. Material thickness
- II. Size of material
- III. Fiber orientation
- IV. Resin Composition
- V. Drop Height



Figure 1 Test Material

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## IV. EXPERIMENTAL DETAILS

Impact tests are performed to assess shock absorbing capacity of materials subjected to suddenly applied loads for the above parameters. First prepare the test materials as per the dimensions and experiment was done in the testing machine and evaluated by Minitab software.



Figure 2 Experimental setup

Experimental setup made in the impact testing machine. The deformation for various possible combinations of the dimensions of the process parameters are obtained with the help of an experimental this set up and prepare the specimen as per the dimensions. The output parameters were evaluated by using Minitab software. Impact testing machine is shown in Figure 3.

## V. THEORETICAL ASPECTS OF RESPONSE SURFACE METHODOLOGY

Response Surface Methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The method was introduced by G.E.P.Box and K.B.Wilson in 1951. An easy way to estimate a first degree polynomial model is to use a factorial experiment or fractional factorial designs. This is sufficient to determine which explanatory variables have an impact on the response variable(s) of interest. Once it is suspected that only significant explanatory variables are left, then a more complicated design, such a Central Composite Design can be implemented to estimate a second degree polynomial model, which is still only an approximation at best. However, the second order model can be used to optimize (maximize, minimize or attain a specific target) for a response. For five independent variables  $x_1, x_2, x_3, x_4$  and  $x_5$  response  $Y$  can be represented as a function of  $x_1, x_2, x_3, x_4$  and  $x_5$  as follows.

$$Y = f(x_1, x_2, x_3, x_4, x_5)$$

Where  $\varepsilon$  represents an error component.

The second order RSM model is adequate which can be represented by the following equation.

$$Y = \beta_0 + \sum_{i=1}^k \beta_i x_i + \sum_{i=1}^k \beta_{ii} x_i^2 + \sum_{i < j}^k \beta_{ij} x_i x_j + \varepsilon$$

Where  $\beta_i$  ( $i = 0, 1, 2, \dots, k$ ) are co-efficient that have to be estimated and  $\varepsilon$  represents a normally distributed random error that accounts for all source of variability. The fitted equation is represented by

$$Y = E(Y - \varepsilon)$$

$$Y = \hat{\beta}_0 + \sum_{i=1}^k \hat{\beta}_i x_i + \sum_{i=1}^k \hat{\beta}_{ii} x_i^2 + \sum_{i < j}^k \hat{\beta}_{ij} x_i x_j$$

where  $\hat{\beta}_0$  is the estimator of intercept,  $\hat{\beta}_1, \hat{\beta}_2, \dots, \hat{\beta}_k$  are the linear terms,  $\hat{\beta}_{11}, \hat{\beta}_{22}, \dots, \hat{\beta}_{kk}$  are quadratic terms and  $\hat{\beta}_{12}, \hat{\beta}_{13}, \dots, \hat{\beta}_{(k-1), k}$  are the second order interaction terms.

### 5.1 Factorial Experiment

In statistics, a factorial experiment is an experiment whose design consists of two or more factors, each with discrete possible values or “levels”, and those experimental units take on all possible combination of those levels across all such factors. Such an experiment allows studying the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable.

For the vast majority of factorial experiments, each factor has only two levels. If the number of experiments for a full factorial design is too high to be logically feasible, a fractional factorial design may be done, in which some of the possible combinations usually, at least half are omitted.

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## 5.2 Central Composite Design

In statistics, a central composite design is an experimental design useful in response surface methodology, for building a second order (quadratic) model for the response variable without needing to use a composite three level factorial experiment. After the designed experiment is performed, linear regression is used, sometimes iteratively, to obtain results. Coded variables are often used when constructing this design.

## 5.3 Analysis

A factorial experiment can be analyzed using ANOVA analysis. It is relatively easy to estimate the main effect for a factor. To compute the main effect of a factor “a”, subtract the average response of all experimental runs for which “a” was at its low or first level from the average response of all experimental runs for which “a” was at its high or second level. Other useful exploratory analysis tools for factorial experiments include main effects plots, interaction plots and a normal probability plot of the estimated effects. When the factors are continuous, two level factorial designs assume that the effects are linear. If a quadratic effect is expected for a factor, a more complicated experiment should be used, such as a central composite design. The experimental values are listed in the following table

Table 1 Experimental output for impact energy

Run numbers	material thickness (t) mm	orientation (o) degree	drop height (h) mm	Width (w) mm	Resin Composition (c) %	Impact energy observed Joules
1.	2	45	600	25	50	163
2.	2	45	1400	25	50	209
3.	2	45	1000	25	50	187
4.	2	45	1400	20	50	203
5.	3	45	1000	25	50	204
6.	2	45	1000	20	50	187
7.	2	45	1000	25	45	185
8.	2	0	1000	25	50	182
9.	2	90	1000	25	50	180
10.	2	45	1000	20	50	189
11.	2	45	1000	25	55	179
12.	2	45	1000	25	50	181
13.	1	45	1000	25	50	165
14.	2	45	1000	30	50	185
15.	1	0	1400	20	55	186
16.	2	45	1000	25	55	185
17.	1	90	600	20	45	157
18.	1	0	1400	30	55	190
19.	1	90	1400	20	55	207
20.	2	45	1000	25	50	187
21.	1	0	600	20	55	135
22.	3	90	1400	20	45	228
23.	1	90	1400	20	45	199
24.	1	0	1400	20	45	186
25..	3	90	1400	30	55	224
26.	3	90	600	20	45	183
27.	1	0	600	20	45	141
28.	3	90	600	20	45	190
29.	1	90	600	30	55	125
30.	3	90	1400	25	55	227
31.	3	0	1400	30	45	235
32.	1	0	600	30	55	132
33.	3	0	600	30	55	177

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34.	2	45	1000	25	50	187
35.	1	0	1400	30	55	180
36.	1	90	600	30	45	139
37.	1	90	1400	30	55	171
38.	2	45	1000	25	50	179
39.	3	90	600	30	55	173
40.	3	90	1400	30	45	219
41.	3	0	1400	20	45	200
42.	2	45	1000	25	50	186
43.	3	0	600	30	45	192
44.	3	0	1400	20	55	232
45.	2	45	1000	25	50	190
46.	3	0	600	20	55	162
47.	1	90	600	20	55	146
48.	2	45	1000	25	50	187
49.	2	45	1000	25	55	185
50.	3	0	600	20	50	173
51.	3	0	1400	30	55	229
52.	1	0	600	30	45	152
53.	3	90	600	30	45	178
54.	1	90	1400	30	45	188

## VI. EXPERIMENTAL DESIGN

Experimental design is the design of all information gathering exercises where variation is present, whether under the full control of the experimenter or an observational study. The experimenter may be interested in the effort of some intervention or treatment on the subjects in the design.

### 6.1 Identification of pr-dominant factors

For this study, the process parameters such as the material thickness (t), orientation (o), drop height (h), material size (s) and composition (c) were identified as the main factors influencing the impact failure. To reduce the total number of experiments and to obtain data uniformly from all the regions a factorial design procedure has been adopted. The analysis was carried out using actual values. The selection of the limits of the process variables is followed by choosing the number of levels within the limits. The upper factor is coded as 1 and the lower factor is coded as -1. these variables are studied in three levels.

### 6.2 Experimental design matrix

In order to optimize the process, central composite rotatable design of second order response surface methodology, a full factorial design is established which takes into account all the possible combinations of process parameters. It establishes the mathematical relation of the response surface using the smallest possible number of experiments without losing its accuracy.

## VII. DEVELOPMENT OF MODEL FOR IMPACT STRENGTH

The response function representing the deformation can be expressed as

$$Y = f\{\text{Thickness (t), orientation (o), drop height (h), width (w), Resin composition(c)}\}$$

$$Y = f(t, o, h, w, c)$$

Where, Y is response or yield.

### 7.1 Estimation of Co-efficient of Models

The values of the coefficient of the polynomial were calculated by the regression method and were reported in Table 4 for impact strength mode. The magnitude of the regression coefficient is a good indication of the parameters. The

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experimental data were analyzed using the software MINITAB version 15 which gives the output in tabular form and was used to calculate the values of this co-efficient. For the required response, all the 54 values for Impact strength mode and the second order general mathematical model for the 5 factors are given to the software as input. The significance of coefficient was evaluated and tabulated.

Table 2 Co-efficient values

$\beta_0$	-	866.386
$\beta_1$	-	39.566
$\beta_2$	-	0.199
$\beta_3$	-	0.010
$\beta_4$	-	-0.353
$\beta_5$	-	-29.681
$\beta_{14}$	-	-0.220
$\beta_{15}$	-	0.151

## 7.2 Developed Final Model for Impact Strength

The final mathematical model of Impact mode as determined by above analysis in natural scale is given below

$$\text{Impact} = 866.386 + 39.566t + 0.199r - 0.353w - 29.681c - 4.370t^2 + 0.306c^2 - 220tw + 0.151tc$$

where t = thickness, r = orientation, w = width, c = composition.

## VIII. RESULTS AND DISCUSSION

The influence of the various geometric parameters on the deformation is studied using graphs.

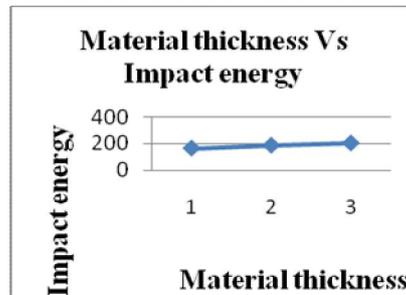


Figure 4 Variation of Impact with respect to thickness

The figure 4 shows that the thickness is directly proportional to the Impact energy. So the Impact I is directly influenced by the thickness of the sheet i.e. the value of I will increase or decrease by the increase and decrease the thickness of fiber reinforced plastic sheet.

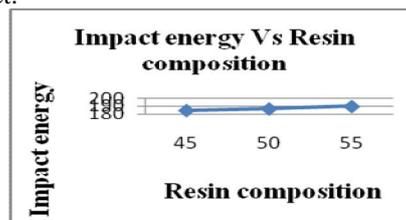


Figure 5 Variation of Resin composition with respect to the Impact energy

The Figure 5 shows the Resin composition is directly proportional to the impact energy. The value of the impact energy will increase towards the Resin composition according to the percentage.

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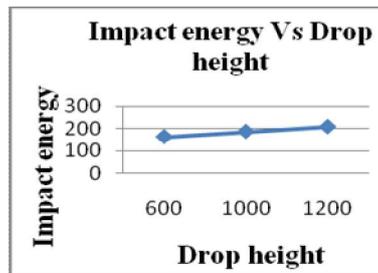


Figure 6 Variation of Impact Energy with respect to Drop height

The Figure 6 shows that the Drop height is directly proportional to the impact energy. When the Drop height increases the impact energy also increases due to increase in height of the pendulum.

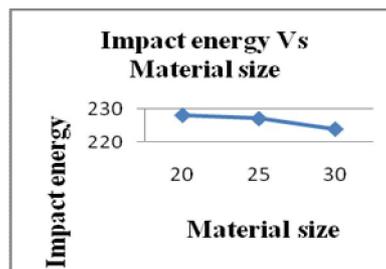


Figure 7 Variation of Impact Energy with respect to Material size

The Figure 7 shows that the impact energy of the specimen varies with the size of material i.e indirectly proportional to the impact energy. So the curve shows inverted and also it gradually decreases with increase in material size.

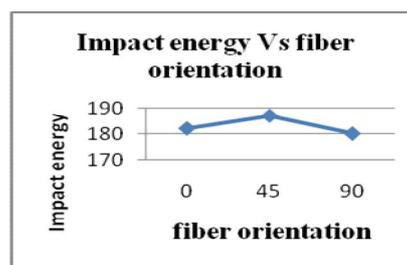


Figure 8 Variation of Impact Energy with respect to fiber orientation

The Figure 8 shows that the fiber orientation of the specimen is vary to the impact energy. So the curve shows that fiber orientation 45° of specimen have good fracture energy when compare with other orientations 0° and 90°.

## IX. CONCLUSION

In this study the effects of fiber reinforced plastic sheets during impact loading were investigated. Impact test performed in fiber reinforced plastic sheets with variable input parameters.

This study facilitates and overview of fiber reinforced plastic sheets during impact loading.

This study pertaining to state of the art in modeling of fracture energy which is important to designer and manufacturer of fiber reinforced plastic sheets.

The effects of process parameters namely thickness of sheet, material size, material composition, drop height, fiber orientation on fracture energy have been studied.

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From this experimental analysis the thickness of sheet, drop height, resin composition is directly proportional to the impact energy and material size is indirectly proportional to the impact energy. Input parameters are analyzed to justify design uncertainties and to provide insurance against failure.

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