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# Delamination analysis using digital image processing by IMAGE J and LabVIEW for drilling on GFRP composite laminates

GokulaKrishnan Velu[1], Sureshkumar Manickam Shanmugasundaram[2], Chanthini Velu [3]
[1,2]*Department of Mechanical Engineering, Sri Ramakrishna Engineering College, Coimbatore, India*
[3]*Department of computer science, PSG College, Coimbatore, India*

***Abstract: Composites are one of the most widely used materials because of their relative ease of combination with other materials to serve specific purposes and exhibit desirable properties. Composites are mostly used in aerospace vehicles due to, increased strength, durability, corrosion resistance, and high strength to weight ratio. Glass Fiber Reinforced Plastic composites have an increased application in recent days. Drilling of holes in GFRP becomes almost unavoidable in fabrication and assembly of components even though heterogeneous nature of this kind of materials makes complications during machining operations. While drilling GFRP the quality of drill is mostly affected by many whole quality characteristics like delamination, cylindricity, surface roughness etc. About 60% of rejections in the drilled components are due to delamination, which is one of the significant hole quality characteristics. Proper Visualization of delamination is obtained by Digital Image Processing. In this work delamination analysis was attempted using digital image processing, experiments are carried out for 27 holes and it was observed that scanned images obtained using a flatbed scanner (HP, 2400 DPI) used for digital image processing by IMAGE J & LabVIEW, gives better visualization for delamination.***

***Index terms: GFRP, Drilling, Delamination, LabVIEW, ANOVA, Taguchi methodology, Full factorial Method.***

## I. INTRODUCTION

In the aerospace industry, drilling accounts for nearly 40% of all the metal-removal operations [1]. Poor hole quality accounts to 60% of parts rejection. Since holes are drilled in finished products, Part rejections due to poor standards in hole quality prove very costly. GFRP is one of the composite materials which are mainly known for its high strength to weight ratio. In these types of materials, machining a perfect hole is a difficult task. Conventional drilling with twist drill still remains as one of the most economical and efficient machining process for hole making as well as riveting and fastening structural assemblies in aerospace and auto motives. Many of these problems are due to improper selection of process parameters, non-optimal cutting tool designs, rapid tool wear, and machining conditions [2, 3]. A novel method was used for finding damage area of delamination with the help of digital image processing [4]. Scanned images from flatbed scanner where used and LabVIEW was used to find the damage area of delamination. The digital images are obtained by using a flatbed scanner (HP Scanjet 3200c) with 2400 DPI [5]. Significant damage to the work piece may be introduced and high wear rates of the tools are experienced. Traditional machining methods such as drilling, turning, sawing, routing and grinding, can be applied to composite materials using appropriate tool design and operating conditions [6]. Glass Fiber Reinforced Plastic composite materials are most commonly used composite materials because of their particular mechanical and physical properties such as specific strength [7]. Among the defects caused by drilling with tool wear, Delamination appears to be the most critical [8]. The application area, can be considered a critical operation owing to their tendency to delaminate when subjected to mechanical stresses. With regard to the quality of machined component, the principal drawbacks are related to surface delamination, fiber/resin pullout and inadequate surface roughness of the hole wall. Among the defects caused by drilling, delamination appears to be the most critical [9]. Design Of Experiments for the input parameters in doing the experiment is given by full factorial design [10-12]. Scanned images from flatbed scanner where used and IMAGE J was used to find the damage area of delamination. The digital images are obtained by using a flatbed scanner (HP Scanjet 3200c) with 2400 DPI [13-14]. ANOVA is used to investigate the process parameters that significantly affect the performance characteristics. The most significant process parameter is obtained by ANOVA [15]. In this work an attempt has been made to find the effect of various input parameters of drilling machine and thickness of composite plate on performance Characteristics for drilling of Glass Fiber Reinforced Plastic material. The damaged area (delamination) while drilling is calculated by Digital Image Processing using IMAGE J & LabVIEW- public domain software (National Instruments) and an attempt is made to find the effect of the input parameters on delamination. Then the delamination analysis was done for each hole from the digital images using IMAGE J & LabVIEW an attempt is made to find the effect of the input parameters on delamination.

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## II. DESIGN OF EXPERIMENT

Pillar drilling has been used for experimental work for drilling 27 holes. Three different diameters of drills has been used with point angle 118˚. Composite laminates are made from cross-ply glass fiber. The reinforcement was in the form of E-glass fiber tape and the matrix was polyester resin, with hardener HY 951.The specimen plates are cut into the same pieces of dimension 15cm×5 cm. 3 layers make the plate thickness of 5mm. Fiber volume fraction is 0.56–0.60 and specimen having a density valued 3.6-3.8gm/m3.The speed, feed rate are the two parameters under investigation in this study. The full factorial design is the most efficient way of conducting the experiment for that three factors and each factor at three levels of experiments is used. Hence as per $Levels^{factor}$ (factors to power of levels) formula $=Levels^{factors}$ ,N = $3^3$ = 27, N- Number of experiments. The selection process input parameters of three different levels is detailed in Table 1.

Table 1: Input parameters for different levels

| Parameters | Levels | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Feed,F(mm/rev | 0.06 | 0.08 | 0.10 |
| Speed,S(rpm) | 310 | 450 | 850 |
| GFRP Plate thickness,t(mm) | 5 | 5 | 5 |

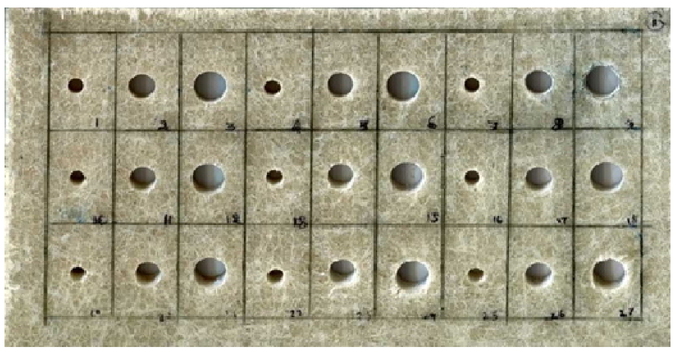

Fig 1: Fabricated GFRP plate

## III. DIGITAL IMAGE PROCESSING

The digital image processing is eminently used for image analysis, the digital images of GFRP composites are obtained from the flatbed scanner (HP Scanjet 3200c of 1300 DPI capacity), then the images were analyzed using IMAGE J & LabVIEW- (National Instruments) to finding the damage area of the GFRP specimens.

In this process both entry and exit of 27 holes were analyzed and the damage area was found out and adjustable delamination factor ($F_{da}$) is calculated by the formulae given below,

$$Amax=\pi*\frac{Dmax^2}{4} .... \quad (1)$$

$$Ao=\pi*\frac{Do^2}{4} .... \quad (2)$$

$$Fda=Fd+\frac{Ad}{(Amax-Ao)}+(Fd^2-Fd).. \quad (3)$$

The equation (1) is used to find the maximal damaged area of the drilled composites, the equation (2) gives the actual area of the hole, The final formulae (3) evaluates the value of $F_{da}$ after calculating the damage area (Ad)using digital image processing.

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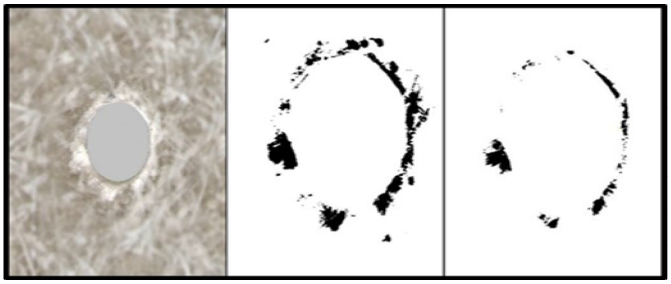
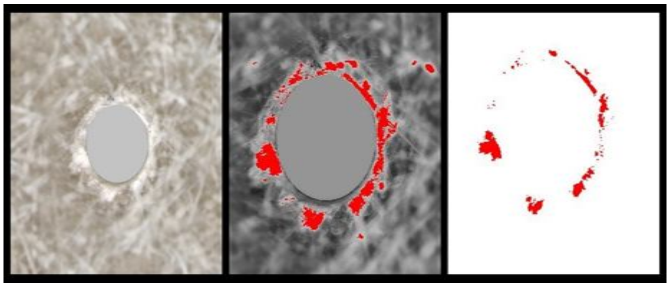


2[i] (a) (b) (c)



2[ii] (a) (b) (c)

Fig 2: Image processing operations by [i] IMAGE J,
[ii] LabVIEW to determine the damage are (a) Digital image (b) Intermediate processed image (c) Final processed image.

## IV. RESULTS AND DISCUSSION

### *A. ANOVA*

The Analysis of variance is extensively used to analyze the experimental results. ANOVA tests the significance of group difference between two or more groups. The normal probability plot represents that all the points on the plot lie close to the straight line (main line) or not. Versus fits plots represents that how far deviation occur from the normal distribution. An interaction plot is occurs when the change in response from the one level of a factor to another level from change in response at the same two level second factor. A main effect plot is present when different levels of an input affect the responses directly.

Analysis of variation in an experimental outcome and especially of a statistical variance in order to determine the contributions of given factors or variables to the variance. In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the t-test to more than two groups. As doing multiple two-sample t-tests would result in an increased chance of committing a statistical type I error, ANOVAs are useful in comparing (testing) three or more means (groups or variables) for statistical significance.

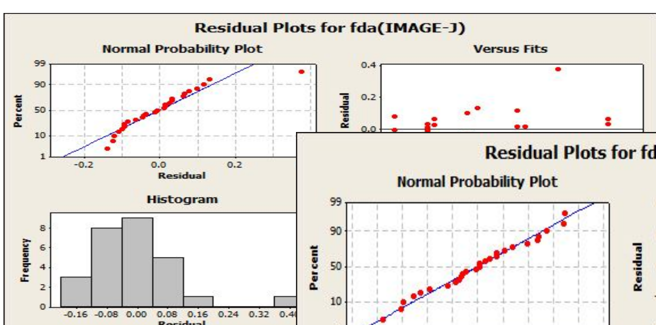
### *B. Mathematical Model*

The regression equation for predicting adjusted delamination factor $F_{da}$ at Entry, where D is Drill Diameter, F is feed and S is Speed for IMAGE-J

$F_{da}$ = 0.766 - 0.0217 dia + 16.3 feed - 0.00111 speed

LabVIEW

$F_{da}$ = 1.19 - 0.0286 dia + 6.37 feed - 0.000420 speed



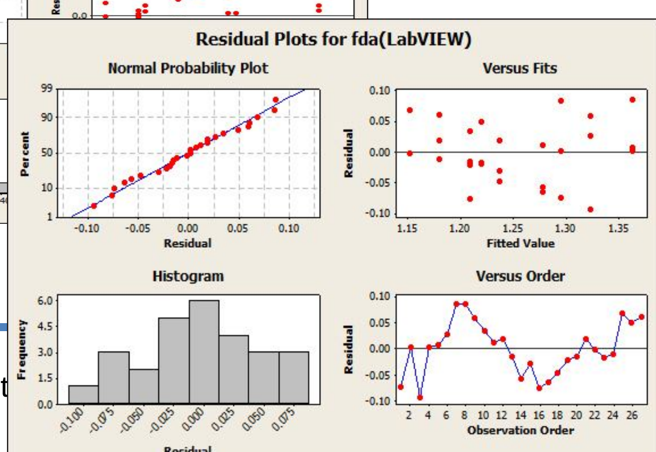




Fig 3: Residual plot for IMAGE-J

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Fig 4: Residual plot for LabVIEW

*C. Taguchi Design Methodology*

A Taguchi design, or an orthogonal array, is a method of designing experiments that usually requires only a fraction of the full factorial combinations.

An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor.

In robust parameter design, the primary goal is to find factor settings that minimize response variation, while adjusting

(Or keeping) the process on target. After you determine which factors affect variation, you can try to find settings for Controllable factors that will either reduce the variation, make the product insensitive to changes in uncontrollable (noise) factors, or both.

A process designed with this goal will produce more consistent output. A product designed with this goal will deliver more consistent performance regardless of the environment in which it is used. Engineering knowledge should guide the selection of factors and responses. Here diameter of hole, feed & speed are the parameters under investigation as shown in the graph below (figure 5 & 6).

In Taguchi design methodology ranking of parameters is done based on the p-values.

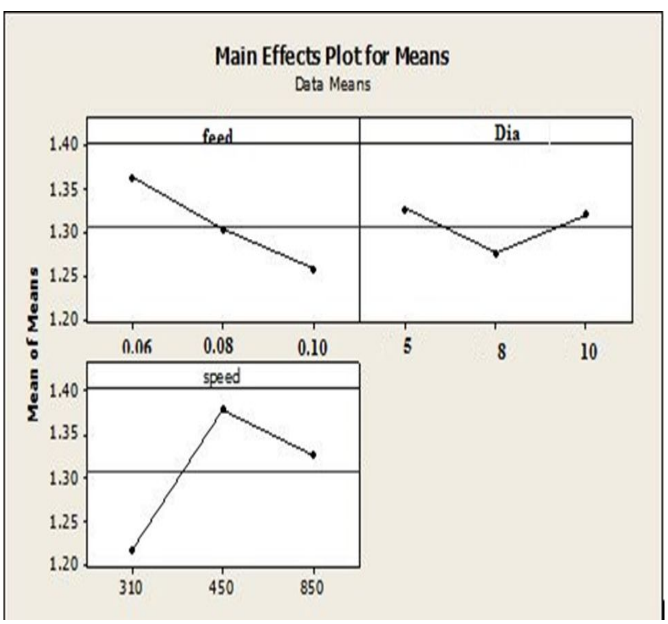


Fig: 5 Main effects plot for IMAGE-J

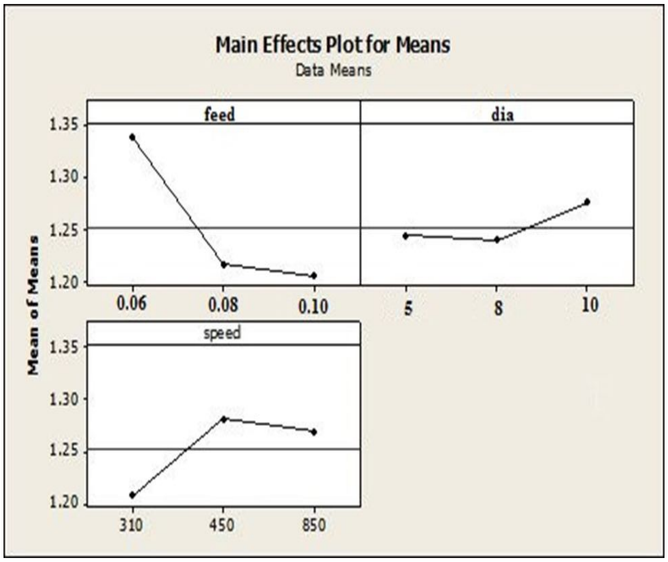


Fig: 6 Main effects plot for LabVIEW

From the above graphs (figure 5 & 6), it is found that Feed is the most influencing parameter among the given input parameters

Table 2: Experimental and Delamination processing results for IMAGE-J

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| WORKPIECE 1 FRONTSIDE, IMAGE J | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HOLE.NO | Do | THICKNESS | FEED | SPEED | $D_{max}$ | $A_d$ | $F_{d(conventional)}$ | $F_{da(DIP)}$ | PREDICTED VALUE |
| 1 | 5 | 8 | 0.06 | 310 | 6.288 | 7.33 | 1.102 | 1.182 | 1.2902238 |
| 2 | 5 | 8 | 0.08 | 450 | 9.5 | 6.09 | 1.206 | 1.367 | 1.4602745 |
| 3 | 5 | 8 | 0.1 | 850 | 11.62 | 11.54 | 1.146 | 1.217 | 1.3412745 |
| 4 | 5 | 8 | 0.06 | 310 | 5.85 | 4.64 | 1.128 | 1.245 | 1.2902238 |
| 5 | 5 | 8 | 0.08 | 450 | 8.46 | 9.42 | 1.354 | 1.493 | 1.4602745 |
| 6 | 5 | 8 | 0.1 | 850 | 11.48 | 10.26 | 1.198 | 1.355 | 1.3412745 |
| 7 | 5 | 8 | 0.06 | 310 | 5.94 | 5.62 | 1.234 | 1.422 | 1.2902238 |
| 8 | 5 | 8 | 0.08 | 450 | 8.38 | 15.94 | 1.372 | 1.525 | 1.4602745 |
| 9 | 5 | 8 | 0.1 | 850 | 10.72 | 22.48 | 1.266 | 1.46 | 1.3412745 |
| 10 | 8 | 8 | 0.06 | 310 | 6.24 | 4.85 | 1.091 | 1.257 | 1.22504 |
| 11 | 8 | 8 | 0.08 | 450 | 8.75 | 12.42 | 1.141 | 1.771 | 1.3950907 |
| 12 | 8 | 8 | 0.1 | 850 | 10.98 | 18.54 | 1.236 | 1.376 | 1.2760907 |
| 13 | 8 | 8 | 0.06 | 310 | 6.12 | 5.92 | 1.16 | 1.237 | 1.22504 |
| 14 | 8 | 8 | 0.08 | 450 | 9.1 | 9.12 | 1.173 | 1.295 | 1.3950907 |
| 15 | 8 | 8 | 0.1 | 850 | 10.64 | 17.52 | 1.141 | 1.233 | 1.2760907 |
| 16 | 8 | 8 | 0.06 | 310 | 6.38 | 3.98 | 1.045 | 1.142 | 1.22504 |
| 17 | 8 | 8 | 0.08 | 450 | 9.08 | 11.28 | 1.126 | 1.256 | 1.3950907 |
| 18 | 8 | 8 | 0.1 | 850 | 11.24 | 7.44 | 1.121 | 1.156 | 1.2760907 |
| 19 | 8 | 8 | 0.06 | 310 | 5.79 | 2.72 | 1.097 | 1.214 | 1.22504 |
| 20 | 10 | 8 | 0.08 | 450 | 8.95 | 8.18 | 1.131 | 1.289 | 1.3516348 |
| 21 | 10 | 8 | 0.1 | 850 | 10.84 | 11.2 | 1.186 | 1.259 | 1.2326348 |
| 22 | 10 | 8 | 0.06 | 310 | 6.04 | 6.22 | 1.097 | 1.175 | 1.1815842 |
| 23 | 10 | 8 | 0.08 | 450 | 9.21 | 13.25 | 1.186 | 1.259 | 1.3516348 |
| 24 | 10 | 8 | 0.1 | 850 | 11.59 | 18.85 | 1.167 | 1.196 | 1.2326348 |
| 25 | 10 | 8 | 0.06 | 310 | 5.88 | 2.21 | 1.176 | 1.26 | 1.1815842 |
| 26 | 10 | 8 | 0.08 | 450 | 9.17 | 5.45 | 1.237 | 1.366 | 1.3516348 |
| 27 | 10 | 8 | 0.1 | 850 | 11.14 | 132.92 | 1.169 | 1.298 | 1.2326348 |

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Table 3: Experimental and Delamination processing results for LabVIEW.

| WORKPIECE 1 FRONTSIDE, LabVIEW | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HOLE.NO | Do | THICKNESS | FEED | SPEED | $D_{max}$ | $A_d$ | $F_{d(conventional)}$ | $F_{da}$ (DIP) | PREDICTED VALUE |
| 1 | 5 | 8 | 0.06 | 310 | 6.288 | 7.33 | 1.158 | 1.22 | 1.2947413 |
| 2 | 5 | 8 | 0.08 | 450 | 9.5 | 6.09 | 1.208 | 1.365 | 1.3633137 |
| 3 | 5 | 8 | 0.1 | 850 | 11.62 | 11.54 | 1.176 | 1.228 | 1.3227582 |
| 4 | 5 | 8 | 0.06 | 310 | 5.85 | 4.64 | 1.17 | 1.297 | 1.2947413 |
| 5 | 5 | 8 | 0.08 | 450 | 8.46 | 9.42 | 1.249 | 1.371 | 1.3633137 |
| 6 | 5 | 8 | 0.1 | 850 | 11.48 | 10.26 | 1.188 | 1.349 | 1.3227582 |
| 7 | 5 | 8 | 0.06 | 310 | 5.94 | 5.62 | 1.276 | 1.38 | 1.2947413 |
| 8 | 5 | 8 | 0.08 | 450 | 8.38 | 15.94 | 1.25 | 1.45 | 1.3633137 |
| 9 | 5 | 8 | 0.1 | 850 | 10.72 | 22.48 | 1.224 | 1.382 | 1.3227582 |
| 10 | 8 | 8 | 0.06 | 310 | 6.24 | 4.85 | 1.135 | 1.244 | 1.2090133 |
| 11 | 8 | 8 | 0.08 | 450 | 8.75 | 12.42 | 1.151 | 1.289 | 1.2775858 |
| 12 | 8 | 8 | 0.1 | 850 | 10.98 | 18.54 | 1.187 | 1.256 | 1.2370302 |
| 13 | 8 | 8 | 0.06 | 310 | 6.12 | 5.92 | 1.146 | 1.194 | 1.2090133 |
| 14 | 8 | 8 | 0.08 | 450 | 9.1 | 9.12 | 1.072 | 1.22 | 1.2775858 |
| 15 | 8 | 8 | 0.1 | 850 | 10.64 | 17.52 | 1.047 | 1.207 | 1.2370302 |
| 16 | 8 | 8 | 0.06 | 310 | 6.38 | 3.98 | 1.05 | 1.132 | 1.2090133 |
| 17 | 8 | 8 | 0.08 | 450 | 9.08 | 11.28 | 1.093 | 1.213 | 1.2775858 |
| 18 | 8 | 8 | 0.1 | 850 | 11.24 | 7.44 | 1.118 | 1.189 | 1.2370302 |
| 19 | 8 | 8 | 0.06 | 310 | 5.79 | 2.72 | 1.064 | 1.167 | 1.2090133 |
| 20 | 10 | 8 | 0.08 | 450 | 8.95 | 8.18 | 1.098 | 1.204 | 1.2204338 |
| 21 | 10 | 8 | 0.1 | 850 | 10.84 | 11.2 | 1.114 | 1.199 | 1.1798783 |
| 22 | 10 | 8 | 0.06 | 310 | 6.04 | 6.22 | 1.084 | 1.15 | 1.1518614 |
| 23 | 10 | 8 | 0.08 | 450 | 9.21 | 13.25 | 1.098 | 1.202 | 1.2204338 |
| 24 | 10 | 8 | 0.1 | 850 | 11.59 | 18.85 | 1.124 | 1.168 | 1.1798783 |
| 25 | 10 | 8 | 0.06 | 310 | 5.88 | 2.21 | 1.137 | 1.22 | 1.1518614 |
| 26 | 10 | 8 | 0.08 | 450 | 9.17 | 5.45 | 1.159 | 1.27 | 1.2204338 |
| 27 | 10 | 8 | 0.1 | 850 | 11.14 | 132.92 | 1.162 | 1.241 | 1.1798783 |

Fig: 7 show the delamination effect for 5mm drill diameter.

In this, low feed and low speed gives the better yield for delamination.

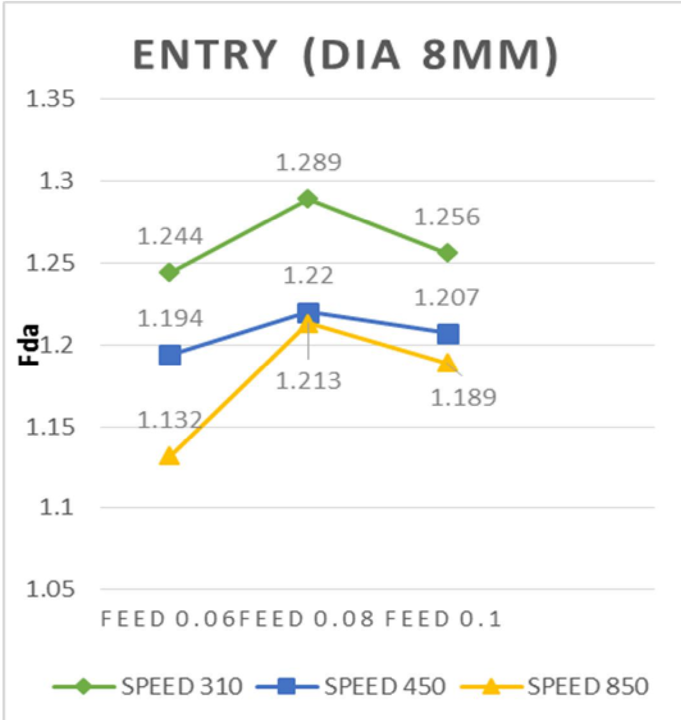


Fig: 8 Shows the delamination effect for 8mm drill diameter, medium speed with low feed gives the better hole quality.

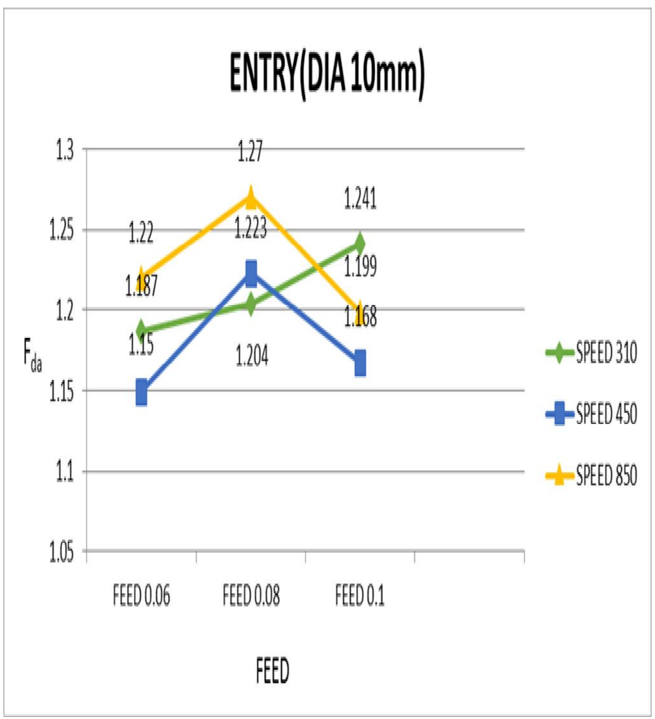


Fig. 9. Shows the delamination effect for 10mm drill diameter, medium speed with low feed gives the better hole quality with minimal delamination.

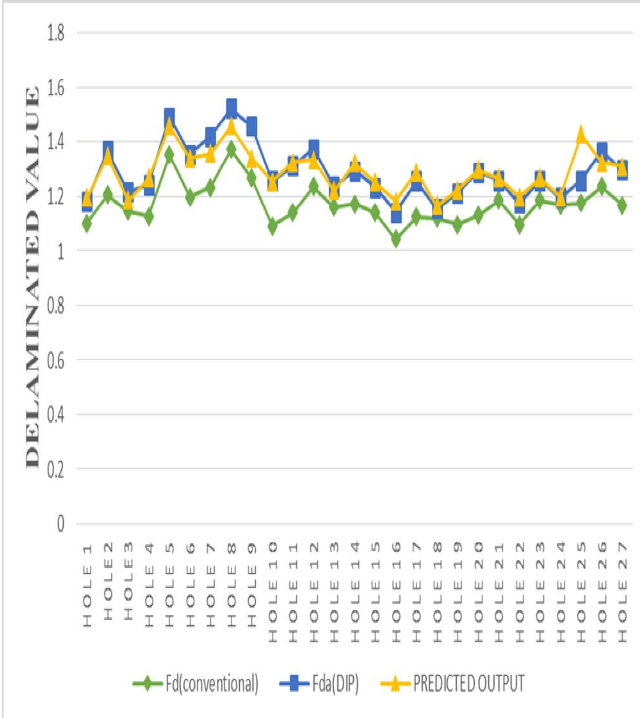


Fig: 10 Correlation between $F_d$ (conventional), $F_{da}$ (DIP) & Predicted value for 27 Holes

## V. CONCLUSION

This experimental investigation shows that delamination of glass fiber reinforced plastic were studied by digital image processing using IMAGE-J & LabVIEW, which was better than conventional method ($D_{max}/D_o$).

*A.* An attempt is made to get the prediction equation for delamination while drilling GFRP composites using HSS drill bits.
*B.* In this case feed rate is found to be most dominating factor, even though speed and drill diameter are contributing factors.
*C.* The optimal results for Drilling the composite laminate were found to be at the maximum thickness of laminate, maximum diameter of drill bit, medium speed and low feed to the work piece.
*D.* The effect of Delamination on the drilled GFRP composites, varies in accordance with change in input parameters.
*E.* Considering damage area in the Delamination factor which is found out from digital image processing; allows better visualization of the damage caused, indicating digital image processing is more suitable for delamination analysis.
*F.* Medium speed with low feed gives better hole quality characteristics for medium size diameter drill.
*G.* The results obtained from IMAGE-j & LabVIEW are found to be in correlation with each other as well as to that from the predicted equation (Regression Equation).

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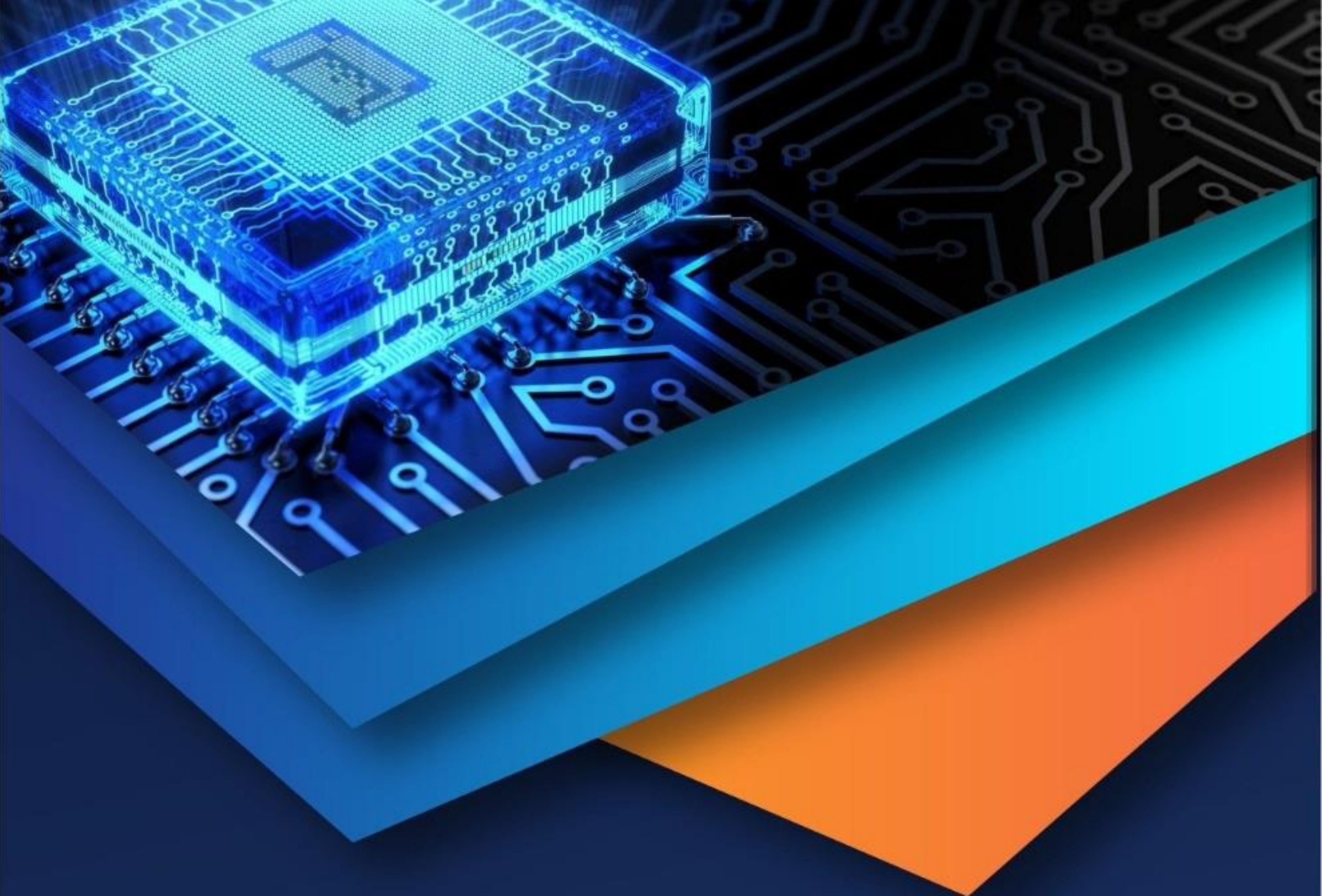

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