DELAMINATION ANALYSIS IN DRILLING OF COMPOSITE MATERIALS USING DIGITAL IMAGE PROCESSING, REGRESSION MODELING AND FUZZY LOGIC

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Abstract- Glass Fiber Reinforced Plastic composites have an increased application in recent days, due to its enhanced structural, mechanical and thermal properties. The heterogeneous nature of this kind of materials makes complications during machining operations. Drilling of holes in GFRP becomes almost unavoidable in fabrication. However, drilling is a common machining practice for assembly of components. The quality of holes produced in the GFRP material is severely affected by surface roughness, Circularity, Delamination, Cylindricity etc. The objective of this study is to apply full factorial design for experimentation and fuzzy logic model prediction to achieve an improved hole quality considering minimum delamination through proper selection of drilling parameters. Calculating the damage area has always been a challenge with conventional methods. An attempt is made with Digital Image Processing (DIP) using Image J software to find the damage area.

Keywords- GFRP, Fuzzy logic, Full Factorial Design, Drilling, Delamination, Digital Image Processing.

I. INTRODUCTION

Glass Fiber Reinforced plastics are widely being used in aerospace, automotive, machine tool industries because of their superior mechanical and physical properties such as specific strength and high specific stiffness. Nowadays the use of lightweight materials have become a necessity in many industries like space, navel, aircraft, automotive, sports, etc. GFRP is one of the composite materials which are mainly known for its high strength to weight ratio. Drilling contributes to 40% of the machining process in aircraft industries. 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 automobiles. An aircraft fuselage structure need 1, 00,000 holes for joining purpose. Poor hole quality accounts to 60% part rejection and since holes are drilled in finished products, Part rejection due to poor hole quality prove very costly. Delamination is the major cause for poor quality in drilling of GFRP composites. Various techniques are in existence to measure delamination after drilling composites such as shop microscope, s-can, digital photography and a method using Digital image Processing has been employed to evaluate the delamination factor after drilling composites. Fuzzy logic is a mathematical formalism for representing human knowledge involving vague concepts and a natural but effective method for systematically formulating cost effective solutions of complex problems problems. A model was developed for drilling of GFRP composites using fuzzy logic. The primary objectives of this study were to quantify the influence of process input parameters on delamination by formulating a mathematical model and validating using Fuzzy logic model. Further, an attempt is made to use Digital Image Processing using Image J software to calculate the damage area created by delamination.

II. DESIGN OF EXPERIMENT

Design of experiment is the design of all information -gathering exercises where variation is present, whether under the full control experiment or not. The cutting speed, feed rate and diameter of the drilled hole are the three parameters under investigation in the present study. A full factorial experimental design with a total number of 27 holes drilled into the GFRP specimen to investigate the hole quality on Delamination. 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, formula = Levels, N = 3, N- number of experiments.

Table 1: Assignment level of process parameters

<table>
<thead>
<tr>
<th>Factors</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed, s(rpm)</td>
<td>3, 10, 450, 852</td>
</tr>
<tr>
<td>Feed, f(mm/rev)</td>
<td>0.06, 0.08, 0.1</td>
</tr>
<tr>
<td>Diameter, d(mm)</td>
<td>6, 8, 10</td>
</tr>
</tbody>
</table>

Fig 1: Fabricated GFRP plate
III. METHODOLOGY

A: Specimen preparation

The glass fiber reinforced plastics (GFRP) were fabricated using hand lay-up process. The matrix material comprises of glass fiber -450 csm (chopped standard matt) as matrix and isophalin resin. It contains a woven type of orientation. The plates were manufactured with thickness of 8 mm.

Experiments were carried out in a pillar drilling machine using HSS drill of 6.8 and 10mm diameter. Experiments were carried out according to Full factorial design. Full factorial designs provide a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. The selected levels of process parameters are given in Table 1. Fig 2 shows the photographic view of the experimental setup.

IV. 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 analysed using imageJ (version 1.4.3.67) - public domain software (National Institute of health,USA) to finding the damage area of the GFRP specimens. In this process both entry and exit of 27 holes were analysed and the damage area was found out and adjustable delamination factor (Fda) is calculated

The equation (2) is used to find the maximal damaged area of the drilled composites. The formul (1) evaluates the value of F_{DA} after calculating the damage area (Ad) using digital image processing.

\[
F_{\text{DA}} = \frac{F_{\text{Dmax}}}{(A_{\text{Dmax}} - A_{\text{D0}})(D_{\text{Dmax}} - F_{\text{D}})} \quad (1)
\]

\[
A_{\text{D}} = \text{Damaged area calculated by Image J} \quad (2)
\]

\[
A_{\text{Dmax}} = \frac{D_{\text{Dmax}}^2}{4}, A_{\text{D}} = \pi \frac{D_{\text{D}}^2}{4} \quad [11]
\]

V. FUZZY LOGIC MODEL

Fuzzy logic refers to a logical system that generalizes the classical two-value logic for reasoning under uncertainty. It is a system of computing and approximate reasoning based on a collection of theories and technologies that employ fuzzy sets, which are classes of objects without sharp boundaries. Fuzzy logic is the best in capturing the ambiguity in input. Fuzzy logic has become popular in the recent years, due to the fact that it is possible to add human expertise to the process. Nevertheless, in the case where the nonlinear model and all the parameters of a process are known, a fuzzy system may be used.

A. Development of fuzzy logic model

The surface roughness and circularity error in drilling of GFRP is assumed as a function of three input variables viz. plate thickness, spindle speed, and feed rate. The Fuzzy logic prediction model is developed using Fuzzy Logic Toolbox available in Matlab version 7.10(R2010a). In this work Mamdani type Fuzzy Inference Systems(FIS) is used for modeling. The steps followed in developing The fuzzy logic model are described below.

B. Fuzzification of I/O variables:

The input and output variables are fuzzified into different fuzzy sets. The triangular membership function is used for simplicity yet computationally efficient. It is easy to use and requires only three parameters to define.

The input variables plate thickness [5-15 mm], spindle speed [280-1800 rpm] and feed rate [0.18-1.4 mm/rev] are fuzzified into three fuzzy sets viz. Low (L), Medium (M), and High (H) as shown in the Fig.11 (a,b,c). The output variable i.e. The surface roughness and circularity error are divided into nine fuzzy sets as Very Very Low(VVL), Very Low (VL), Low (L), Medium1 (M1), Medium2 (M2), Medium3 (M3), High (H), Very High (VH), Very Very High (VVH) as shown in Fig.11 (d) to increase the resolution and accuracy of prediction.
C. Evaluation of IF-THEN rule

The three input variables are fuzzified into three fuzzy sets each, the size of rule base becomes 27(3x3x3). For generating the Fuzzy rules, the level of the variable having more membership grade on a particular fuzzy set is considered. With appropriate level of all the input variables representing the corresponding fuzzy set, the surface roughness values are used for 27 data sets of fuzzy rule base. Since all the parts in the antecedents are compulsory for getting the response value, the AND (min) operator is used to combine antecedents parts of each rule. The implication method min is used to correlate the rule consequent with its antecedent. For example, the first rule of the FIS can be written as Rule 1: ‘if Thickness is Low and Speed is Low and Feed rate is Low then surface roughness is Very Very low (VVL)’.

D. Aggregation of Rules

The aggregation of all the rule outputs is implemented using max method, the commonly used method for combining the effect of all the rules. In this method the output of each rule is combined into single fuzzy set whose membership function value is used to clip the output membership function. It returns the highest value of the membership functions of all the rules.

E. Defuzzification

The aggregate output of all the rules which is in the form of fuzzy set is converted into a numerical value (crisp number) that represents the response variable for the given data sets. In the present work, the centroid defuzzification method is used for this purpose. It is the most popular method used in most of the fuzzy logic applications. It is based on the centroid calculation and returns center of area under the curve.

VI. RESULTS AND DISCUSSION

The delaminated holes of composite materials can be analyzed by many methods [10-15]. Among the many methods the digital image processing is one of the methods which provides better results. In this work, Image J is used for digital image processing and to find the damage area around the hole of the composite material. This software provides a better view of the damage area which helps to find the affected area of the delaminated holes. This software was successfully utilized in analyzing Delamination in drilled GFRP composites for calculating damaged area. The regression equation was developed for delamination factor at entry and exit of the hole. Predicted delamination factor at entry and exit for the given experimental conditions were summarized in Table 2. The developed equation for the delamination at entry and exit dependent with parameters speed, feed and drill diameter. The developed regression model indicates the feed rate is the most influencing parameters for prediction of delamination while drilling of GFRP composite laminates. The regression equation for predicting adjusted delamination factor $F_{DA}$ at Entry, where $D$ is Drill Diameter, $F$ is Feed and $S$ is Speed, $F_{DA}$ (entry) = 1.24 - 0.0083 $D$ - 0.000006 $S$ + 0.103 $F$ The regression equation for predicting adjusted delamination factor $F_{DA}$ at Exit, where $D$ is Drill Diameter, $F$ is Feed and $S$ is Speed, $F_{DA}$ (exit) = 1.20 - 0.0116 $D$ + 0.000134 $S$ + 0.033 $F$
The ImageJ values of delamination is compared with the fuzzy output. The comparison of prediction performance in fuzzy logic output with the experimental results is given in the Table 2. Fig 6 and 7 indicates the correlation of F\text{DA} values obtained from LabView software and fuzzy output during entry and exit. They are in good correlation with each other. The variation of delamination with different combinations of input variables is studied using the output surface FIS. Fig.8,9,10 shows the functional dependence of delamination with diameter, feed rate and spindle speed.

**CONCLUSION:**

Delamination was analysed as a function of process input variables. A simple regression prediction model was developed based on the function of process variables and validated using fuzzy logic model. Based on the results from digital image processing, regression model and Fuzzy output for delamination after drilling GFRP composites, following conclusions can be inferred.

- The results obtained from Image J, fuzzy logic model and prediction output are in good correlation with each other. The results obtained from Image J, fuzzy model and predicted output are in good correlation with each other.
- The effect of Delamination on the drilled GFRP composites, varies in accordance with change in input parameters.
- Considering damage area $A_D$ in the Delamination factor, found out from digital image processing; allows better visualization of the damage caused, indicating digital image processing is more suitable for delamination analysis.
• In this case feed rate is found to be more dominating factor, even though speed and drill diameter are contributing factors.
• A mid range feed of 0.08 mm/rev and mid range speed of 450 rpm is considered to be the better condition to get good quality holes.
• On the whole, the adjusted Delamination factor \( F_{DA} \) obtained through digital image processing is suitable for characterizing Delamination.

REFERENCES: