ABSTRACT

Glass Fibre Reinforced Plastics (GFRP) composites find wide application in numerous manufacturing fields such as aerospace, automobile etc, because of their distinct properties such as low weight, high strength and stiffness. Even though the GFRP composite components are produced to near-net form, machining is usually required to meet the requirements associated with tolerances of assembly needs. Drilling is the most indispensable method for the fabrication of products with composite panels. The performance of these products is mainly dependant on surface quality and dimensional accuracy of the drilled hole. The quality of the hole drilled is influenced by the cutting conditions, composite properties, tool material and geometry. The material anisotropy resulting from fibre reinforcement considerably influences the quality of the drilled hole. Hence, precise machining must be performed to ensure the dimensional stability and interface quality. Since drilling in GFRP composites involves numerous variables which will influence the quality of the drilled hole, it is very essential to study the effect of these individual variables over the response. Control over the individual variables and optimization is important to obtain sensible results.

The scope of the present research work is to experimentally identify the effect of drill point angle, drill diameter, material thickness, spindle speed and feed rate on thrust force, torque, surface roughness and delamination in drilling of composite material. The test specimen used is the glass fiber reinforced polymer (GFRP) composite laminate which was manufactured by hand lay-up method. The specimen consists of general purpose polyester resin as matrix, methyl ethyl ketone peroxide was used as the binder. The specimen was reinforced with E glass fiber. The weight fraction of the composite is 44% which was confirmed by the burn test method. Design of experiment (DOE) method has been implemented to design the experiments. A full factorial design
of five factors and three levels has been adopted in order to obtain the complete machining data. Hence, number of estimated runs are $3^5 = 243$ and experiment has been done for a replication. Solid carbide drills of various diameter and drill point angles were used as the drilling tools.

Systematic experiments have been designed and conducted in order to evaluate the machining characteristics during drilling. Since the quality of the drilled hole is influenced by various individual parameters, following individual variables are considered for the present work.

- Material variables: thickness.
- Machining variables: spindle speed and feed rate.
- Cutting tool variables: drill diameter and drill point angle.

The specimens are drilled without backing using a standard solid carbide drill bits of size 6mm, 8mm and 10mm. Drill point angles of $90^0$, $103^0$, $118^0$ have been adopted to drill the specimen. In this work the drilling process was carried out with feed rates of 75, 110, 150 mm/min and spindle speed of 900, 1200, 1500 rpm. The machining has been done on TRIAC VMC CNC machining center and the machining condition is dry.

The thrust force and torque developed during drilling were measured with the help of KISTLER Dynamometer and a charge amplifier, and the output data has been stored in computer. The surface roughness of the drilled hole was measured by Taylor Hobson Surtronic 3+ roughness measuring instrument. In order to measure the delamination the drilled holes were initially scanned using a scanner of 1200 dpi resolution and there after the dimensions of the scanned images are measured with the help of CATIA V19 software.

Significance level of each parameter and the order of significance has been analyzed using ANOVA technique. To obtain the good quality holes, the optimization of the process parameters was done through Taguchi and Response Surface Methodology (RSM). The regression equations
which show the correlation between individual variables and output responses were developed for each response parameter. The confirmation tests were conducted at optimum levels of process parameters and obtained results were compared with the predicted values to check the acceptance level of the regression model. The correlation of the thrust force with the delamination factor and surface roughness were also predicted. Further, an attempt has been made to develop the simulation through System Dynamics approach for the first time in the field of machining. In addition to the System Dynamics, simulations by ANN and RSM were also developed and comparison between the results of these three techniques has been made.

To develop the System dynamics simulation the following steps are followed:

- The mathematical equation has been developed with the experimental data which shows the relation between input and output parameters.
- System Dynamics model (causal loop diagram) has been developed using VENSIM® software and the mathematical equation was entered in the model.
- The model was run for various combinations of parameters and the corresponding responses were tabulated.
- With the help of tabulated results, simulation graphs were plotted using MATLAB® software.

The ANN simulation was done using genetic algorithm multilayer perceptron ANN model which consists of single hidden layer. Out of 243 data, 170 data (70%) were used for training and 73 (30%) data were used for testing the neurons. The number of epochs used are 2000 and number of iterations considered are 100. After trial and error, the hidden neuron number is set to 58. The learning rate of the model is 0.0158 and the momentum rate is 0.0033.
To develop the RSM simulation, numbers of intermediate values of independent variables are selected within the considered range. Each of these selected values was entered in the RSM optimization plot and the corresponding output was noted down. After tabulating entire output values, simulation graphs were developed using MATLAB® software.

The results reveal that drill point angle is the parameter which has significant effect on the thrust force. The feed rate is the parameter which has least effect on the thrust force. According to the regression equation, the thrust force increases with increase in drill point angle, drill diameter, material thickness and feed rate, but decreases with increase in spindle speed.

Drill diameter is the parameter which has the maximum influence on the torque. Spindle speed and material thickness are next to drill diameter. Drill point angle is the least significant parameter. Regression equation for the torque indicates that the torque increases with increase in drill diameter, material thickness and feed rate, but decreases with increase in drill point angle and spindle speed.

Material thickness is the most significant parameter for the delamination factor. Spindle speed is the least significant one. According to the regression equation, except for the spindle speed, increment in the level of all process parameters increases the delamination factor.

Material thickness is the parameter which is affecting surface roughness significantly. Spindle speed is the least influencing parameter. For all responses, the optimum combination of parameters was obtained by Taguchi, RSM and SD methods. The confirmation tests were conducted at optimum combination of levels and the obtained actual results were compared with the estimated results. A good agreement between results was observed.

Results also reveal that for the considered range of parameters, the delamination factor and surface roughness are directly proportional to the thrust force. It was ascertained that compared to
ANN simulated results, SD simulated results are found sensible agreement with the experimental ones. Further, SD results also found good agreement with the experimental and RSM results with the acceptance level more than 90 percent.