LITERATURE REVIEW ON MACHINING OF CFRP COMPOSITES

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Abstract—Carbon Fiber Reinforced Polymer (CFRP) composites are characterized by their excellent mechanical properties (high specific strength and stiffness, light weight, high damping capacity etc.) as compared to conventional metals, which results in their increased utilization especially for aircraft and aerospace applications, automotive, defense as well as sporting industries. With increasing applications of CFRP composites, determining economical techniques of production is very important. However, as compared to conventional metals, machining behavior of composites is somewhat different. This is mainly because these materials behave extremely abrasive during machining operations. Machining of CFRP appears difficult due to their material discontinuity, inhomogeneity and anisotropic nature. Moreover, the machining behavior of composites largely depends on the fiber form, the fiber content, fiber orientations of composites and the variability of matrix material. Difficulties are faced during machining of composites due to occurrence of various modes of damages like fiber breakage, matrix cracking, fiber–matrix debonding and delamination. Hence, adequate knowledge and in-depth understanding of the process behavior is indeed necessary to identify the most favorable machining environment in view of various requirements of process performance yields. In this context, present paper attempts to investigate aspects of machining performance optimization during machining (drilling) of CFRP composites. In case of turning experiments, the following parameters viz. cutting force, Material Removal Rate (MRR), roughness average (Ra) and maximum tool-tip temperature generated during machining have been considered as process output responses. In case of drilling, the following process performance features viz. load (thrust), torque, roughness average (of the drilled hole) and delamination factor (entry and exit both) have been considered. Attempt has been made to determine the optimal machining parameters setting that can simultaneously satisfy aforesaid response features up to the desired extent. Using Fuzzy Inference System (FIS), multiple response features have been aggregated to obtain an equivalent single performance index called Multi-Performance Characteristic Index (MPCI).

Keywords—Design of Experiments, Optimization, Analysis of Variance, Machining Parameters, Drilling, CFRP material and MINITAB software, Fuzzy logic design.

1. INTRODUCTION

Carbon fiber reinforced polymer (CFRP) composites may be defined as fiber reinforced composite material that utilizes carbon fiber as the primary structural component (reinforcement) and thermosetting resins such as epoxy, polyester, or vinyl ester as matrix. In recent years, CFRP composites are becoming quite popular in the manufacturing industries especially in aerospace and automobile industries due to their excellent mechanical and thermal properties including high mechanical strength and low weight, good fatigue resistance, good corrosion and weather resistance, very low coefficient of thermal expansion and high strength-to-weight ratio. With the increased demand of CFRP composites in aforementioned industries, manufacturers are emphasizing more to study the machinability aspects of these composites. In general, CFRP products are made to near-net-shape; however, machining is often carried out in order to remove excess material to meet dimensional accuracy and tolerance. But machining of these composites is somewhat different from machining of conventional metals; it is quite difficult due to their material discontinuity, anisotropic and inhomogeneous nature. There are several challenges with machining CFRP material:

The fibers are characterized by high strength, which makes the material difficult to cut, leading to: wear on the cutting tool and splintering/fraying. It has a high elastic modulus, making it abrasive. The plastic matrix is sensitive to heat and can melt. The structure is built up by layers of material, which can lead to delamination.

The major drawbacks associated in machining of these composites are fiber pull out, breakage of fibers, delamination, matrix burning, matrix cracking and subsurface damage which lead to poor surface quality and dimensional inaccuracy. Hence, it becomes indeed essential for the manufacturer to understand machining behavior of CFRP composites. Out of several conventional machining operations, turning and drilling operations are commonly performed for machining of CFRP composites to make/assemble desired shape and size of product and to achieve required level of dimensional accuracy.

Earlier trend was to select the machining variables randomly based on the operator's skills in which product quality might not be as per the desired level. With advancement of time, manufacturers are giving more attention to enhance both quality and productivity, simultaneously. As machining parameters significantly influence on machining performance features, appropriate setting and proper control of machining parameters is of utmost importance to achieve desired product quality and satisfactory process performance. (productivity).

Hence, it is of vital necessity to go for optimization of machining parameters towards enhancing overall machining performance.

2. MATERIALS AND METHODS

In the present work, series of experiments have been executed in order to collect response values: thrust force, torque, roughness average (Ra), entry delamination factor and exit delamination factor during drilling of different polymer matrix composites (CFRP).

Input parameters: 1) Speed,2) Feed & 3) drill bit type & 4) fibre orientation.

Output parameters: 1) Thrust, 2) Torque, 4) Delamination factor at entry & 5) Delamination factor at exit.

Specimen material: Carbon fiber epoxy polymer material.

Methods used for optimizing machining parameters:

A) Design of experiments, B) ANOVA method.

C) Multi performance characteristic index.

Used software's: MINITAB & MATLAB.

A. Design of experiments (DOE):

In this research, drilling operations have been performed on CNC drilling machine. In order to perform experimentation, it is quite necessary to develop a set of experiments for determining the response measurements. For this, Taguchi method has been applied for selecting design of experiment as it examines the effects of entire machining process parameters with less (i.e. limited) number of experiments in comparison to full-factorial design of experiments. The present study focuses on the effects of drilling parameters such as composite type, drill speed, feed rate and drill bit type and fiber orientation; each has been varied at three different levels.

Input parameters are Drill speed, feed, drill bit type and angle of orientation and Output parameters (response parameters are torque, thrust, surface roughness, delamination factor at entry and exit. Design of experiment used is L27 array selected based on degrees of freedom.

STEPS OF METHODOLGY TO BE ADOPTED

1. Initial study to determine the various controlled and uncontrolled parameters.

2. Selection of work materials (CFRP), tool materials and their combination based on literature.

3. Selection of process parameters, responses and their levels.

4. Selection of experimental layout using Taguchi method

5. Conduction of experiment with different work tool material combination to study and measure various performance characteristics like surface roughness, thrust, delamination factor and machining accuracy

6. Measurement of response using standard equipment's

7. Parameter optimization using Taguchi method and analysis of data using statistical tools.

8. Creating mathematical models by multiple regression analysis using Minitab-17 Software

9. Comparison of results of theoretical analysis with experimental results by conducting confirmation experiments.

B. Multi-Response optimization in Drilling of composite material:

Fuzzy rule matrix: Writing fuzzy logic rule for output parameters: surface roughness, Torque, Thrust, delamination factor at entry and exit to get MPCI.

In recent years, the application of polymer composites has been enormously increased particularly in aerospace as well as in automobile sector due to its light weight, high specific stiffness and high specific strength. Machining of those composites has really become an emerging area of research. A considerable volume of research has already been carried out by the pioneers in order to study machining and machinability aspects of these composites, thereby, maintaining both product quality as well as productivity. Drilling is considered as one of the most common machining processes for assembly of composites. In case of Fiber Reinforced Polymer (FRP) composites, delamination and fiber pull out are the major problems that arise during drilling operations. Defect free drilling whilst ensuring satisfactory machining performance (in terms of quality as well as productivity) is definitely a challenging task. In this context, the present study mainly attempts to reduce drilling induced damages and at the same time to improve machining performances during drilling of polymer composites by determining an optimal parametric combination in view of multiple process responses and by considering effects of drilling process control parameters, drill geometry (diameter of drill bit) as well as composite type. Attempt has also been made to understand the relationship (influence) between input-output(s); where, inputs i.e. process parameters have been considered like composite type, drill speed, feed rate, drill diameter and outputs have been and drilling responses like thrust force, torque, delamination at entry and exit and average surface roughness of the drilled hole. Multi-response optimization has been performed using Deng's similarity-based method in combination with Taguchi's optimization philosophy. Results obtained thereof have been compared with TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) based Taguchi approach.

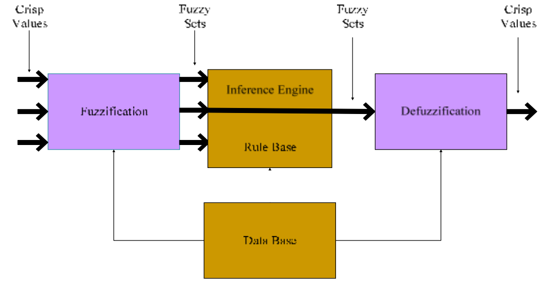

Fig.1: Basic structure of Fuzzy Inference System (FIS)

3. PROBLEM DEFINATION

Literature depicts that much work has been highlighted addressing machining process behavior- parametric optimization in Angle1 composites, whilst it has been pointed out that lesser attention has been made on aspects of Angl2 machining and also to Angle3 composites. It is obvious that composite type is utmost important (influential) in achieving satisfactory process performances. Therefore, the present work also considers composite type as one of the process variables. The present work highlights the effect of the machining variables such as drill bit type, drill speed, feed rate and orientation of fiber (along with composite type) on various process performance indicators like thrust force, torque, roughness average (of the drilled surface) and delamination (in terms of delamination factor both at entry and exit) in drilling of composites. Based on the results from the experiments, an optimal parametric combination has been obtained by using Deng's similarity-based approach in combination with Taguchi's optimization module. Degree of similarity approach helps in aggregating multiple performance features in a unique performance index, called overall performance index (OPI), which has been finally optimized by Taguchi's technique. Application feasibility of degree of similarity-based Taguchi approach has been compared with TOPSIS based Taguchi method.

4. MACHINING PERFORMANCE EVALUATION CHARACTERISTICS

Drilling operations have been carried out on different composite samples for assessing performance characteristics such as thrust force, torque, entry delamination factor and exit delamination factor. Thrust force is mainly responsible for damages induced during drilling and it may lead to cause delamination and fiber pull put and reduce mainly the performance of FRP composites. Thrust force and Torque has been evaluated by using Digital Drilling Tool Dynamometer.

Delamination is the failure mechanism of fibrous composites and it can be observed in optical microscope. The image thus grabbed could be transferred into MATLAB workstation; and the value could be computed through image processing technique in MATLAB.

A. Equations

Nominal the best characteristic

$$S/N = 10 \log y/s^2y$$

2.Smaller the better characteristic;

$$S/N = -10 \log 1/n (\sum y^2)$$

3.Larger the better characteristic;

$$S/N = -10 \log 1/n (\sum 1/y^2)$$

5. CONCLUSION

The following conclusions can be drawn from the result of drilling of a CFRP composite. 1. The model created by method of design software (MINITAB) bundle demonstrates the impact of process parameters on delamination and surface roughness. 2.Taguchi technique, the most predominant process parameter was found to be feed rate, followed by cutting speed, drill bit type and fiber orientation respectively2.The ANOVA demonstrates that the spindle speed and drill bit type have only a negligible impact on drilling affected delamination. 3. The study covers that delamination component increment with expansion in feed rate.4. The study exhibits that the minimum delamination is obtained for the optimum process parameters (spindle pace, feed rate).

ACKNOWLEDGMENT

It gives me enormous pleasure to express my first thanks and sincere gratitude to my supervisor and co-supervisor for their insistent help and constant guidance; otherwise, it would not have been possible for me to complete this work.

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