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Analysis of Surface Roughness and Delamination of Sheet Moulding Composite (SMC) During End Milling Using Taguchi Method

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Abstract: **-- This study aims to develop a mathematical model for analyzing the surface roughness and delamination factor and to infer the influence of the individual input machining parameters (cutting speed, depth of cut and feed rate) on the responses in milling of Sheet Metal Composite (SMC) with solid carbide end mill cutter coated with PCD using Taguchi methodology. In Taguchi methodology, three factors and two responses were employed to carry out the experimental investigation. Multiple Regression Analysis from "Minitab" software was used for regression and graphical analysis of the data were collected. The optimum values of the selected variables were obtained by solving the regression equation. Analysis of variance (ANOVA) was applied to check the validity of the model and for finding the significant parameters. It is seen that Feed rate is the most influencing factor in affecting the surface roughness and delamination. In SMC composite as the speed and feed increases the surface roughness value decreases. Moderate feed and speed gives ideal finish. But the parameter depth of cut shows a wavy nature. Only for a very high depth, the roughness increases. The optimized values of the machining parameters were used to calculate the surface roughness and delamination factor of the machined surfaces, with the chosen range resulting with 93 per cent.**

Keywords**:SMC composites, Taguchi methodology, Surface roughness, Delamination.**

1. INTRODUCTION

Modern era has reached such a stage wherein easy machinability is required. This is the main reason for evolution of composite materials, as a substitute for conventional metals. One such composite is sheet moulding composite (SMC), whose machinability under end milling is analysed in this paper. There can be wide range of possible input parameters for which different output parameters can be obtained. After these, an analysing tool must be used for graphical representation. Being non- homogeneous, anisotropic and reinforced by very abrasive components, these materials are difficult to machine. Significant damage to the work piece may be introduced and high wear rates of the cutting tools are experienced. Experiments show that conventional machining practices, such as turning, drilling and milling, are widely applied to the machining of composite materials [1]. There are different types of composite materials, which are Polymer Matrix Composites (PMC), Metal Matrix Composites (MMC), and Ceramic Matrix Composites (CMC). MMC are used for the aerospace industry, but new applications are found in the automotive industry, such as in automobile engine parts, making use of continuous fibre, discontinuous fibre or particle reinforced MMC. Continuous fibres provide the highest stiffness and strength properties in MMC materials.

Machining is the heart for a production technology. Of all the properties of a material its surface finish is the most important which defines the quality of the material at most important in defining the productivity of machine tools and machined parts [2]. Of all the input factors speed, feed and the depth of cut are the controllable ones which can be controlled by the operator himself. The uncontrollable factors include the tool properties, tool and work piece material. Machining behaviour and results vary for each composite due to its material behaviour, nature, form and relative content of reinforcement, fabrication, tool selection and tool life. Volume fraction:

Vf = (reinforcement volume)/ (composite volume) and (1)

Vm = (matrix volume) / (composite volume), (2)

Where Vf+ Vm = 1.

When we consider conventional metals like aluminum, the texture and surface roughness of the material is mainly dependent on the speed, feed and the depth of cut [3]. As in the case of hardened steel the feed rate has more significance on the surface roughness which is suggested by research [4]. As far as composites are concerned, selecting the input parameters and the desired output heavily depends on many factors. GRFP which is a Glass Reinforced Polymer for which it has been found that of all the machining parameters given in, only one single parameter influences the output of the process. The

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experiments suggested the same, which retreats the same. And the main parameter affecting the machinability is the feed rate [5-6]. When considering the tool life, of all the parameters cutting speed, the orientations were found to be the most influencing one on GFRP. This analysis was done using ANOVA method. Of all the statistical analysis method available Taguchi method is found to be the most suited for multi-objective analysis of the parameters [7].And during machining the best type of cutting was orthogonal cutting method which is best suited since in orthogonal cutting where the forces increases as tool wear increases [8]. During machining of composites the excessive forces acting on the material must be avoided for preventing the damage of the work piece. Hence predicting the forces is a must one and it is found that the main three parameters that affect the forces are feed, speed and the cut thickness [9]. In case of micro end milling the optimum parameters are medium value of spindle speed, higher value of depth of cut and higher value of feed rate for maximum MRR in micro-end milling. Thus we come to a vague conclusion that for the optimization of the machining best suited are to vary these three parameters [10].

After the statistical analysis of CFRP, the combination of low cutting speed and high feed rate is recommended in terms of improving surface roughness, with feed rate being a significant factor [11]. When GFRP is analyzed using mathematical modeling and ANN for surface roughness and delamination factor cutting speed and depth of cut were influential in roughness and for delamination factor tool material and feed rate [12]. Hence from all these analysis there is a need for us to fix up a method and continue the experiment. Surface roughness measurements for laminate composites were significantly influenced by the variation in ply angles and measurement direction [13]. Added to that the surface roughness, machining force and delamination factor also might increase with increase in fibre orientation angle and feed rate, and decreases with increase in cutting speed [14].In recent years, the interest in the machining of composite materials by conventional techniques has grown and attempts have been made to predict cutting forces from the observation of the failure modes. Machining of composite materials is difficult to carry out due to the anisotropic and non-homogeneous structure of composites and to the high abrasiveness of their reinforcing constituents [15]. This typically results in damage being introduced into the work piece and in very rapid wear development in the cutting tool.

There are wide ranges of applications of composite materials superior to conventional materials like steel, aluminum. Few of them are resistance to a wide range of chemical agents, resilience, low weight, reduced cost, strength, stiffness, thermal properties, adhesive and coating compactness and good damping characteristics.

SMC are used in body-shell of automotive vehicles, front panels, bumper systems, air deflectors, steps, toolboxes and roof spoilers to side protection and side spoilers, composite components include control panels, roof compartments, seat consoles and highly integrated floor panels. In construction field used to produce water tanks panels, doors, manhole covers, chairs. It is used extensively in the construction of ships and marine structures like hull, ship's superstructure.

This paper encounters the influences of machining parameters on various combinations of machining characteristics with the help of Taguchi method, which gives statistical analysis by focusing on individual machining output.

II. EXPERIMENTAL SET-UP

SMC is ready to mould glass fibre reinforced polyester material primarily used in compression moulding. Sheet is provided in rolls weighing up to 1000kg. It is both process and reinforced composite material which is manufactured by dispersing long strands of chopped fibre. Paste reservoir dispenses a measured amount of specified resin paste onto a plastic carrier film. This carrier film passes under a chopper which cuts the fibre onto the surface. Once these are drifted through the depth of resin paste, another sheet is added on top which sandwiches the glass. The sheets are compacted and then enter onto a take-up roll, which stores the product while it matures. Carrier film is then removed and material is cut into charges. Heat and pressure act on the charge and this is removed as a finished product once it is fully cured. Composite materials are formed from two or more materials producing properties that could not be obtained from any one material. The properties are shown in Table I. One of the constituent materials acts as the matrix and at least one other constituent material act as the reinforcement in the composite. Fig 1 shows the material which is being used.

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Fig.1.Work piece before machining

Table 1 Properties of SMC

Property	**Value**
Impact strength	8-13 ft-lb/in
Flex strength	18-34 KPSI
Tensile strength	8-18 KPSI
Compressive strength	23-32 KPSI

2.1. *Tool*

Solid carbide tool of 8mm diameter, 4 flutes, rake angle=0”, two relief angles of 7” and 15” were adopted which is shown in Fig **2.**

Fig.2. Cutting tool

3. Process

Milling is a machining process where a rotating tool cutter is employed for the removal of materials as shown in Fig 3. As in this case thin slots of 8 mm width are being made on these materials vertical end milling machine is being preferred here.

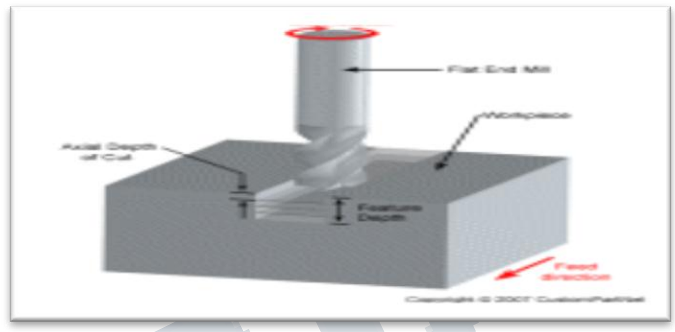

Fig.3. Tool and work piece orientation

The experimental setup was done by placing the work piece in a vertical CNC machine. A vertical CNC, Computer Numerical Control machine, as shown in Fig 4, where the movements and the coordinates of the system are measured and controlled by a computer maintained system. Its specifications are enlisted in table II.

Fig.4. Vertical CNC machine

Table 2 Specifications of CNC milling machine

Type of machine	Vertical CNC machine
Make	AMS
Model	MCV 450

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Power	11 KW
Maximum Speed	8000 rpm
X axis	800 mm
Y axis	450 mm
Z axis	500 mm
Table size	1000 x 450 mm

The parameters mainly considered here are speed, feed and depth of cut and these are arranged in L9 series. The levels for each parameter are selected as shown in Table III.

Table 3 Cutting parameters levels.

Factors	Cutting parameters	Units	Levels 1	Levels 2	Levels 3
A	Feed Rate	mm/min	0.1	0.15	0.2
B	Speed	m/min	1500	3000	4500
C	Depth of cut	mm	0.5	1	1.5

Orthogonal array testing is a "black box testing" technique which is systematic and statistical way of software testing. It finds errors associated with faulty logic within computer software systems. It is useful in user interface testing, system testing and regression testing. Instead of testing all the possible combinations of parameters (exhaustive testing), orthogonal array select only the subsets of combinations. The end mill cutter a Solid carbide tool of 8mm diameter, 4 flutes is being fed into the vertical spindle of the CNC and the work piece is set up on the bed of the machine using the clamps as shown in Fig 5.

Fig.5. Setup while machining SMC

The required parameters are arranged in an array based on Taguchi analysis and the machine is made to run as per the different combination. After making of slots surface roughness and delamination factor measurements were taken. The slots are made along the material as shown in Fig 6.

Fig.6. SMC material after End milling

The Roughnesses of the slots made were measured using Surface roughness tester and the delamination factor using Visual inspection method and the following table was formed.

Delamination factor = W_{max} / W (3) Where, W= 8mm

IV. RESULTS AND DISCUSSION

From the above experiment we find that the analysis on SMC has yielded the same results as per other composite materials [16]. Also from the mathematical analysis we finally see that feed rate is found to most affecting one. This is seen from both the techniques employed here – from regression analysis and using Taguchi analysis. The response table obtained from the taguchi analysis is shown in Table IV for surface roughness and for delamination factor in table V.

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Table 4ResponseTable for Surface Roughness

Level	**Feed**	**Speed**	**Depth of cut**
1	1.880	1.783	**1.677**
2	1.753	1.687	1.680
3	**1.463**	**1.627**	1.740
Delta	0.417	0.157	0.063
Rank	**1**	**2**	**3**

Table 5 Response Table for Delamination factor

Level	**Feed**	**Speed**	**Depth of cut**
1	**1.003**	**1.005**	**1.008**
2	**1.008**	**1.009**	**1.011**
3	**1.016**	**1.013**	**1.008**
Delta	**0.013**	**0.007**	**0.003**
Rank	**1**	**2**	**3**

From these tables we infer the most influential parameter, its impact and optimal parameter. The chips were also found to be in powdery form.

Regression Analysis: Surface roughness (R_a) versus Feed, Speed, DOC

$$R^2 = 92.66\%$$

Regression Equation:

$$R_a = 2.417 - 4.167 \text{ Feed} - 0.000052 \text{ Speed} + 0.0633 \text{ DOC} \quad (4)$$

Regression Analysis: Delamination factor (F_d) versus Feed, Speed, DOC

$$R^2 = 88.68\%$$

Regression Equation:

$$F_d = 0.98261 + 0.1296 \text{ Feed} + 0.000002 \text{ Speed} - 0.00030 \text{ DOC} \quad (5)$$

V. INFERENCE

5.1. *Chip formation*

Orthogonal cutting tests were carried out on sheet moulding composites, holding the cutting direction parallel to the fibre direction. The chip-tool interaction forces occurring at the tool face seem to be unaffected by wear phenomena [17]. Also the chips formed are powdery in nature as shown in figure 7. From figure 8 and 9, we see that the value of roughness decreases as feed and speed of the spindle increases. But in case of depth of cut the value of surface roughness increases as depth of cut increases which is seen from figure 10.

Fig.7. Chip formation

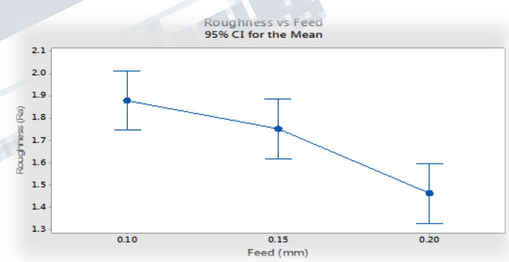

Fig.8. Roughness Vs Feed

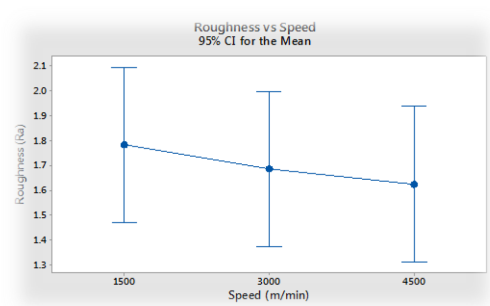

Fig.9. Roughness Vs. speed

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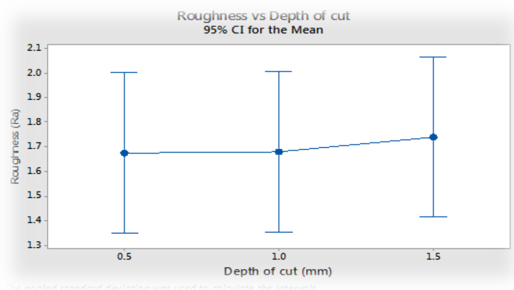

Fig.10.Roughness Vs DOC

This is due to increase in feed per tooth, causing a significant rise in surface roughness. This may be attributed to the heat generated as a result of higher friction. In case of Delamination factor as speed and feed increases the delamination factor increases which can be seen from figure 11 and 12.

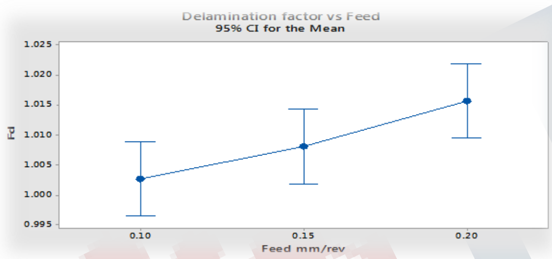

Fig.11.Delamination factor Vs feed

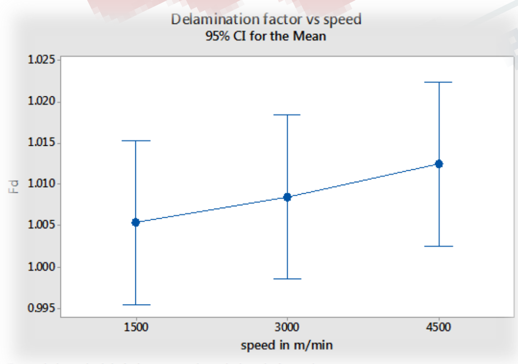

Fig.12. Delamination factor Vs speed

This is due to a sharp rise in feed force which in turn causes a higher friction and produces more damage to the surface. In case of depth of cut the delamination factor first increases and then decreases as the depth of cut increases i.e., as the cutting depth is more which is evident from figure 13. The overall regression equation is also obtained from which the various possible results can be obtained using other mathematical techniques. From figure 14 and figure 15, we find the overall trend each parameter influences upon the response parameters. This coincides with the individual plots. Also we can find the interaction of two parameters through the interaction plot as shown in figure 16 for surface roughness and in figure 17 for delamination factor. From these two plots for given levels of two parameters the effect on each response is deduced graphically.

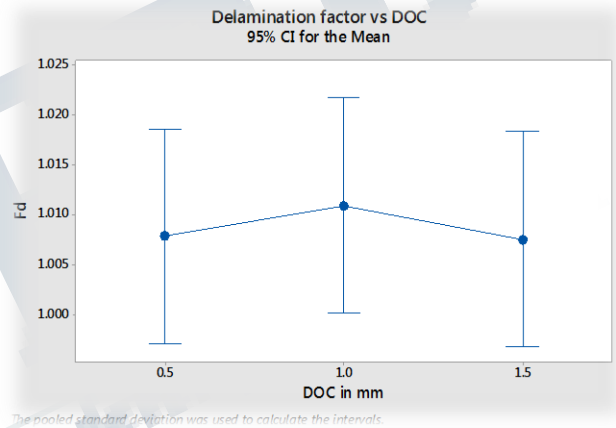

Fig.13. Delamination factor Vs DOC

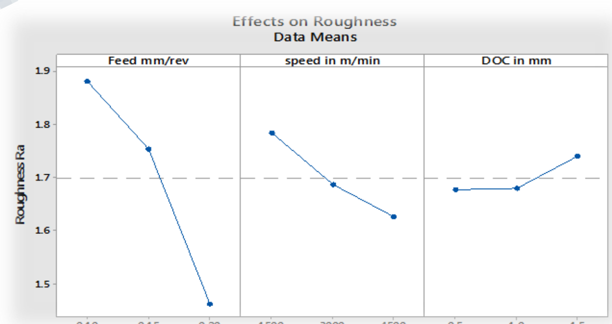

Fig.14.Overall effects of feed, speed and depth of cut on surface roughness

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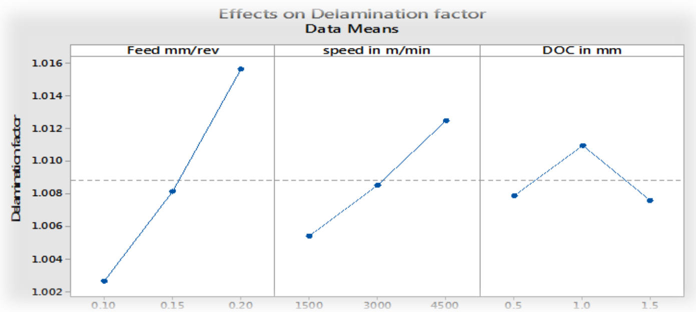

Fig.15. Overall effects of feed, speed and depth of cut on delamination factor

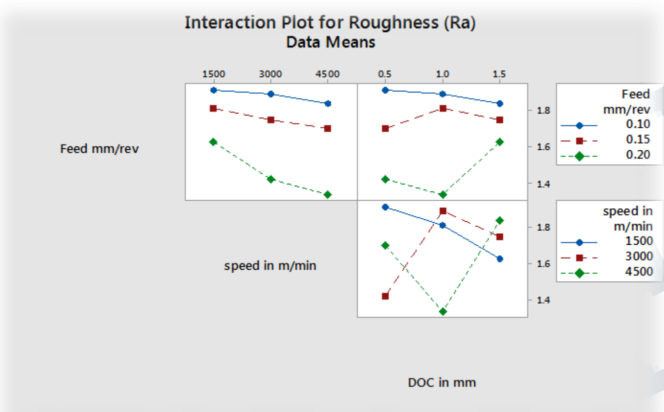

Fig.16. Interaction plot for surface roughness

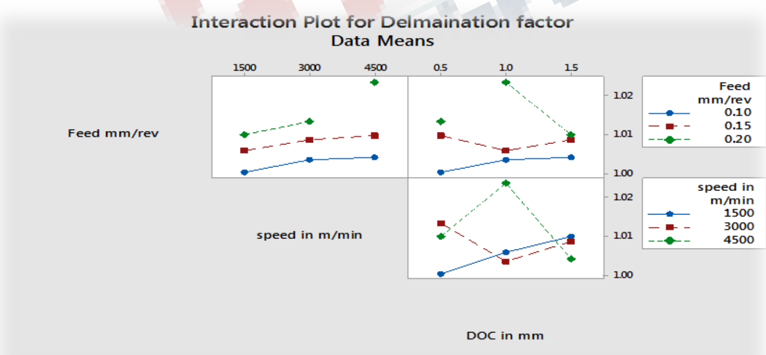

Fig.17. Interaction plot for delamination factor

VI. CONCLUSION

From the experimental results presented, the following conclusions were drawn from milling SMC material with solid carbide coated with PCD tool using Taguchi analysis:

- From Taguchi analysis and ANOVA we see that the feed rate is the most influencing factor in affecting the surface roughness and delamination. Hence the method is more reliable and is approximately nearer to the actual result.
- The other machining parameters like the spindle speed, depth of cut are of least significance when compared with that of feed rate.
- In the SMC composite as the speed and feed increases the surface roughness value decreases. Hence for a smooth surface finishes the feed rate and the speed must not be very high as higher the R_a value which leads to higher wearing of the material. Moderate feed and speed gives ideal finish. But the parameter depth of cut shows a wavy nature. Only for a very high depth the roughness increases.
- From the optimum values of machining parameters, we find it as time and cost efficient. This technique is convenient to predict the main effects and interaction effects of different influential combinations of machining parameters.

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