# Effect of Material Thickness and Ultrasonic Machine Parameters on Material Removal Rate While Ultrasonic Machining of Glass Fiber Reinforced Plastic

B. V. Kavad#, K. S. Vaghosi*

# Mechanical Engineering Department, Dr. J. N. Mehta Government Polytechnic, Amreli, Gujarat, India
* Mechanical Engineering Department, Government Engineering College, Rajkot, Gujarat, India

***Abstract*— Drilling is an important process for making and assembling components made from Glass Fiber Reinforced Plastic (GFRP). Various processes like conventional drilling, vibration assisted drilling and ultrasonic assisted drilling have been attempted in order to maintain the integrity of the material and obtain the necessary accuracy in drilling of GFRP. In conventional machining feed rate, tool material and cutting speed are the most influential factor in the machining of GFRP. This paper attempts to show effect of material thickness and ultrasonic machine parameters like amplitude and pressure on material removal rate while ultrasonic machining of glass fiber reinforced plastic.**

***Keywords*— GFRP, Ultrasonic Machining, MRR, Amplitude, Pressure, Design of Experiment.**

## I. INTRODUCTION

Glass fiber reinforced plastic (GFRP) composites have been widely used in engineering application such as automotive, aircraft and manufacture of spaceships and sea vehicles' industries due to their significant advantages over other materials. They provide high specific strength/stiffness, superior corrosion resistance, light weight construction, low thermal conductivity, high fatigue strength, ability to char and resistance to chemical and microbiological attacks. As a consequence of the widening range of applications of GFRP, the machining of these materials has become a very important subject for research [1, 2]. Machining composite materials is a rather complex task owing to their heterogeneity, anisotropy, and high abrasiveness of fibers, and it exhibits considerable problems in drilling process such as delamination, fiber pull-out, hole shrinkage, spalling, fuzzing and thermal degradation [3]. High speed machining (HSM) is an outstanding technology capable of improving productivity and lowering production costs in manufacturing companies. Rubio et al. [4] found the effect of high speed in the drilling of glass fiber reinforced plastic. The experimental results indicate that to obtain larger material removal rates associated with minimal delamination, higher spindle speeds should be used when drilling GFRP. Ramkumara et al. [5] studied effect of work piece vibration on drilling of glass/epoxy (GFRP) laminates using three types of drill, e.g. tipped WC, 2-flute solid carbide and 3-flute solid carbide. A UD-GFRP laminate of 4mm thickness was prepared and drilling was carried out using a vertical drilling machine. The result indicate that (I) Giving small amplitude low frequency vibration to work piece results in much better drill performance in drilling of GFRP laminates. (II) The number of holes that can be drilled with vibrating work piece before drill performance deteriorates is much larger than for conventional drilling. (III) Hole quality is improved and delamination reduced when work piece is given a small amplitude low frequency vibration. Thrust force is an important factor leading to propagation of delamination during drilling process. One of effective methods to reduce machining forces is application of ultrasonic vibrations. Mehbudi et al. [6] applying ultrasonic vibration to decrease drilling induced delamination in GFRP laminates. A setup for making holes in composite laminates was designed and fabricated which was capable of giving rotation and ultrasonic vibration to drill bits. It was concluded that increasing vibration amplitude may thrust force and delamination damage significantly. The results of ultrasonic assisted drilling were compared with conventional drilling results. This comparison showed applying ultrasonic vibrations during drilling GFRP laminate may reduce the drilling thrust force and drilling-induced delamination up to 50 per cent. It was observed that using ultrasonic vibration is an effective method to improve hole quality in drilling of GFRP laminates. B.V.Kavad et al. [7] review paper shows that Pure ultrasonic machining for drilling on GFRP can be investigated.

## II. DESIGN OF EXPERIMENT

Design of experiments (DOE) is a systematic, rigorous approach to engineering problem-solving that applies principles and techniques at the data collection stage so as to ensure the generation of valid, defensible, and supportable engineering conclusions.

- DOE is a formal mathematical method for systematically planning and conducting scientific studies that change experimental variables together in order to determine their effect of a given response.
- DOE makes controlled changes to input variables in order to gain maximum amounts of information on cause and effect relationships with a minimum sample size.
- DOE is more efficient that a standard approach of changing “one variable at a time” in order to observe the variable’s impact on a given response.
- DOE generates information on the effect various factors have on a response variable and in some cases may be able to determine optimal settings for those factors. DOE encourages “brainstorming” activities associated with discussing key factors that may affect a given response and allows the experimenter to identify the “key” factors for future studies.

Four elements associated with DOE:

1. The design of the experiment.
2. The collection of the data,
3. The statistical analysis of the data, and
4. The conclusions reached and recommendations made as a result of the experiment.

Planning a DOE

- Everyone involved in the experiment should have a clear idea in advance of exactly what is to be studied, the objectives of the experiment and the results anticipated.
- Select a response/dependent variable (variables) that will provide information about the problem under study and the proposed measurement method for this response variable, including an understanding of the measurement system variability.
- Select the independent variables/factors (quantitative or qualitative) to be investigated in the experiment, the number of levels for each factor, and the levels of each factor chosen either specifically (fixed effects model) or randomly (random effects model).
- Choose an appropriate experimental design (relatively simple design and analysis methods are almost always best) that will allow your experimental questions to be answered once the data is collected and analyzed, keeping in mind tradeoffs between statistical power and economic efficiency. At this point in time it is generally useful to simulate the study by generating and analyzing artificial data to insure that experimental questions can be answered as a result of conducting your experiment.
- Perform the experiment (collect data) paying particular attention such things as randomization and measurement system accuracy, while maintaining as uniform an experimental environment as possible. How the data are to be collected is a critical stage in DOE.
- Analyze the data using the appropriate statistical model insuring that attention is paid to checking the model accuracy by validating underlying assumptions associated with the model. Be liberal in the utilization of all tools, including graphical techniques, available in the statistical software package to insure that a maximum amount of information is generated.
- Based on the results of the analysis, draw conclusions/inferences about the results, interpret the physical meaning of these results, determine the practical significance of the findings, and make recommendations for a course of action including further experiments.

In this paper, the experimental data obtained by conducting experiments to produce holes using ultrasonic machining process on Glass Fiber Reinforced Plastic is analyzed using Design of Experiment to find the significance of process parameters.

## III. DESIGN OF EXPERIMENT FOR ULTRASONIC DRILLING ON GFRP

A full factorial design of experiment with replication is used with three control factors – amplitude, pressure and thickness of the GFRP sheet. Three values selected for the low, medium and high level for each of the control parameters as listed in Table 1. The amplitude is varied in terms of percentage of amplitude delivered at full power by the converter.

Table 1. Parameters and their Levels

| Amplitude | Pressure | GFRP Thickness |
|---|---|---|
| A1 = 70% | P1 = 1 bar | t1 =1.3 mm |
| A2 = 80% | P2 = 2 bar | t2 =2 mm |
| A3 = 90% | P3 = 3 bar | t3 = 2.3 mm |

Material removal rate (MRR), is selected as response parameters. Conical sonotrode is designed and manufactured as amplitude of propagated sound wave is inversely proportional to the cross-sectional area in solids. The shape of the tool is obtained at the end of the sonotrode itself. An approximate gain of 3 is selected for the sonotrode. The design of the sonotrode is carried out using CARD (Computer Aided Resonator Design) software.

The detailed procedure followed for ultrasonic drilling is described as under:

1. Select GFRP sheet and measure its weight.
2. Melt the mounting wax in beaker and pour it in Petri-dish.
3. Place the GFRP sheet having aluminum foil attached at its bottom in wax and allow curing.
4. Make buzzer-LED circuit by connecting with 9 volt D.C. Battery. join one end with horn and another with aluminum foil which is placed between work and support plate.
5. Prepare slurry having 27% concentration.
6. Prepare slurry agitation system in the tank for getting uniform density of slurry.
7. Securely tighten the sonotrode.
8. Start slurry circulation and adjust the flow.
9. Set the control parameters.
10. Start vibrations using foot switch.
11. Start machining holding Petri-dish in hand.
12. Machining is completed when through cut is obtained.
13. Record machining time using stopwatch.
14. Switch off slurry pump and clean the blank by washing it in Acetone.
15. Remove work piece from Petri-dish.
16. Measure the weight of cut blank and slide
17. Note down the data in the observation table and marked on the sample and blank.
18. Repeat process for all the samples.

## IV. DATA COLLECTION OF ULTRASONIC DRILLING

The experimental results are listed in Table 2. The measurements during the replications are presented in columns with suffix 1 for first set and suffix 2 for second set. The material removed on weight basis is obtained by subtracting the sum of mass of blank and mass of slug from the mass of GFRP sheet before machining. The MRR is then obtained in terms of volumetric material removal rate by taking density of GFRP.

Table 2. Experimental result

| Sr. No. | Thickness mm | Amplitude micron | Pressure bar | MRR $H_1$ $mm^3/min$ | MRR $H_2$ $mm^3/min$ |
|---|---|---|---|---|---|
| 1 | 1.3 | 36.82 | 1 | 28.460 | 34.211 |
| 2 | 1.3 | 36.82 | 2 | 38.015 | 38.454 |
| 3 | 1.3 | 36.82 | 3 | 28.409 | 38.186 |
| 4 | 1.3 | 42.08 | 1 | 30.823 | 42.872 |
| 5 | 1.3 | 42.08 | 2 | 23.514 | 45.605 |
| 6 | 1.3 | 42.08 | 3 | 38.010 | 43.516 |
| 7 | 1.3 | 47.34 | 1 | 33.628 | 45.745 |
| 8 | 1.3 | 47.34 | 2 | 38.226 | 56.566 |
| 9 | 1.3 | 47.34 | 3 | 31.140 | 64.024 |
| 10 | 2 | 36.82 | 1 | 13.508 | 15.121 |
| 11 | 2 | 36.82 | 2 | 14.441 | 17.503 |
| 12 | 2 | 36.82 | 3 | 16.815 | 15.507 |
| 13 | 2 | 42.08 | 1 | 25.802 | 22.371 |
| 14 | 2 | 42.08 | 2 | 26.192 | 27.374 |
| 15 | 2 | 42.08 | 3 | 29.632 | 26.976 |
| 16 | 2 | 47.34 | 1 | 37.998 | 35.561 |
| 17 | 2 | 47.34 | 2 | 40.785 | 35.418 |
| 18 | 2 | 47.34 | 3 | 44.995 | 38.331 |
| 19 | 2.3 | 36.82 | 1 | 14.778 | 15.337 |
| 20 | 2.3 | 36.82 | 2 | 20.179 | 10.560 |
| 21 | 2.3 | 36.82 | 3 | 17.603 | 13.834 |
| 22 | 2.3 | 42.08 | 1 | 21.707 | 25.972 |
| 23 | 2.3 | 42.08 | 2 | 24.250 | 28.928 |
| 24 | 2.3 | 42.08 | 3 | 24.908 | 27.227 |
| 25 | 2.3 | 47.34 | 1 | 27.170 | 27.552 |
| 26 | 2.3 | 47.34 | 2 | 26.750 | 28.299 |
| 27 | 2.3 | 47.34 | 3 | 31.734 | 30.123 |

## V. ANALYSIS OF VARIANCE (ANOVA)

The Analysis of variance is the most frequently applied of all statistical analyses. Analysis of variances are used extensively in many areas of research, such as psychology, biology, medicine, education, sociology, engineering, anthropology, economics, political science, as well as in industry and commerce.

Analysis of variance for MRR, is carried out using MINITAB software for experimental data obtained during ultrasonic drilling of GFRP as listed in Table 2. 3-Way ANOVA technique is used for determining level of significance for individual parameter effect as well as interaction effect of combination of input parameters. Results are represented in Table 3 for MRR. Fig. I shows the main effects of control variables on MRR and Fig. II shows the interaction effect of control variables on MRR.

Table 3 ANOVA (3-Way) For MRR, Using Adjusted SS For Ultrasonic Drilling

Analysis of Variance for MRR mm3/min, using Adjusted SS for Tests

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| THICKNESS | 2 | 2418.56 | 2418.56 | 1209.28 | 24.85 | 0.000 |
| AMPLITUDE | 2 | 2227.05 | 2227.05 | 1113.52 | 22.88 | 0.000 |
| PRESSURE | 2 | 112.71 | 112.71 | 56.35 | 1.16 | 0.329 |
| THICKNESS*AMPLITUDE | 4 | 343.24 | 343.24 | 85.81 | 1.76 | 0.165 |
| THICKNESS*PRESSURE | 4 | 17.52 | 17.52 | 4.38 | 0.09 | 0.985 |
| AMPLITUDE*PRESSURE | 4 | 40.65 | 40.65 | 10.16 | 0.21 | 0.931 |
| THICKNESS*AMPLITUDE*PRESSURE | 8 | 73.34 | 73.34 | 9.17 | 0.19 | 0.990 |
| Error | 27 | 1313.79 | 1313.79 | 48.66 | | |
| Total | 53 | 6546.86 | | | | |

## VI. EFFECT OF THICKNESS, AMPLITUDE AND PRESSURE ON MRR

From the results for ANOVA of Data Means for MRR listed in Table 3 and main effects plot shown in Fig 1. It is clearly observed that thickness and amplitude are the most significantly affecting factor for MRR in ultrasonic drilling of glass fiber reinforcing plastic and pressure is not significant factor. F-value and p-value from the ANOVA table also shows that thickness is most significant compared to amplitude and thickness. It is also observed from the Fig. 1. that MRR decrease as the thickness increase and MRR increases as the amplitude and pressure increases. Also observed that MRR decreases non linearly with the thickness but MRR increases almost linearly with the increase in amplitude and pressure. Fig. 2 Interaction Plot: Data means for MRR shows that the lower thickness have higher MRR as compared to higher thickness and as the amplitude and pressure is increased MRR is increased for the same thickness of GFRP sheet. It is also shows that as the pressure is increased MRR is increased for the same amplitude. Table 3 ANOVA (3-WAY) for MRR, using adjusted SS for Ultrasonic Drilling shows that no one interaction is significant for the MRR.

With increase in thickness the friction between the abrasive particles and side surfaces of the work as well as the returning abrasive particles and debris may increases substantially which leads to sharp decrease in MRR.

Fig. 1 Main Effect Plot: Data means for MRR

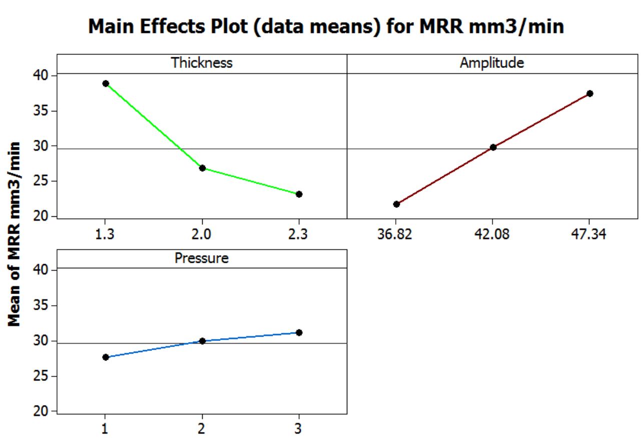
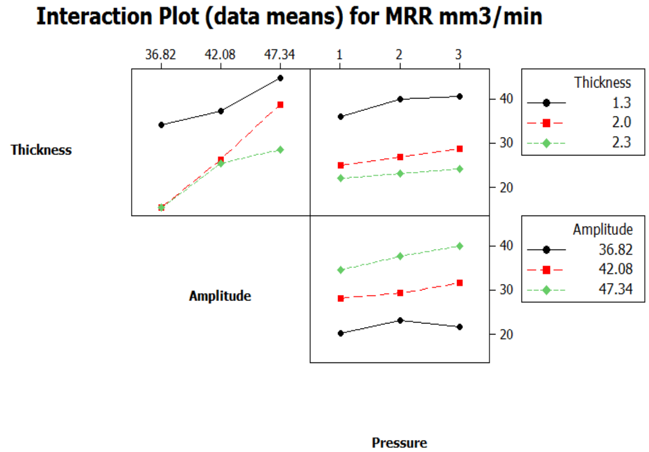



Fig. 2 Interaction Plot: Data means for MRR




The increase in MRR with increase in amplitude may be attributed to the higher momentum imparted to the abrasive particles before striking the work piece at higher amplitudes. The larger momentum increases the energy with which the abrasive particles collide with the work surface and hence the size of the micro-crack or micro-crater created by each impact. This in turn increases the MRR.

The increase in pressure, increases the force with which the abrasive particles hit the work piece surface causing an increase in the impact generated at the work surface. This leads to increase in the MRR with increase in pressure.

## VII. CONCLUSIONS

It is clearly observed that thickness and amplitude are the most significantly affecting factor for MRR in ultrasonic drilling of glass fiber reinforcing plastic and pressure is not significant factor. MRR decrease as the thickness increase and MRR increases as the amplitude and pressure increases. Also observed that MRR decreases non linearly with the thickness but MRR increases almost linearly with the increase in amplitude and pressure. Interaction Plot for MRR shows that the lower thickness have higher MRR as compared to higher thickness and as the amplitude and pressure is increased MRR is increased for the same thickness of GFRP sheet. It also shows that as the pressure is increased MRR is increased for the same amplitude.

## REFERENCES

[1] ASM Handbook (2002). Volume: 21 composites (pp. 27–34, 940, 951). USA.

[2] Pihtili, H., & Tosun, N. (2002). Investigation of the wear behaviour of a glass-fibrereinforced composite and plain polyester resin. Composites Science and Technology, 62, 367–370.

[3] Faraz A, Biermann D and Weinert K. Cutting edge rounding: an innovative tool wear criterion in drilling CFRP composite laminates. Int J Mach Tools Manuf 2009; 49: 1185–1196.

[4] J. Campos Rubioa,_, A.M. Abraoa, P.E. Fariaa, A. Esteves

Correiab, J. Paulo Davimc. Effects of high speed in the drilling of glass fibre reinforced plastic: Evaluation of the delamination factor. International Journal of Machine Tools & Manufacture 48 (2008) 715–720.

[5] J. Ramkumara, S.K. Malhotra R. Krishnamurthy. Effect of work piece vibration on drilling of GFRP laminates. Journal of Materials Processing Technology 152 (2004) 329–332.

[6] P. Mehbudia, V. Baghlania, J. Akbaria, A.R. Bushroab, N.A. Mardib. Applying ultrasonic vibration to decrease drilling-induced delamination in GFRP laminates. Procedia CIRP 6 ( 2013 ) 578 – 583.

[7] B. V. Kavad, A.B.Pandey, M.V.Tadavi, H.C.Jakharia , A Review Paper on, “Effects of Drilling on Glass Fiber Reinforced Plastic”, Procedia Technology 14 (2014 ) 457 – 464.

[8] K.S.Vaghosi and B. V. Kavad. Modeling Ultrasonic Machining Process using Fuzzy Inference System. International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS) Volume VI, Issue VI, June 2017 | ISSN 2278-2540