

THE OPTIMIZATION OF DRILLING PARAMETERS OF GLASS FIBER REINFORCED PLASTICS VIA TAGUCHI METHOD

İlknur Çavuşoğlu¹, Mustafa Çakir², Numan M. Durakbasa³, Eva Maria Walcher⁴

¹Assis. Prof. Dr., Marmara University Istanbul, ilknur@marmara.edu.tr

²Assis. Prof. Dr., Marmara University Istanbul, mcakir@marmara.edu.tr

³Prof.Dr., Vienna University of Technology, AuM, numan.durakbasa@tuwien.ac.at

⁴Dipl.Ing., Vienna University of Technology, AuM, eva.walcher@tuwien.ac.at

ABSTRACT

In the competitive world today, increasing importance of conservation of energy have directed designers and engineers into search for light and mechanically high resistant material when choosing material. Glass Fiber Reinforced Plastics (GFRP) are polymer based materials made of reinforced with fiber glass. GFRPs are strong and light, showing resistance characteristics similar to metallic materials. Furthermore, the rates of the density of strength of materials are higher in comparison to metallic material. Therefore, their use has been increasing in aviation industry, wind power plant and marine applications every passing day. Assembly based process stages are used especially in aviation industry and wind power plant. In order to assemble, making a hole by drilling or CNC milling are common methods. So as to manufacture products in the required quality in making a hole in the GFRP, it is necessary to optimize cutting performance and conditions. This study aims at evaluating delamination factor in the GFRP.

This study focuses on investigation, analysis and evaluation of the delamination factor in the GFRP using high precision metrology techniques that have been an indispensable part of the advanced production engineering. The parameters affecting the quality and accuracy of the workpieces are defined and experimental measurements are carried out to develop procedures in order to improve the quality and accuracy of the workpieces and machining processes.

Keywords: Glass fiber reinforced plastic - GFRP, drilling, Taguchi method, ANOVA, quality, accuracy

1. INTRODUCTION

The changes in the advanced production industry with intensified high quality and complex product realization face new challenges. To overcome these challenges, there is a strong need for precise production technology.

Today, the general principles of quality management with various efficient tool, methods and techniques are introduced to offer the manufacturing industry efficient and low cost operation. Quality management systems in compliance with the international standards of the ISO 9000 series provide the guideline for establishing an integrated management system that solves the organizational challenges of efficiency and quality [1,2].

Modern machining processes continuously face cost pressures and high quality expectations. To remain competitive a company must continually identify cost reduction opportunities in production, exploit economic opportunities, and continuously improve production processes [3]. At the same time, the products of the next generation manufacturing with significant complexity of geometry and material require tighter tolerances and quality specifications, which put an increasing importance of modern precision metrology applications. Thus, high precision metrology has become of high priority at the implementation of crucial requirements for quality of products [4].

Both designed system and developed product are desired to reach having maximum performance in engineering research and development works. Properties which are introduced qualifications, obtained maximum performance, are firstly determined and then are investigated the factors which influence the properties. Experiments are made for identifying effects of factors which are specified properties on the performance and finding the most proper combination. Obtained performance indicators are evaluated at the end of performed experiment, so that optimum conditions are attained.

Taguchi's design of experiment is a successful method in the solution of the optimization problem. With Taguchi's applications, do not only provide the solution with the lowest number of experiments, but also they support high quality process and the development a product in every respect. Concordantly, the method is not a statistical approach, it is a technic which could be used in all research and development actions, raises quality, reduces cost, and makes firm of reliability of results.

Although, the products, which are manufactured from GFRP have got desired formal and positional precision (wholeness), assembling is usually required for getting final product by GFRP Drilling on composites materials is a popular demand for making assembly.

2. MACHINING OF COMPOSITE MATERIALS

Drilling process takes part 40 % in machining process [5]. Some kind of problems occurs while drilling the composites. The problems are delamination and fibre breakage. The holes are required to have fine surface quality in mechanical assembling with screw and rivet. The holes' surface quality forms surface roughness and dimensional precision [6]. Occurred damage on the holes' area is a significant problem for composite materials. To prevent this to happen; working piece, cutting tool and cutting parameters take a huge part [7]. According to the researches, which have made before, the surface quality of the hole depends on cutting parameters, tool geometry and cutting force [8]. The delamination on the material affects the product's quality. Studies about drilling of composite materials are still being made to prevent the delamination and decrease the damage of delamination, in engineering and in research – development.

The delamination factor is determined, which is given by;

$$Fd = \frac{D_{max}}{D_0} \quad [6, 12]$$

where D_{max} is the maximum diameter of the damaged zone and D_0 is the diameter of the hole [6, 12].

Canpolat used HSS and carbide drill bit in the study about drillability of GFRP materials. When HSS is used, surface roughness increases, on the other hand it decreases with usage of carbide. Additionally, the best surface quality was obtained by using carbide drill bits [9].

Karnik et al., investigated about delamination while fibre material was drilled with higher spindle speed. Carbide drill bits which had 25° helix angle, 130°, 115° and 85° point angle were used in the experiment. It was obtained that delamination increased using higher point angle drill bits [10].

Chen, had focused on tool's geometry and cutting parameters effects on delamination factor and mentioned that feed rate has got powerful effects on cutting forces [11].

Kilickap, worked on GFRP composite for evaluating of influence the cutting parameters which were cutting speed and feed rate. In the study, the effects of cutting parameters and point angles were observed that the delamination factor increased at the same cutting parameters with the higher point angles [12].

Mohan et al., identified, by using Taguchi's optimisation method, that the lowest delamination factor occurred when lower feed rate and higher spindle speed were used on the drilling process of GFRP. The results were verified via ANOVA analyses [13].

During some of the studies on delamination factors, researchers didn't only analyse the cutting parameters, but also the tool geometry. Elisa et al., worked on the affects of cutting parameters, tool geometry and fiber orientation on delamination with GFRP material. At the end of the research, it is mentioned that delamination factor decreased, increasing of rotation and drill bit geometry [14].

Bhatnagar and et al. determined that cutting parameters and tool geometries had important influences on drilling of glass fibre reinforced composite materials [15].

3. EXPERIMENTAL STUDY

In this study, glass Fiber Reinforced Plastic, which includes % 30 glass fiber, was produced by Vacuum Assisted Resin Transfer Molding (VARTM). Here, evaluation of delamination factor was done through Taguchi's design of experiment method (1 factor 2 level and 3 factors 3 level with L18 matrix various cutting parameters). Depending on surface condition of drill bit, drill diameter, cutting speed and feed rate, it was drilled and it was determined at which parametric values this material was produced at the required quality. % 30 unmodified GFRP was drilled without using any cooling liquid by JohnFord VMC-550A CNC machining centre. This machine could operate (work) 60 – 6000 rpm spindle speed and 0 – 4000 mm/min cutting feed rate. The measurements were made by Zeiss SteReo Discovery V20 microscope [16] which was equipped to PlanApo S 1.0x 60 mm objective and Zeiss AxioCam Icc 5 camera. Magnification of the microscope characterized with the properties is

maximum 150x and its maximum resolution is 2,33 μm . In the study, all the holes and the damage around the holes were measured with 13x magnification. A delamination measurement view and the microscope are shown in figure 1.



Figure 1: The delamination measurement view using optical stereomicroscopy [16]

In table 1, Taguchi's L18 experiment matrix and in table 2, 2 level 1 factor and 3 level 3 factors for Taguchi experiment plan are shown. In this study, deformation on the GFRP, which was occurred after drilling, was interpreted by using delamination that was evaluation method. Delamination factor which was output of drilling process made with coated and uncoated, 4, 5, and 6 mm diameter, machining tools, was calculated by measuring hole diameter and maximum diameter which was deformation area diameter around the hole.

Table 1. Taguchi's L18 Experiment Matrix

Experiment	Factors and Levels			
	A	B	C	D
	Surface Condition	Drill Diameter (mm)	Spindle Speed (rpm)	Feed Rate (mm/min)
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	2
5	1	2	2	3
6	1	2	3	1
7	1	3	1	1
8	1	3	2	2
9	1	3	3	3
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	3
14	2	2	2	1
15	2	2	3	2
16	2	3	1	2
17	2	3	2	3
18	2	3	3	1

Table.2 Levels of the variables used in the experiment plan

Factors	Unit	1. Level	2. Level	3. Level
1 (A) Surface Condition		TiN	Uncoated	-
2 (B) Drill Diameter	(mm)	4	5	6
3 (C) Spindle Speed	(rpm)	2000	2800	3600
4 (D) Feed Rate	(mm/min)	240	480	720

Taguchi improved series of statistical methods which were to use as a performance criterion, calling as a signal to noise ratio, for aim of reducing variation in design of experiment. The obtained experimental results are transformed into a signal /noise (S/N) ratio to evaluate in the experimental design method. Taguchi classified problems, in the usage, into three categories according to the type of target and identified different a signal/noise ratio for each them. The categories are “the – lower – better”, “the – higher – better” and “the – nominal – better. The aim is the level with the greatest S/N ratio in each of kind three problems. In this manner, the value which has the greatest S/N ratio gives the best performance in experiments [17, 18, and 19].

In this case study, delamination factor which was worked out according to performed experiment result from characteristic of output by selected factors should have been the lowest value, therefore “the lower – better” was utilized for computation of S/N ratio in the analysis of the experiments. The S/N ratio of the smaller the better characteristic is presented as follows;

$$\eta = -10 \log_{10} \left[\frac{1}{n} * \sum_{i=1}^n y_i^2 \right] \quad [18]$$

S/N ratio values which were calculated based on “the lower – better” approach for both % 30 modified GFRP materials are given in table 3.

Table 3. Experiment result and S/N ratio according to Taguchi L18 DoE

Experiment	Factors and Levels				Delamination Factor F_d	S/N Ratio (dB)
	A	B	C	D		
	Surface Condition	Drill Diameter (mm)	Spindle Speed (rpm)	Feed Rate (mm/min)		
1	TiN	4	2000	240	1,085391	-0,713654
2	TiN	4	2800	480	1,254092	-2,02026
3	TiN	4	3600	720	1,117241	-0,963764
4	TiN	5	2000	480	1,349707	-2,63127
5	TiN	5	2800	720	1,314851	-2,39073
6	TiN	5	3600	240	1,077338	-0,648162
7	TiN	6	2000	240	1,200883	-1,66313
8	TiN	6	2800	480	1,180317	-1,46697
9	TiN	6	3600	720	1,126826	-1,03844
10	Uncoated	4	2000	720	1,473711	-3,37229
11	Uncoated	4	2800	240	1,075770	-0,635365
12	Uncoated	4	3600	480	1,102057	-0,847205
13	Uncoated	5	2000	720	1,371761	-2,77399
14	Uncoated	5	2800	240	1,086541	-0,747357
15	Uncoated	5	3600	480	1,085332	-0,712597
16	Uncoated	6	2000	480	1,157073	-1,27595
17	Uncoated	6	2800	720	1,133537	-1,09149
18	Uncoated	6	3600	240	1,092673	-0,774513

4. RESULTS

Figure 2 is shown that both spindle speed and feed rate changing were influenced on the delamination. The lowest delamination was obtained with feed rate 240 (mm/min) and spindle speed 3600 (rpm).

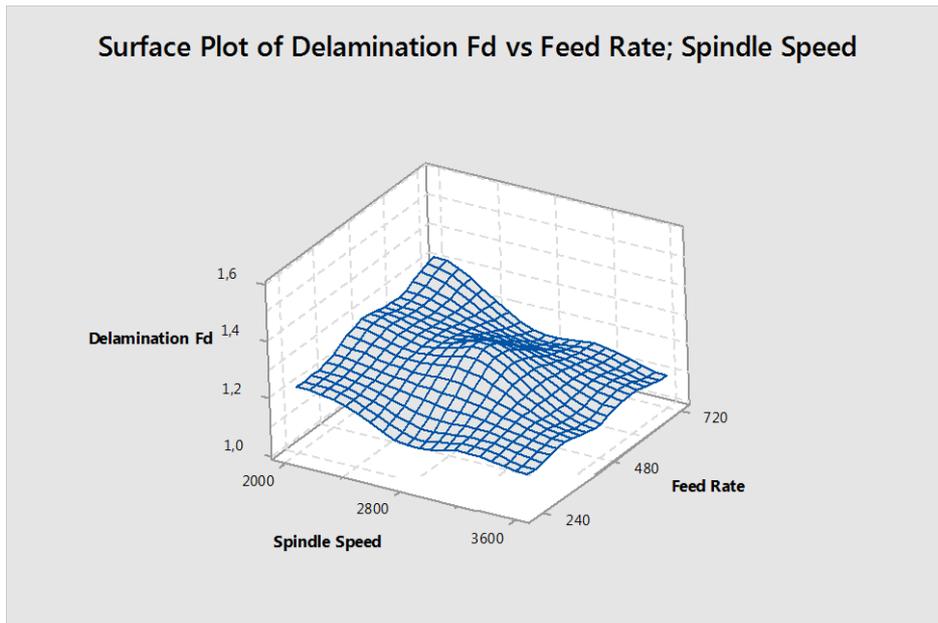


Figure 2: Spindle speed and feed rate changing were influenced on the delamination.

Spindle speed and feed rate were more important factors in the four chosen factors as shown in figure 3 for 30 % unmodified. Operating tools which were TiN coated and uncoated on the % 30 unmodified part's delamination wasn't influential factor. It could be seen that choosing the highest spindle speed (3600 rpm), the lowest feed rate (240 mm/min), the biggest drill diameter (6 mm) and uncoated surface condition results in the optimum factor level combination for getting lowest delamination while drilling process.

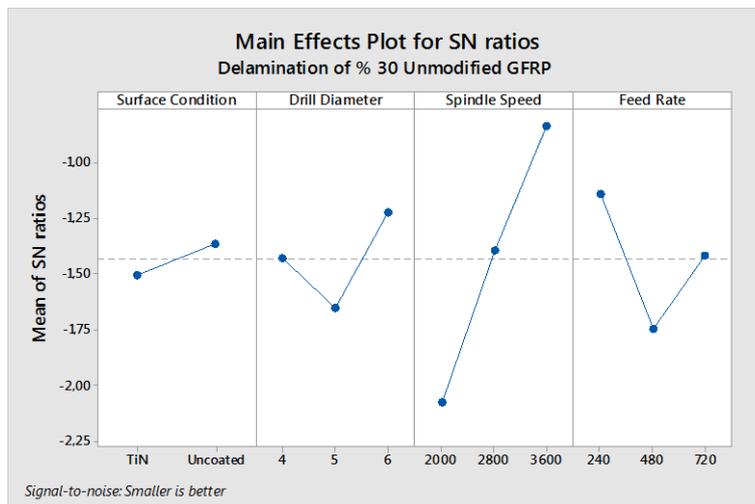


Figure 3: Main effects plot for % 30 unmodified GFRP

The intended results were achieved with one-third of experiment numbers by Taguchi design of experiment instead of using full factorial analyse. If full factorial analyse had been used in the study, it would have been made 162 experiments instead of 54.

5. CONCLUSION

The developments in the manufacturing industry bring the challenges of next generation technology challenges of product quality control and quality assurance. The solution to overcome these challenges lays in the modern metrological applications.

This study focuses on investigation, analysis and evaluation of the delamination factor in the GFRP using high precision metrology techniques that have been an indispensable part of the advanced production engineering. According to pre-determined matrix depending on Taguchi DoE, carrying out as few experiments as possible, the optimum values with the minimum of delamination are determined. Consequently, with these values in all sectors use of free of damage and delayed damage will be achieved.

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