Konya Mühendislik Bilimleri Dergisi, c. 11, s. 1, 160-179, 2023
Konya Journal of Engineering Sciences, v. 11, n. 1, 160-179, 2023
ISSN: 2667-8055 (Electronic)
DOI: 10.36306/konjes.1186888

INVESTIGATION OF DRILLING PERFORMANCE OF REINFORCED POLYAMIDE 6 POLYMER COMPOSITE

[1]Abdurrahman GENÇ, [2*]Ferhat YILDIRIM, [3]Murat KOYUNBAKAN, [4]Salih Hakan YETGİN, [5]Volkan ESKİZEYBEK, [6]Gözde KUŞ

[1,6] *Kütahya Dumlupınar University, Institute of Science, Advanced Technologies Department, Kütahya, TÜRKİYE*
[2] *Çanakkale Onsekiz Mart University, Biga Vocational School, Machine and Metal Technologies Department, Çanakkale, TÜRKİYE*
[3] *Kütahya Dumlupınar University, Simav Technology Faculty, Mechanical Engineering Department, Kütahya, TÜRKİYE*
[4] *Tarsus University, Engineering Faculty, Mechanical Engineering Department, Mersin, TÜRKİYE*
[5] *Çanakkale Onsekiz Mart University, Engineering Faculty, Material Science and Engineering Department, Çanakkale, TÜRKİYE*
[1]abdurrahman.genc@ogr.dpu.edu.tr, [2]ferhatyildirim@comu.edu.tr, [3]murat.koyunbakan@dpu.edu.tr, [4]shakanyetgin@tarsus.edu.tr, [5]veskizeybek@comu.edu.tr, [6]gozde__kus88@hotmail.com

Highlights

- Polyamides are preferred polymer materials for manufacturing industrial products due to their lightness, resistance to corrosion, ease of processing, and recyclability.
- The machinability properties of Polyamide 6 (PA6) polymer composite plates reinforced with chopped carbon fiber (CF) and multi-walled carbon nanotube (MWCNT) in different proportions were investigated by the drilling method using different cutting tools and cutting parameters.
- Multi-response Taguchi optimization shows successful approach to obtaining minimum Ra, inlet, and outlet deformation.
- High cutting speed and low feed rate are ideal parameters to achieve low Ra and low inlet-outlet deformations.
- The particle addition made to the PA6 polymer reduced the Ra.
- MWCNT has more positive effect on both reducing Ra and reducing inlet-outlet deformations compared to the CF.

Graphical Abstract

Material Manufacturing   Drilling   Analysis   Results

Flowchart of the applied experimental method

***Corresponding Author:** Ferhat YILDIRIM, ferhatyildirim@comu.edu.tr

Konya Mühendislik Bilimleri Dergisi, c. 11, s. 1, 160-179, 2023
Konya Journal of Engineering Sciences, v. 11, n. 1, 160-179, 2023
ISSN: 2667-8055 (Electronic)
DOI: 10.36306/konjes.1186888

INVESTIGATION OF DRILLING PERFORMANCE OF REINFORCED POLYAMIDE 6 POLYMER COMPOSITE

[1]Abdurrahman GENÇ, [2*]Ferhat YILDIRIM, [3]Murat KOYUNBAKAN, [4]Salih Hakan YETGİN, [5]Volkan ESKİZEYBEK, [6]Gözde KUŞ

[1,6] *Kütahya Dumlupınar University, Institute of Science, Advanced Technologies Department, Kütahya, TÜRKİYE*
[2]*Çanakkale Onsekiz Mart University, Biga Vocational School, Machine and Metal Technologies Department, Çanakkale, TÜRKİYE*
[3] *Kütahya Dumlupınar University, Simav Technology Faculty, Mechanical Engineering Department, Kütahya, TÜRKİYE*
[4] *Tarsus University, Engineering Faculty, Mechanical Engineering Department, Mersin, TÜRKİYE*
[5] *Çanakkale Onsekiz Mart University, Engineering Faculty, Material Science and Engineering Department, Çanakkale, TÜRKİYE*
[1]abdurrahman.genc@ogr.dpu.edu.tr, [2]ferhatyildirim@comu.edu.tr, [3]murat.koyunbakan@dpu.edu.tr, [4]shakanyetgin@tarsus.edu.tr, [5]veskizeybek@comu.edu.tr, [6]gozde__kus88@hotmail.com

(Geliş/Received: 10.10.2022; Kabul/Accepted in Revised Form: 12.12.2022)

ABSTRACT: Polyamides are preferred polymer materials for manufacturing industrial products due to their lightness, resistance to corrosion, ease of processing, and recyclability. In this study, the machinability properties of Polyamide 6 (PA6) polymer composite plates reinforced with chopped carbon fiber (CF) and multi-walled carbon nanotube (MWCNT) in different proportions were investigated by the drilling method using different cutting tools and cutting parameters. The experiments were carried out according to the L16 orthogonal array. Drilling experiments were carried out in a dry environment. The deformations occurring on the inlet and outlet surfaces of the drilled samples were calculated, and the surface roughness (Ra) of the hole walls was measured. According to the results obtained, the particle addition made to the PA6 polymer reduced the Ra. It has been observed that high cutting speed and low feed rate are ideal parameters to achieve low Ra and low inlet-outlet deformations.

Keywords: *Drilling, Polymer Composite, Optimization, Polyamide 6*

1. INTRODUCTION

In recent years, the use of materials with high-level properties has increased in many rapidly developing industries. Due to the fact that these materials are intended to be lightweight, studies on particle reinforced polymer composites are one of the current research topics [1-2]. Polyamide's (PA) is the most widely used semi-crystalline polymer type among engineering plastics due to its high strength/weight ratio, corrosion resistance, resistance to UV and gamma rays, very simple and economical production processes compared to conventional materials [3-7]. PA6 polymer are used in automotive, aviation, energy industries, in areas where flexibility as well as temperature and chemical resistance is required, packaging, household appliances, sport equipment's etc. [4-5]. However, due to the presence of polar amide groups, high moisture absorption, low dimensional stability, low heat deflection temperature, low impact resistance at low temperatures and sensitivity to heat with easy flammability limit the usage areas of PA polymer [7-8].

Although polymers and polymer composites are produced by molding methods, some machining operations are required to be transform them into the final product. Drilling is one of the most important

***Corresponding Author:** Ferhat YILDIRIM, ferhatyildirim@comu.edu.tr

machining operations and involves approximately 33% of the machining operations. Again, 25% of the total time spent in machining processes is spent as drilling [9]. In machining operations, the main target has always been to achieve optimum machining conditions in order to reduce cost and increase performance [9]. For example, while millions of holes are required for rivets and bolted connections in the manufacture of aircraft, delamination, and micro-cracking in the holes significantly reduce the performance of the composite material. In the aviation industry, 60% of all parts rejected during the final assembly of an aircraft structure are due to defects in drilling operations associated with delamination [10-11]. For this reason, the study of the quality and performance of holes in composite structures is of great importance when considering the large financial losses that they can cause and the irreparable loss of life.

To reduce or eliminate the problems encountered in the processing of composite materials, researchers are conducting different studies. These studies focus on issues such as cutting parameters, cutting conditions, tool geometries, and different cutting tool materials [12]. The including high data amount and the size of the number of variables be required complex statistical analysis in the improvement studies. Early in the 60s, Genichi Taguchi's new methodology is start to use due its success in improving all kind of industrial performance. The small number of experiments, easy implementation and easy evaluation of the variables are the features that increase the prevalence of the Taguchi method [13-16].

Composite materials can be produced as different combinations using different reinforcing materials, resin materials, and production methods. Different materials used in the production of composite materials improve these structures' mechanical, impact, thermal, and abrasion properties [4-5, 17]. However, it is necessary to investigate how the machining processes of these composite structures. Although there are many studies in the literature on the machining processes of composite materials, studies are generally carried out on drilling tests of layered polymer composite materials using thermoset resin.

[18] conducted a study using different cutting parameters and drill bit diameters to reduce the deformation that occurs when drilling glass fiber reinforced polyester composite materials. In addition to these parameters, [19] also took into account the fiber orientation angle. The effects of cutting parameters on surface quality were also examined in the studies conducted on machinability. It has been observed that increasing the number of cutting edges and decreasing the point angle reduce the damage factor on the entry surfaces [20]. It is believed that reducing the thrust forces and torque that occur in drilling experiments will reduce surface damage. The thrust force increases due to the increase in the feed rate and drill bit diameter [21-22]. As a result of increasing the number of revolutions and drill bit diameter, it is observed that the Ra of hole surface increases [23].

In the studies conducted on the machinability of reinforced and non-reinforced polyamide materials, the effects of cutting parameters and cutting tool geometries were investigated. [24] found that the increase on PA66 hole quality with the addition of glass fiber whiskers. On another study according to the findings it is said that tool wear is greater in machining of reinforced Polyamide 6 composite material [25]. [26] investigated the milling of multi-walled carbon nanotube reinforced Polyamide 6 composite. They pointed out the feed rate was most effective parameter on Ra. Low feed rate and high spindle speed were the best combination for obtaining good Ra. They explained that the multi-walled carbon nanotube slightly improved the surface quality compared to non-reinforced Polyamide 6. In experimental studies conducted with different drill bit materials, it is observed that the surface roughness of the drill bit material affects, and carbide was found the ideal drill bit material [27]. [28-29] investigated the hole quality, surface roughness in drilling of polyamide (PA6) and 30% glass fibers reinforced polyamide (PA66 GF30) using cemented carbide (K20) tool. The effects of cutting speed, feed rate, tip point was analyzed by response surface methodology based second order and third-order mathematical models. PA66 GF30 material provides better surface finish by employing low feed rate with low to medium speed for all the surface results compared to the neat PA6. Performed analysis also showed that the quality of holes can improved by employing higher spindle speed with low feed rate and point angle during drilling for both neat and reinforced polyamides. The drill bit temperature and chip formations were experimentally investigated in the drilling of neat and carbon black reinforced polyamide by [30]. According to the results, the drill bit temperature increased with increasing the cutting speed and with decreasing the feed for both polyamides. In addition, higher drill tip temperatures were observed in the drilling of carbon black reinforced polyamide compared to the neat polyamide. The regular chips were formed at low cutting speed and high feed rate values. In addition, the carbon black reinforced polyamide has created more uniform chips compared to neat polyamide due to the more heat was transferred to the drill bit from the drilling region.

According to the literature, composite reinforcement materials affect the properties of the production processes such as molding, machinability due to its characteristic properties in forming compounds. The exposure of production strategies to the effects of additive-based unknown variables constitutes an important node point that needs to be investigated in terms of efficiency. In this study, the machinability properties of carbon fiber (CF), and multi walled carbon nanotube (MWCNT) reinforced Polyamide 6 polymer composite materials were investigated by experimentally and statistically on drilling experiments. Inlet and outlet surface damages and hole wall surface roughness were examined in experiments conducted using different cutting speed, feed rate and four kind of drill bit materials. Manufactured composite used parameters and drill bit materials were not evaluated together in the literature before. Thus, it was aimed to contribute to the literature and production industry by examining its multivariate machinability processes of Polyamide 6 and that one of the highly used polymers in the industry.

2. MATERIAL AND METHOD

2.1. Materials

In the study, the used Polyamide 6 (PA6) polymer (Cas Number:25038-54-4) was purchased from the EMAŞ A.Ş. (Sumika Polymer Compounds, Bursa/Türkiye). Mechanical properties of PA6 according to the supplier were given in Table 1 (http://www.emasplastik.com.tr/). The chopped carbon fiber (CF) used as the micro sized filler was purchased with AC-4101 commercial code from DOWAKSA Advanced Composite Materials Industry (Yalova/Türkiye). The physical and mechanical properties of CF according to the supplier were given in Table 2 (https://www.dowaksa.com/tr). The multi-walled carbon nanotube (MWCNT) was used as the nano sized filler and purchased from DETSAN A.Ş. (Eskişehir/Türkiye). The technical properties of MWCNT according to the supplier were given in Table 3 (https://www.detsankimya.com.tr).

Table 1. Technical specifications of Polyamide 6 (PA6) [31].

Material	Polyamide 6
Density g/cm^3	1.12
Viscosity (%96 H_2SO_4)	2.40-2.80
Melting Temperature (°C)	220
Moisture absorption (23 °C, %50RH)	%2.50-3.50

Table 2. Technical specifications of Carbon fiber (CF) [32].

Material	Carbon Fiber
Tensile Strength (MPa)	4200
Modulus of Elasticity (Tensile) (MPa)	240
Elongation (%)	1.8
Density(g/m^3)	1.76
Fiber length (mm)	6
Typical bulk density (6 mm length) (G/l)	500
Emulsion type	Polyamide based

Table 3. Technical specifications of Multi Walled Carbon Nanotube (MWCNT) [33].

Material	Multi Walled Carbon Nanotube
Outer diameter (nm)	< 8
Inner diameter (nm)	2-5
Purity (%)	> 97
Length (μm)	10-30
Specific surface area (m^2/g)	500
Electrical conductivity (S/cm)	> 10^{-2}

2.2. Manufacturing of Composite Materials

Composite manufacturing process was designed according to the PA6 supplier, literature, and past studies of our study group [4-5] PA6 material was dried for 4 hours at 80 °C in the Nüve FN120 model oven before production due to its high moisture absorption property. The dried PA6 and CF materials were mixed using the mechanical mixing method in a dry form. In the mixture of MWCNT and PA6, the MWCNT solution prepared in alcohol essence was added to the polymer for maximum wetting and dispersion, and mechanical mixing was applied again, and then the alcohol was evaporated in the drying oven. Thus, it was tried to obtain homogeneous mixtures for both groups of materials. The materials prepared from the mixture were then passed through two different extruder processes and made into a composite mixture ready for final injection production. The extrusion process of the CF and PA6 mixture was carried out in a Coperion branded extruder with a screw diameter of 26 mm, an L/D ratio of 46, and 11 heat zones located in Gama-Alfa Plastic Co. İstanbul. The extruded polymer was cooled and then granulated again in the crusher. Materials prepared by mixing MWCNT and PA6 were produced in a co-rotating twin-screw extruder with a screw diameter of 22 mm, an L/D ratio of 32, and 6 heat sections located in Kütahya Dumlupınar University, Faculty of Engineering, Department of Mechanical Engineering. After the mixture of MWCNT and PA6 was also granulated in the crusher. In injection molding process, the polymer material heated around the ball screw melts and is mixed again thanks to the ball screw. Mixing the remelted material within itself again ensures that the unbalanced parts are dispersed. The polymer material pushed into the mold from the outlet nozzle at the end of the machine is produced here as the desired drilling sample plate. Figure 1 shows the production stages of a polymer composite material [4-5].

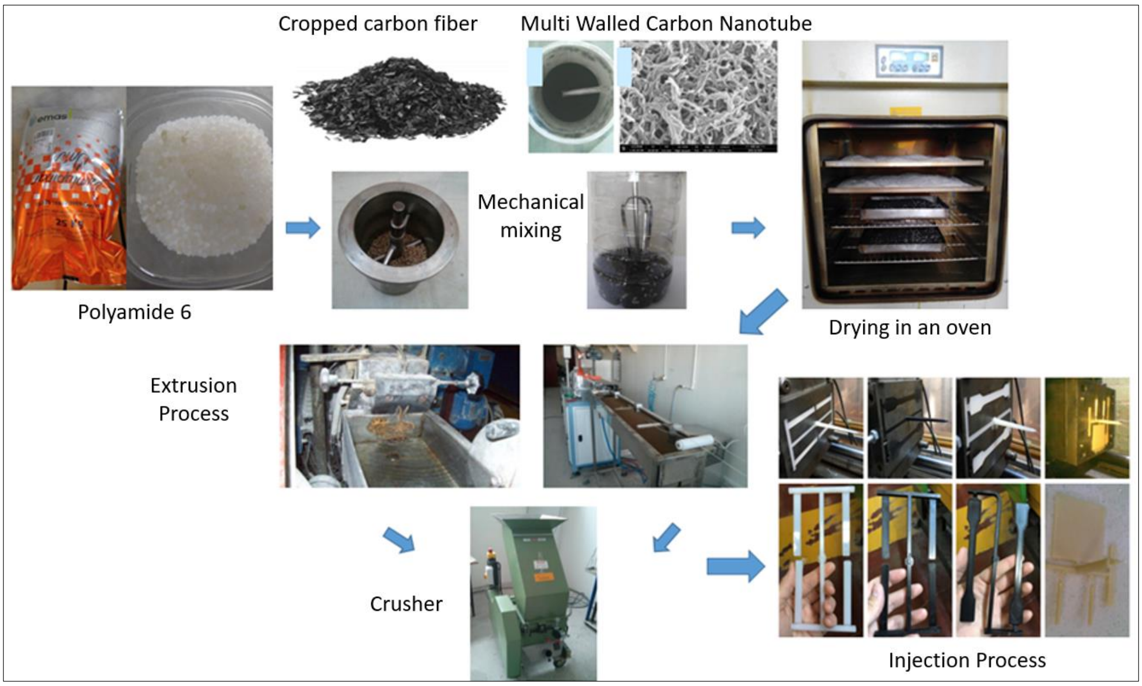

Figure1. Manufacturing process of PA6 composites.

Scanned Electron Microscopy (SEM) images of the reinforced PA6 composite samples are given in Figure 2 and Figure 3. Also, Table 4 shows the materials used in the experiments and their abbreviations. In the study, with PA6 polymer, 6 different samples were produced, including by weight 10%, 20%, and 30% CF added and 0.1%, 0.2%, and 0.3% MWCNT added composites. In addition, neat PA6 polymer was manufactured with the same procedure except reinforcement process.

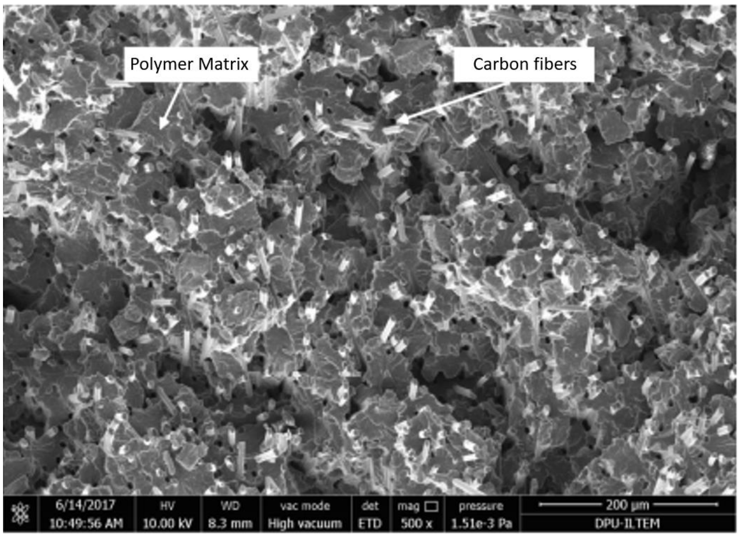

Figure 2. SEM images of CF reinforced polymer composite.

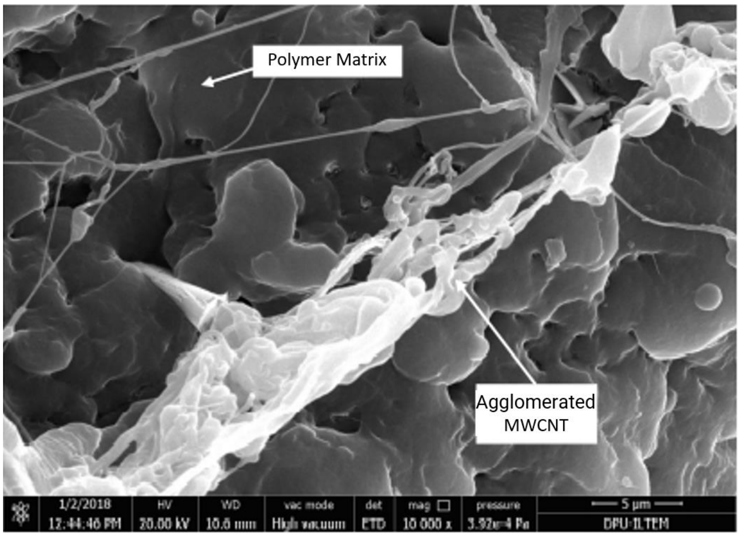

Figure 3. SEM images of MWCNT reinforced polymer composite.

Table 4. Experimental materials and their abbreviations.

Materials	Abbreviations
Polyamide 6	PA6
Polyamide 6 + 10 % wt. Carbon Fiber	PA6+10CF
Polyamide 6 + 20 % wt. Carbon Fiber	PA6+20CF
Polyamide 6 + 30 % wt. Carbon Fiber	PA6+30CF
Polyamide 6 + 0.1 % wt. Multi Walled Carbon Nanotube	PA6+0.1MWCNT
Polyamide 6 + 0.2 % wt. Multi Walled Carbon Nanotube	PA6+0.2MWCNT
Polyamide 6 + 0.3 % wt. Multi Walled Carbon Nanotube	PA6+0.3MWCNT

2.3. Experimental Study

Drilling experiments of all PA6 composite were carried out in the VMC850B branded CNC vertical machining center (Figure 4). The maximum number of revolutions of the machine is 8000 rpm, and drilling operations were carried out in a dry environment. Drilling experiments were carried out using different cutting speeds (40, 70, 100, and 130 m/min), feed rates (0.1, 0.2, 0.3, and 0.4 mm/rev), and drill bits material. High Speed Steel (HSS), Tungsten Carbide, Polished Tungsten carbide (cutting faces has been polished for composite materials), and Polly Crystal Diamond (PCD) are selected as drill bit materials. The diameter of all drill bits were 6 mm. Cutting parameters and drill materials were selected from the most widely used and preferred ones in the machining industry. It has been decisive in criteria such as cost and availability.

Figure 4. CNC Machining center.

Figure 5 shows the drill bits used in the study. The cutting parameters and the experimental design are given in Table 5. A L16 orthogonal experimental design was performed for drilling experiments, and the Taguchi method was used to determine the effects of the experimental parameters on machinability. Factor levels in the experimental design were determined as Cutting Speed (m/min) (A), Feed Rate (mm/rev) (B), and Drill bit Material (C).

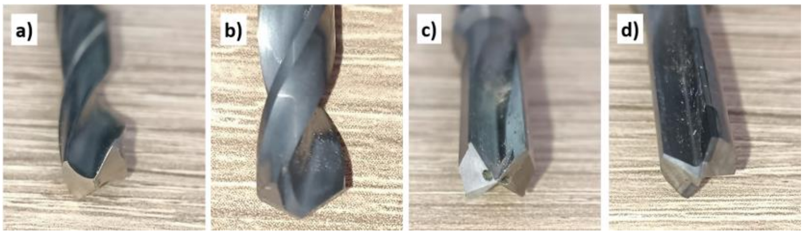

Figure 5. Drill bit materials: a) HSS, b) Tungsten carbide, c) Polished tungsten carbide, d) PCD.

Because of the drill bit materials data was non-numerical, they were assigned numerical values as 1, 2, 3, and 4 for HSS, Tungsten carbide, Polished tungsten carbide and PCD respectively for use in Taguchi. Thus, the meaning of each factor can be better interpreted in prediction and validation experiments. The recommendations of cutting tool providers and the literature have been considered in the selection of cutting parameters [18, 20-23, 27].

Table 5. L16 Orthogonal array.

Test No	Cutting Speed (m/min) (A)	Feed Rate (mm/rev) (B)	Drill bit Material (C)
1	40	0.1	HSS (1)
2	40	0.2	Tungsten carbide (2)
3	40	0.3	Polished tungsten carbide (3)
4	40	0.4	PCD (4)
5	70	0.1	Tungsten carbide (2)
6	70	0.2	HSS (1)
7	70	0.3	PCD (4)
8	70	0.4	Polished tungsten carbide (3)
9	100	0.1	Polished tungsten carbide (3)
10	100	0.2	PCD (4)
11	100	0.3	HSS (1)
12	100	0.4	Tungsten carbide (2)
13	130	0.1	PCD (4)
14	130	0.2	Polished tungsten carbide (3)
15	130	0.3	Tungsten carbide (2)
16	130	0.4	HSS (1)

The lowest results for Ra are detected from experiments with cutting parameters, and drill bits materials can be determined as optimal cutting conditions. As a result of the experiments, the TIME TR 200 surface roughness measuring device was used to measure the roughness of the inner walls of the hole on. The roughness measurements were performed perpendicular to the hole surface at 4 mm length with 3 repetitions on the prepared measuring setup [34]. The calibration of the device was checked before each measurement group. Optical images of the inlet and outlet surfaces of the holes were taken to detect surface deformations. An INSIZE brand optical microscope was used to take the images. D_{max} and D_{min} diameters were measured by image processing on obtaining images. Where D_{max} is maximum diameter of the delamination region and D_{min} is the diameter of the hole. The ratio of these values to each other gives the deformation factor [14-15]. The performed experimental study are given in Figure 6.

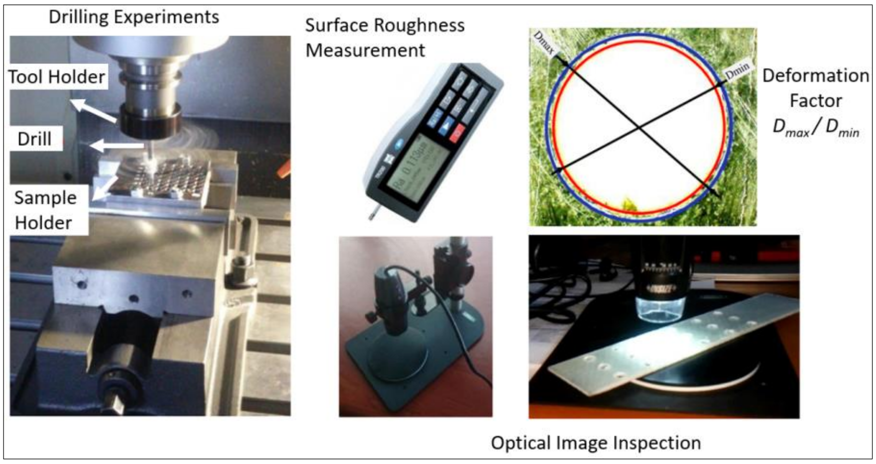

Figure 6. Experimental procedure.

3. RESULT AND DISCUSSION

3.1. Drilling Results of CF Reinforced PA6

As a result of drilling experiments of CF reinforced PA6 composite materials, Ra was measured, and deformation factor values were calculated. The obtained results were examined and interpreted in two groups. The measured Ra values are given in Table 6, and the calculated deformation factors are given in Table 7.

Table 6. Surface roughness (Ra) of CF reinforced PA6 composites.

Test No	Surface Roughness (Ra), (μm)			
	PA6	PA6+10CF	PA6+20CF	PA6+30CF
1	0.489	0.484	0.422*	0.744
2	0.701	0.569*	0.843	0.917
3	0.951	0.590	0.467	0.437*
4	0.911	0.722	0.614*	0.711
5	0.810*	1.458	1.956	1.673
6	0.337*	0.882	0.669	0.790
7	1.081	0.881	0.749	0.705*
8	0.822*	0.913	1.078	1.147
9	1.046	0.796*	0.966	1.565
10	1.324	1.410	1.164	0.875*
11	0.665	1.070	0.760	0.493*
12	0.528	0.744	1.670	0.561*
13	1.089	1.420	0.738*	0.719
14	1.274	1.347	0.966*	2.327
15	0.998*	1.531	1.366	1.455
16	0.966	1.738	0.751*	0.790

*: Lowest value.

When Table 6 and Table 7 are examined, the surface roughness and deformation factor values obtained from PA6+20CF reinforced material were generally found as the lowest or close to the lowest than the other CF reinforced materials. Taguchi analysis was performed on the experiments conducted for this material and presented in detail. The S/N ratio is determined according to three basic performance characteristics. Since the Ra and deformation factor were required to be low in the drilling of PA6+20CF composite materials, the “smaller-better” performance characteristic was chosen for the S/N ratio. The Equation (1) used to calculate the S/N ratios is given below [13, 15, 35-36].

$$S/N_{SB} = \eta = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \quad (1)$$

Statistical analyses were performed with Minitab 17 software. The S/N ratio response table for PA6+20CF material is given in Table 8. The main effect graphs for the S/N ratios prepared according to the Ra and deformation factors which derived from the "smaller-better" rule for 4-level cutting speed, feed rate, and drill bits material, which are the parameters in drilling the composites, are shown in Figure 7. The results of the analysis of variance for S/N ratios are given in Table 9.

Table 7. Inlet and outlet deformation factors of CF reinforced PA6 composites.

Test	Inlet deformation factors				Outlet deformation factors			
No	PA6	PA6+10CF	PA6+20CF	PA6+30CF	PA6	PA6+10CF	PA6+20CF	PA6+30CF
1	1.047	1.023	1.019*	1.028	1.063	1.030	1.020*	1.033
2	1.010	1.017	1.015	1.009*	1.011	1.009*	1.015	1.012
3	1.014	1.013	1.017	1.010*	1.036	1.019	1.015*	1.017
4	1.016*	1.018	1.028	1.017	1.028	1.019	1.028	1.015*
5	1.013*	1.019	1.031	1.066	1.024	1.039	1.018	1.017*
6	1.036	1.027	1.022*	1.034	1.060	1.033	1.028*	1.035
7	1.019*	1.019*	1.019*	1.022	1.027	1.018	1.018	1.015*
8	1.018	1.019	1.019	1.014*	1.024	1.015*	1.020	1.018
9	1.032	1.017	1.018	1.007*	1.046	1.018	1.012*	1.017
10	1.022	1.015*	1.025	1.017	1.029	1.019	1.013	1.011*
11	1.023*	1.028	1.024	1.034	1.035	1.016*	1.020	1.030
12	1.016*	1.018	1.018	1.018	1.007*	1.013	1.015	1.015
13	1.020	1.016	1.019	1.013*	1.040	1.038	1.015*	1.019
14	1.021	1.023	1.033	1.015*	1.027	1.018	1.015*	1.017
15	1.011*	1.020	1.039	1.020	1.020	1.033	1.017	1.008*
16	1.016*	1.021	1.030	1.039	1.023*	1.024	1.026	1.038

*: Lowest value.

Table 8. Response table for PA6+20CF sample surface roughness (Ra) S/N ratio.

Level	Surface Roughness (Ra)			Inlet deformation factors			Outlet deformation factors		
	CS	FR	DM	CS	FR	DM	CS	FR	DM
1	4.9523	1.1470	3.9566	-0.1753	-0.1912	-0.2079	-0.1713	-0.1428	-0.2045
2	-0.1215	0.9867	1.6398	-0.1998	-0.2080	-0.1929	-0.1859	-0.1566	-0.1401
3	-0.7745	2.1978	-2.8775	-0.1856	-0.2160	-0.2226	-0.1343	-0.1573	-0.1445
4	0.6757	0.4005	2.0130	-0.2624	-0.2078	-0.1996	-0.1601	-0.1948	-0.1624
Difference	5.7268	1.7973	6.8341	0.0871	0.0248	0.0297	0.0516	0.0520	0.0644
DoI	2	3	1	1	3	2	3	2	1

CS: Cutting Speed (m/min), FR: Feed Rate (mm/rev), DM: Drill bit Material, DoI: Degree of Importance.

When the results for PA6+20CF polymer material were examined, the lowest Ra was obtained as 0.422 μm in an experiment using a 40 m/min cutting speed, 0.1 mm/rev and HSS drill bit. The lowest inlet deformation factor was found as 1.015 in the experiments using 40 m/min cutting speed, 0.2 mm/rev feed rate, and tungsten carbide drill bit, and the lowest outlet deformation factor was found as 1.012 in the experiments using 100 m/min cutting speed, 0.1 mm/rev cutting speed and polished tungsten carbide drill bit for PA6+20CF. However, it should be noted that the while the 1.012 was the lowest value for outlet deformation factor, 1.015 was the second lowest value for inlet deformation factors. The PA6+30CF sample has the lowest inlet deformation factor with 1.009 value. It can be thought that the 30%CF reinforced sample is better than the other but when the Ra and outlet deformation factors taken into account PA6+30CF sample was not enough good as the PA6+20CF sample. This unusual situation is thought to be due to the anisotropic structure of the composite. In addition, beside to the parameters, different drill bit material also lead to the differences in the cutting results due to the interactions that occurred between drilling bit and composite during drilling [15].

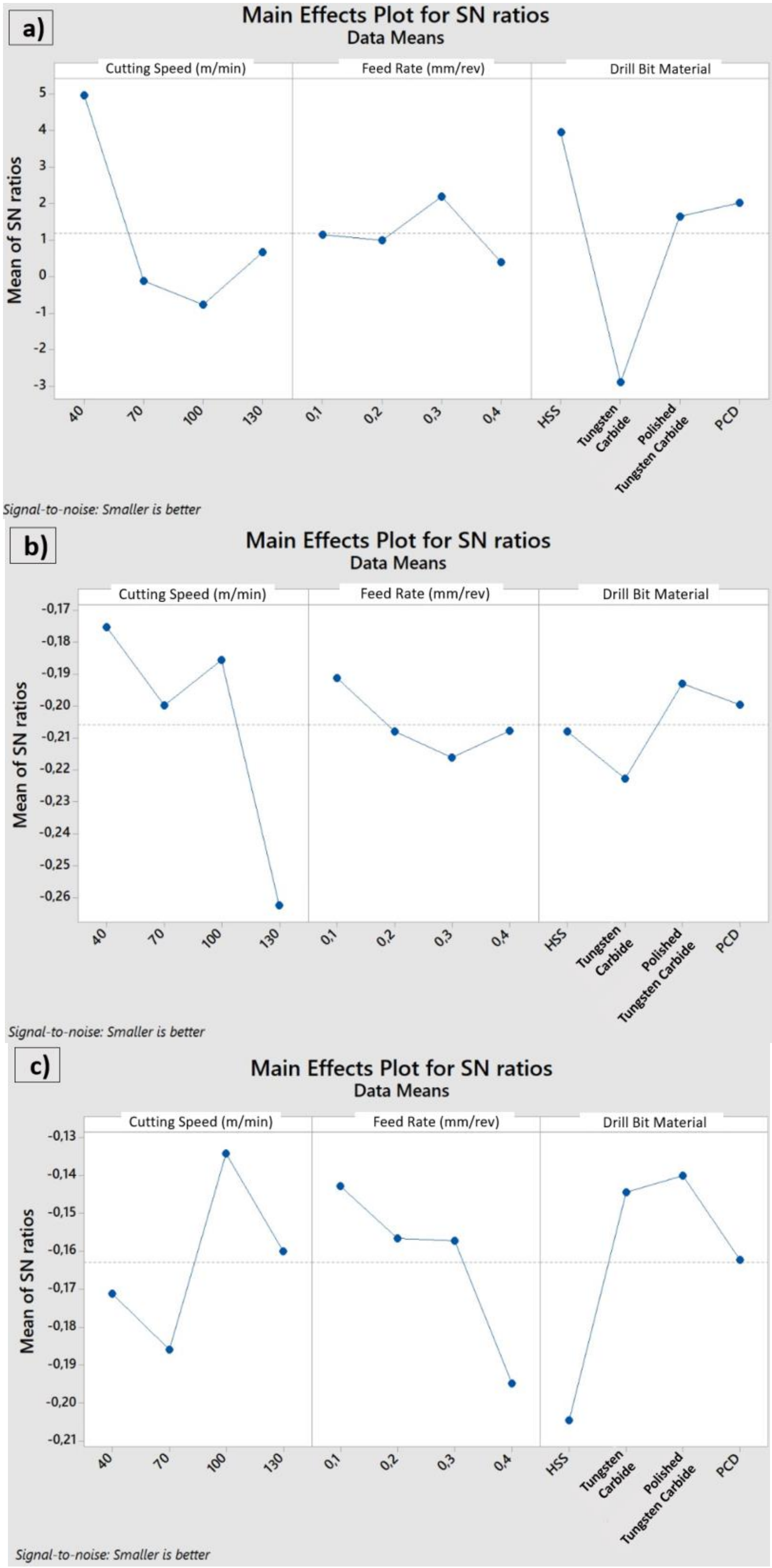

Figure 7. Main effect graphs for PA6+20CF sample S/N ratios a) Surface Roughness (Ra), b) Inlet deformation factors, c) Outlet deformation factors.

When the results obtained were interpreted by performing Taguchi analysis, drill bit material was found to be the most effective parameter for Ra and outlet deformation factor. However, the cutting speed was the most effective parameter for inlet deformation factor in line with the principle of smallest is the best. When Figure 7 is examined, A1B3C1 combination is the most suitable for optimum Ra level, while

A1B1C3 for inlet deformation, and A3B1C3 for optimum outlet deformation factors. The drill bit material and cutting speed are predominantly the most influential parameter. The analysis of variance (ANOVA) was performed, to determine the effect of differences between the factors affecting the process for PA6+20CF polymer composite. The effects of parameters in ANOVA are calculated by comparing the F-values of each factor [13]. As seen from Table 9, drill bit material is the most effective parameter on surface roughness and outlet deformation factor, while cutting speed only effect the inlet deformation factor. Drill bit material and cutting speed are the main factors to be considered statistically. The semantic coefficients are quite close to each other. Although statistically feed rate has less meaning, cannot be excluded due to the nature of machinability process and it is one of the parameters that must be selected in the system. However, the weakness of its statistical significance can be evaluated as flexibility of parameter selection in the machinability process.

Table 9. Analysis of variance (ANOVA) for PA6+20CF sample S/N ratio.

Source	DoF	SS			MS			F			P		
		SR	IDF	ODF	SR	IDF	ODF	SR	IDF	ODF	SR	IDF	ODF
Cutting Speed (m/min)	3	79.993	0.018315	0.000078	79.993	0.006105	0.000026	26.664	1.27	2.63	0.004	0.367	0.145
Feed Rate (mm/rev)	3	6.728	0.001308	0.000082	6.728	0.000436	0.000027	2.243	0.09	2.76	0.0383	0.963	0.134
Drill bit Material	3	100.312	0.001968	0.000143	100.312	0.000656	0.000048	33.437	0.14	4.79	0.002	0.935	0.049
Residual Error	6	11.087	0.028878	0.000060	11.087	0.004813	0.000010	1.848					
Sum	15	198.119	0.050469	0.000364									

DoF: Degree of Freedom, SS: Sequential sum of squares, MS: Mean sum of squares, F: F-Value, P: Probability, SR: Surface Roughness (Ra), IDF: Inlet Deformation Factor, ODF: Outlet Deformation Factor,

Most studies in the literature are on the machinability of composites obtained by layered production of woven fibers. When the machinability of these materials is examined, high cutting speed and low feed rate are the most recommended cutting parameters for optimal cutting of fiber integrity [3, 10, 21]. However, when the machinability of composites is made of thermoplastic polymers is examined, there are opposite findings. Accordingly, it has been determined that the heat at the drill bit disrupts the chip formation cut from the polymer, thus negatively affecting the performance of the cutting process and the Ra. To compensate for this, it is thought that the cutting speed should be reduced, and the feed rate should be increased. Due to the low cutting speed, the drill bit will heat up less. The drill bit material will quickly move away from the cutting zone. Thus, the negative effect of heat on the chip form and the material surface will be eliminated [30, 34-37].

3.2. Drilling Results of MWCNT Reinforced PA6

A similar detailed examination was also made for MWCNT added PA6 polymer materials. Surface roughness's for all doped samples are given in Table 10. According to the findings 0.2% MWCNT added PA6 polymer composites generally has the lowest Ra values compared to other MWCNT reinforced composite materials. All deformation factors occurring on the inlet and outlet surfaces have been calculated for PA6 polymer materials versus MWCNT reinforcement are given in Table 11.

Table 10. Surface roughness (Ra) of MWCNT reinforced Polyamide 6 composites.

Test No	Surface Roughness (Ra), (μm)			
	PA6	PA6+0.1MWCNT	PA6+0.2MWCNT	PA6+0.3MWCNT
1	0.489*	1.204	1.654	0.729
2	0.700	0.918	0.497*	0.732
3	0.951	0.640	0.888	0.599*
4	0.911	0.789*	1.101	1.385
5	0.810	1.551	0.679*	1.540
6	0.337*	1.214	0.614	1.457
7	1.081	0.738	0.663*	0.847
8	0.822	1.876	0.649*	1.231
9	1.046*	1.457	1.716	3.005
10	1.324	1.005	0.413*	0.832
11	0.665	1.725	0.653*	2.446
12	0.528	0.619	0.483*	0.627
13	1.089*	1.431	1.094	2.290
14	1.274	2.069	0.657*	1.652
15	0.998	1.419	1.033	0.526*
16	0.966	0.562*	1.251	0.972

*: Lowest value.

Table 11. Inlet and outlet deformation factors of MWCNT reinforced PA6 composites.

Test No	Inlet deformation factors				Outlet deformation factors			
	PA6	PA6+0.1 MWCNT	PA6+0.2 MWCNT	PA6+0.3 MWCNT	PA6	PA6+0.1 MWCNT	PA6+0.2 MWCNT	PA6+0.3 MWCNT
1	1.047	1.053	1.030*	1.038	1.063	1.046	1.028*	1.055
2	1.010*	1.012	1.036	1.034	1.011*	1.019	1.066	1.028
3	1.014	1.018	1.011*	1.025	1.036	1.013*	1.028	1.014
4	1.016*	1.055	1.020	1.029	1.028*	1.052	1.054	1.057
5	1.013	1.024	1.012*	1.022	1.024	1.019*	1.019*	1.033
6	1.036	1.035	1.020*	1.034	1.060	1.042	1.024*	1.039
7	1.019	1.045	1.017*	1.027	1.027	1.016*	1.056	1.078
8	1.018	1.017	1.015*	1.020	1.024	1.034	1.024	1.017*
9	1.032	1.031	1.013*	1.035	1.046	1.021	1.027	1.019*
10	1.022	1.061	1.015	1.010*	1.029*	1.042	1.044	1.077
11	1.023*	1.042	1.031	1.030	1.035	1.035	1.023*	1.037
12	1.016*	1.026	1.016*	1.016*	1.007*	1.025	1.020	1.017
13	1.020*	1.052	1.021	1.028	1.040	1.082	1.035*	1.109
14	1.021	1.062	1.018*	1.040	1.027	1.066	1.036	1.023*
15	1.011*	1.069	1.026	1.051	1.020*	1.034	1.080	1.051
16	1.016	1.030	1.025	1.029	1.023	1.034	1.023	1.029

*: Lowest value.

The lowest Ra was obtained as 0.337 μm at 70 m/min cutting speed, 0.2 mm/rev feed rate, and HSS drill bit in experiments conducted for neat PA6. Thus, for PA6+0.2MWCNT sample Ra was measured as 0.413 μm at 100 m/min cutting speed, 0.2 mm/rev feed rate, and PCD drill bit parameters. It has been observed that the MWCNT reinforcement was reduces the Ra. However, this Ra value was lower than the CF reinforced PA6 composites. Similarly, while [26], stated that the Ra decrease with CNT addition compared to neat PA6 in their study, [24] found out the increase on PA66 hole quality with the addition of glass fiber whiskers. It was declared that the decrease of Ra was corelated with the heat transformation from drilling region to tool bit and chip [30]. It has been thought that carbon-based particles improve the heat transfer mechanism in the structure, and the removed heat contributes to the improvement of the cutting surface between the drill bit-polymer. The results showed that the PA6+0.2MWCNT sample are better than the other MWCNT reinforcement ratios. The lowest inlet and outlet deformation factors found as 1.030 and 1.028 respectively, for PA6+0.2MWCNT sample in MWCNT reinforcement composite group. However, both of the deformation factor obtained at 40 m/min cutting speed, 0.1 mm/rev and HSS drill bit parameters. It is thought that the obtaining better result of the 0.2% reinforcement ratio is attributed to the efficiency of the cutting surface between the drill, the reinforcement material, and the polymer. Amount of the carbon-based reinforcement materials let the friction decrease more than the other ratios between the drill and composite. This phenomenon also related with the manufacturing process of composite. Efficient contact interface with the PA6 and MWCNT was observed by mixing, extrusion, and injection manufacturing process. However, it is possible to talk about the efficiency of dissipating the friction-induced heat and removing the chips in an ideal way [30, 37]. Taguchi analysis was performed for the results obtained from this material for Ra, inlet, and outlet deformation factors. The S/N ratios response table is given in Figure 8.

According to the Figure 8, A2B2C2 parameters are the required combination for ideal Ra level. For obtaining optimum inlet deformation and outlet deformation factors, A2B1C3 and A3B1C1 combinations have to be chosen, respectively. While the drill bit material and feed rate are looks likes the most influential parameters, according to the graphs all parameters have close and high effects for getting optimum drilling performance of MWCNT reinforced composites. Moreover, this effect is even greater compared to the drilling of CF reinforced PA6 composites. The meaning of the feed rate parameter is greater compared to the drilling of CF reinforced materials. Feed rate is usually directly proportional to the increase in deformation factors when drilling polymer composites. It has been determined that feed rate is the most important factor in many machinability studies conducted in the literature [14]. Similar to these results, which are valid for thermoset polymers and layered composites, the low feed rate in thermoplastic composites resulted in less deformation. For low Ra, medium feed rates were found to be effective. The lower the feed rate, the more friction it causes. Therefore, it can be said that the feed rate for Ra, unlike deformation, should be moderate and high.

In Table 12, The results of the ANOVA for the PA6+0.2MWCNT composite are given. According to the analyzes, it is seen that the feed rate parameter for the Ra, and the drill bit material for the inlet and outlet deformation factors are the effective parameters. It is observed that the outlet deformation factor for carbon fiber and carbon nanotube reinforced materials is greater than the inlet deformation factor. Also, [38] stated in his study that the output deformation is larger than the input. In this case, it is consistent with our study. This is due to the blasting force's effect when the material exits the lower surface of the drill bit. The material that is not supported from the bottom is partially stretched during exit, which causes contact failure on the cutting surface of the drill bit. However, the thickness of the material itself provides good support for the drill bit during entry. Thus, the cutting mouth of the drill bit is in contact with the material at a better angle. The importance of cutting angles in the cutting process is known. The deterioration of these angles by the wear of the cutter or the deterioration of the material by deformation adversely affects the efficiency of the cutting process.

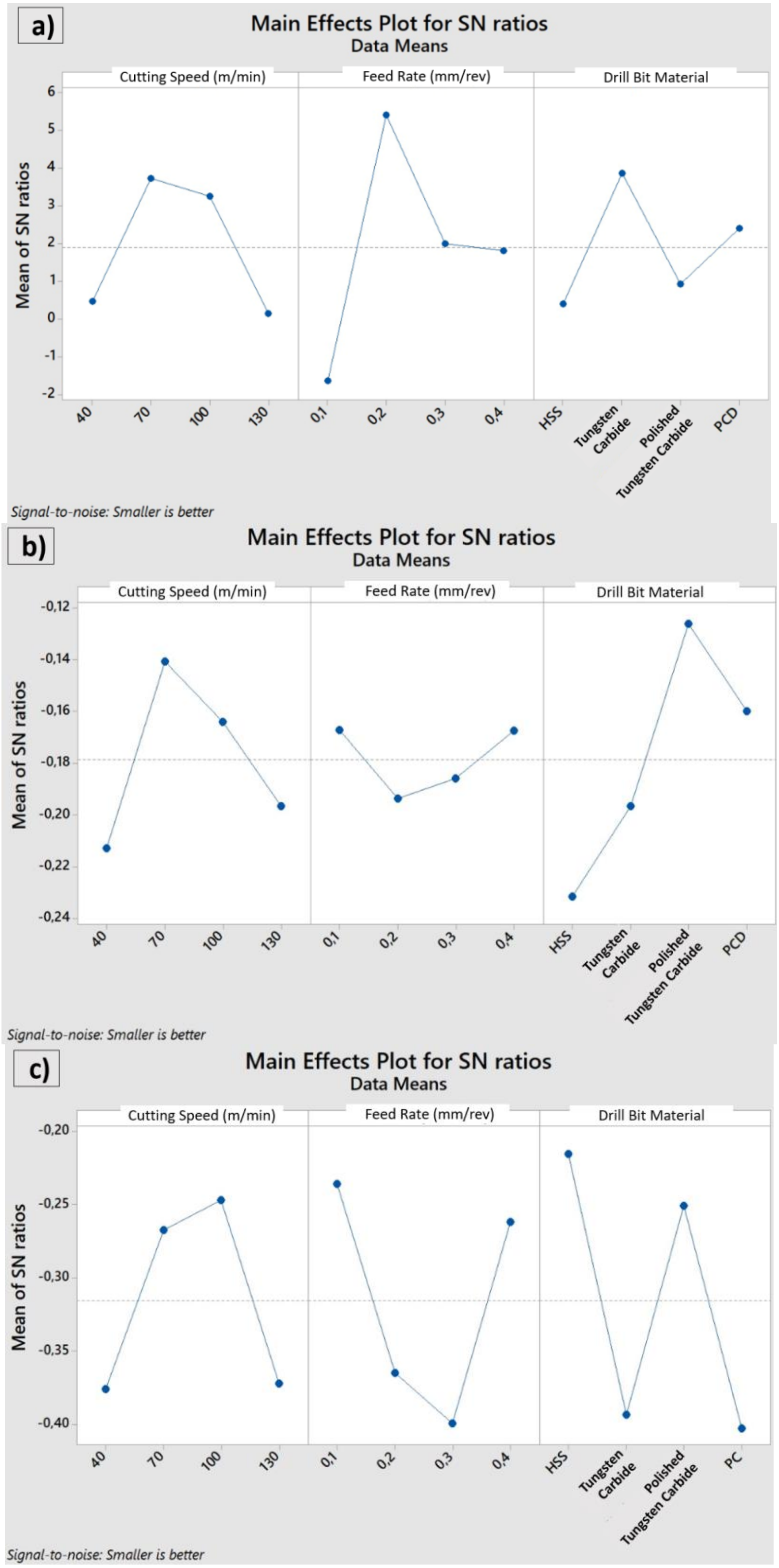

Figure 8. Main effect graphs for PA6+0.2MWCNT sample S/N ratios a) Surface roughness (Ra), b) Inlet deformation factors, c) Outlet deformation factors.

When the effects of the factors on the cutting parameters are examined one by one, it can be thought that a factor affects only one parameter. According to the F and P values given on Table 12, feed rate has no effect on results except the Ra. On the other hand, it seems that the drill bits' material has an effect only deformation factors. But cutting speed are not statistically enough significant. The statistical weakness of the parameters does not negate the fact that they must be selected for workability. However, it is an inevitable fact that machinability can be done efficiently by bringing together the independent variables in an optimum level. For this reason, it is important to research and find the most effective parameters on results such as deformation and Ra and to work on formulas that will be brought together at an optimum level. In addition, the weakness of the effect of a parameter can be turned into an advantage as flexibility in production processes for manufacturers. According to the statistical results, choice of the feed rate and drill bit material should be emphasized in the efficient drilling of MWCNT reinforced PA6 composites.

Table 12. Analysis of variance (ANOVA) for PA6+0.2MWCNT sample S/N ratio.

Source	DoF	SS			MS			F			P		
		SR	IDF	ODF	SR	IDF	ODF	SR	IDF	ODF	SR	IDF	ODF
Cutting Speed (m/min)	3	40.93	0.012565	0.05562	13.644	0.004188	0.01854	2.09	1.36	1.14	0.203	0.342	0.406
Feed Rate (mm/rev)	3	98.88	0.002133	0.07482	32.960	0.000711	0.02494	5.05	0.23	1.53	0.044	0.872	0.300
Drill bit Material	3	29.21	0.024957	0.11134	9.736	0.008319	0.03711	1.49	2.69	2.28	0.309	0.139	0.180
Residual Error	6	39.15	0.018522	0.09770	6.525	0.003087	0.01628						
Sum	15	208.17	0.058177	0.33948									

DoF: Degree of Freedom, SS: Sequential sum of squares, MS: Mean sum of squares, F: F-Value, P: Probability, SR: Surface Roughness (Ra), IDF: Inlet Deformation Factor, ODF: Outlet Deformation Factor.

3.3. Confirmation Experiments

In the experimental study, optimal results of surface roughness, inlet, and outlet deformation factors according to the independent variables of cutting speed, feed rate and drill bit material were obtained by using the Taguchi optimization method. In addition, the validity of the statistically derived ideal parameters was tested with the confirmation experiments [9, 13]. Relation between the statistically prediction levels and confirmation experiment were given in Table 13. The suggested confirmation experiment for the Ra, inlet and outlet deformation factors were the A1B1C1 parameter test in our experimental design. The results obtained in the estimation analysis with Minitab 17 software was overlapped with the results obtained from the current experiment for PA6+20CF composite.

Table 13. Comparison of prediction levels and confirmation experiments result.

Taguchi Optimization	**Prediction**			**Confirmation Experiment**		
Level	A1	B1	C1	A1	B1	C1
Drilling parameters	40 m/min	0.1mm/rev	HSS	40 m/min	0.1 mm/rev	HSS
Surface Roughness (Ra)		0.3606062			0.42267	
Inlet Deformation Factor		1.018912			1.01975	
Outlet Deformation Factor		1.022462			1.02008	

Taguchi Optimization	**Prediction**			**Confirmation Experiment**		
Level	A1	B1	C1	A1	B1	C1
Drilling parameters	40 m/min	0.1mm/rev	HSS	40 m/min	0.1 mm/rev	HSS
Surface Roughness (Ra)		1.6085			1.65433	
Inlet Deformation Factor		1.02975			1.03096	
Outlet Deformation Factor		1.02276			1.02803	

According to the obtained prediction levels with Minitab 17 software, suggested confirmation experiment for the Ra, inlet and outlet deformation factors was the A1B1C1 parameter. The performed test results confirm the levels of optimum control factors determined based on Taguchi optimization method for Ra, inlet, and outlet deformation factors in our experimental design.

4. CONCLUSIONS

An experimental study was carried out to examine the machinability properties of PA6 thermoplastic composite materials produced by adding carbon fiber and multi-walled carbon nanotubes at different rates. In the study, feed rate and cutting speed were used as cutting parameters, and 4 different drill bit materials were used as cutters. To examine the effects of Ra, inlet deformation, and outlet deformation factors on the material, Taguchi analysis was used. Based on the analysis, the following conclusions were obtained within the selected parameters.

According to the Ra, inlet deformation, and outlet deformation results, 20% ratios for CF reinforced composites and 0.2% ratios for MWCNT reinforced composites generally gave better results.

MWCNT has more positive effect on both reducing Ra and reducing inlet-outlet deformations compared to the CF. The CF reinforcement increased the Ra while reduced the inlet and outlet deformation factors.

Lowest Ra value was obtained at A1B3C1, lowest inlet deformation obtained at A1B1C3, and the lowest outlet deformation obtained at A3B1C3 parameters for the PA6+20CF composite. Drill bit material was found to be the most effective parameter for Ra and outlet deformation factor, while cutting speed was the most effective parameter for inlet deformation factor for drilling of PA6+20CF composite material.

The lowest Ra was obtained at A2B2C2, lowest inlet deformation A2B1C3, and the lowest outlet deformation A3B1C1 parameters are required for the PA6+0.2MWCNT composite. While the feed rate has great effect on the Ra, the drill bit material for both inlet deformation and outlet deformation factors are the effective parameter for drilling of PA6+0.2MWCNT composite material.

It is observed that the outlet deformation factor for both carbon fiber and carbon nanotube reinforced materials is greater than the inlet deformation factors.

According to the confirmation experiments, Multi-response Taguchi optimization shows successful approach to obtaining minimum Ra, inlet, and outlet deformation.

When all variables are optimized, the A1B1C1 are the ideal parameters for drilling both PA6+20 CF and PA6+0.2MWCNT composite.

As further research, the effects of lubricating additives and different fiber types can also be examined. In addition, possible damage mechanism can be analyzed by simulating usage processes by performing fractured sample tests.

Declaration of Ethical Standards

The authors declare that all ethical guidelines including authorship, citation, data reporting, and publishing original research are followed.

Credit Authorship Contribution Statement

Abdurrahman Genc: Investigation, Resources, Writing, Original
Ferhat Yildirim: Conceptualization, Methodology, Supervision, Editing, Draft, Validation.
Murat Koyunbakan: Writing – Review & Editing, Visualization.
Volkan Eskizeybek: Investigation, Resources, Visualization
Gozde Kus: Investigation, Resources.

Declaration of Competing Interest

The authors declare that there is no conflict of interest.

Funding / Acknowledgements

This work was supported by Kütahya Dumlupınar University Scientific Research Coordination Unit, Project number: 2016-90.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

[1] Ş. Bayraktar, Y. Siyambaş, ve Y. Turgut, "Delik Delme Prosesi: Bir Araştırma", *Sakarya Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, Cilt. 21, ss. 120-130, 2016.

[2] P. S. İçli, "Polimerik Kompozitler: Geleceğin Teknolojileri", *I. Polimerik Kompozitler Sempozyumu ve Sergisi*, 2006, ss. 43-46,

[3] T. Grilo, R. Paulo, C. Silva, and J. Davim, "Experimental Delamination Analyses of CFRPs Using Different Drill Geometries", *Composites: Part-B*, Vol. 45, pp. 1344-1350, 2013.

[4] G. Kuş, M. Koyunbakan, S. H. Yetgin, F. Yıldırım, V. Eskizeybek, ve A. Genç, "Çok duvarlı karbon nanotüp katkılı poliamit 6 polimerinin mekanik özelliklerinin incelenmesi", *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, Cilt. 11, No. 2, ss. 543-551, 2020.

[5] G. Kuş, S. H. Yetgin, M. Koyunbakan, F. Yıldırım, V. Eskizeybek, ve A. Genç, "Çok Duvarlı Karbon Nanotüp Katkılı Poliamit 6 Polimerinin Termal, Termo-Mekanik Ve Tribolojik Özelliklerinin İncelenmesi", *Erzincan University Journal of Science and Technology*, Cilt. 13, No. 3, pp. 1389-1402, 2020.

[6] L. Huimin, X. Xiangmın, L. Xiaohong, and Z. Zhijun, "Morphology, crystallization and dynamic mechanical properties of PA66/nano SiO2 composites", *Bulletion Materials Science*, Vol. 29, No. 5, pp. 485–490, 2006.

[7] P. Renê Anisio da, L. Amanda Melissa Damião, A. Edcleide Maria, M. Vanessa da Nóbrega, M. Tomás Jeferson Alves de, and P. Luiz Antônio, "Mechanical and thermomechanical properties of polyamide 6/ Brazilian organoclay nanocomposites", *Polímeros*, Vol. 26, No.1, pp. 52-60, 2016.

[8] S. S. Kumar, and G. Kanagaraj, "Investigation on Mechanical and Tribological Behaviors of PA6 and Graphite-Reinforced PA6 Polymer Composites", *Arabian Journal of Science Engineering*, Vol. **41**, pp. 4347–4357, 2016.

[9] G. Meral, M. Sarıkaya, and H. Dilipak, "The optimization of cutting of parameters in drilling processes by Taguchi method", *Erciyes Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, Cilt. 27, No. 4, pp. 332-338, 2011.

[10] U. Khashaba, I. El-Sonbaty, A. Selmy, A. Megahed, "Machinability Analysis in Drilling Woven GFR/Epoxy Composites: Part I-Effect of Machining Parameters", *Composites: Part-A*, Vol. 41, pp. 391-400, 2010.

[11] A. Alberdi, T. Artaza, A. Suárez, A., Rivero, F. Girot, "An experimental study on abrasive waterjet cutting of CFRP/Ti6Al4V stacks for drilling operations", *The International Journal of Advanced Manufacturing Technology*, Vol. 86, pp. 1-14, 2015.

[12] U. Köklü, Y. Kaynak, O. Demir, A. Avcı, ve A., Etyemez, "Fonksiyonel Derecelendirilmiş Kompozit Malzemelerin Talaşlı İşlenebilme Performansı", *6. Ulusal Talaşlı İmalat Sempozyumu (UTİS 2015),* 2015, ss. 198-206.

[13] M. Özsoy, and N. Özsoy, "Experimental And Statistical Investigation of Drilling of AISI 1040 Steel At Dry And Wet Conditions", *Konya Journal of Engineering Sciences*, Cilt. 8, No. 2, pp. 384-391, 2020.

[14] H. B. Kaybal, A. Ünüvar, M. Koyunbakan, and A. Avcı, "A novelty optimization approach for drilling of CFRP nanocomposite laminates", *The International Journal of Advanced Manufacturing Technology,* Vol. 100, pp. 2995–3012, 2019.

[15] M. A. Karataş, "Evaluation Of The Effect Of Machining Parameters On Delamination Damage In Drilling Of Carbon Fiber Reinforced Polymer Composite With Different Drill Bits", *Dicle University Journal of Engineering (DUJE),* Vol. 13, pp. 19-25, 2022.

[16] F. Kahraman, G. Başar, Z. Koçoğlu, ve E. Yeniyıl, "Delik Büyütme Işleminde Kesme Parametrelerinin Çok Yanıtlı Taguchi Deneysel Tasarım Yaklaşımı Kullanılarak Optimizasyonu", *Politeknik Dergisi*, Vol. 21, No. 2, pp. 283-290, 2018.

[17] A. Maslavi, H. Ünal, ve S. H. Yetgin, "Karbon Fiber Takviyeli Grafit Ve Ptfe Katkili Poli-Eter-Eter-Keton (Peek) Polimer Kompozitin Tribolojik Performanslarina Kayma Hizinin Etkisinin Belirlenmesi", *Konya Journal of Engineering Sciences*, Cilt. 10, No. 2, pp. 457-467, 2022.

[18] T. Panneerselvam, and S. Raghuraman, "Optimization of Drilling Parameters For Delamination Associated with Pre-Drill in Chopped Strand Mat Glass Fibre Reinforced Polymeric Material", *Pertanika Journal Science and Technology*, Vol. 23, pp. 61-72, 2015.

[19] T. Rajamurugan, K. Shanmugam, K. Palanikumar, "Analysis of Delamination in Drilling Glass Fiber Reinforced Polyester Composites", *Materials and Design*, Vol. 45, pp. 80-87, 2013.

[20] B. Işık, and E. Ekici, "Experimental Investigations of Damage Analysis in Drilling of Woven Glass Fiber-Reinforced Plastic Composites", *International Journal Advanced Manufacture Technology,* Vol. 49, pp. 861-869, 2010.

[21] M. Ramesh, K. Palanikumar, and K. Reddy, "Experimental Investigation and Analysis of Machining Characteristics in Drilling Hybrid Glass-Sisal-Jute Fiber Reinforced Polymer Composites", *5th International and 26th All India Manufacturing Technology, Design and Research Conference*, Vol. 461, pp.1-6, 2014

[22] K. Palanikumar, "Experimental Investigation and Optimization in Drilling of GFRP Composites", *Measurement*, Vol. 44, pp. 2138-2148., 2011.

[23] U. S. Rao, and L. Rodrigues, "Controlling Process Factors to Optimize Surface Quality in Drilling of GFPR Composites by Integrating DOE, Anova, and RSM Techniques", *Indian Journal of Science and Technology*, Vol. 8, pp. 1-9, 2015.

[24] J. C. Rubio, L. Silva, W. Leite, T. Panzera, S. Filho, and J. Davim, "Investigations on the Drilling Process of Unreinforced and Reinforced Polyamides Using Taguchi Method", *Composites:Part-B*, Vol. 55, pp. 338-344, 2013.

[25] E. Kuram, "Micro-Machinability of Injection Molded Polyamide 6 Polymer and Glass-Fiber Reinforced Polyamide 6 Composite", *Composites:Part-B*, Vol. 88, pp. 85-100, 2016.

[26] R. F. Zinati, and M. Razfar, "Experimental and Modeling Investigation Of Surface Roughness in End-Milling Of Polyamide 6/Multi-Walled Carbon Nano-Tube Composite", *International Journal Advanced Manufacture Technology*, Vol. 75, pp. 979-989, 2014.

[27] F. Fıçıcı, ve Z. Ayparçası, "%30 Cam Fiber Takviyeli Polipitilamit (PPA) Matriksli Kompozit Malzemenin Yüzey Pürüzlülüğünün İncelenmesi", *5. Ulusal Talaşlı İmalat Sempozyumu (UTIS 2014)*, 2014, ss. 473-481.

[28] V. Gaitonde, S. Karnik, SJ. C. C. Rubio, A. Abrão, A. E. Correia, and J. P. Davim, "Surface roughness analysis in high-speed drilling of unreinforced and reinforced polyamides", *Journal of Composite Materials*, Vol. 46, No. 21, pp. 2659-2673, 2012.

[29] V. Gaitonde, S. Karnik, J. C. C. Rubio, W. de Oliveira Leite, and J. Davim, "Experimental studies on hole quality and machinability characteristics in drilling of unreinforced and reinforced polyamides", *Journal of Composite Materials*, Vol. 48, No. 1, pp. 21-36, 2014.

[30] A. Uysal, "Relation Between Drill Bit Temperature and Chip Forms in Drilling of Carbon Black Reinforced Polyamide", *Journal of Thermal Engineering Yildiz Technical University Press*, Vol. 1, pp. 655-658, 2015.

[31] Detsan Kimya A.Ş., "Technical properties of Polyamide 6" Technical datasheet, October 2017.

[32] Dowaksa A.Ş., "Technical data sheet of Carbon fiber", November 2017.

[33] Detsan Kimya A.Ş., "Technical properties of Multi Walled Carbon Nanotube" Technical datasheet, January 2018.

[34] S. Korucu, G. Samtaş, "The effect of cutting parameters on wear, surface roughness and chip formation in drilling of Vanadis 4E steel with uncoated drill bits", *Dokuz Eylül University Faculty of EngineeringJournal of Science and Engineering (DEÜ FMD),* Vol. 23, No. 69, 961-971, 2021.

[35] H. Gökçe, İ. Çiftçi, "Cutting parameter optimization in shoulder milling of commercially pure Molybdenum", *Journal of the Brazilian Society of Mechanical Sciences and Engineering,* Vol. 40, pp. 360, 2018.

[36] T. N. Valarmathi, K. Palanikumar and B. Latha, "Measurement and analysis of thrust force in drilling of particle board (PB) composite panels", *Measurement*, Vol. 46, pp. 1220–1230, 2013.

[37] A. Uysal, and E. Altan, "Karbon Siyahı Takviyeli Elektriği İleten Polipropilen Kompozite Delik Delinmesinde İşlem Parametrelerinin İncelenmesi", *Politeknik Dergisi*, Cilt. 18, ss. 241-249, 2015.

[38] E. Kılıçkap, "CETP Kompozitlerin Delinmesinde Oluşan Deformasyona Delme Parametrelerinin Etkisinin İncelenmesi," *2. Ulusal Tasarım İmalat ve Analiz Kongresi*, 2010, pp. 77.