ANOVA OPTIMIZATION OF DRILL BIT TEMPERATURE IN DRILLING OF PURE AND CARBON BLACK REINFORCED HIGH DENSITY POLYETHYLENE

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Abstract: High density polyethylene materials have many application areas in automotive, aviation, electrical and electronic etc. industries. In some applications, their mechanical properties need to be improved. For this reason, some particles such as carbon black, graphite, carbon nanotubes, carbon fibers etc. were added to the polymer matrix. Although these types of material can be manufactured in near net shape, some machining operations such as drilling need to be performed. In this study, the drill bit temperatures in drilling of pure and carbon black reinforced high density polyethylene (HDPE) were optimized by using ANOVA (analysis of variance) statistical method.

Keywords: HDPE, carbon black, drilling, drill bit temperature, ANOVA

1. INTRODUCTION

Polymers are widely used in many industries due to their properties such as corrosion resistance, good strength to weight ratio, light in weight, easy and rapid shaping etc. [1]. However, their thermal and electrical conductivities need to be improved. For this reason, some reinforcements are added to the polymers. Some of the reinforcement materials are carbon black, carbon fiber, graphite, graphene, metals and metal oxides, and carbon nanotubes. These reinforcements are generally added during the producing steps of polymers. As is known, polymers are produced by injection molding and shaping in molds, but some machining operations especially drilling are required. In general, traditional machining methods and cutting tools can be used. However, there is the lack of knowledge on their machinability due to the mechanical, thermal, and rheological properties [1]. During machining of polymers, the heat cannot be quickly conducted to the cutting tool because of the low thermal conductivity of the polymers.

In addition to that, the localized heating may cause excessive heating at the machined surface such as burning for thermoset polymers, gumming for thermoplastic polymers [2]. Rubio et al. [3] investigated the effects of drilling parameters on the circularity error, surface roughness and thrust force in drilling of engineering plastics as ultra-high molecular weight polyethylene (UHMWPE), polyoxymethylene (POM), and polytetrafluoroethylene (PTFE) as engineering plastics. Budan and Vijayarangan [4] performed drilling experiments on bidirectional glass fiber reinforced plastic composites to investigate the effects of drilling parameters and fiber concentration on the surface finish, hole quality and delamination.

Kishore et al. [5] made an investigation on drill bit geometry in the drilling of unidirectional glass fiber reinforced plastic composites by selecting three different drill bit geometries. Gaitonde et al. [6] performed some drilling experiments of pure polyamide and glass fiber reinforced polyamide composites and investigated the surface roughness.

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Based on the results, lower surface roughness was measured for reinforced polyamide by comparison with pure polyamide. Uysal et al. [7] examined the effects of the drilling parameters on the drill tool wear in drilling of fiber reinforced polymer composite. Based on the measurement results, lower tool wear was obtained during drilling with a drill tool having small point angle at higher feed. Ramesh et al. [8] studied the influences of feed and spindle speed on surface roughness and ovality during drilling of pultruded and sheet molding compound glass fiber reinforced plastic composites. Uysal [9] performed a study to investigate the effects of drill tool point angle, cutting speed, and feed on surface roughness and cutting temperature in drilling of pure polypropylene (PP) and carbon black reinforced polypropylene materials and the statistical analyses were also performed.

In this study, the influences of drill tool point angle, cutting speed, and feed on the drill bit temperature were experimentally and statistically examined in drilling of pure and carbon black reinforced high density polyethylene (HDPE) polymers.

2. EXPERIMENTAL SETUP

In the experimental studies, pure and carbon black reinforced high density polyethylene (HDPE) polymers were chosen as workpiece materials. The pure HDPE is BPC brand and the carbon black reinforced HDPE (CB-HDPE) is Premix brand. The technical specifications of pure HDPE and CB-HDPE were given in Table 1.

Table 1. Technical specifications of pure and carbon black HDPE polymers.

Specifications	Pure HDPE	CB-HDPE
Specific gravity (g/cm^3)	0.95	1.12
Yield strength (MPa)	23	24
Flexural modulus (MPa)	800	1100
Elongation at break (%)	>50	40
Elongation at yield (%)	9	12
Volume resistivity (Ωcm)	$\geq 10^{14}$	$<10^{13}$
Surface resistance (Ω)	$\geq 10^{14}$	$<10^{15}$

The polymer granules were dried at 60°C for 2 hours. Then, the workpieces were produced in dimensions of 150x150x10 mm by an injection molding machine with the mold given in Figure 1. The mold temperature was adjusted at 60ºC, the granules were melted at 230°C and the injection pressure was 90 MPa.

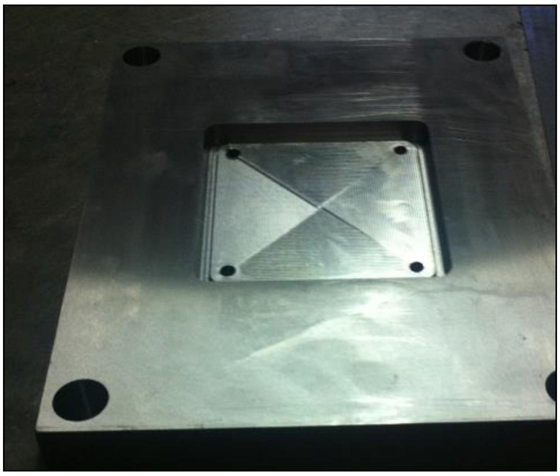

Fig. 1. The mold used for manufacturing the workpieces.

Drilling experiments were conducted at a CNC machining center with uncoated high speed steel (HSS) twist drills. The drill diameter was 8 mm and the drills were sharpened at three drill point angles as 80°, 120°, and 80°-120° (double-angled) as given in Figure 2.

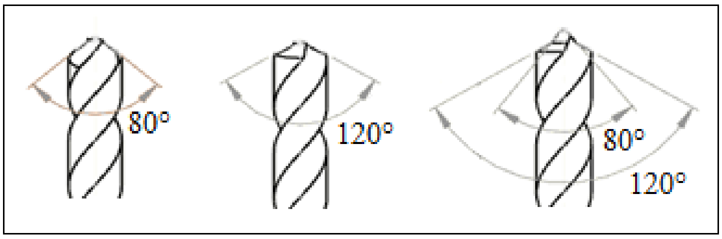

Fig. 2. The drills with three drill point angles.

During drilling processes, the drill bit temperatures (T) were measured by using Optris® CTlaser LT two-wire infrared thermometer having measurement range of -50°C to 975°C with ±1% measurement accuracy and response time of 9 ms.

3. EXPERIMENTAL PLAN AND PARAMETERS

In the designing of experiments, Taguchi full-factorial design was planned to obtain the optimal drilling conditions for the lowest drill bit temperature and to determine the effects of the drilling parameters on the results. The experimental plan is given in Table 2. The signal-to-noise (S/N) ratio was used to obtain the quality characteristic and the "smaller is better" quality characteristic was chosen and defined by equation 1.

$$S/N = -10\log\left[\frac{1}{n}\cdot\sum_{i=1}^{n} y_i^{\,2}\right] \tag{1}$$

Where n is the data sets number and y_i is the measured value for the i_{th} data set.

Table 2. The experimental plan.

Experiment number	Drill point angle, α (°), A	Feed, f (mm/rev), B	Cutting speed, V (m/min), C
1	80°	0.1	40
2	80°	0.1	80
3	80°	0.1	120
4	80°	0.2	40
5	80°	0.2	80
6	80°	0.2	120
7	80°	0.3	40
8	80°	0.3	80
9	80°	0.3	120
10	120°	0.1	40
11	120°	0.1	80
12	120°	0.1	120
13	120°	0.2	40
14	120°	0.2	80
15	120°	0.2	120
16	120°	0.3	40
17	120°	0.3	80
18	120°	0.3	120
19	80°-120°	0.1	40
20	80°-120°	0.1	80
21	80°-120°	0.1	120
22	80°-120°	0.2	40
23	80°-120°	0.2	80
24	80°-120°	0.2	120
25	80°-120°	0.3	40
26	80°-120°	0.3	80
27	80°-120°	0.3	120

In order to compare the effects of each drilling parameter on drill bit temperature, analysis of variance (ANOVA) statistical technique was used. In this study, the S/N graphs and the ANOVA results were obtained by using a statistical software.

4. RESULTS AND DISCUSSION

In the drilling of pure HDPE and carbon black reinforced HDPE, the effects of drilling parameters on the drill bit temperatures are given in Figure 3. As the cutting speed increases, the friction between the drill tool and workpiece increases and so higher drill tip temperature may occur for each polymer material as shown in Figure 3(a) and Figure 3(b).

In addition, the drill tip temperature decreases with increase of feed as given in Figure 4(c) and Figure 4(d) due to the fact that the drill tool comes into contact more cold material and more heat is transmitted from the drill tool to the polymer material at higher feed for a constant cutting speed.

Smaller drill point angles make the cutting operation easier and reduce the friction. Thus the small drill point angles generate lower drill tip temperature. In addition, it can be seen that the drill tip temperature increases with increase of the drill point angle. Although the double-angled (80°-120°) drill tool design causes a decrease in the drill bit temperature as comparing to the drill tool with 120° point angle. But it cannot be effective on reducing of drill bit temperature as much as drill tool with 80° point angle. When compared to both polymer materials, carbon black reinforcement makes the polymer material stiffer and so the cutting operation can be performed easily.

In addition, this reinforcement increases the thermal conductivity. Thus, more heat can be conducted to the drill tool in the drilling of carbon black reinforced HDPE. As is known, the generated heat is collected at the upper surface of polymer materials and it cannot be well transmitted to the drill tool. Therefore, lower drill tip temperatures are measured in the drilling of pure HDPE when compared to the drilling of carbon black reinforced HDPE. For this reason, polymer material is less affected from the heat due to carbon black reinforcement.

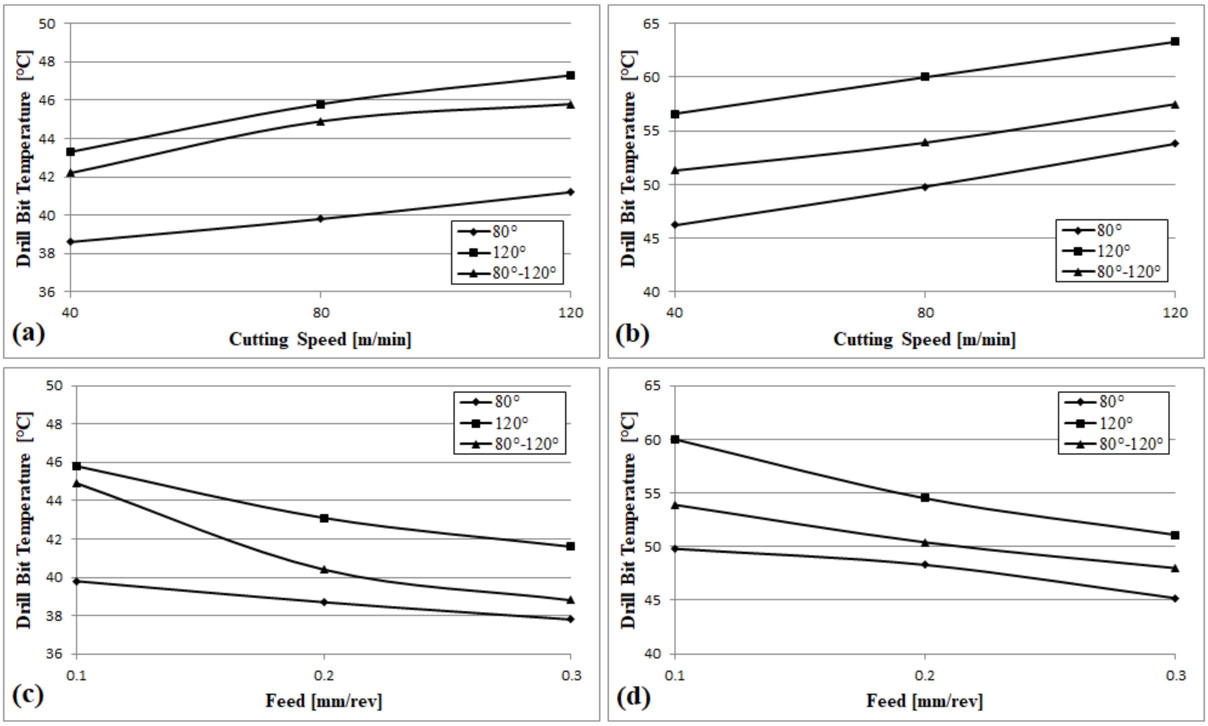

Fig. 3. The effects of drilling parameters on drill bit temperature, a) pure HDPE and f=0,1 mm/rev, b) CBR-HDPE and f=0,1 mm/rev, c) pure HDPE and V=80 m/min, d) CBR-HDPE and V=80 m/min.

For pure and carbon black reinforced HDPE polymers, the corresponding S/N ratios are given in Figure 4 and the response table of the S/N ratios is given in Table 3. Depending on the results, the optimal drilling parameters for the minimum drill bit temperature were obtained as A1B3C1. This means the drill point angle of (80°, the feed of 0.3 mm/rev and the cutting speed of 40 m/min for both HDPE polymers. This set of data (A1B3C1) is included in the design of experiment and corresponds to the 7th experiment with the smallest drill bit temperatures of 36.5°C and 40.7°C for pure HDPE and carbon black reinforced HDPE, respectively.

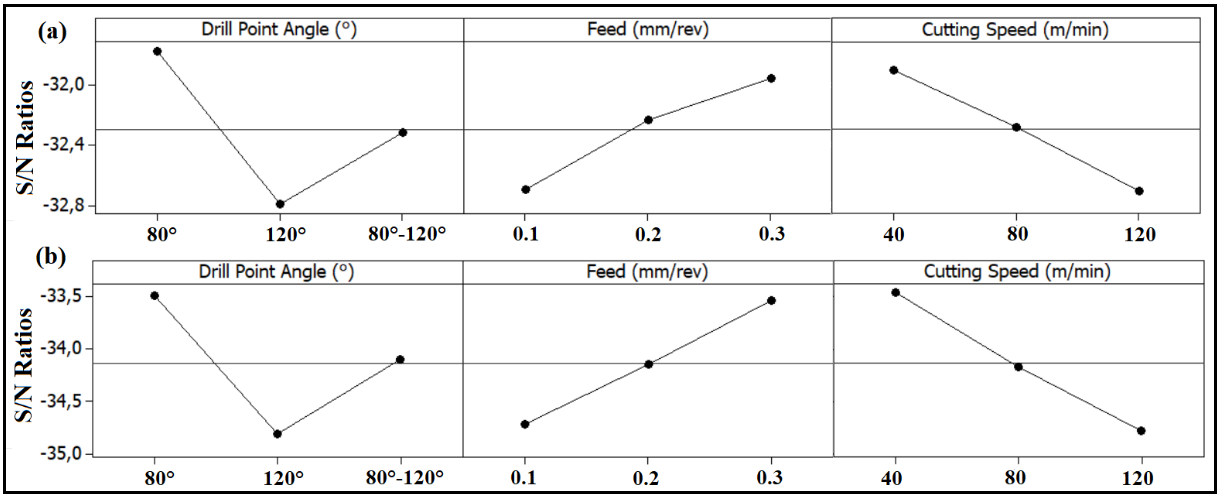

Fig. 4. S/N graphs of drill bit temperatures for a) pure and b) carbon black reinforced HDPE.

The highest delta value in Table 3 correspond to the most effective drilling parameter on the output. For both HDPE polymers, the most effective parameter was determined as the drill point angle and the least effective parameter was found as the feed.

Table 3. Response table for S/N ratios.

	Level	Drill Point Angle, A (°)	Feed, B (mm/rev)	Cutting Speed, C (m/min)
Pure HDPE	1	-31.78	-32.69	-31.90
	2	-32.79	-32.23	-32.28
	3	-32.31	-31.96	-32.70
	Delta	1.02	0.73	0.81
Carbon Black Reinforced HDPE	1	-33.49	-34.73	-33.46
	2	-34.82	-34.14	-34.17
	3	-34.10	-33.54	-34.78
	Delta	1.33	1.19	1.31

Based on the ANOVA statistical results given in Table 4, the drill point angle is the most significant parameter for both HDPE polymers. The highest percentage contribution is determined for the drill point angle and the least effective parameter is obtained as the feed. The selected drilling parameters are found as statistically significant since the P-values are 0.000 for pure and carbon black reinforced HDPE polymers.

Table 4. ANOVA results.

Parameter	Sum of Square	Degree of Freedom	Mean Square	F-ratio	P-value	Percentage Contribution (%)
Pure HDPE						
Drill Point Angle (°)	106.192	2	53.096	79.14	0.000	43.68
Feed (mm/rev)	56.910	2	28.455	42.41	0.000	23.41
Cutting Speed (m/min)	66.599	2	33.299	49.63	0.000	27.40
Residual	13.419	20	0.671			5.51
Total	243.119	26				
Carbon Black Reinforced HDPE						

Drill Point Angle (°)	279.16	2	139.58	150.51	0.000	35.80
Feed (mm/rev)	220.54	2	110.27	118.90	0.000	28.28
Cutting Speed (m/min)	261.49	2	130.74	140.98	0.000	33.54
Residual	18.55	20	0.93			2.38
Total	779.73	26				

5. CONCLUSION

In this study, drilling experiments were performed on pure and carbon black reinforced HDPE polymers and the drill bit temperatures were measured. The effect of drill point angle, feed and cutting speed on the drill bit temperatures were investigated. The experiments were planned based on Taguchi full-factorial design and the measurement results were evaluated by ANOVA statistical method. The optimal drilling conditions and the significant parameters were determined. Based on the experimental and statistical results, the following results were obtained:

- The drill bit temperatures increased with increasing cutting speed for both HDPE polymers.
- The drill bit temperatures decreased with increase of feed for both HDPE polymers.
- The drill bit temperatures decreased with decreasing drill point angle. In addition, the double-angled (80°-120°) drill tool caused a decrease in the drill bit temperatures but the lowest values were obtained with the drill tool having point angle of 80°.
- As compared to pure HDPE and carbon black reinforced HDPE, drill bit temperature were higher in the drilling of reinforced HDPE.
- The optimal cutting parameters for the minimum drill bit temperature were determined as 80°, 0.3 mm/rev and 40 m/min for both HDPE polymers.
- The most effective drilling parameter was determined as the drill point angle whereas the least effective drilling parameter was calculated as the feed for both HDPE polymers. But all the selected drilling parameters were determined as statistically significant.

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