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## **RELATION BETWEEN DRILL BIT TEMPERATURE AND CHIP FORMS IN DRILLING OF CARBON BLACK REINFORCED POLYAMIDE**

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### **ABSTRACT**

Polyamides have many application fields due to their good mechanical strength, high impact strength, good sliding properties etc. Recently, electrically conductive polyamides can be produced by adding carbon black, graphene, metals and carbon nanotubes and their usage have increased. Polyamides are generally manufactured by injection molding and extrusion method but drilling is often needed for the final product. In literature, there are not many studies on the drilling of polyamides and polyamide composites. In this study, drill bit temperature and chip forms were investigated during the drilling of unreinforced polyamide and carbon black reinforced electrically conductive polyamide. Drilling experiments were performed at three different feeds and cutting speeds. Depending on the experimental results, the drill bit temperature increased with increasing the cutting speed and decreasing the feed. Higher drill tip temperatures were measured in the drilling of carbon black reinforced polyamide than that occurred in the drilling of unreinforced polyamide. The chips were more deformed at high cutting speed and low feed. In addition, the chip forms of carbon black reinforced polyamide were observed more regular than that of unreinforced polyamide due to the fact that the chips of carbon black reinforced polyamide could conduct the heat to the drill bit and they were less affected by the heat.

### **INTRODUCTION**

Polymer products are widely used due to having properties of processing, low density compared to metals, cost effectiveness etc. In addition, many unreinforced polymers are

good electrical insulator. However, conducting or semiconducting polymers have been used in some applications such as automotive housings, boxes for electronic components. Electrical conductivity in polymers can be achieved by reinforcing carbon black, graphite, metallic powders, some metal oxides, and aluminum flakes etc. (Kim, 2007; Saad et al., 2004). Through these additives, carbon black is commonly preferred because of being cheaper and lighter than metallic additives (Saad et al., 2004). Unreinforced and reinforced polymers can be produced by molding methods, but machining operations are generally applied to the molded parts to obtain the desired final shape. Within these operations, the drilling is widely performed to fixing and assembling processes and has been investigated by researchers. The effects of feed and spindle speed on the radial error were examined during the drilling of some polymers and minimum radial error was obtained at high feed and low spindle speed (Rubio et al., 2015; Endo and Mauri, 2006). In some researches, the drilling of 30% glass fiber/whisker reinforced polyamide was studied and the effects of feed rate, spindle speed, and drill point angle on the surface roughness, hole diameter, radial error, and thrust force (Rubio et al., 2011; Rubio et al., 2013; Gaitonde et al., 2012(a); Gaitonde et al. 2012(b)). According to the results, the drill point angle was found as main drilling parameter for given experimental conditions. The surface roughness decreased with increase of feed rate and the hole quality increased at high spindle speed, low feed and drill point angle. Some researchers investigated the drill wear in the drilling of reinforced polymers and it was found that the feed was found the important factor and the main wear type was the edge rounding wear (Uysal et al., 2012; Wang et al., 2013). Altan and Altan (2014) studied the chip forms in the drilling of UHMWPE (ultra high molecular

weight polyethylene) and the irregular and deformed chips were observed at high cutting speed and low feed.

In literature, there is not any study about the drilling of electrically conductive polymers. Therefore, in this study, the drill bit temperature and chip forms were investigated in the drilling of unreinforced polyamide and carbon black reinforced electrically conductive polyamide.

**EXPERIMENTAL WORK**

Drilling operations were performed at First MCV-300 CNC machining center and unreinforced polyamide (PA) and carbon black reinforced electrically conductive polyamide (CBR-PA) materials were chosen as polymer specimens and their properties can be seen in Table 1. The brands of commercial unreinforced and carbon black reinforced polyamides are Eutotec® and Premix PRE-ELEC® PA 1411, respectively.

**TABLE 1 PROPERTIES OF UNREINFORCED AND CARBON BLACK REINFORCED POLYAMIDES**

Properties	PA 6	CBR-PA
Specific gravity	1,14 gr/cm <sup>3</sup>	1,25 gr/cm <sup>3</sup>
Yield strength	76 MPa	70 MPa
Flexural modulus	3250 MPa	3100 MPa
Elongation at break	≥50%	12%
Elongation at yield	12%	8%
Volume resistivity	≥10 <sup>14</sup> Ωcm	<50 Ωcm
Surface resistance	>10 <sup>13</sup> Ω	<10 <sup>4</sup> Ω

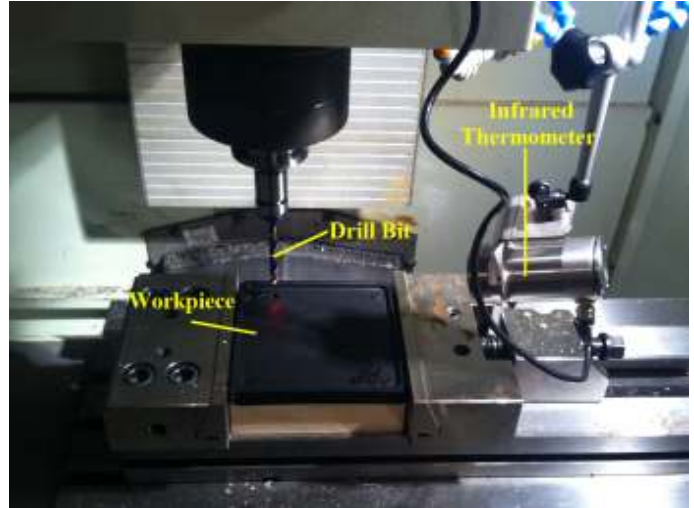
Polyamide samples were produced by injection molding in dimensions of 150x150x10 mm. Unreinforced and carbon black reinforced polyamide granules were dried at 60°C for 2 hours just before molding process. During the injection molding operations, the granules were melted at 220°C. The mold temperature and injection pressure were set at 60°C and 70 MPa, respectively. In drilling experiments, uncoated HSS (High Speed Steel) twist drill tools were used. The drill diameter was 8 mm and the point angle was selected 80° due to the fact that the small point angle was suggested in drilling of polymers and their composites (Uysal et al., 2012). Drilling parameters are given in Table 2.

**TABLE 2 DRILLING PARAMETERS**

Parameters	Levels
Cutting speed, $V_c$ [m/min]	40-80-120
Feed, $f$ [mm/rev]	0,1-0,2-0,3
Drill point angle, $\alpha$ [°]	80
Drill tool diameter, $d$ [mm]	8
Material	PA and CBR-PA

Drill bit temperatures ( $T$ ) were measured by Optris® CTlaser LT two-wire infrared thermometer immediately after the drilling tool exited from the drilled hole as seen Figure 1. The temperature measurement device has -50°C to 975°C

measurement range with ±1% measurement accuracy and its response time is 9 ms. The chip forms were viewed by SOIF XLB45-B3 digital stereo microscope which has 0,7x-4,5x zoom properties and 3 MP camera.



**FIGURE 1 DRILL BIT TEMPERATURE MEASUREMENT SYSTEM**

**RESULTS AND DISCUSSION**

Drill bit temperature results and variation of the temperatures according to the cutting speed and feed can be seen in Figures 1-2 for unreinforced polyamide and carbon black reinforced electrically conductive polyamide, respectively. The drill bit temperatures increased with increase of the cutting speed for both polyamides due to the fact that higher friction occurred between the drill tool and work piece at higher cutting speed. As investigating the effect of feed on the drill tool temperature, it decreased with increasing feed as seen in Figures 1-3. Because, in drilling of unreinforced and carbon black reinforced polyamides, the drill tool moved rapidly forward and drilling operation was performed quickly at higher feed for a constant cutting speed. By this way, lower temperature occurred on the drill bit when the feed increased.

It is known that the heat cannot be easily conducted to the drill tool in the machining of polymers owing to their low thermal conductivity (Ahmad, 2009). The carbon black reinforcement is added to the polymer materials to increase the electrical conductivity (Kim, 2007; Saad et al., 2004; Zhijun et al., 2009). But this addition increases as well the thermal conductivity. For this reason, more heat is conducted to the drill tool during the drilling of carbon black reinforced electrically conductive polyamide than that conducted in the drilling of unreinforced polyamide. Due to higher thermal conductivity of the carbon black reinforced polyamide, the drill bit temperatures were higher than that of the unreinforced polyamide as seen in Figure 3.

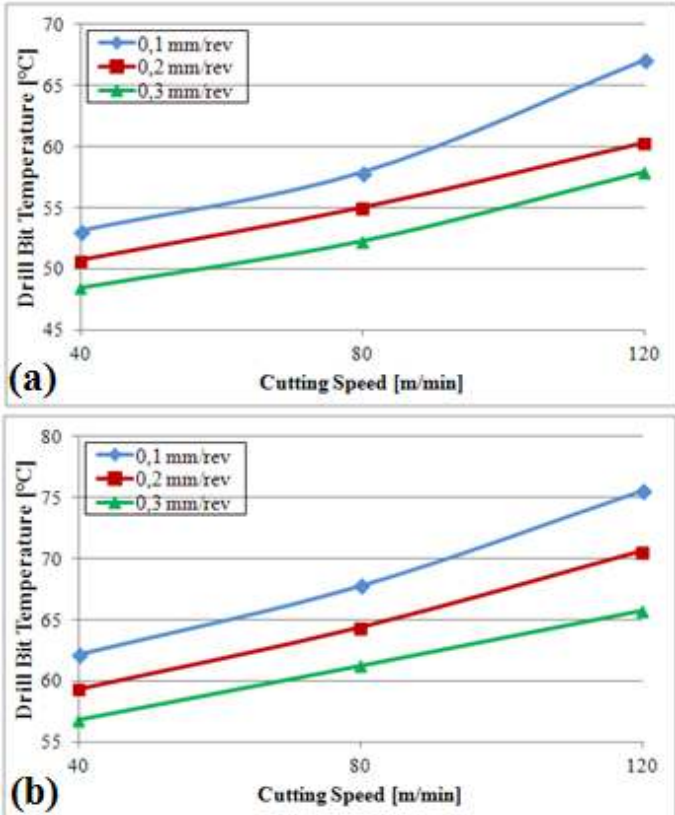


FIGURE 2 DRILL BIT TEMPERATURE VS. CUTTING SPEED, A) UNREINFORCED POLYAMIDE AND B) CARBON BLACK REINFORCED POLYAMIDE

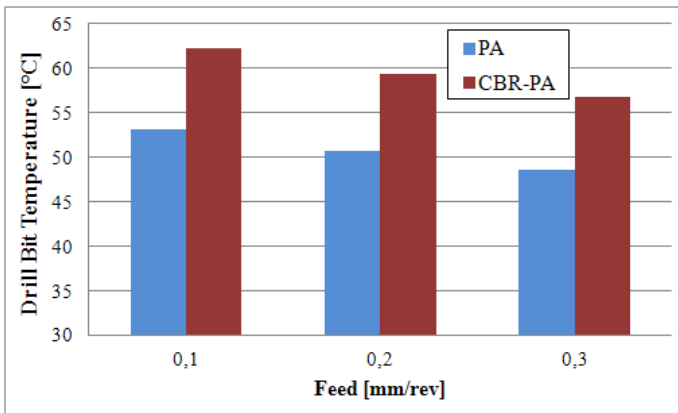


FIGURE 3 VARIATION OF DRILL BIT TEMPERATURE WITH FEED AND REINFORCEMENT (V= 40 M/MIN)

In the drilling of polymers, the heat can be conducted away by chips and drill tool. In addition, it is known that the polymers are thermally non-conductive and the heat occurs on the surface of polymer material. The helical chip forms were obtained in the drilling of polyamides as seen in Figures 4-5. The undesired and more irregular chips were formed with increase of the

cutting speed and decrease of the feed. Because, more heat occurred at higher cutting speed and lower feed and more deformed chips occurred. The polyamides can conduct the heat as well as the electricity by adding carbon black reinforcement. For this reason, better chip forms were obtained in the drilling of carbon black reinforced electrically conductive polyamide owing to conducting the heat to the drill bit (Figures 4-5). When the relation between the drill bit temperature and the chip form was investigated, higher drill bit temperature caused more regular chip forms due to the fact that the heat was transmitted from the polyamide surface to the drill bit and therefore the chips conducted away less heat and so they were less affected by heat.

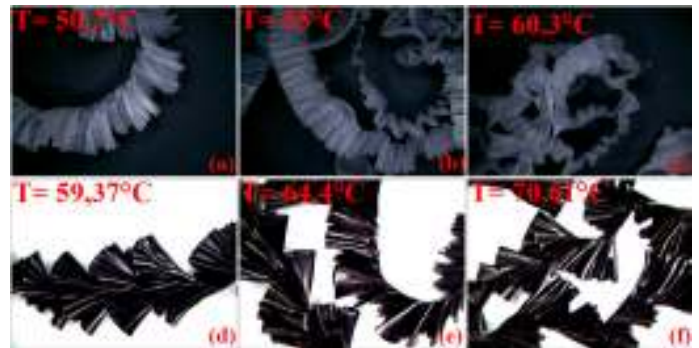


FIGURE 4 CHIP FORM, F= 0,2 MM/REV A) PA, V<sub>c</sub>= 40 M/MIN, B) PA, V<sub>c</sub>= 80 M/MIN, C) PA, V<sub>c</sub>= 120 M/MIN, D) CBR-PA, V<sub>c</sub>= 40 M/MIN, E) CBR-PA, V<sub>c</sub>= 80 M/MIN, F) CBR-PA, V<sub>c</sub>= 120 M/MIN (7X MAGNIFICATION)



FIGURE 5 CHIP FORMS, V<sub>c</sub>= 80 M/MIN A) PA, F= 0,1 MM/REV, B) PA, F= 0,2 MM/REV, C) PA, F= 0,3 MM/REV, D) CBR-PA, F= 0,1 MM/REV, E) CBR-PA, F= 0,2 MM/REV, F) CBR-PA, F= 0,3 MM/REV (7X MAGNIFICATION)

### CONCLUSION

The drill bit temperature and chip forms were experimentally investigated in the drilling of unreinforced polyamide and carbon black reinforced electrically conductive polyamide. 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 than that obtained during the drilling of unreinforced polyamide. When the chips were investigated, the helical chip forms were observed and more regular chips were formed with decrease of the cutting speed and increase of the feed. Besides, the carbon black reinforced polyamide gave more uniform chips in comparison to the unreinforced polyamide. During the drilling of carbon black reinforced polyamide, the heat was conducted to the drill tool from the polyamide surface and so the chips of this kind of polyamide were less affected by the heat.

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## NOMENCLATURE

CBR-PA	carbon black reinforced electrically conductive polyamide
d	drill tool diameter
f	feed
HSS	high speed steel
PA	unreinforced polyamide
T	drill bit temperature
$V_c$	cutting speed
$\alpha$	drill point angle

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