Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 7 (1): 141-144, 2007
ISSN 1812-5654

Machining Accuracy and Stability During Drilling of Thermoplastics

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Abstract: This study is an attempt to present experimentally the effect of poor thermal conductivity of thermoplastic on machining accuracy. In this case the machined surface roughness, maximum temperature generated during cutting and the dimensional accuracy of the drilled specimens were determined. The executed study shows that, the temperature generated increases by increasing the tool feed, cutting speed and hole depth. The use of large drill diameter leads to insignificantly increase the cutting temperature. The cutting speed during drilling teflon without cooling should not exceed 100 m min^{-1}, if the temperature of the machined material is taken into account. At cooling with pressurized air, the drilling operation may be carried at speed up to 200 m min^{-1}, since in this case the temperature generated in the cutting zone decreases approximately to 30-40°C. It is possible to drill holes with length equals twice the diameter at high speed and attain the desired accuracy.

Key words: Thermoplastic, conductivity, drilling, accuracy

INTRODUCTION

Engineering plastics are used in making various machine parts because they are light and have superior specific strength (that is, the ratio of tensile strength to density) compared with carbon steel. Also, the material cost of engineering plastics is competitive and their mach inability is fairly good (Hiroki and Etsuo, 2006). The good properties have enabled plastics to be efficiently used as substitutes for nonferrous metals and alloys and sometimes can replace ferrous in many different industries. For example, the laminate fabric base gears have the advantages over metal gears of being mute in operation and stable against the attack of various aggressive media.

Compression and injection moulding and machining are the main processes by mean of which plastic articles are formed (Danilevskey, 1976; Doley *et al*., 1985; Kalpakjian, 1995; Ostwald, 1997; Schey, 1987). The machining of plastics by different operations such as turning, drilling and milling has special features primarily due to the structure of the plastic.

Xiao and Zhang (2002) investigated the orthogonal cutting of engineering plastics. It was suggested here that the visco-elastics properties of engineering plastics have some effects on the magnitude of cutting force and the surface roughness of machined surfaces.

The machining of plastics was also reviewed in reference (Alauddin *et al*., 1995). It was found that the heating up of the work piece due to build-up of swarf on drill flutes is an obstacle to the drilling process of engineering plastics.

Recently, some experiments have been attempted on drilling different engineering plastic sheets. In papers (Chen, 1997; Capello, 2004) it was reported that the delamination phenomenon decreases the drilled hole integrity of glass-fiber-reinforced engineering plastic sheets, when holes of about 5 mm diameter are drilled. Hiroki and Etsuo (2006) investigated the small hole drilling in plastic sheet and its accuracy estimation.

Therefore, the problems encountered during plastic materials drilling are completely different from those encountered during metals drilling. The situation is further complicated by the fact that the problems encountered in drilling thermo-setting plastics are different from those encountered in drilling thermoplastic materials. Again, within these main groups there are hundreds of individual material specification where each require special consideration.

All plastic materials have poor thermal conductivity, however, thermoplastic are not exception and therefore, any heat generated when drilling cannot be dissipated by conduction. This causes the material to overheat rapidly, soften and weld itself to the drill. Since softening occurs at temperature little above the boiling point of water, overheating is the problem only affecting the component, the temperature being too low affect the temper of an ordinary high speed steel drill. Coolant cannot be used, only an air blast.

The heat generated in the hole whilst drilling causes the plastic component to expand and shrink again on cooling. This effect is even more acute on thermoplastic drilling than thermo-settings and allowances has to be made when drill sizes, where the diameter of the finished hole is critical.

Table 1: Some mechanical and physical properties of the examined teflon

Property	Specific gravity	Melting point (°C)	Tensile strength (Mpa)	Ultimate elongation (%)	Compression strength (Mpa)	Hardness Shore D
Grade	2.15	257-263	28	300	15.2	56

This study presents experimentally the effect of Teflon thermal conductivity on machining accuracy. Different machining conditions were examined to reveal the stability of drilling process.

Experimental study: Laboratory research on cutting process accuracy of teflon was carried out (Table 1). In accordance with cutting variables and processing method, the following parameters were determined: (1) the machined surface roughness, (2) maximum temperature generated during cutting and (3) the dimensional accuracy of the machined specimens. As it was expected, the most difficult was the processing of holes via drilling method, since in this case the cutting process elapses in constrained conditions.

The following cutting conditions were used: (a) the work rotational cutting speed ranged from 470 to 2000 rpm, (b) the tool feed from 0.3 to 1 mm rev^{-1} and (c) the depth of holes ranged from 24 to 100 mm. The drilling operations were carried out by means of high speed steel twist drill with point angle of 118° and with the help of engine lathe. A twist drill with various diameters (12, 18 and 30 mm) were used.

The diametrical dimensions at the entrance and hole bottom were measured with expanding indicated inside measuring instrument of 0.002 mm scale graduation.

The limit values of the cutting data were determined with respect to the drilling process stability. As a stability criterion, the following phenomena were admitted: (1) the vibration absence during processing, (2) the chip is not baked or burned and (3) the fusion of the hole walls is not discovered. For stable processing, the temperature in cutting zone was measured with the help of artificial thermocouple during drilling with and without pressurized air (ranging from 4 to 5 kgf cm^{-2}) as a coolant.

The relationship between the drilling conditions used and the generated cutting temperature is presented in Fig. 1 and 2.

The stability of the drilling process was examined at the feed from 0.12 to 1.25 mm rev^{-1} and the rotational speed from <470 to 2000 rpm. However, at the feed beyond than 0.75-1 mm rev^{-1}, the machined hole surface show very coarse roughness. The cutting data and the temperature measured for stable drilling process of teflon are presented in Table 2.

The surface finish and the dimensional accuracy of the machined surfaces are presented in Table 3 and 4.

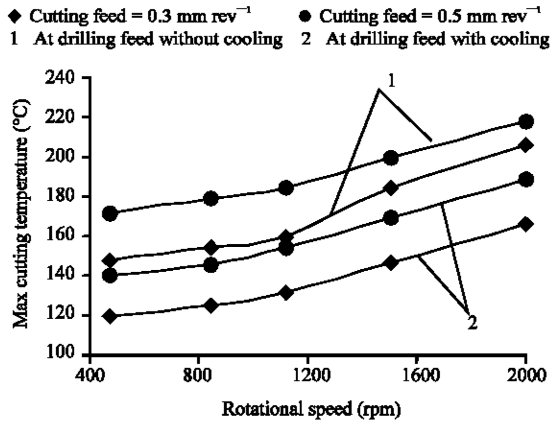

Fig. 1: The relationship between the rotational cutting speed and the cutting temperature at hole drilling depth equal to 100 mm and with the use of drill diameter equal to 18 mm

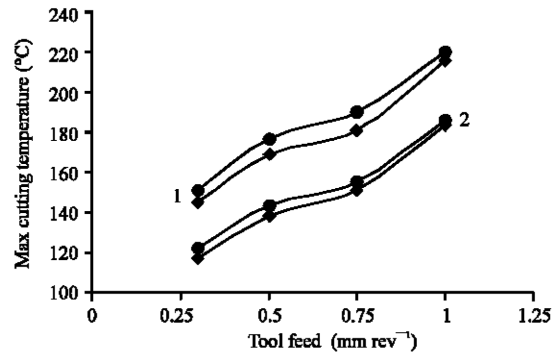

Fig. 2: The relationship between the tool feed and the cutting temperature at hole drilling depth equaled 100 mm and with the use of drill diameter equaled 12 mm, (◆ Rotational speed = 470 rpm, ● Rotational speed = 840 rpm), (1-At drilling without cooling, 2-At drilling with cooling)

It is that the surface roughness is independent on drill diameter. In a very insignificant degree at a small drill diameter an increase in t he height of irregularities was observed.

In every case, the surface finish attained by teflon drilling was better than that of metal drilling. In all cases, the teflon during drilling shrinks and this leads to diminution in hole diameter. It is evident that the cause of the shrinkage is the elastic and temperature deformations of the processed material.

The shrinkage values were determined as the difference between the diameters of the hole and the drill. It was observed that the cutting feed and speed have a direct proportional relationship with the shrinkage value.

According to Table 2, with increase of cutting feed and speed the temperature generated in the cutting zone increases.

Table 2: Stability of drilling process and cutting temperature generated without cooling

Cutting feed ($mm\ rev^{-1}$)	Stability of drilling process and maximum temperature generated in (°C) Rotational cutting speed (rpm)					Drill diameter = 30 mm At hole depth (L)
	470	840	1120	1500	2000	
0.3	150	155	163*	Non stable process		L = 100 mm
0.5	175	179*	Non stable process			
0.75	185*					
1	Non stable process	Non stable process				
1	142					L = 30 mm
0.75	125	131				
0.5	110	118	130			
0.3	98	107	118	129	141	

* Coarse machined surface

Table 3: Machining accuracy according to drill diameter and tool feed at hole depth equals 100 mm and with the use of coolant

Actual drill diameter (mm)	Cutting variables: Rotational speed (rpm)	Cutting variables: Tool feed ($mm\ rev^{-1}$)	Hole diameter at the middle of the work (mm)	Shrinkage (mm)	Ra (µm): At the hole entrance	Ra (µm): At the hole bottom
11.958	470	0.30	11.936	0.022	1.3	6
		0.50	11.931	0.027	2.4	6
		0.75	11.923	0.035	3.7	10
		1.00	11.913	0.045	4.0	13
17.952		0.30	17.922	0.030	1.2	6
		0.50	17.918	0.034	2.3	7
		0.75	17.888	0.064	3.6	11
		1.00	17.854	0.098	3.9	12
29.793		0.30	29.758	0.035	1.0	5
		0.50	29.729	0.064	2.2	6
		0.75	29.673	0.120	3.5	10
		1.00	29.633	0.160	3.8	15

Table 4: Machining accuracy according to drill diameter and cutting speed at hole depth equals 100 mm using coolant

Actual drill diameter (mm)	Cutting variables: Feed ($mm\ rev^{-1}$)	Cutting variables: Rotational speed (rpm)	Hole diameter at the middle of the work (mm)	Shrinkage (mm)	Ra (µm): At the hole entrance	Ra (µm): At the hole bottom
11.958	0.3	470	11.936	0.022	1.3	6
		840	11.932	0.026	1.5	6
		1120	11.926	0.032	2.1	8
		1500	11.920	0.038	3.1	9
17.952		470	17.922	0.030	1.2	6
		840	17.910	0.042	1.6	7
		1120	17.900	0.052	2.2	10
		1500	17.884	0.068	3.3	11
29.793		470	29.758	0.035	1.0	5
		840	29.726	0.067	1.8	7
		1120	29.704	0.089	2.4	12
		1500	29.688	0.105	3.5	12

CONCLUSIONS

- The temperature generated increases by increasing the tool feed, cutting speed and hole depth.
- The use of large drill diameter leads to insignificantly increase the cutting temperature.
- The holes machined in teflon specimens with twist drill have minus deviations in consequence of material shrinkage. These holes may be used for interference joint.
- The cutting speed during drilling teflon without cooling should not exceed 100 m min^{-1}, if the temperature of the machined material is taken into account.
- At cooling with pressurized air, the drilling operation may be carried at speed up to 200 m min^{-1}, since in this case the temperature generated in the cutting zone decreases approximately to 30-40°C.
- It is possible to drill holes with length equals twice the diameter at high speed and attain the desired accuracy.

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