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Micro-machinability of injection molded polyamide 6 polymer and glass-fiber reinforced polyamide 6 composite

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ABSTRACT

Polymer and glass-fiber reinforced polymer composites are extensively employed in the aerospace and automotive industries. As a result, the demand for accurate machining of these materials has increased in recent years. Especially, the trend of miniaturization of the components or parts makes the micro-machining such as micro-milling very important in the machining area. In current study, an attempt has been made to better understand the micro-machinability of polyamide 6 and glass-fiber reinforced polyamide 6 manufactured by injection molding. To achieve this aim, tool wear, cutting force, surface roughness and burr formation during micro-milling of these materials were evaluated and results were compared. The experiments were conducted at various spindle speeds and feed rates and the influences of these parameters on output responses were investigated. It was concluded that forces increased with feed rate and spindle speed, but surface roughness decreased with spindle speed for both workpiece materials. Adhesion on micro tool was observed for unreinforced polyamide 6, however adhesion, abrasive wear, rounding of cutting edges and micro chipping were seen for glass-fiber reinforced polyamide 6. Protrusion of fibers, fiber failure/fracture and fiber/matrix debonding were observed on the workpiece surface when micro-milling was conducted at glass-fiber reinforced polyamide 6. It was found that the top burr size of down micro-milling was higher than that of up micro-milling for both materials. The main burr shape was wall type for unreinforced polyamide 6 and wavy burr for glass-fiber reinforced polyamide 6. From micro-machinability point of view, unreinforced polyamide 6 gave better results as compared to glass-fiber reinforced polyamide 6.

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1. Introduction

In recent years, polymer and polymer composites have attracted considerable attention in the manufacturing area owing to their good mechanical, physical and thermal properties [1]. As a result of these advantageous properties, there is a demand to understand the machinability performance of polymers or polymer composites.

High specific strength, modulus and good damping properties are the advantages of polymer composites over conventional materials [2]. Using of composite materials in place of conventional materials has been growing in some structural applications [3–6] such as automotive [3–5,7], aircraft [3–5], marine and space structures [5,7] owing to their special mechanical and physical properties [8]. These materials have nonhomogeneous and anisotropic properties [7,9] therefore the machining of them is different from the traditional materials [7].

Most of the products made from fiber reinforced plastics can be manufactured to near-net-shape, but excess material is removed by means of machining to meet dimensional requirements [10], tolerances or assembly requirements [11]. Furthermore, machining process may be more economic than molding process when lower production volumes are demanded [12].

Nowadays, the use of glass-fiber reinforced plastic is increasing. As the application areas of these composites expand, the employing of machining such as milling, turning and drilling has increased to fabricate glass-fiber reinforced plastic [13,14]. But, operators have faced difficulties during machining process of glass-fiber reinforced plastics since knowledge and experience obtained from conventional materials cannot be applied directly to machining of glass-fiber reinforced plastic [14]. Machining of fiber reinforced polymers is a very challenging task due to the poor surface quality [15]. The factors for poor quality are fiber pullout and fragmentation, burning [15], fiber-matrix delamination [15–22], matrix cracking

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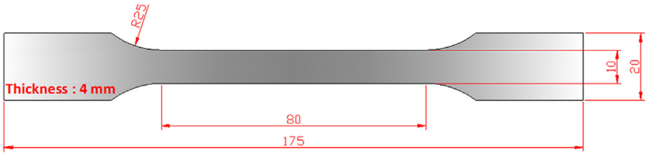
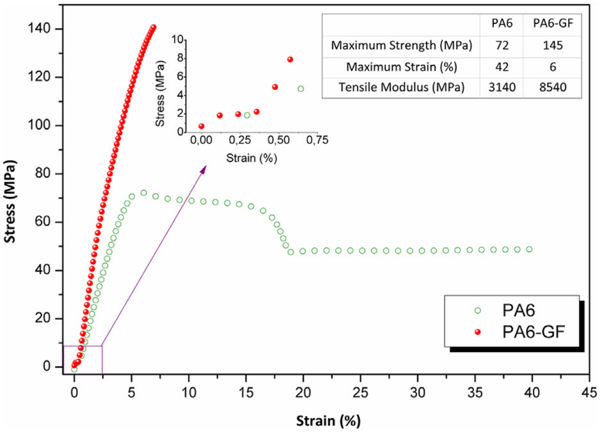


Fig. 1. Molded sample (ISO 527).

Table 1
Injection molding conditions for PA6 and PA6-GF.

	PA6	PA6-GF
Nozzle temperature (°C)	255	270
Injection pressure (bar)	80–85	80
Injection speed (mm/s)	50–60	60
Cooling time (s)	25	25
Holding pressure (bar)	8	39
Holding time (s)	0.7	2.2
Mold temperature (°C)	80	80



	PA6	PA6-GF
Maximum Strength (MPa)	72	145
Maximum Strain (%)	42	6
Tensile Modulus (MPa)	3140	8540

Fig. 2. Results for tensile properties of molded PA6 and PA6-GF.

Table 2
Experimental conditions for micro-milling of PA6 and PA6-GF.

Experiment number	Material	Spindle speed (rpm)	Feed rate (mm/min)	Depth of cut (μm)	Width of cut (μm)
1	PA, PA-GF	18,000	50	200	200
2			75		
3			100		
4		27,000	50		
5			75		
6			100		

and fiber/matrix debonding [7]. It is known that the machining of composite materials is a very complex task due to the some reason such as abrasive effect of reinforcements, heterogeneous structure and heat sensitivity [23].

Though the machinability of polymer or polymer composites has already been the subject of numerous studies during the turning [24–32] and drilling processes [33–58], there has been little interest on milling process up till now. The effect of cutting speed and feed rate on the cutting force, surface roughness, delamination factor and international dimensional precision in the milling of glass-fiber reinforced plastic was determined by Davim et al. [59]. Davim et al. [59] proposed employing higher cutting speed and lower feed rate in the milling of glass-fiber reinforced plastic to obtain better surface quality. The machinability of glass-fiber reinforced polymer was investigated in terms of the tool life, surface quality and cutting forces during end milling in the literature [60,61]. The influence of spindle speed, feed per tooth and nano-$CaCO_3$ content on the machinability of PA 6/nano-$CaCO_3$ composites was studied in the milling process through analysis of variance and harmony search-based neural network in the literature [1]. Dhokia et al. [62] presented information about machining of polypropylene and developed a surface roughness model based on neural networks during milling process. Puw and Hocheng [63] investigated the cutting force and surface quality as a function of fiber directions and cutting conditions (feed rate and cutting speed) during milling of carbon fiber reinforced plastic. Hintze et al. [64] studied the occurrence and propagation of delamination during milling of carbon fiber reinforced plastic having different fiber orientations. Davim and Reis [65] investigated the effect of cutting speed and feed rate on the surface roughness, delamination factor and international dimensional precision during end milling of carbon fiber reinforced plastic using Taguchi experimental design method. They established a regression model between the cutting parameters (cutting speed and feed rate) and the outputs (damage and surface roughness). An attempt for the determination of the optimum spindle speed, feed rate and depth of cut for obtaining minimum surface roughness and delamination factor during end milling of glass-fiber reinforced plastics by coupling neural network and genetic algorithm was presented by Razfar and Zadeh [66]. Azmi et al. [67] developed a model to predict and monitor the tool wear during end milling of glass-fiber reinforced polymer composites employing multiple regression analysis and neuro-fuzzy modelling.

Compared to the macro-machining, studies on micro-machining of plastic materials are limited. Micro-drilling performance of glass-fiber reinforced plastics was investigated in the literature [68,69]. The influence of spindle speed and feed rate on the radius error was studied in the micro-drilling of polyacetal (POM) and polyetherimide (PEI) plastics [70]. The machinability of PA 66 and 30% of glass-fiber reinforced PA 66 was investigated

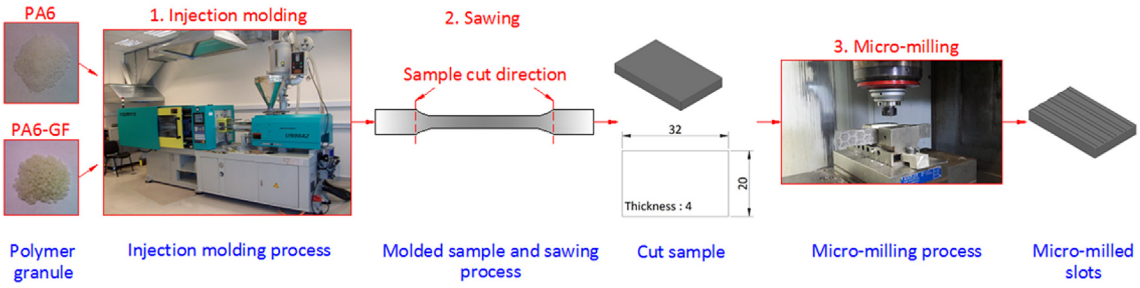


Fig. 3. Procedure to prepare the samples for micro-milling experiments.

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