Hindawi
Advances in Materials Science and Engineering
Volume 2017, Article ID 5408691, 8 pages
https://doi.org/10.1155/2017/5408691

Research Article

The Effects of Humidity on Cast PA6G during Turning and Milling Machining

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Received 23 April 2017; Revised 10 July 2017; Accepted 2 August 2017; Published 30 August 2017

Academic Editor: Belal F. Yousif

We compared the foundry PA6G samples in several dry and humid but different storage environments by processing them under the same cutting conditions such as progress rate (100, 120, 140, and 160 mm/min), cutting rate (90, 110, and 130 m/min), and cutting depth (1, 1.5, 2, 2.5, and 3 mm), in terms of formation of average surface roughness values. An improvement of 10.4% in average surface roughness was observed in the measurements performed after the milling process on the humid material and then the process was carried out under a dry condition. Degradation of about 14% in the average surface roughness was observed. The measurement was carried out after the samples were used in milling measurement which was performed on the dry PA6G material that was kept in a humid environment. An improvement of 6.4% in average surface roughness was observed. The measurements were performed after CNC machines process was applied on humid and dried PA6G material. This difference between milling and turning procedures is caused by the workpiece losing its humidity in the turning machine due to the turning effect. It was noted that the processes performed on the CNC turning stand were less affected by the humidity factor.

1. Introduction

Thanks to technological innovations, more and more engineering plastics are used. They are now used in many different fields from space technology to construction industry. There are different types and properties of engineering plastics. Polyamides are one of the most widely used types of plastics [1]. Polyamides produced by means of casting (as a result, some features are improved) are called foundry polyamides or Castamides as a commercial name. Castamides can be used instead of many metals as cheap, easily handled, lightweight, highly strong, and corrosion-resistant engineering materials. Being cheaper when compared with metals such as aluminum, copper, bronze, and brass increases their attractiveness. Despite all these, it is also known that Castamide materials are influenced by fluids and environmental humidity. The materials can get moisture from the liquid contact in unattended and uncontrolled environments. When humidified Castamides are processed in machines, they cause different results on the surface quality in the same processing parameters. In this case, the change in the processing parameters of moist and dry materials must be examined. Polyamides have been tested for many features ever since they have been used as engineering plastics since the 1960s. Some of these studies involved investigation of the frictional properties of polyamide materials [2]. Friction force is lower compared to metals in dry Castamides without lubricant. There have also been studies in which various lubricants were included in the Castamide materials to further reduce the friction forces [3–6]. Castamide materials can be processed using the methods of machining. Machinability, cutting forces, and surface roughness analyses of different types of polyamides are beyond the scope of this research. Many parameters, such as types of cutters, cutting speed, cutting depth, and the nature of the material used, are effective in cutting forces and surface quality [1, 7]. Many different studies have been conducted to determine the relationship between surface roughness and cutting conditions. Wang et al. analyzed the effect of certain cutting conditions. They investigated surface roughness using micro cutters and set out a mathematical model [8]. Paulo Davim et al. [1] analyzed the differences between processing conditions and surface roughness formation of turning lathe of glass fiber reinforced and normal PA66 polyamide materials. On the other hand, in some other studies, the differences in the machinability or cutting parameters of very hard metals such as cobalt alloy have been investigated and experimental results have been analyzed with various techniques. Surface roughness values were examined using optimization methods and estimates have been made based on artificial intelligence techniques. Ozcelik and Bayramoglu formed a model that defines the predictability of surface roughness with the statistical method [9]. We tried to use related links between controlled cutting conditions and surface roughness relations in some situations while the effects of turning forms on machinability were investigated [10]. In general, cutting conditions, the cutting tool geometry, the cutting tool type, the use of cooling liquid, the rigidity of the machine tool used, the cutting method, and the type of material used are effective on average surface roughness in the machining processes. Cutting parameters such as feed rate, cutting depth, cutting speed, and the number of cutting edges have some effects on cutting processes [11, 12].

Surface roughness value is established as a function of all machining parameters as mentioned earlier, under the machining conditions performed with cast PA6G. In addition, reaction of the materials with environmental conditions and with chemical materials is one of the factors that are effective in the formation of surface roughness. Therefore, chemical and environmental conditions should be thoroughly analyzed in case of the industrial plastics such as polyamides in the manufacture of important machinery and devices in terms of surface roughness.

Polyamide is a polymer class with a high molar mass and a linear structure. It is a solid, opaque, sometimes translucent-looking thermoplastic material and its relative density ranges from 1.07 to 1.18. Transparent types transmit light in proportion of about 85–90%. It has resistance against oils, aliphatic and aromatic hydrocarbons, ketones, and esters. On the other hand, phenol, cresol, and formic acid dissociate polymer at room temperature. Polyamides may increase by about 1% in size due to their dehumidification properties and therefore this feature should not be ignored in mold design and manufacturing [13].

The tool condition is mainly represented by the progressive tool wear and edge fracture. Statistical [9] and numeric [14] methods have been proposed to estimate the surface roughness. Benardos and Vosniakos [15] have presented the various methodologies and practices that are being used for the prediction of surface roughness. Also, studies by Brezocnik and Kovacic [16], Pal and Chakraborty [17], Özel and Karpat [18], and Durmus et al. [19] brought new technology and knowledge in machining theory, experimental investigation, designed experiments, and artificial intelligence. Moreover, Yalçin et al. [20] studied the effects of various cooling systems on surface roughness and tool wear during computer aided milling of soft workpiece materials.

The surface roughness for air cooling end milling is lower than dry end milling but is higher than fluid cooling end milling. Çolak et al. [21] carried out studies on surface roughness of the milling surface in relation to cutting parameters by using the genetic expression programming method. Topal [22] worked on the role of stepover ratio in surface roughness. Zain et al. [23] suggested a model about surface roughness in the milling process which could be improved by modifying the number of layers and nodes in the hidden layers of the artificial neural network (ANN) structure. Basheer et al. [24] have run an experiment for the analysis of machined surface quality on composites leading to an ANN model to predict the surface roughness. The predicted roughness of machined surfaces based on the ANN model was found to be in conformance with experimental data.

In this study, the effects of humidity on machinability were investigated. Average surface roughness measurements were performed after the humid and dry samples were treated with the same conditions. Then, the changes in surface roughness were recorded again by keeping the humid samples under dry storage conditions and the dry samples under humid storage conditions. The obtained results put forth different surface roughness formations in machining processes performed with the same cutting parameters under the humid and dry conditions. Similarly, humidity causes a negative change on surface roughness that forms as a result of machining. The detailed information obtained from the experiments and the surface roughness changes obtained depending on humidity are given in tables and graphs.

2. Experimental Setup

Humid and dry ambient conditions were created to allow humidification of the cast PA6G material before and after machining and the steps were performed in turn depending on the feature of the experiments carried out on the samples. Average surface roughness values were experimentally examined by changing the cutting parameters of the samples that were exposed to changed humidity conditions on CNC benches. The schematic image of the experiment setup, which is used during the experiments, is given in Figure 1.

In the experimental studies, Castamide samples that were kept in humid and dry environments for a specific time were treated with hard metal cutters. To obtain the average surface roughness value (Ra), cutting velocity (V_c), feed rate (f), and cutting depth (a_p) were changed and the samples that were kept in the atmosphere that was suitable for the machining experiment were treated on CNC milling and CNC turning benches with the same cutting parameters. The samples that were kept in humid and dry storage environments were attached to the bench table immediately after they were taken from their storing containers and the surface procedures were performed under the determined cutting conditions.

2.1. Test Samples. The samples used in the experiment were supplied as plate and circular sections from Polimersan Company. Castamide material is defined as Polikes® (PA6G) in the product catalog of the company. PA6G supplied as plate was cut in 112 × 82 × 46 mm parts and the one as circular section in 100 × 200 mm parts and they were kept ready for the experiment by being stored in humid and dry conditions.

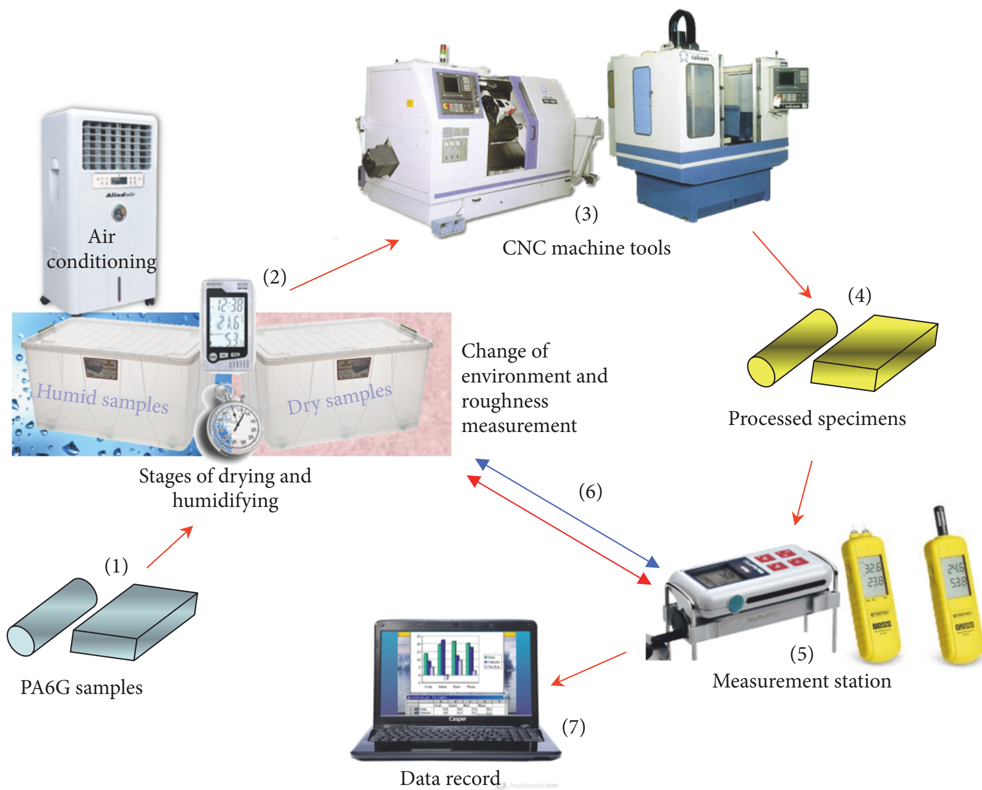

Figure 1: The scheme image of the experimental setup.

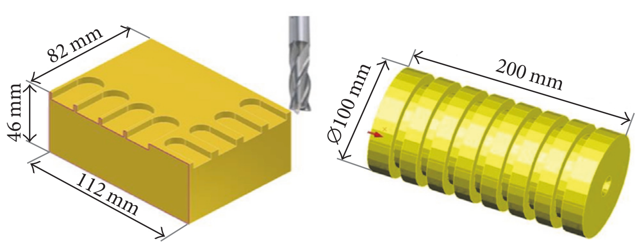

Figure 2: CAD models of the test samples.

The physical features of the samples used in the experiment are given in Table 1.

Computer Aided Design (CAD) models of the samples used in CNC turning and CNC milling in the experiment are given in Figure 2.

2.2. CNC Machines and Cutting Tools. After the samples were kept in a humid environment, a Taksan brand TMC 700V CNC vertical machining center and TTC 630 CNC turning were used for machining procedures. The vertical machining center has a system that can perform linear and circular interpolation in three axes programmable in ISO format with 15 kW power.

A turning chisel and end mill cutter tools of 14 mm diameter made of hard metal were used for cutting operations. The end mill cutter tool is produced in compliance with DIN 81800 standard and has four cutting edges, 30° helix angle, a WC (tungsten carbide) helix angle of 87.7%, a cobalt rate of 12.3%, TRS (transverse rupture strength) of 4200 MPa, hardness of 92.5 HRA (Rockwell hardness value), grain size of 0.5 μm, and high abrasion capability. Average surface roughness was obtained by using the cutting parameters including cutting velocity, feed rate, cutting depth, and humid/dry Castamide materials in the machining procedure. The cutting parameters used in the experiments are given in Table 2.

2.3. Measurement and Control. CNC laboratory has an air conditioning system and its average temperature is 21 ± 1°C. Humid Castamide materials were humidified at a rate of about 7% as a result of being kept in water for 30 days. This value is the maximum moisture extraction as specified in the manufacturer's catalog for the Castamide material. Castamide samples that were kept dry were stored in a special protective container and they were kept away from humidity. The samples taken from the dry storing container were attached to the bench immediately and the experiment was performed under the desired machining parameters.

A Trotec T2000S measuring device and an electronic weighing scale were used in the measurement of humidity of the atmosphere and materials. The heart of the T2000S is a 24-bit analog/digital converter which supplies long-term, stable, precise results which analog instruments cannot achieve even in a rough environment. The digital technology of the "Serial Digital Interface" (SDI) opens up a new dimension

Table 1: The physical properties of the cast PA6G material.

Properties	Unit	Value
Specific gravity	g/cm^3	1.15
Service temperature	°C	100
Melting point	°C	190
Thermal elongation	1/K∗10^5	(8-9)10^{-5}
Tensile strength	MPa	55–85
Rapture strength	MPa	88–90
Elongation at break	%	10–40
Modulus of elasticity	MPa	3900–4200
Water absorption	%	6-7
Volumetric resistance	W·cm	>1015
Surface resistance	Ω	>1012
Dielectric strength	kV/mm	80–100
Rockwell	scala	M88
Ball notch 358/30	MPa	110–160

Table 2: The cutting parameters for cast PA6G.

Cutting conditions	Unit	Data	Number of data
Processing type	—	CNC milling; CNC turning	2
Material	—	Humid, dry	2
Type of tool	—	Carbide	1
Feed rate (f)	mm/min	100; 120; 140; 160	4
Depth of cut (a_p)	mm	1; 1.5; 2; 2.5; 3	5
Cutting speed (V_c)	m/min	90; 110; 130	3

in flexibility in measuring missions for the user. With its microwave technology, the TS350 SDI *(microwave moisture sensor)* is suitable for nondestructive moisture measurement up to a material depth of 30 cm. Another advantage is the independence of the degree of salination of the material.

The changes in the average surface roughness when treating the Castamide material with machining on the CNC tool benches were recorded by using the MarSurf PS1 portable surface roughness device. There are various simple surface roughness amplitude parameters used in industry, such as roughness average (Ra), root-mean-square (rms) roughness (Rq), and maximum peak-to-valley roughness (Ry or Rmax). The parameter Ra is used in this study. The average roughness (Ra) is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length. The needle of the device has a measurement radius of 2 μm and a pressure force of 0.7 mN. The scanning length of the roughness measurement was set to 5.6 mm.

3. Results and Discussion

Cutting depth, feed rate, cutting velocity, whether the material was humid or dry, and average surface roughness formed depending on the cutter tools used were experimentally examined during the CNC milling procedure. Various surface roughness values of the humid and dry materials were

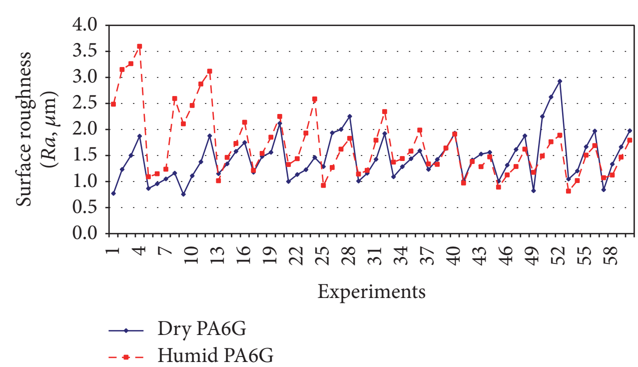

Figure 3: The change in surface roughness of humid and dry materials.

measured in machining cutting parameters by using the experiment combinations stated in the machining conditions. The graphic that shows the average surface roughness in the experiments carried out in the milling processes is given in Figure 3.

The graphic that is given in Figure 3 has an arrangement that shows an increase in cutting depth as the number of experiments increases. Based on this arrangement, it is observed that the surface roughness change formed in the machining of the humid and dry materials is inversely related. It is observed that as the cutting depth of the dry material increases, the surface roughness deteriorates in general and

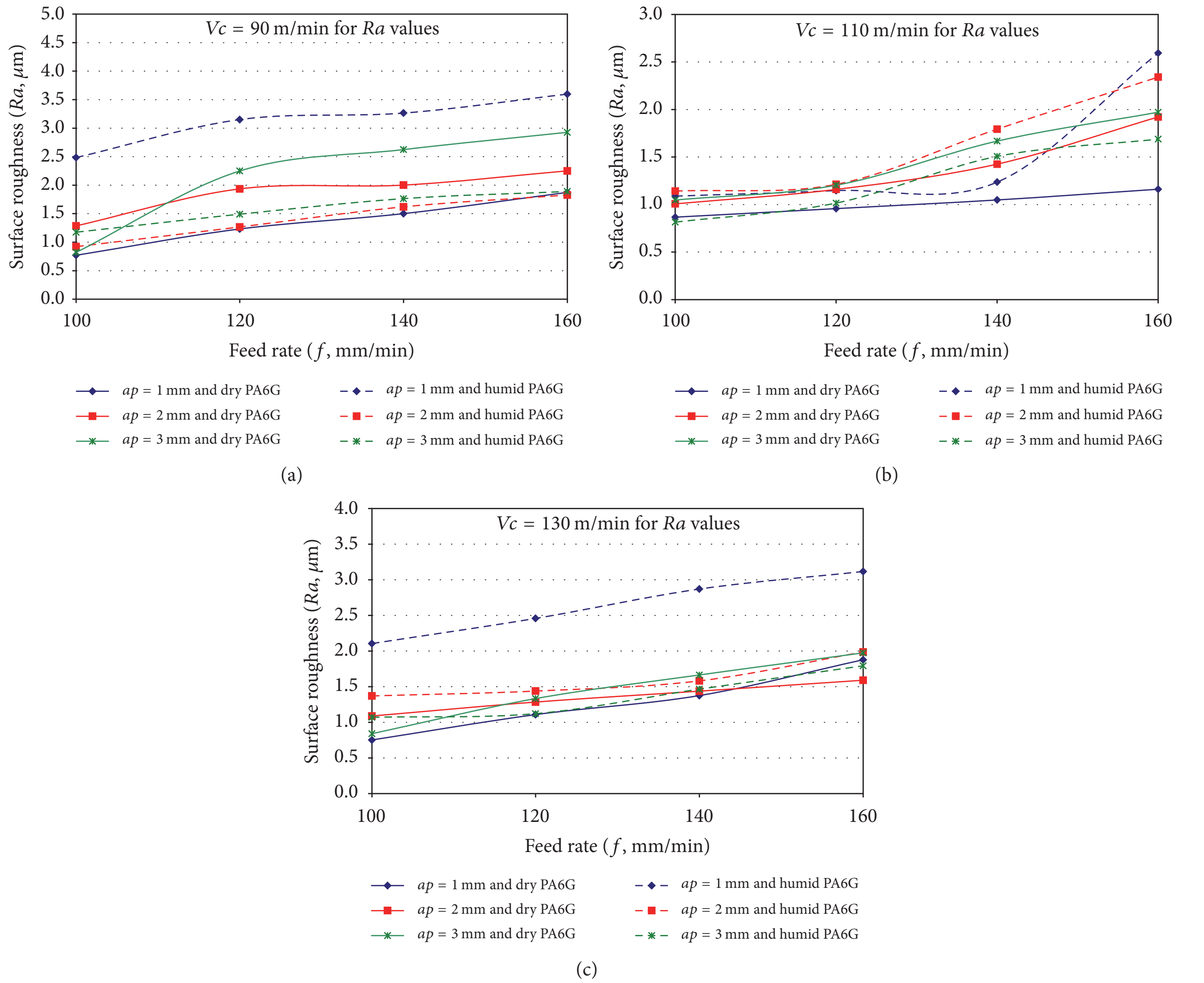

FIGURE 4: The progress of the average surface roughness formation in different cutting speeds for humid and dry materials: (a) $V_c = 90$ m/min, (b) $V_c = 110$ m/min, and (c) $V_c = 130$ m/min.

the increase in the cutting depth of the humid material has a positive effect in the formation of average surface roughness. The reason for this unexpected quality surface formation is thought to be the reduction of the friction force of the test sample's inner surface and the effect of the cooling fluid on the cutting tool.

On the other hand, a weaker surface roughness formation is observed in the results of the experiment in which the humid material was treated in low cutting depth when compared to the treating parameters of the dry material. Average surface roughness changes obtained in feed rates used in the experiments and with $V_c = 90$ m/min, 110 m/min, and 130 m/min cutting rates were examined in Figure 4.

When the graphic given in Figure 4(a) is analyzed, it is observed that the surface roughness values that formed when the material is humid and when the cutting depth is 1 mm at $V_c = 90$ m/min cutting velocity get weaker depending on the increase in feed rate. All graphics given in Figure 4 show that the increase in feed rate affects average surface roughness negatively. However, it is observed that, with the increase of cutting velocities to $V_c = 110$ m/min and $V_c = 130$ m/min, the average surface roughness formation is improved when compared to $V_c = 90$ m/min. In general, cutting velocity increase has a positive effect on the surface quality formation in humid and dry materials.

In Figure 5, the surface roughness formation depending on cutting depth and the feed rate is shown. The negative effect of the increase in feed rate on surface roughness when treating the humid and dry samples is given in Figures 5(a), 5(b), 5(c), and 5(d). A combination of low cutting depth and high feed rate created negative surface roughness particularly for humid materials. When the graphics are analyzed in detail, it is observed that cutting depth has a positive contribution to the formation of average surface roughness after 2 mm for humid materials. In cases where the same humid samples have cutting depths lower than 2 mm in spite of their different feed rates, average roughness is affected

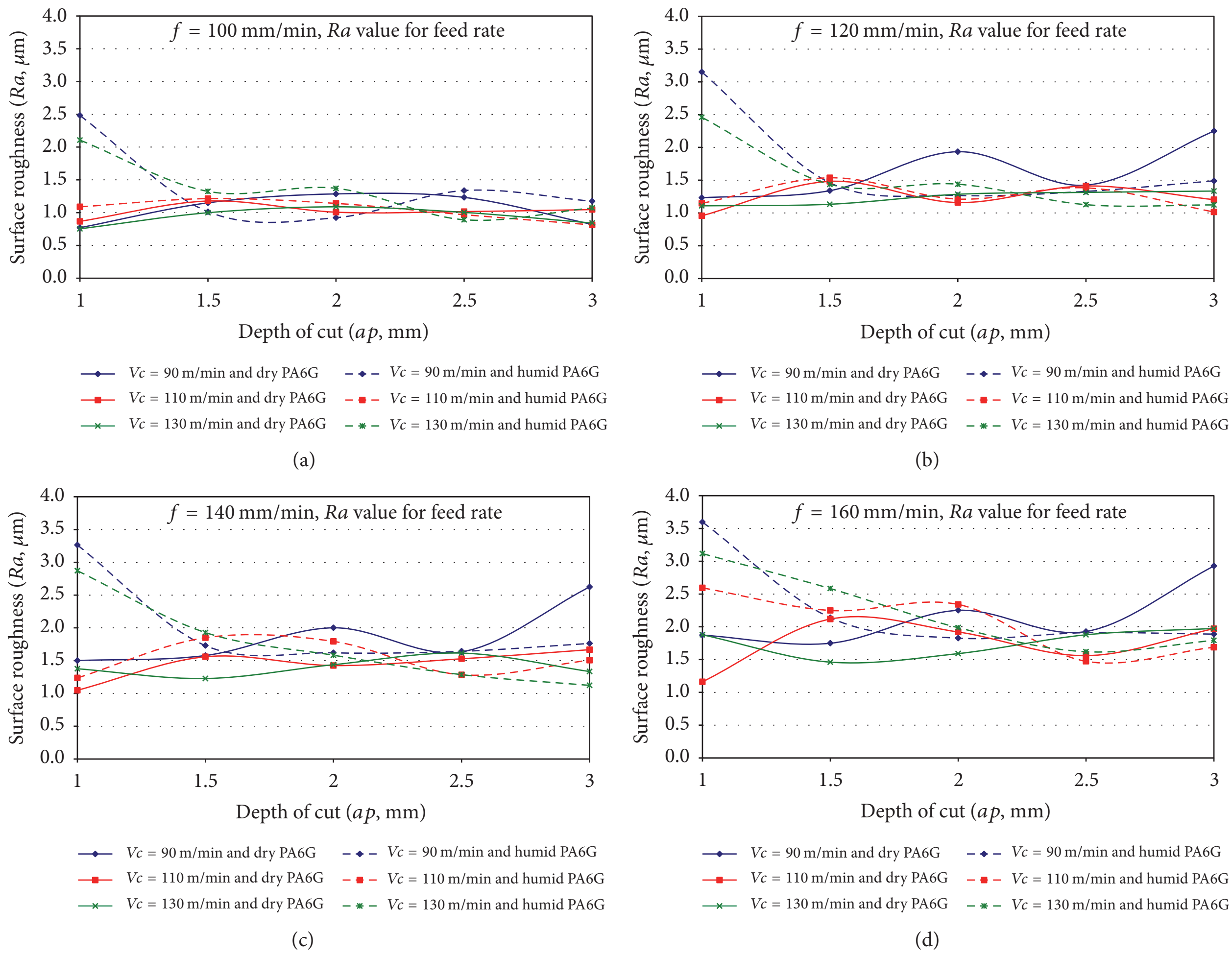

Figure 5: The relationship between surface roughness and depth of the cut for humid and dry samples at different feed rates: (a) f = 100 mm/min, (b) f = 120 mm/min, (c) f = 140 mm/min, and (d) f = 160 mm/min.

negatively. This can be interpreted as a chilling effect on the cutting tool.

To investigate the effect of humidity on surface roughness, the changing average roughness was remeasured by keeping the samples, of which surface roughness measurements were performed after being treated with the parameters suitable for the determined machining conditions, in reverse (in humid environment if dry and in dry environment if humid) humidity conditions. The difference between the first average roughness measurement value and the average surface roughness measurement after the change of atmosphere was determined to be the effect of the humidity factor on the average surface roughness of a treated surface. Some results of these experiments are given in Table 3. The main idea that appears when examining Table 3 is that surface roughness of test specimens increases when dry test specimens are kept in a humid environment after being processed in the machine. On the same table, the surface roughness is reduced when the moisture samples are dried after being processed in the machine. In general, the moisture factor increases the surface roughness on the Castamide materials after machining.

The results of the experiments are given as a collective graphic in Figure 6. When the obtained values and the graphic are analyzed, an improvement of about 10.4% is observed in the surface roughness of the cast materials that were dried after being treated as humid.

A deterioration of about 14% was observed in the surface roughness values when the dry materials were remeasured after a storing period of 15 days in humid atmosphere when compared to the measurement performed after the CNC machining process. The graphics of all ambient changes and the obtained surface roughness values are given in Figure 6.

4. Conclusions

In this study, it was aimed to study the effect of humidity on samples when machining the cast PA6G material on CNC turning and CNC milling benches as well as how the average roughness value that is formed on the surface after the machining is or is not affected under humid environmental conditions.

Table 3: The effect of humidity on the change of surface roughness.

CNC milling (dry)		CNC milling (humid)	
After processing, *Ra* (μm)	After leaving in a humid environment, *Ra* (μm)	After processing, *Ra* (μm)	After leaving in a dry environment, *Ra* (μm)
2.253	2.589	2.490	2.135
2.742	3.112	3.185	2.993
2.649	2.981	3.620	3.314
2.250	2.453	3.700	3.453
2.142	2.342	2.826	2.486
2.414	2.765	3.233	3.103
2.856	3.231	3.479	3.110
2.920	3.436	3.526	3.203
2.923	3.452	2.246	1.967
2.232	2.564	2.825	2.143
CNC turning (dry)		CNC turning (humid)	
After processing, *Ra* (μm)	After leaving in a humid environment, *Ra* (μm)	After processing, *Ra* (μm)	After leaving in a dry environment, *Ra* (μm)
9.544	10.213	5.764	5.178
1.874	2.025	1.814	1.693
3.186	3.420	2.956	2.760
8.360	8.945	6.296	5.668
2.556	2.799	1.750	1.573
1.878	2.010	2.144	1.929
7.340	7.876	6.423	5.781

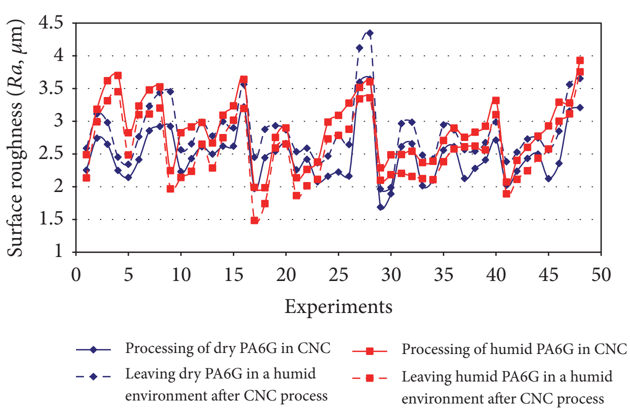

Figure 6: The effect of humidity on the average surface roughness.

The experiments were compared using the same cutting parameters in CNC turning and CNC milling by analyzing the average surface roughness on the PA6G material prepared under dry and humid conditions. The results obtained as a result of the humidity factor in CNC turning and CNC milling can be summarized as follows.

(i) An improvement of 10.4% was observed in the surface roughness of the cast (humid) samples in the measurement performed when the milling procedure was applied under the machining conditions given in Table 2 and in the measurement performed after they were dried.

(ii) A deterioration of about 14% was observed in the surface roughness of the cast (dry) samples in the measurement performed when the milling procedure was applied under the machining conditions given in Table 2 and in the measurement performed after they were kept in humid environment.

(iii) An improvement of 6.4% was observed in the surface roughness of the cast (humid) samples in the measurement performed when the CNC turning procedure was applied under the machining conditions given in Table 2 and in the measurement performed after they were dried. The reason of this difference between milling and turning is interpreted as the loss of humidity due to the turning effect.

(iv) As expected in surface roughness formation, the increase in the cutting velocity affected the surface roughness positively while the feed rate increase affected the surface roughness negatively when treating the humid and dry cast samples.

(v) In cases where the cutting depth of the humid samples was higher than 2 mm, better surface roughness was obtained when compared with dry samples. The reason is interpreted as humidity having a chilling effect on cutting edges.

(vi) In case the cast and polyamide type industrial plastics are used in the machinery and for devices that require sensitive surface roughness, atmosphere conditions and particularly humidity should be considered as important surface roughness factors. Change in roughness occurs on the surface depending on the humidity even after machining.

Conflicts of Interest

The author declares that there are no conflicts of interest.

Acknowledgments

The research described here was supported by the Scientific and Technological Research Council (TUBİTAK, no. 109M031) and Scientific Research Projects Coordination Unit of Kırıkkale University (KU BAP, no. 2015/82).

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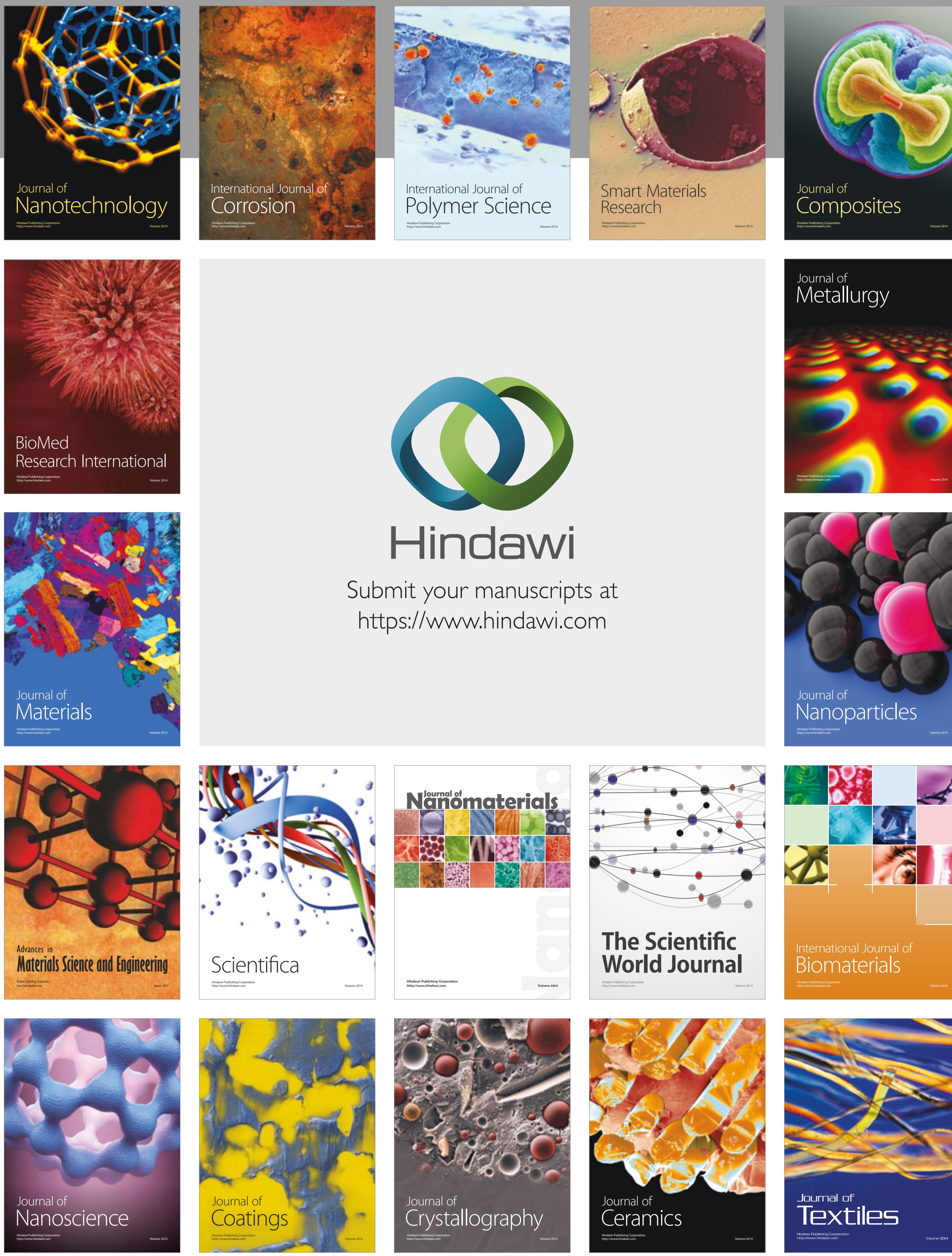
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