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Analyzing Surface Quality Factors in CNC Milling of Polypropylene Plates

Yasin AKIN*[1], Ömer ÇERLEK[1] , Kubilay HAN[1]

[1]*Mechanical Engineering/Faculty of Technology, Sakarya University of Applied Sciences, Turkey*

**(yasinakin@subu.edu.tr)*

Abstract **–** This study focuses on the analysis of surface quality factors in the CNC milling of polypropylene plates. Polypropylene, a versatile and widely used polymer, poses specific challenges during the milling process due to its unique properties. The research involves the utilization of a CNC machine to conduct milling operations on polypropylene plates with varying spindle speeds and feed rates. Surface roughness measurements are taken using a Mahr brand surface roughness measurement device, and the average values are recorded. The study aims to identify the key parameters that affect surface quality and to optimize the CNC milling process for polypropylene materials. Looking at the results, it has been observed that the milling of polypropylene plates results in different outcomes for average surface roughness and Rz values under various parameters.

Keywords – Polypropylene, Surface Roughness, Feed Rate, Spindle Speed, CNC

I. Introduction

Milling is a commonly used cutting process in the manufacturing industry. This method is highly effective for producing parts with high surface quality and precision requirements. Milling is widely employed in processing metals, plastics, wood, and various other materials, playing a significant role in many industries [1]. This method is a highly effective approach for producing parts with high surface quality and precision requirements.

Machining of polymer materials is a more intricate process compared to metallic materials. This process must be carried out carefully to prevent issues such as delamination, burning, or even the application of excessive stress to the polymers. Therefore, achieving high-quality results during a CNC milling operation is challenging, and it necessitates optimization research for this purpose [2].

Polypropylene, commonly known as PP, is one of the polymers. Polypropylene offers a wide range of applications in industries such as the packaging industry, automotive sector, medical devices, textile products, and more due to its properties like high impact resistance, chemical resistance, lightweight nature, heat resistance, and electrical insulation. Being available in both solid and flexible forms, polypropylene is a versatile polymer that can be processed using various methods.

Carefully adjusting the correct machining parameters is important to achieve precise results when milling polypropylene. Cutting speed (n), feed rate (F), and depth of cut (dc) are among the key factors that influence surface roughness efficiency during milling operations. These parameters directly affect the surface roughness (Ra) of the workpiece being machined [3-6].

While there is a wealth of information available on the machining of metal materials, knowledge about the machining of customized products like polymers is limited. The machining of polymers [7] often requires designers to behave differently compared to traditional metal processing. This study will focus on defining the optimum machining parameters to achieve the desired surface roughness for polypropylene materials.

II. MATERIALS AND METHOD

In this study, Polypropylene material with the mechanical properties demonstrated in Table-1 was used as the material to be formed. Haas CNC milling machine tool was employed for the execution of the operations. An 8 mm diameter milling cutter was used as the milling tool.An 8 mm diameter milling cutter was used in the milling process of the PP material with the properties specified in Table-1.

Table 1. Properties of Polypropylene Used in Milling Processes

Property	Unit	Value	Standart
Density	g/cm2	0.91	ISO 1183-1
Hardness	Shore	72	ISO 868
Yield Strength	MPa	32	ISO 527-1
Elasticity Modulus	MPa	1700	ISO 527-1
Strain Failure	%	>50	ISO 527-1

The process has been conducted as follows: Polypropylene material was fastened to the table of milling machine. Consecutive chip removal operations were done with a cutting tool of 8 mm diameter at cutting speeds of 500, 700, and 900 RPM, feed rates of 40, 60, and 80 mm/min, and cutting depths of 0.5, 1, and 1.5 mm, respectively.

Following the processes were completed, three surface roughness values were measured from each channel of the Polypropylene material's surface using a Mahr S1 surface roughness measurement tool, as demonstrated in Figure-1, and their average values were noted.

Fig. 1 Surface Roughness Measurement Setup

III. RESULTS

In this study, measurements attained as follows:

Table 2. Average Surface Roughness Measurements for Different Spindle Speed, Cutting Depth and Feed Rates

Process Nr.	Spindle Speed (rpm)	Feed Rate (mm/min)	Cutting Depth(mm)	Rz(µm)
1	400	30	0.5	4.407
2	600	50	0.5	3.663
3	800	70	0.5	4.219
4	400	30	1	5.709
5	600	50	1	8.01
6	800	70	1	2.517
7	400	30	1.5	12.34
8	600	50	1.5	3.109
9	800	70	1.5	2.47

Table-2 depicts the average surface roughness measurements acquired at various spindle speed, cutting depth and feed rate values.

Table 3. Rz Roughness Measurements for Different Spindle Speed, Cutting Depth and Feed Rates

Process Nr.	Spindle Speed(rpm)	Feed Rate(mm/min)	Cutting Depth(mm)	Ra(μμ)
1	500	40	0.5	25.23333333
2	700	60	0.5	30.26666667
3	900	80	0.5	34.73333333
4	500	60	1	29.33333333
5	700	80	1	27.66666667
6	900	40	1	23.63333333
7	500	80	1.5	35.76666667
8	700	40	1.5	22.06666667
9	900	60	1.5	22.43333333

Table-3 depicts the Rz roughness values acquired from measurements at various spindle speed, cutting depth and feed rate values.

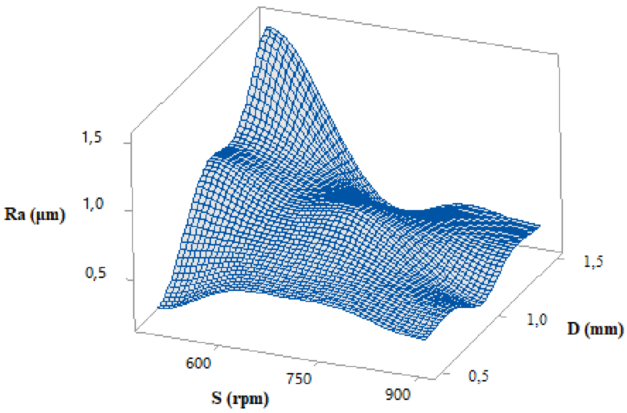

Fig. 2 Surface Plot of Ra(μm) vs S(rpm); D(mm)

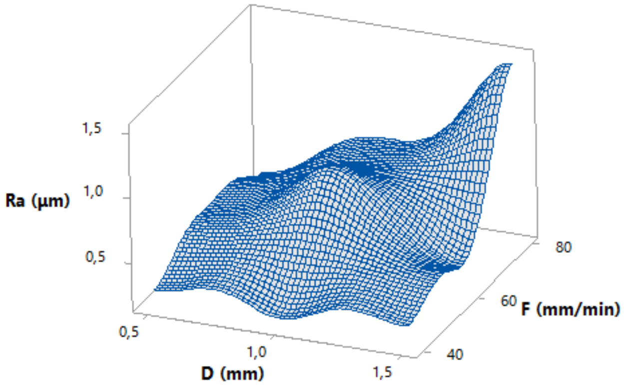

Fig. 3 Surface Plot of Ra(μm) vs D(mm); F(mm/min)

In Figures 2, 3, and 4, average roughness measurements are demonstrated for cutting speed-cutting depth, cutting depth-feed rate and cutting speed-feed rate, respectively. When all these parameters are examined together, it can be seen that the highest average surface roughness(Ra) values emerge at a feed rate of 80 mm/min, a cutting depth of 1,5 mm, and a cutting speed of 700 rpm. In addition, the lowest average roughness(Ra) values are seen at a feed rate of 40 mm/min, a cutting depth of 1 mm, and a speed of 900 rpm.

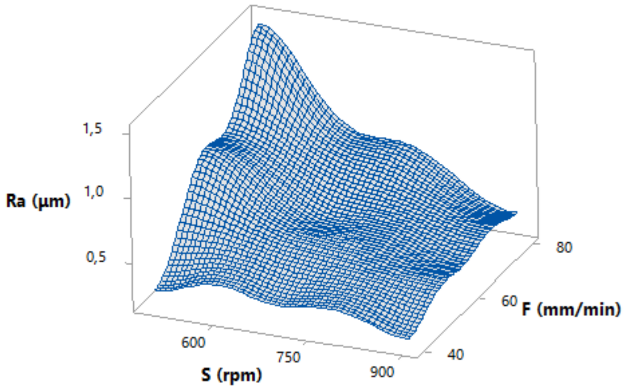

Fig. 4 Surface Plot of Ra(μm) vs S(rpm); F(mm/min)

When the results are evaluated for the machining of HDPE material with milling process, within the given parameters, it can be said that the optimal process parameters are S: 900 rpm, F: 40 mm/min, and D: 1 mm.

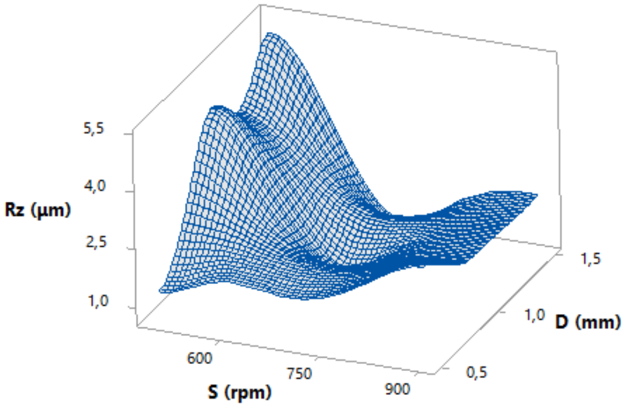

Fig. 5 Surface Plot of Rz(µm) vs S(rpm); D(mm)

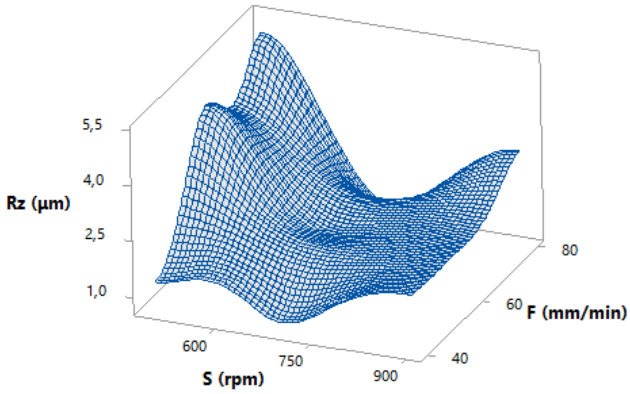

Fig. 7 Surface Plot of Rz(µm) vs S(rpm); F(mm/min)

In Figures 5, 6, and 7, Rz roughness measurements are shown for cutting speed-cutting depth, cutting depth-feed rate and cutting speed-feed rate, respectively. When all these parameters are examined together, it can be said that the highest Rz surface roughness values acquired at a feed rate of 80 mm/min, a cutting depth of 1,5 mm, and a cutting speed of 500 rpm. In addition, the lowest Rz roughness values are occurred at a feed rate of 40 mm/min, a cutting depth of 1,5 mm, and a speed of 700 rpm.

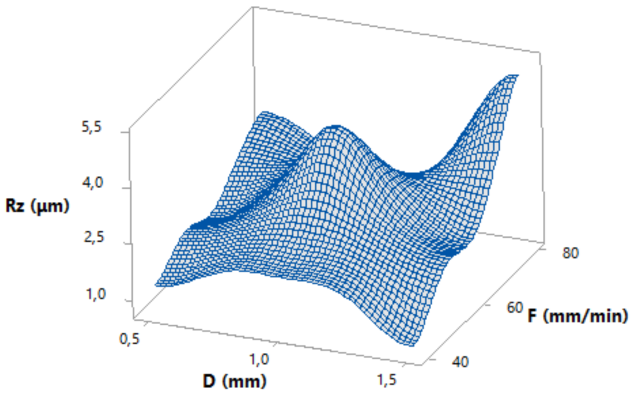

Fig. 6 Surface Plot of Rz(µm) vs D(mm); F(mm/min)

Upon evaluating the Rz roughness values, it has been observed that, according to the given parameters, the optimal process parameters for machining Polypropylene material with milling are S: 700 rpm, F: 40 mm/min, and D: 1.5 mm .

IV. DISCUSSION

Entensive research on the milling of polymer materials has been limited and this caused the need for the present study. Specifically, the scarcity of studies focused on Polypropylene (PP), a material that is increasingly prevalent, has created a noticeable research gap. Within this context, our study is designed to investigate the achievable surface quality when subjecting Polypropylene plates to milling processes.

A prior study by Dhoika et al reported that as the process parameters; cutting speed, feed rate and cutting depth increases, surface roughness values are also increase.[8]. However, it's essential to note that our study employs different and various process parameters, better results could be obtained in terms of surface quality.

In future research endeavors, exploring processes at different parameters may uncover novel insights and further contribute to the advancement of scientific knowledge.

V. CONCLUSION

When the results are examined, it has been monitored that the average surface roughness value and Rz roughness values of Polypropylene materials processed with milling machine, produced different results in almost every operation. When looking at each individual chip removal operation, the highest average roughness values are observed at the parameters of feed rate of 80 mm/min, a cutting depth of 1,5 mm, and a cutting speed of 700 rpm. However, the lowest average (Ra) surface roughness measurements are observed at the parameters of 40 mm/min, a cutting depth of 1 mm, and a speed of 900 rpm.

In addition, the highest Rz roughness values are observed at the parameters of feed rate of 80 mm/min, a cutting depth of 1,5 mm, and a cutting speed of 500 rpm. And lowest measurements for Rz are attained at the feed rate of 40 mm/min, a cutting depth of 1,5 mm, and a speed of 700 rpm.

As can be understood from these values, the average and Rz surface roughness values have yielded different results in the milling of polypropylene plates. In the future, conducting more comprehensive studies would be beneficial for achieving higher levels of surface quality.

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