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Investigating Surface Quality Parameters in CNC Milling of UHMW-PE Sheet

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Abstract – Ultra High Molecular Weight Polyethylene (UHMW-PE) is a specialized type of polyethylene, representing a variation of thermoplastic polyethylene with high impact resistance and hardness. This material exhibits exceptional mechanical properties due to its long molecular chains. Additionally, the long-term use of UHMW-PE in biomedical applications can lead to wear issues. To enhance its mechanical and tribological properties, efforts have been made to incorporate different materials into UHMW-PE. In this study, the process of machining Ultra High Molecular Weight Polyethylene (UHMW-PE) plates has been thoroughly investigated. Using a CNC milling machine, the roughness of surfaces processed with different feed rates, cutting speeds, and machining depths was measured and compared with similar studies available in the literature. The obtained results will assist in understanding which parameters affect surface roughness during the machining of UHMW-PE. Such research plays a crucial role in industrial processes to improve the quality of machined parts and achieve desired surface properties.

Keywords – UHMW, Roughness, Rz, Spindle Speed, CNC, Polyethylene

I. INTRODUCTION

Ultra-High Molecular Weight Polyethylene (UHMWPE) is a type of polyethylene with a density that varies between 0.930 and 0.935 g/cm3 and a molecular weight ranging from 2 to 6 million. UHMWPE is a special variation of thermoplastic polyethylene and is also referred to as High Modulus Polyethylene (HMPE). This material is characterized by its extremely long molecular chains, often extending up to 3.5 to 7.5 million atomic mass units. These long chains strengthen interactions between molecules, providing exceptional impact resistance and hardness to the material. Thanks to its long-chain structure, UHMWPE is one of the thermoplastic materials with the highest impact resistance and hardness[1].

Highly crosslinked Ultra-High Molecular Weight Polyethylene (UHMWPE) is a unique polymer with distinctive physical and mechanical properties. Its chemical stability, low friction coefficient (lubricity), impressive impact resistance, and abrasion resistance are standout features. These characteristic properties have found a wide range of industrial applications since the 1950s. UHMWPE is used in various applications, such as collectors in textile machinery, surface coatings for dump truck beds and coal bunkers, distributor rails in bottle production lines, bumpers, and fenders in shipyards and ports. About 90% of UHMWPE produced worldwide is used for various industrial purposes[2].

In high-performance biomedical applications, UHMWPE is frequently employed due to its excellent biocompatibility and robust impact resistance. This ultra-high molecular weight polyethylene is a semi-crystalline polymer, offering superior mechanical properties like high impact resistance and a lower friction coefficient compared to other thermoplastics. However, wear issues arising from long-term use can limit the lifespan of artificial joints and lead to bone resorption, joint loosening, or infections. Additionally, the low melting temperature of UHMWPE can be seen as a disadvantage in biomedical applications[3-7].

Currently, enhancing the mechanical and tribological properties of UHMWPE is an active research area. Many researchers have attempted to improve the wear resistance of UHMWPE by incorporating different materials, especially metals (carbon fiber, carbon nanotubes, graphite), ceramics (alumina, titania, zirconia, hydroxyapatite, quartz, wollastonite), and various polymers (polyurethane, phenyl p-hydroxybenzoate, etc.) into the UHMWPE matrix. These studies have demonstrated that UHMWPE matrix composites, with micro and nano-scale second phases, inorganic particles, ceramics, and bio-material reinforcements, can enhance not only mechanical but also wear properties[8-12].

During machining processes, the method used, the type of cutting tool, and processing conditions can lead to the formation of undesirable machining marks on the processed surfaces. These marks typically manifest as scratches, grooves, or cuts and result in irregular deviations in surface roughness, both above and below the nominal surface. Surface roughness is a critical factor that significantly influences the quality of machined parts. To minimize machining marks and achieve the desired surface roughness, it is essential to select appropriate cutting tools, employ correct cutting parameters, and meticulously control processing conditions. This can lead to smoother surfaces with the desired characteristics, significantly improving the appearance and performance of the final product[13].

In this study, UHMWPE plates were processed on a CNC milling machine using an 8mm-diameter end mill cutter at different feed rates, spindle speeds, and depths. The surface roughness of the processed surfaces was measured and compared with studies available in the literature.

II. Materials and Method

In the work, UHMW-PE material with the mechanical properties shown in Table-1 was used as the material to be formed. Haas CNC milling machine was employed for the execution of the operations. material with the mechanical properties listed in Table-1 was used as the material to be chip removed. An 8 mm-diameter milling cutter was employed as the milling tool.

Table 1. Mechanical Properties of UHMW Used in Milling Processes

Property	Unit	Value	Standart
Density	g/cm^2	0.94	ISO 1183-1
Hardness	Shore	62-65	ISO 808
Yield Strength	MPa	>=22	ISO 527-1
Elasticity Modulus	MPa	800	ISO 527-1
Strain Failure	%	300	ISO 527-1

The process was conducted for the operations as follows:

UHMW-PE material was fixed to the table of CNC milling machine. Chip removal operations were done in turn with a cutting tool of 8 mm diameter at spindle speeds of 400, 600, and 800 rpm, feed rates of 30, 50, and 70 mm/min, and cutting depths of 0.5, 1, and 1.5 mm, respectively.

After the processes were completed, three surface roughness measurements were taken from each channel of the UHMW-PE sheet's surface using a Mahr surface roughness measurement deevice, as shown in Figure-1, and their average values were noted.

Fig. 1 Roughness Measurement Setup for UHMW

III. RESULTS

In this study, roughness measurements attained as follows:

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

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

Table-2 shows the average surface roughness measurements acquired at various cutting 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(μm)
1	400	30	0.5	20.1
2	600	50	0.5	17.866
3	800	70	0.5	19.6
4	400	50	1	29.166
5	600	70	1	37
6	800	30	1	11.856
7	400	70	1.5	53.266
8	600	30	1.5	14.933
9	800	50	1.5	12.9

Table-3 displays the Rz surface roughness values obtained from measurements at various cutting speed, cutting depth and feed rate values.

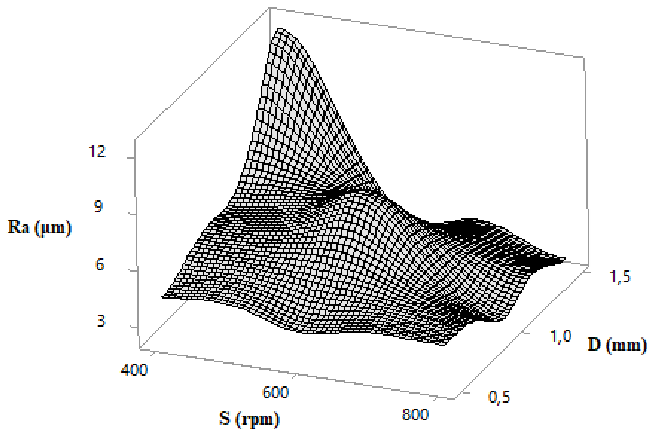

Fig. 2 Surface Plot of Ra(μm) vs S(rpm); D(mm)

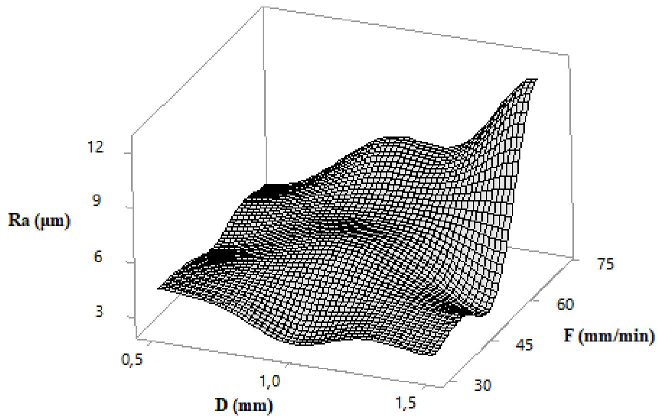

Fig. 3 Surface Plot of Ra(μm) vs D(mm); F(mm/min)

In Figures 2, 3, and 4, average roughness measurements are shown for spindle 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 average surface roughness(Ra) values occur at a feed rate of 70 mm/min, a cutting depth of 1,5 mm, and a cutting speed of 400 rpm. In addition, the lowest average roughness(Ra) values are attained at a feed rate of 30 mm/min, a cutting depth of 1 mm, and a speed of 800 rpm.

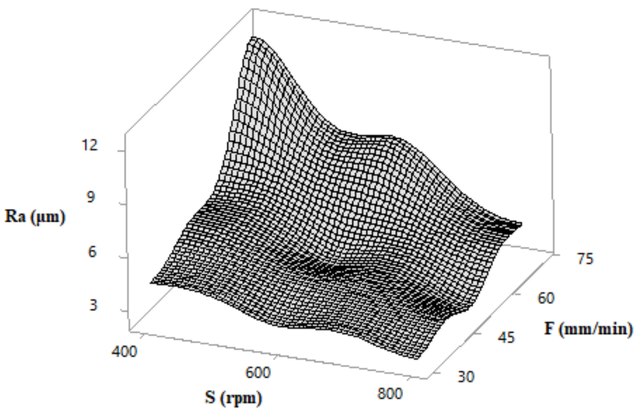

Fig. 4 Surface Plot of Ra(µm) vs S(rpm); F(mm/min)

When the results are examined for the machining of UHMW-PE material with milling operations, within the given parameters, it can be said that the optimum process parameters are S: 800 rpm, F: 30 mm/min, and D: 1 mm according to average roughness measurements.

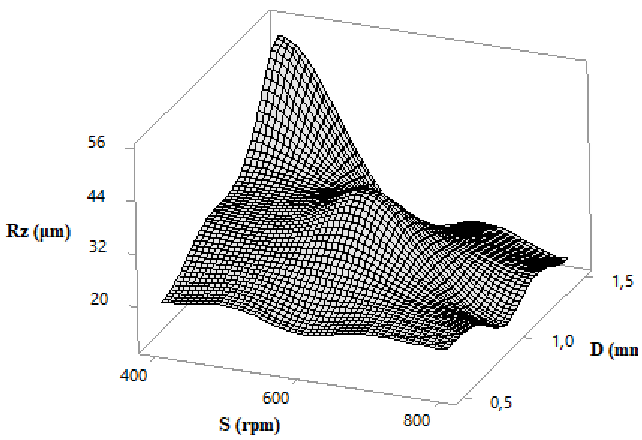

Fig. 5 Surface Plot of Rz(µm) vs S(rpm); D(mm)

In Figures 5, 6, and 7, Rz roughness measurements are demonstrated for spindle speed-cutting depth, cutting depth-feed rate and cutting speed-feed rate, respectively. When all these parameters are evaluated together, it can be said that the highest Rz surface roughness values acquired at a feed rate of 70 mm/min, a cutting depth of 1,5 mm, and a cutting speed of 400 rpm similar to Ra values. In addition, the lowest Rz roughness values are attained at a feed rate of 30 mm/min, a cutting depth of 1 mm, and a speed of 800 rpm just as at Ra.

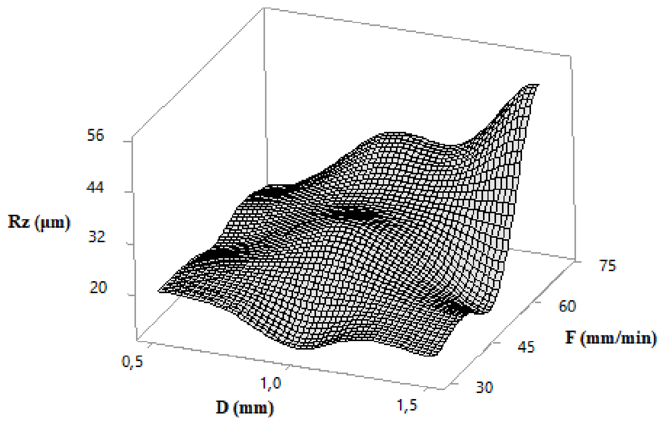

Fig. 6 Surface Plot of Rz(µm) vs D(mm); F(mm/min)

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: 800 rpm, F: 30 mm/min, and D: 1 mm according to Rz measurements.

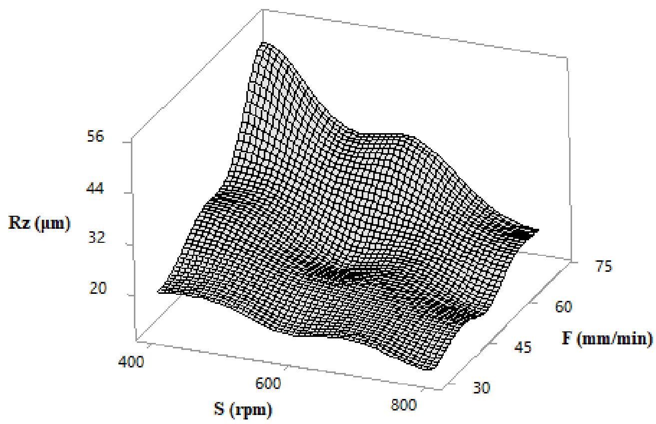

Fig. 7 Surface Plot of Rz(µm) vs S(rpm); F(mm/min)

IV. DISCUSSION

The tribological behavior of UHMW-PE was investigated in a dry environment, focusing on its influence on the machining process. Processing parameters were determined as feed rate, cutting speed, and chip depth. In this study, the polymeric structure of the semi-crystalline polymer was analyzed using a Differential Scanning Calorimeter (DSC) device. The tribological behavior of the processed UHMWPE material was correlated with changes in its polymeric structure and surface texture.

The average coefficient of friction increased within the first 60 seconds after the start of processing and then reached a stable level, with the initial average coefficient of friction ranging from 0.12 to 0.15. After one hour, the average coefficient of friction was measured between 0.17 and 0.23. No significant relationship was determined between the chip depth and the coefficient of friction or between cutting speed and the coefficient of friction. However, an increase in cutting speed could potentially damage the subsurface structure of the processed UHMWPE material. Under conditions where the feed rate was kept constant, an increase in cutting speed was observed to reduce the wear factor. The optimum cutting depth, determined for the best surface roughness and abrasion resistance, was found to be 0.127 mm under the studied conditions[14].

V. CONCLUSION

Upon reviewing the results, it has been observed that the average surface roughness(Ra) value and Rz roughness values of UHMW-PE materials processed with CNC milling machine, produced similar results in almost every operation. When looking at each individual chip removal process, the highest roughness values are observed at the parameters of 400 rpm of spindle speed, 70 mm/min feed rate, and 1,5 mm cutting depth. The lowest roughness values, on the other hand, are observed at the parameters of 800 rpm, 30 mm/min feed rate, and 1 mm cutting depth. As pointed out in the results section, when all measurements are considered together, it can be understood that the parameters of 800 rpm 30 mm/min feed rate, and 1 mm cutting depth provide that both Ra and Rz values remain at the lowest levels for the processing of UHMW-PE material. It is believed that more beneficial findings regarding the machinability of polymer materials can be acquired in future studies by considering various parameters.

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