

Comparative Study of Surface Quality on Flat and Curved UHMWPE Surfaces Using Robotic Milling

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ABSTRACT

In the context of robotic machining for advanced thermoplastics, surface geometry plays a critical role in determining surface quality. This study investigates the effect of surface geometry on the surface quality of ultra-high molecular weight polyethylene (UHMWPE) during robotic milling. Flat and curved geometries were machined using a 6-axis KUKA KR 120 R2700-2 F at spindle speeds of 6500 and 9500 RPM. Surface roughness parameters (R_a , R_q , R_z) were evaluated through a Mitutoyo SJ-410 stylus profilometer to assess the resulting surface quality. The results show that increasing spindle speed improved surface finish across both geometries. Curved surfaces consistently achieved lower roughness values compared to flat surfaces, with R_a improved by 27.5% (from $1.669\text{ }\mu\text{m}$ to $1.209\text{ }\mu\text{m}$) and R_z by 33.1% (from $8.778\text{ }\mu\text{m}$ to $5.877\text{ }\mu\text{m}$) on curved geometries. Conversely, flat surfaces experienced higher roughness but R_a still showed improvement by 29% (from $2.331\text{ }\mu\text{m}$ to $1.656\text{ }\mu\text{m}$) and R_z by 36.2% (from $11.765\text{ }\mu\text{m}$ to $7.509\text{ }\mu\text{m}$) with increased spindle speed. Despite fluctuations, all roughness values remained acceptable for industrial use, particularly in sliding components, structural spacers, and food-grade parts. The findings emphasize the importance of considering surface geometry in tool path planning and thermal compensation strategies for high-precision robotic milling of UHMWPE.

Keywords: Surface Geometry; Surface Roughness; Robotic Milling; UHMWPE

Abbreviations

CNC	computer numerical control
UHMWPE	ultra-high molecular weight polyethylene
DoF	degree of freedom
CAM	computer aided manufacturing
SEM	scanning electron microscopy
ATC	automatic tool change
RPM	rotation per minute

1.0 INTRODUCTION

The advent of the Industrial Revolution 4.0 has catalysed rapid developments in machining technology, especially as the industry faces the challenge of producing complex-shaped components such as angular and curved surfaces. Collaborative manufacturing of structural form and surface integrity can shorten processing cycles, improve machining quality, and reduce costs for complex engineering [1]. In high-tech sectors such as aerospace, automotive, energy and medical engineering, the demand for components that require high levels of dimensional accuracy, consistent surface smoothness and wide process flexibility is increasing. Components such as turbine blades, orthopaedic implants and mechanical protective housings often have geometries that are difficult to process using conventional CNC systems [2]. This makes traditional machines less suitable when it comes to maintaining high tolerances on uneven or complex surfaces. In response to these constraints, the approach of using industrial robotics, in particular KUKA robots, has gained widespread acceptance among researchers and engineers. These robots are designed with six degrees of freedom (6-DoF) as shown in Fig. 1, allowing them to perform multi-axis machining tasks with a wider and more flexible range of motion. Furthermore, the robust structure of the robot and its ability to be integrated with adaptive control systems and smart sensors make it more competitive in producing high-quality surfaces.

The comparison between KUKA Robots and Conventional CNC is depicted in Table 1. Robots offer a wide working range and high geometric flexibility for complex shapes, but offer lower accuracy (± 0.4 mm). CNC only offers 3 to 4 axes, limited range and is suitable for linear/axial shapes with finer accuracy (± 0.02 mm).

Several recent studies have found that KUKA robots using closed-loop calibration and control systems can achieve positioning accuracies as high as ± 0.4 mm, especially in machining free-geometry surfaces [3], [4], [5], [6]. In addition to mechanical aspects, the structure and capabilities of its control system also play a key role in maintaining surface smoothness and shape integrity during cutting operations [7], [8].

Despite these advancements, the machining of components with non-flat geometries such as curved or contoured surfaces still presents significant challenges in terms of tool engagement stability and surface quality consistency [9], [10], [11]. Unlike flat surfaces that offer uniform tool contact and predictable chip removal, curved surfaces introduce continuously changing contact angles, localised forces, and variations in tool loading. These geometric complexities often lead to inconsistent surface finishes, increased vibration, and micro-defects such as chatter marks or irregular material deformation [12]. According to Chen et al. (2025), surface roughness on curved workpieces was shown to be 30–50% higher than on flat surfaces, even when the same machining parameters were applied [13]. Similarly, Wang et al. (2022) observed that robotic milling on curved profiles resulted in more pronounced tool path deviations due to inconsistent orientation between the tool and surface normal [14]. On curved surfaces, maintaining a consistent orientation between the tool and the surface normal is challenging, leading to deviations from the intended path and affecting surface quality. These effects become more critical when using machining materials such as Ultra-High-Molecular-Weight Polyethylene (UHMWPE), which are known for their high ductility, low thermal conductivity, and susceptibility to surface smearing under inappropriate cutting conditions as shown in Table 2.

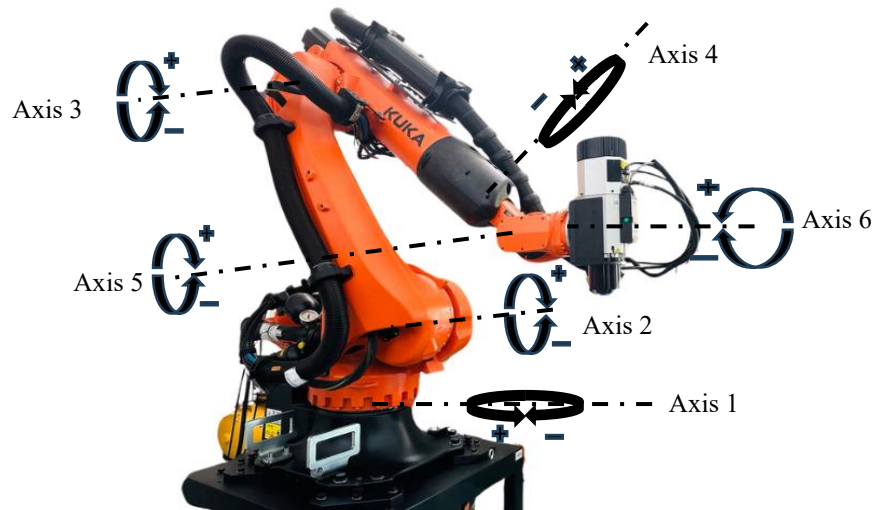


Figure 1. KUKA KR 120 R2700-2 F six Degree of Freedom (6-DoF)

Table 1. Comparison of KUKA Robots and Conventional CNC

Parameter	Robot KUKA	Conventional CNC
Degrees of Freedom	6 DoF (Degrees of Freedom)	3–4 axes only
Working Range	Wide (multi-axis, flexible)	Limited to fixed axis
Position Accuracy	± 0.4 mm	± 0.02 mm (finer, but static)
Geometric Flexibility	High (can take complex shapes)	Limited to simple linear/axial shapes

Table 2. Key mechanical and chemical properties of UHMWPE

Property	UHMWPE Value
Density, g/cm ³	0.93
Yield Stress (MPa)	20
Tensile Modulus of Elasticity (MPa)	680
Melting Temperature (°C)	135
Heat Deflection Temperature (°C)	79
Coefficient of Thermal Expansion	150-230
Dielectric Strength (kV/mm)	45

UHMWPE is a high-performance polymer with exceptional wear resistance, low friction, biocompatibility and chemical resistance, suitable for tribological, biomedical and food grade applications [15], [16]. It is used in bearing/sliding components as well as implants/prosthetics [17]. For high-precision complex components, geometry aware robotic manufacturing enables precise machining while ensuring surface finish and dimensional accuracy [18], [19]. To address this issue, various studies have explored the use of sensor-based adaptive systems or real-time trajectory correction methods. While these solutions show promise, they often require costly hardware and complex integration. In contrast, strategic toolpath planning using computer aided manufacturing (CAM) software such as SprutCam offers a practical, software-driven approach to improving machining performance, especially in resource-constrained environments such as education, prototyping, or low-volume production. To determine the relationship between all these problems and surface quality, surface roughness is measured. In surface metrology (ISO 4287), R_a , R_q , and R_z are roughness parameters that indicate different aspects of surface texture [20], [21]. R_a reflects the average amplitude, R_q is more sensitive to irregularities, while R_z emphasizes the extreme differences between peaks and valleys. The combination of all three improves the understanding of surface quality. In UHMWPE components, a low R_q reduces frictional heat and wear debris, while a low R_z prevents micro-damages such as notches [22]. Therefore, simultaneous reporting of R_a , R_q , and R_z is more meaningful in assessing process stability, cutting quality, and tribological performance.

This study, therefore, aims to investigate the impact of surface geometry, specifically flat versus curved surfaces on the surface quality of UHMWPE machined using a KUKA robotic arm. The analysis focuses on measuring surface roughness parameters (R_a , R_q , R_z), evaluating surface morphology through Scanning Electron Microscopy (SEM), and assessing the machining stability under identical cutting conditions. The findings are expected to highlight critical considerations for robotic machining of polymer-based curved components and provide insights into effective CAM programming strategies without relying on real-time sensor feedback.

2.0 METHODOLOGY

This study aims to investigate the influence of surface geometry; both flat and curved on the surface roughness of ultra-high-molecular-weight polyethylene (UHMWPE) when machined using an industrial robotic system. The main focus is to compare how geometric curvature affects the quality of machined surfaces under identical cutting conditions, thereby evaluating the suitability of robotic milling for complex shapes without the aid of real-time correction systems.

2.1 Machining setup

The test specimens were made from UHMWPE rectangle blocks with dimensions of 50 mm x 50 mm. The specimens were then divided into 20 mm x 50 mm of machining work for both flat and curved geometries. Specimens were selected for their wide application in medical, aerospace, and engineering sectors due to their excellent wear resistance, high toughness, and biocompatibility. Two different surface profiles were prepared: a flat surface and a curved surface, both with consistent dimensions and thickness to ensure fairness in comparison as shown in Fig. 2.

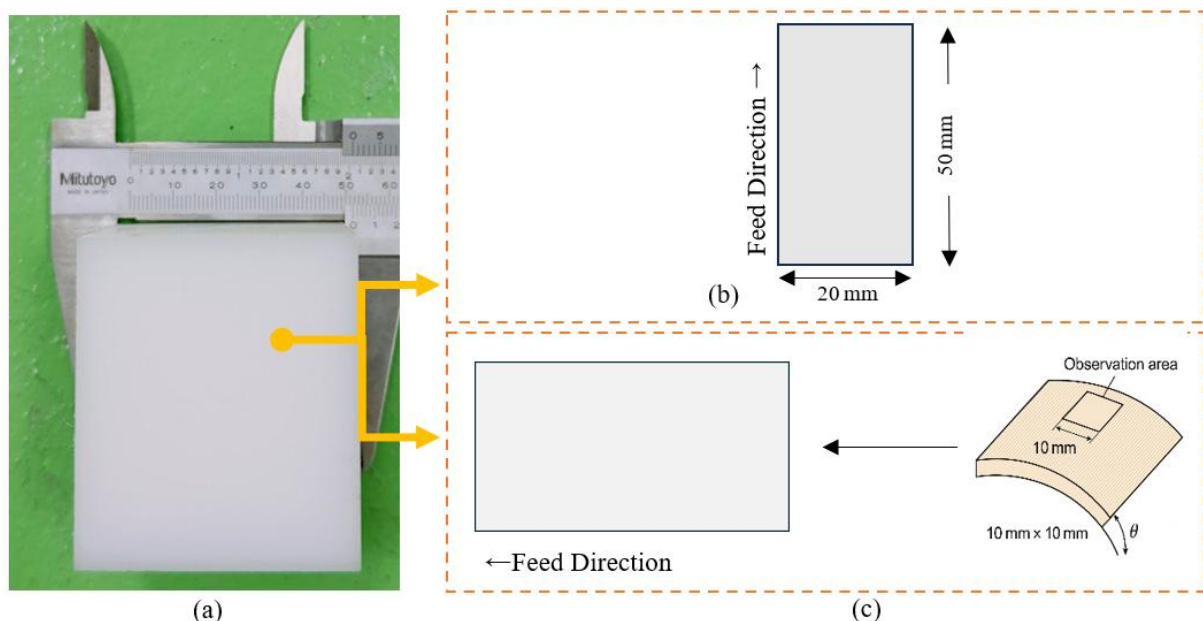


Figure 2. Dimension of rectangular test specimen block (a) UHMWPE specimen block (b) Flat surface (c) Curved Surface

The robotic milling operations in this study were performed using a KUKA KR 120 R2700 industrial robotic arm, integrated with a HQD GDL70-24Z/9.0 CNC spindle, tool interface ISO30, air-cooled with ATC, 3-phase asynchronous, rated power 9 kW, rated voltage 380 V, base frequency 400 Hz ($\approx 12\,000$ RPM), maximum speed 24 000 RPM, protection IP64, insulation class F and fitted with an end mill cutting tool. The cutting tool chosen for this operation was RicoCNC High Speed Steel end mill, D10 $\times$ 100 $\times$ 150mm, 4-flute and uncoated, selected for its durability and ability to maintain cutting accuracy in polymer-based materials such as UHMWPE.

The KUKA KR 120 R2700 was designed with six degrees of freedom (6-DoF), which allows for a wide range of multi-directional movements and the generation of complex tool paths. This flexibility is particularly beneficial for performing milling operations on components with both flat and curved geometries, ensuring consistent contact angles and surface engagement throughout the cutting process.

All robotic machining procedures were conducted under controlled laboratory conditions (23 ± 2 °C, $50 \pm 10\%$ relative humidity) to ensure consistent environmental stability during the experiments. These controlled settings are essential to ensure accuracy and reproducibility of results by eliminating or minimizing the effects of external disturbances, such as ambient temperature fluctuations, unwanted vibrations, or tool misalignment. Special attention was paid to the stability of the end detector, as any inconsistency in the tool position could directly affect the surface quality and dimensional accuracy during the milling process. The experimental setup is illustrated in Fig. 3.

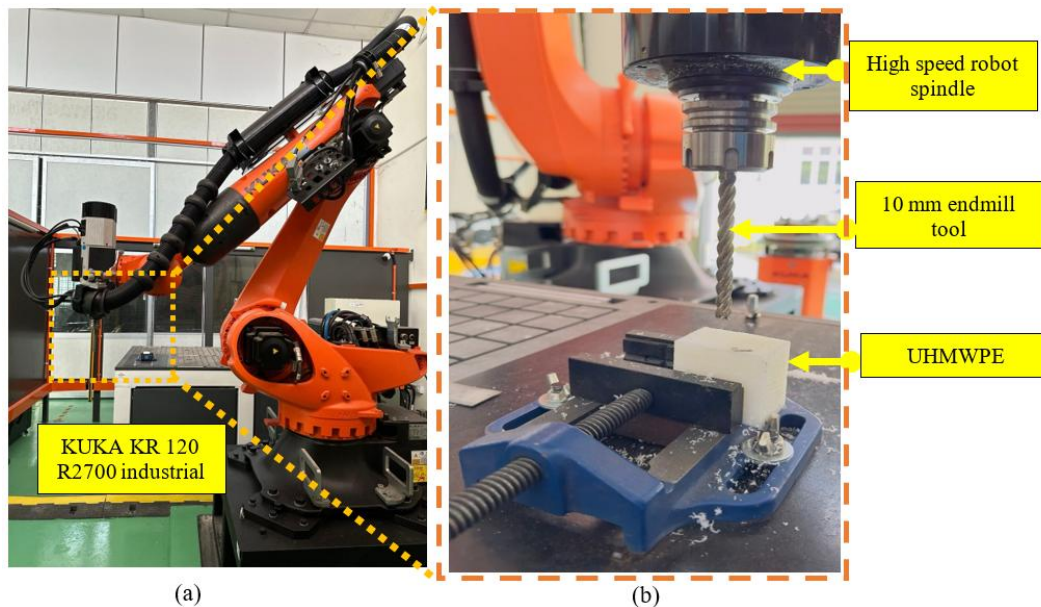


Figure 3. Experimental setup (a) Overall setup of experiment (b) Machining setup for flat and curve milling

2.2 Toolpath generation and simulation

The toolpaths for both flat and curved specimens were designed and simulated using SprutCAM, a computer-aided manufacturing (CAM) software that allows for accurate path planning and robotic simulation. A parallel finishing toolpath strategy was applied to both geometries. The tool orientation remained consistent across both surfaces, and no real-time feedback system or sensor-based correction was used.

2.3 Experimental procedure and surface roughness measurement

The experimental setup was designed to evaluate the surface quality of UHMWPE when machined on two distinct surface geometries: flat and curved surfaces respectively. To observe the influence of spindle speed on both surface types, two cutting conditions were established as shown in Table 3.

Table 3. Cutting parameter setting

Experiment No.	Surface Geometry	Spindle Speed RPM	Feed rate (mm/min)	Depth of Cut (mm)
1,2,3	Flat	6500	1500	0.1
4,5,6	Curved	6500	1500	0.1
7,8,9	Flat	9500	1767	0.1
10,11,12	Curved	9500	1767	0.1

For each surface type (flat and curved), machining was carried out under both cutting conditions, resulting in a total of four experimental groups. Each group underwent three machining repetitions ($n = 3$). Each independent variable was varied in four values determined based on the recommendations of the cutting tool's manufacturer and the knowledge gathered through contemporary literature on machining polymeric-based material. All machining operations were conducted using identical tooling and path strategies in SprutCAM, with no real-time correction or sensory feedback. The tool paths were verified for consistency and simulated in advance to predict machining time and detect potential collisions. Surface roughness (R_a , R_q , R_z) was measured using Mitutoyo SJ-410 stylus profilometer in accordance with ISO 4287/ISO 4288 (Gaussian filter $\lambda_c = 0.8$ mm; sampling length 0.8 mm; evaluation length 4.0 mm ($5\times$); traverse speed 0.5 mm/s; stylus tip radius 2 μm). For each condition, measurements were taken at three random locations with three repeats per location ($n = 9$ per group), and the results were reported as mean $\pm$ standard deviation. SEM micrographs were obtained using a Hitachi TM3030 tabletop scanning electron microscope (SwiftED3000) in charge-reduction/low-vacuum mode to mitigate polymer charging; with magnification and scale bars reported on each image (e.g., $\times 100$; 1 mm).

3.0 RESULTS AND DISCUSSION

3.1 Surface quality

The surface roughness results in Table 4. show that increasing spindle speed led to significant improvements in surface finish across both flat and curved geometries. For flat geometries, the average R_a improved from 2.331 μm at 6500 RPM to 1.656 μm at 9500 RPM (a 29% improvement), while R_z improved from 11.765 μm to 7.509 μm (a 36% improvement). Similarly, for curved surfaces, R_a improved from 1.669 μm to 1.209 μm , and R_z from 8.778 μm to 5.877 μm as spindle speed increased. These findings are consistent with Chen et al. (2025) where higher spindle speeds are shown to improve surface roughness quality [13]. While R_a and R_z demonstrated clear improvement in surface roughness with increased spindle speed, the accompanying improvement in R_q (flat: 3.044 μm to 2.075 μm ; curved: 2.246 μm to 1.559 μm) confirms a concurrent reduction in peak-to-valley variation, implying a more uniform surface profile. The lower R_q/R_a ratio at higher speeds suggests fewer extreme deviations, contributing to enhanced surface quality essential for UHMWPE applications in load-bearing or low-friction environments. Therefore, optimizing the spindle speed is essential to achieve the desired surface quality in robotic machining of UHMWPE.

Curved specimens exhibited lower R_a because the local tool surface contact shifted away from the cutter centre, where the instantaneous cutting speed approached zero and promoted rubbing/smearing in UHMWPE. This finding aligns with the results reported by Michał Gdula (2020) which stated that the reduced contact area between the tool and the machined surface will produce higher values of areal roughness. On a flat surface with zero tool tilt, most of the contact occurs near the centre resulting in reduced effective rake angle. Consequently, plunging dominates the cutting process, generating higher cusps and torn fibrils as shown in Fig. 4.

In contrast, curvature continuously changes the surface normal so the engaged zone sits at a larger effective radius with higher local cutting speed, improving shear-type chip formation and reducing centre rubbing. Curvature also yields a more uniform chip-thickness modulation along the path, which lowers peak forces and robot/external-spindle vibrations, consistent with the smaller standard deviations observed. At higher spindle speed (with matched chip-load), the thinner chip further decreases compressive deformation, so R_q drops alongside R_a , indicating fewer outlier asperities and a narrower peak–valley distribution (lower R_z). For UHMWPE, the low thermal conductivity and high ductility, in combination with (i) higher effective cutting speed away from the tool centre, (ii) reduced ploughing, and (iii) smoother force transients on curved geometry, suppress smearing and stringer debris, yielding improved $R_a/R_q/R_z$.

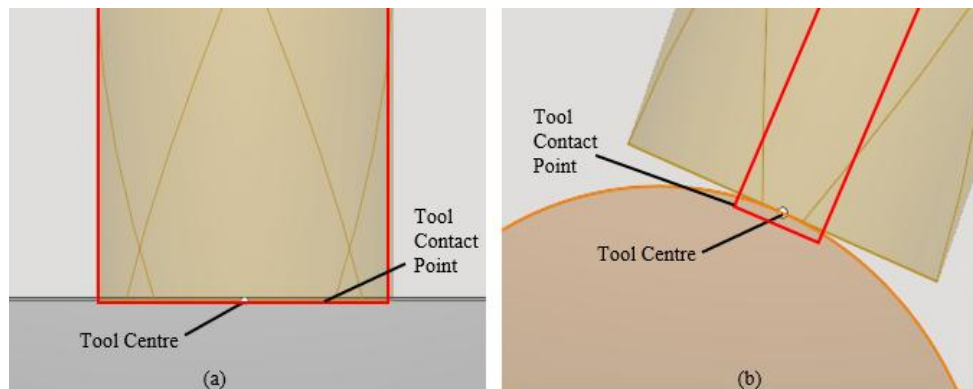


Figure 4. Tool surface contact (a) Flat surface (b) Curve surface

Table 4. Surface Roughness Result

Spindle Speed (RPM)		Flat Geometry			Curved Geometry			
		Surface Roughness (μm)						
		Ra	Rq	Rz	Ra	Rq	Rz	
6500	Experiment	1	2.285	2.899	10.914	1.609	2.235	8.763
	2	2.128	2.9	11.563	1.783	2.392	9.428	
	3	2.579	3.334	12.817	1.616	2.11	8.143	
	Std	0.229	0.251	0.967	0.099	0.141	0.643	
	Average	2.331	3.044	11.765	1.669	2.246	8.778	
9500	1	1.504	1.92	7.3	1.294	1.637	6.266	
	2	1.918	2.428	8.314	1.213	1.573	5.999	
	3	1.547	1.876	6.914	1.121	1.466	5.367	
	Std	0.228	0.307	0.723	0.0866	0.0864	0.4617	
	Average	1.656	2.075	7.509	1.209	1.559	5.877	

3.2 Morphology analysis

At 6500 RPM, as shown in Fig. 5(a), the surface exhibited deep, irregular groove formations with overlapping patterns. The tool marks appeared disoriented, and micro-tears were visible across the surface. These features indicate instabilities in tool-material interaction, where the cutting action is not sufficiently smooth. The relatively high surface roughness value ($R_a = 2.128 \mu\text{m}$) further supports the presence of material deformation and poor chip evacuation during the milling process. Such irregularities may lead to increased friction and faster wear in functional applications. In contrast, the surface machined at 9500 RPM, as depicted Fig. 5(b), demonstrated a more uniform and consistent groove structure, with well-aligned tool paths and significantly fewer surface defects. The SEM micrograph revealed smoother, continuous machining traces with minimal plastic deformation. The R_a value for this condition ($1.504 \mu\text{m}$) reflected a 29% improvement in surface roughness compared to the 6500 RPM condition. This improvement can be credited to enhanced cutting stability, reduced cutting force, and better chip flow at higher spindle speeds [23]. The increased rotational velocity minimizes tool vibration and enables cleaner shearing of UHMWPE, which is known for its ductility and low thermal conductivity.

At 6500 RPM, as shown in Fig. 6(a), the average surface roughness (R_a) was $1.609 \mu\text{m}$. The optical micrograph displays moderately coarse surface patterns with noticeable feed marks running across the curved profile. The SEM image further revealed discontinuous groove formations, potentially caused by minor tool vibration or chip adhesion during cutting. While the surface was relatively smoother than flat geometries at the same speed, small-scale waviness was still visible, indicating moderate instability in chip formation and evacuation. At 9500 RPM, as displayed in Fig. 6(b), the surface finish improved noticeably, with R_a reduced to $1.466 \mu\text{m}$. The optical image showed more uniform and parallel groove structures, while the SEM micrograph highlighted cleaner and deeper machining lines with minimal micro-fracturing or tool-induced deformation. The improved finish is associated with higher effective cutting speeds that shift material removal from plowing/rubbing to shear-type chip formation, together with better tool orientation on curved surfaces (larger effective lead/tilt), which stabilizes chip thickness and reduces force peaks. This mechanism explains the observed cleaner effect [24], [25], [26]. Fig. 7 shows that the R_q/R_a ratio assesses the presence of extreme asperities relative to the average amplitude. The lower values at 9500 RPM, especially for the curve, indicate a tighter height distribution (reduced outliers), consistent with a transition from plowing/rubbing to shear-type chip formation as the effective speed increases [24]. For UHMWPEs that smear easily at low speeds, cleaner chip release also contributes to the decrease in this ratio [25].

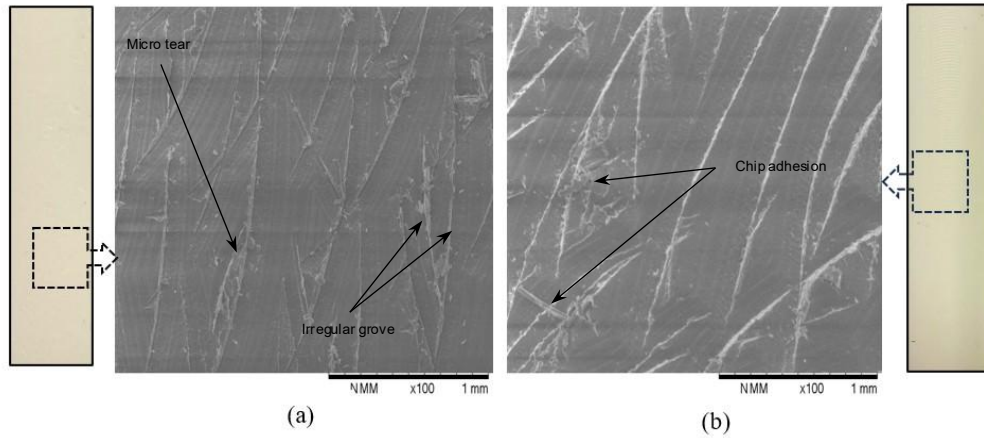


Figure 5. Flat surface SEM micrographs at (a) 6500 RPM and (b) 9500 RPM; ×100, scale bar 1 mm. Higher speed yields more uniform grooves and fewer defects.

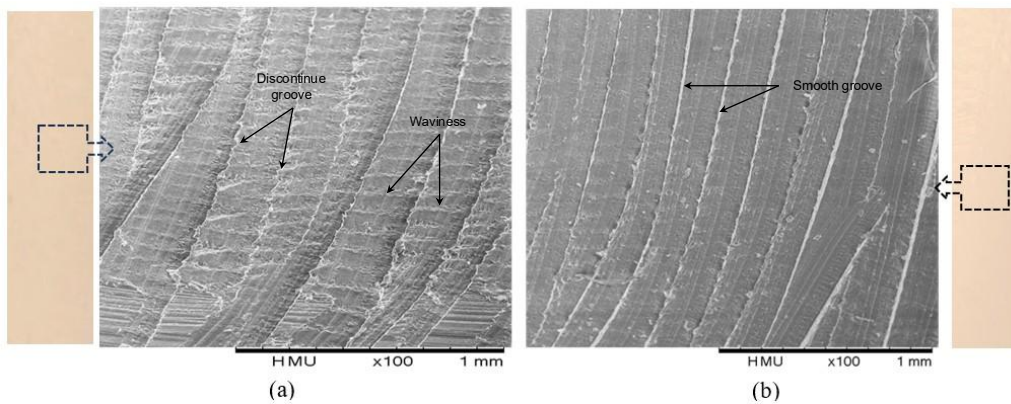


Figure 6. Curved surface SEM micrographs at (a) 6500 RPM and (b) 9500 RPM; ×100, scale bar 1 mm. Curvature with higher speed promotes continuous shear-type traces

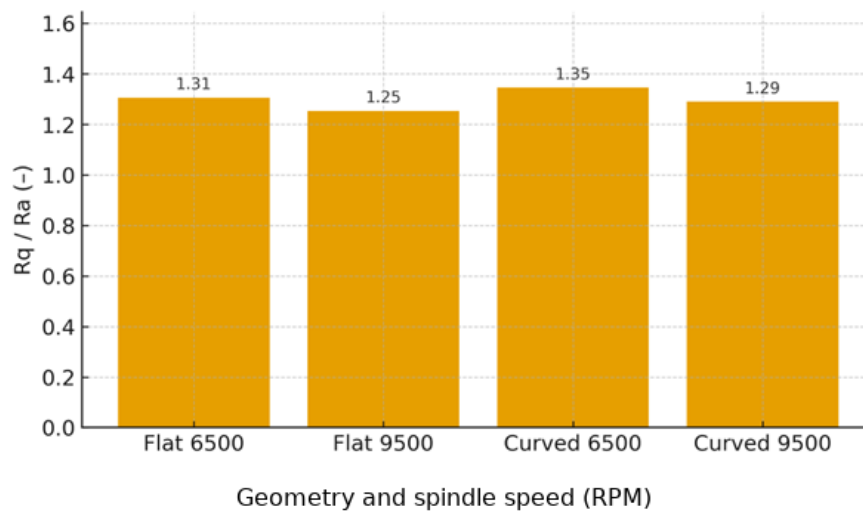


Figure 7. Ratio of R_q / R_a for flat and curved UHMWPE at 6500 and 9500 RPM; lower values indicate fewer outlier asperities and a narrower height distribution

The R_z/R_a relationship in Fig. 8 showed that as R_a decreased, R_z also decreased for both geometries. This indicates that not only is the average asperity smaller, but the extreme peaks and valleys are also reduced. This is consistent with the more uniform cutting effect at higher speeds, as the contact zone shifts to a larger tool radius on a curved surface that exhibits more effective lead/sag [24], [27].

Fig. 9 shows the Coefficient of Variation (CoV) for R_q used as a proxy for process stability where lower values for curved 9500 RPM indicate smaller force/chip thickness fluctuations. This finding is consistent with the observation that tool orientation either lead or tilt, and appropriate robot posture stabilizes tool–material interactions on curved surfaces [24], as well as proving that UHMWPE improves surface quality at higher speeds with uniform chip-load [28].

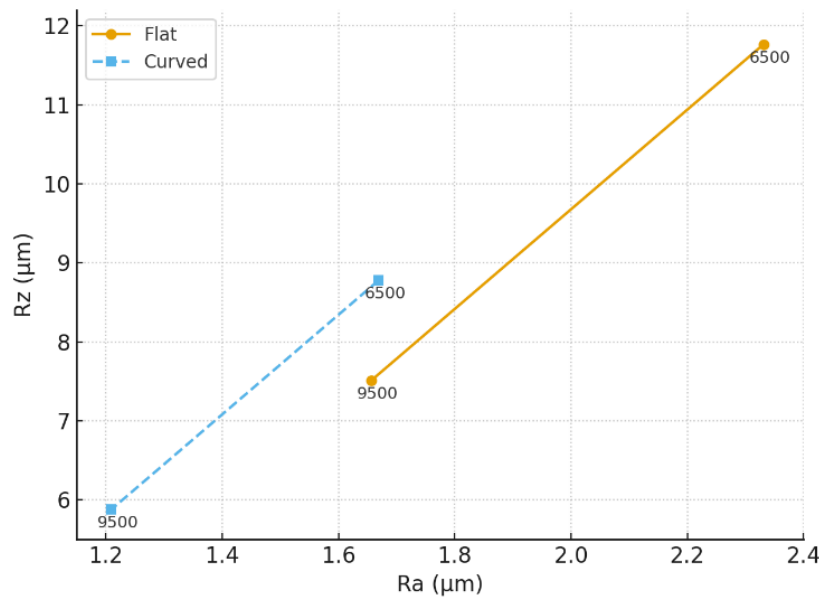


Figure 8. Relationship between R_z and R_a (flat/curved, 6500–9500 RPM). The concurrent decreases indicate fewer extreme peak–valley features at higher speeds and on curved geometries

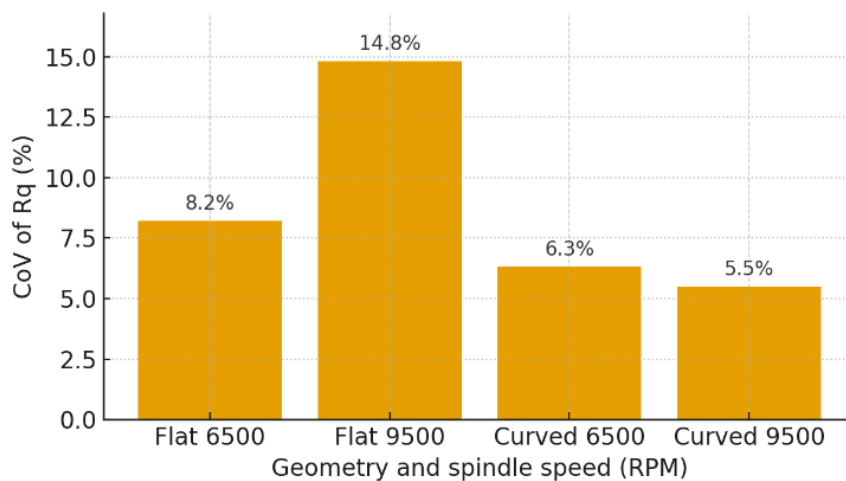


Figure 9. Coefficient of variation (CoV) of R_q as a proxy for process stability (lower is better). Curved surfaces at 9500 RPM exhibit the lowest CoV, indicating steadier chip formation

3.3 Effect of geometries toward surface quality

Experimental results, as shown in Fig. 10, indicate a significant influence of surface geometry on the surface roughness of UHMWPE, produced during robotic milling. At both spindle speeds tested (6500 RPM and 9500 RPM), curved geometries consistently achieved lower surface roughness values (R_a and R_z) than flat geometries. Specifically, R_a for flat surfaces decreased from $2.331\text{ }\mu\text{m}$ to $1.656\text{ }\mu\text{m}$, while curved surfaces improved from $1.669\text{ }\mu\text{m}$ to $1.209\text{ }\mu\text{m}$ as spindle speed increased. A similar pattern was observed in R_z values in Fig. 11, with curved surfaces showing a larger relative reduction (from $8.778\text{ }\mu\text{m}$ to $5.877\text{ }\mu\text{m}$).

This trend is supported by recent literature that emphasizes the role of geometric contours in determining surface quality. Chen et al. developed a 3D surface topography simulation model and showed that CNC milling of curved surfaces leads to smoother finishes due to improved cutting stability and consistent contact between the tool and workpiece [13]. Similarly, Yazid and Razak observed that complex pocket geometries, including curved profiles, resulted in lower R_a values when machined with optimized spiral toolpath strategies [29]. Although this previous study supports the experimental findings, to the author's knowledge, the effects of geometry and robotic milling machining parameters have received little attention.

Hao and Liu presented a surface roughness prediction model for thin-walled parts with curvature, confirming that the shell height, cutting edge, and impact deformation due to curvature significantly affect the roughness results [30]. This factor is particularly critical in materials such as UHMWPE, where it contributes to performance in load-bearing or biomedical applications. Furthermore, Budi (2025) reported that achieving a surface impact below $2\text{ }\mu\text{m}$ is essential in machining UHMWPE to avoid bacterial growth on the implantable surface [31]. Although feed rate is the dominant factor, the study acknowledged the benefits of smoother engagement associated with curved geometries in maintaining surface integrity. The observed differences in surface roughness between flat and curved geometries are also due to the interaction between tool geometry and machining conditions. Specifically, when milling UHMWPE with an end mill tool, the tool material contact on the flat surface occurs near the tool center, where the cutting velocity approaches zero, resulting in material smearing and higher surface finish. In contrast, with a curved geometry, the tool engages the material farther from the tool center, resulting in cleaner cuts and smoother finishes. In addition, higher spindle speeds improve surface quality by increasing cutting velocity and reducing the possibility of thermal deformation in UHMWPE. These results are consistent with findings in simulations of curved surface milling [29] and experimental studies of UHMWPE milling, which confirm that tool engagement and material properties jointly influence surface quality. Fig. 12 shows that curved surfaces produce lower impact (R_q) than flat surfaces for UHMWPE materials at speeds of 6500 RPM and 9500 RPM.

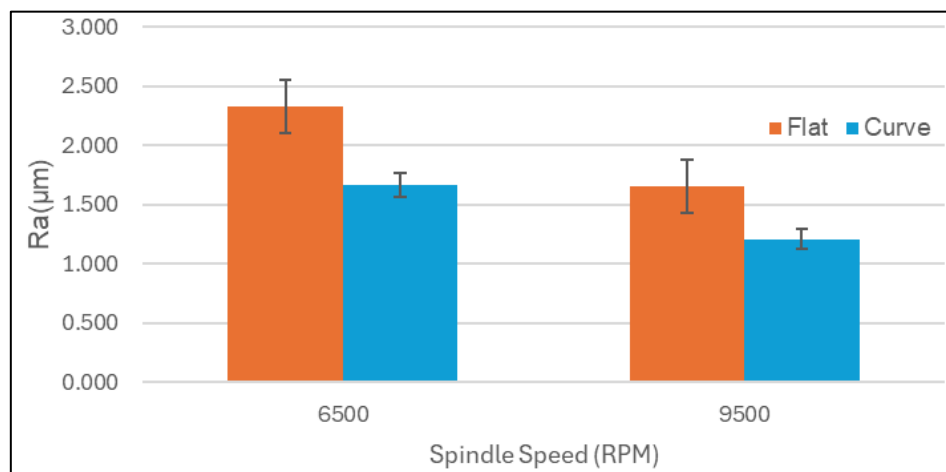


Figure 10. Influence of surface roughness parameter (R_a) on geometry of flat and curve surfaces of UHMWPE produced during robotic milling, showing the best result at 9500 RPM

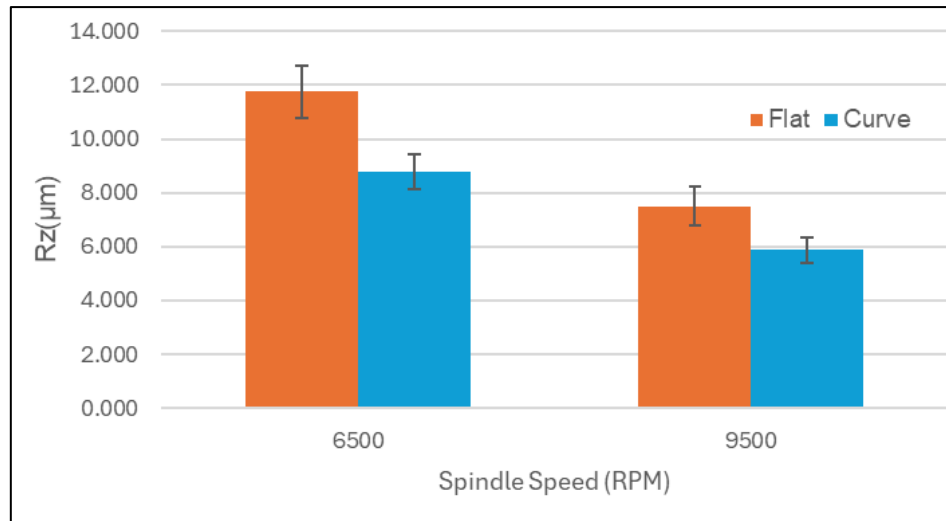


Figure 11. Influence of surface roughness parameter (Rz) on geometry of flat and curve surfaces of UHMWPE produced during robotic milling showing curve with a larger relative reduction

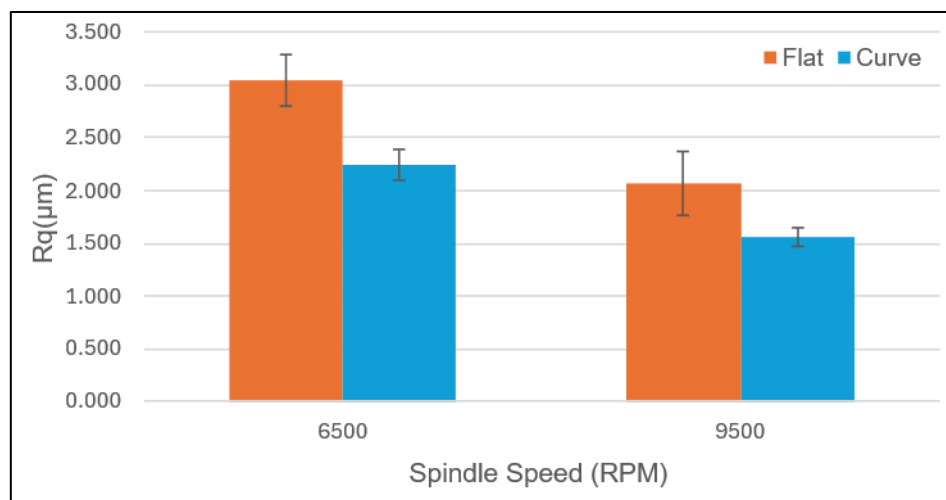


Figure 12. Influence of surface roughness parameter (Rq) on geometry of flat and curve of UHMWPE produced during robotic milling

This agrees with the findings of Edidin et al. (2001), which showed that the cutter interaction is more stable on curved geometries, thus reducing vibration and improving surface quality [32]. In addition, increasing cutting speed also significantly reduces Rq [33], where high speed reduces burr formation. Another study also showed that thermoplastic materials such as UHMWPE tend to have smoother surfaces when cutting is performed consistently on curved surfaces [34].

This is important because the smoother surface of UHMWPE has been shown to reduce wear and increase the life of orthopedic implants such as acetabular cups in hip replacements [32]. Studies have also shown that low impact values ($<2 \mu\text{m}$) reduce microscopic formations that cause tissue damage around the implant [35]. Below 9500 RPM, the curved sample reached $R_a \approx 1.21 \mu\text{m}$, which is comparable to CNC milled UHMWPE liners reported in the implant literature ($R_a \approx 0.85\text{--}1.16 \mu\text{m}$) prior to wear testing [35]. Together with the concomitant reduction in Rz and Rq/Ra, these results are consistent with well-established tribological evidence that smoother surfaces and less extreme asperities reduce wear of UHMWPE in articulating joints. Thus, the observed improvements (particularly on curved geometries) are directionally consistent with implant grade finish targets and reported wear mechanisms for clinical components.

4.0 CONCLUSION

The influence of surface geometry on surface roughness of UHMWPE during robotic milling using a 6-axis robotic arm at spindle speeds of 6500 and 9500 RPM was investigated in this study. The results show that increasing spindle speed improves surface quality across all samples. More importantly, curved geometries consistently achieve lower surface roughness values (R_a , R_q , R_z) than flat surfaces. This is due to better tool engagement away from the tool center, which promotes cleaner cutting and reduces material smearing. The novelty of this work lies in how surface geometry, not just machining parameters, affects the surface finish of UHMWPE in robotic milling. While most existing studies focused on feed rates or speeds, this research highlighted the often overlooked role of curvature in improving cutting dynamics. With the inference that geometry significantly impacts surface quality, this study offers new insights into toolpath planning and machining strategies for polymer-based materials. These findings are valuable for further studies for applications in biomedical implants, food-grade components, and high-precision polymer structures using robotic where surface integrity is critical.

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AUTHORS CONTRIBUTION

Shukri Zakaria: Conceptualisation, methodology, formal analysis, investigation and writing-original draft; Wan Norshela Ezwane Wan Jusoh, Mohammad Hisyam Mahamad Basri: Conceptualisation, methodology, and formal analysis; Mohamad Irwan Yahaya: Conceptualisation, formal analysis, and validation; Md Razak Daud: Conceptualisation, supervision, writing- review and editing, and validation.

DECLARATION OF COMPETING OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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