



Surface Roughness in Robotic Milling of UHMWPE Relative to CNC Machining: A Topical Review

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ABSTRACT

Computer numerical control (CNC) milling remains the most established machining method for ultra-high molecular weight polyethylene (UHMWPE), where surface roughness is primarily governed by spindle speed, feed rate and depth of cut. Industrial robotic milling has attracted increasing interest for its flexibility, large workspace and accessibility to complex geometries, but it is generally associated with reduced surface quality because of structural compliance. This topical review examines whether the material-specific machining behaviour of UHMWPE reduces the surface roughness penalty usually attributed to robotic milling. Fourteen studies were synthesised under an explicit relevance-based evidence hierarchy. Across the CNC studies reviewed, reported average roughness for UHMWPE spans Ra 0.577 to 2.61 μm . The single available robotic study on UHMWPE reports Ra 1.209 to 2.331 μm , narrowing to 1.209 to 1.656 μm at 9500 rpm, values that fall within the CNC range rather than an order of magnitude above it. Because the studies differ in tooling, workpiece geometry and measurement configuration, this overlap indicates that a smaller difference between CNC and robotic surface roughness is mechanically plausible for UHMWPE, not that the two platforms are equivalent. The review identifies the absence of matched comparative experiments as the principal gap and sets out the design that such a study would require.

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1. INTRODUCTION

Surface quality is a key factor in the functional performance of ultra-high molecular weight polyethylene (UHMWPE) components. In biomedical bearings, sliding elements and guide pads, the machined surface governs friction, wear resistance and service life [1-5], [7]. How that surface is produced is therefore a process decision with measurable functional consequences.

Among the available machining routes, computer numerical control (CNC) milling remains the most established process for UHMWPE. Existing studies show that spindle speed, feed rate and depth of cut strongly influence surface generation, and that optimised conditions produce roughness values suitable for finishing applications [6], [8-10]. Recent work has moved beyond roughness minimisation alone,

integrating surface quality with productivity metrics such as material removal rate and machining time [8], [10]. CNC milling therefore holds a relatively mature benchmark status in UHMWPE machining.

Despite this maturity, conventional CNC systems are not always suited to applications requiring high geometric accessibility, wide workspace flexibility, or rapid reconfiguration for low-volume and customised production [11-13]. These limitations have increased interest in industrial robotic milling as an alternative or complementary platform. Six-axis robotic systems offer better accessibility for complex geometries and greater flexibility in reconfigurable manufacturing environments [12-14], and progress in offline programming, simulation, posture optimisation and compensation has improved the feasibility of robotic machining in advanced manufacturing settings [13], [15-16].

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Robotic milling nevertheless remains constrained by lower and posture-dependent stiffness. Industrial robots are more susceptible than rigid machine tools to compliance-induced deflection, vibration and positioning error during cutting [13], [17-18], and in metallic machining these effects reduce surface quality and dimensional accuracy [13], [19-20]. That evidence is drawn almost entirely from high-force contexts, and it does not follow that the same penalty applies uniformly across materials.

UHMWPE is an informative case in this respect. Its viscoelastic response, elastic recovery and comparatively low cutting resistance suggest that the machined surface is not governed by platform stiffness alone [23-26], while the roughness mechanisms reported in CNC machining of UHMWPE remain strongly parameter-dependent [6], [9-10]. Neither observation implies equivalence between the two platforms, but together they suggest that material response may moderate the surface-quality gap. The interaction between the low cutting resistance of UHMWPE and robotic structural compliance remains largely unexplored.

This topical review therefore synthesises the CNC and robotic evidence in order to assess whether reduced surface roughness differences between the two platforms are mechanically plausible for UHMWPE, and to identify the knowledge gaps that still prevent firm conclusions from being drawn.

2. METHODOLOGY

This study adopts a targeted topical review approach. The approach was selected because the evidence bearing on the review question is sparse, heterogeneous and drawn from two literatures that do not overlap, namely CNC machining of UHMWPE and robotic milling of low-force materials. No matched comparative study of the two platforms on the same UHMWPE workpiece has been reported. A systematic review protocol presupposes a body of comparable studies whose findings can be pooled, and that body does not yet exist for this question. A topical synthesis, in which evidence of differing strength is interpreted through an explicitly stated hierarchy, is the appropriate instrument at this stage of maturity. The term topical review is used consistently throughout, including in the title.

2.1 Identification of Studies

The corpus reviewed here was assembled by iterative thematic searching rather than by a formal screening protocol. Searches were conducted in Google Scholar across the three themes set out above, using combinations of the terms UHMWPE machining, CNC milling of UHMWPE, robotic milling, thermoplastic machining, surface roughness, robot stiffness and toolpath planning. Publications identified as relevant were then used as entry points for backward citation tracking through their reference lists and forward citation tracking through works citing them. This second route accounts for studies that no keyword query would return, including two that report the time-dependent and recovery-related behaviour of UHMWPE rather than a machining trial [24-25]. Fourteen studies were retained for synthesis, each judged against the

criteria in Table 1 and classified by the hierarchy defined in Section 2.3.

An iterative search of this kind cannot be re-executed exactly by a reader. To document the field from which the corpus was drawn, a verification search was therefore carried out in Scopus on 3 September 2026 using three queries, one for each theme:

Query 1, conventional machining of UHMWPE: TITLE-ABS-KEY ("UHMWPE" OR "ultra-high molecular weight polyethylene") AND ("milling" OR "machining" OR "turning") AND ("surface roughness" OR "surface quality" OR "surface integrity"))

Query 2, robotic machining of polymeric and other low-force materials: TITLE-ABS-KEY ("robotic milling" OR "robot milling" OR "robotic machining" OR "cobot machining") AND ("polymer" OR "thermoplastic" OR "soft material" OR "plastic") AND ("surface roughness" OR "surface quality" OR "machining performance"))

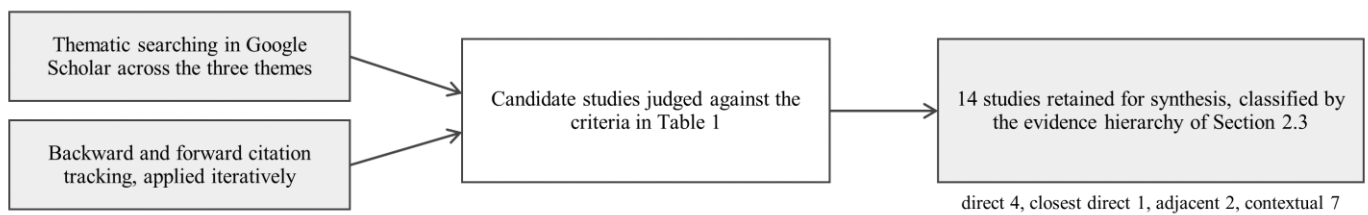
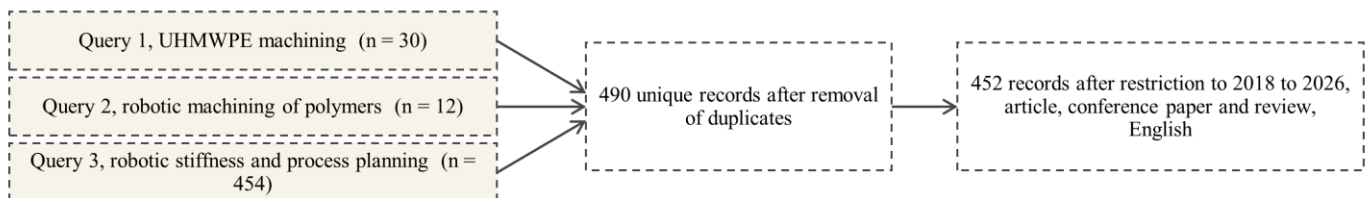
Query 3, robotic machining capability, stiffness and process planning: TITLE-ABS-KEY ("robotic milling" OR "robotic machining") AND ("stiffness" OR "posture" OR "compliance" OR "toolpath" OR "compensation" OR "chatter"))

The three queries returned 30, 12 and 454 records respectively, giving 490 unique records once duplicates were removed. Restricting these to the period 2018 to 2026, to journal articles, conference papers and review articles, and to publications in English left 452 records. The lower bound of the window was not chosen in advance but set by the publication year of the earliest study meeting the criteria in Table 1.

This verification search is reported for coverage and reproducibility. It was not the mechanism by which the reviewed studies were selected, and no title and abstract screening ledger was maintained across the 452 records. The present work is a topical review rather than a systematic one, and its selection was purposive: studies were drawn in where they bore directly on the interaction between the machining behaviour of UHMWPE and the characteristics of the machining platform. Figure 1 shows both the route by which the corpus was assembled and the verification search, and distinguishes between them.

2.2 Inclusion and Exclusion Criteria

Table 1 sets out the criteria against which each candidate study was judged. Each line is a single decision on the publication in hand, so that the outcome does not depend on interpretation by the reviewer. Because the corpus is small, the criteria were applied to the full text of every candidate rather than to its abstract. Publications cited elsewhere in this review for background on UHMWPE properties, biomedical application or robotic machining technology are supporting citations and were not judged against these criteria.

A. Assembly of the reviewed corpus**B. Verification search, Scopus, 3 September 2026**

Panel B documents the coverage of the field from which the corpus was drawn. It was not used to select the studies in Panel A, and no title and abstract screening ledger was maintained across the 452 records.

Fig. 1. Assembly of the reviewed corpus and the verification search. The two are distinct: the corpus was identified by thematic searching and citation tracking, while the Scopus search documents the coverage of the field and was not used to select the studies.

Table 1. Inclusion and exclusion criteria applied in selecting the reviewed studies

Inclusion criteria	Exclusion criteria
Experimental studies reporting milling of UHMWPE on a CNC or robotic platform	Studies reporting no machining experiment
Experimental studies reporting robotic or collaborative-robot machining of polymeric or other low-force materials	Studies in which the workpiece is metallic only
Studies reporting at least one quantitative surface roughness descriptor (Ra, Rq, Rz or Sa), or a stated machining outcome bearing on surface generation	Studies reporting neither a roughness descriptor nor a surface-generation outcome
Studies addressing robotic machining stiffness, posture, compensation or toolpath planning in which the outcome is linked to surface quality or dimensional accuracy	Robotic automation studies with no stated link to milling performance, surface quality or dimensional accuracy
Studies on UHMWPE material behaviour in which the property reported bears on surface formation during cutting	Studies on UHMWPE biomaterial performance, wear or clinical use with no process discussion
Peer-reviewed journal articles and review articles, and conference papers whose content bears directly on robotic machining behaviour	Editorials, extended abstracts, theses, book chapters and items that are not peer reviewed
Publications available in English	Publications not available in English

2.3 Evidence Hierarchy

The retained studies differ in how directly they bear on the review question, so each was assigned to one of four evidence levels. The criteria are as follows. A study is classified as Direct if it reports an experimental machining trial on UHMWPE

using a CNC platform and reports at least one quantitative surface roughness descriptor. It is classified as Closest direct evidence if it reports an experimental machining trial on UHMWPE using a robotic platform and reports at least one quantitative surface roughness descriptor. This is the only level that bears directly on the CNC to robot comparison, and only one study meets it. A study is classified as Adjacent if it reports experimental robotic or collaborative-robot machining of a polymeric or other low-force material other than UHMWPE. It is classified as Contextual if it addresses robotic machining capability, stiffness, posture, compensation or UHMWPE material behaviour without reporting a machining trial on UHMWPE on either platform.

The level assigned to each study is given in the final column of Table 2. Assignment depends only on what a study measured, and not on how strongly its findings agree with the interpretation developed here.

3. CNC MILLING OF UHMWPE

CNC milling remains the most established machining route for UHMWPE, particularly where controlled surface finish and dimensional consistency are required [5-6], [9]. Compared with the wider polymer-machining literature, the UHMWPE studies provide a more coherent process benchmark because they examine the relationship between cutting parameters and surface quality under controlled finishing conditions [6], [8-10].

Across the available studies, feed rate, spindle speed, depth of cut and step over all influence UHMWPE surface generation, but the reported ranking of these variables differs between studies [6], [8-10]. Reported roughness spans a wide range. Lestari et al. measured Ra between 0.577 and 1.758 micrometres across 27 CNC finishing runs on an acetabular cup, with a response surface optimum of 1.72 micrometres at 7219 rpm [10]. Ninggar et al. obtained optimum Ra values of 0.881 and 0.928 micrometres on the inner and outer surfaces of the same component at 8000 rpm and a step over of 0.01 mm

[8]. Basuki and Ismail reported a minimum Ra below 2 micrometres and identified feed rate as the only statistically significant factor, with depth of cut returning no significant effect [9]. Piska and Urbancova measured Ra of 2.49 to 2.61 micrometres, Rz of 18.68 to 19.84 micrometres and Sa of 3.63 to 3.68 micrometres on the as-milled surface, before any post-processing [6].

The direction of the spindle speed effect is not consistent across this evidence. Lestari et al. identified spindle speed as the leading factor, with higher speeds improving surface finish [10]. Piska and Urbancova reported the reverse, obtaining their best surface quality at the lowest cutting speed, which they attributed to heat accumulation and localised softening of the polymer [6]. Basuki and Ismail held cutting speed constant at 150 m/min and so cannot be cited on this point [9]. The two studies that do address it examine different speed regimes, which offers the most plausible explanation for the divergence. The kinematic benefit of additional cutting-edge passes appears to dominate at moderate speeds, while thermally mediated softening becomes influential at higher ones. Surface roughness in UHMWPE is therefore governed by the interaction between cutting kinematics, thermal response and the stability of local material removal, rather than by any single dominant parameter.

The CNC literature also moves beyond single-metric reporting. Ra remains the most used descriptor, but of the four CNC studies synthesised here only Piska and Urbancova report Rz and areal measures alongside it [6], [27]. A condition that appears favourable under Ra may not represent the surface equally well under a broader topographical description. A comparable development appears in process performance, where recent studies assess machining time, material removal rate and multi-response optimisation alongside surface finish [8], [10]. Ninggar et al. report machining times of 1746.37 and 942.21 seconds for the inner and outer acetabular cup surfaces at their optimum condition [8]. Robotic milling should therefore be judged not against isolated best-case roughness values, but against a CNC reference that already integrates surface quality with process efficiency.

The CNC evidence further supports a material-specific reading of surface formation. UHMWPE does not behave as a rigid metallic material during cutting. Its viscoelastic response,

elastic recovery and time-dependent deformation shape the measured texture after tool passage [24-26], so the machined surface is formed by tool motion together with the recovery behaviour of the material [6], [24-25]. This makes the CNC benchmark the appropriate baseline for assessing robotic milling under low-force conditions.

4. ROBOTIC MILLING OF LOW-FORCE MATERIALS AND IMPLICATIONS FOR UHMWPE

Industrial robotic milling has attracted growing interest because it offers workspace flexibility, geometric accessibility and adaptability for low-volume or customised production that conventional CNC systems cannot always provide [12-13], [28]. These advantages do not remove its principal limitation, which is lower and posture-dependent stiffness.

Across the robotic machining literature, stiffness-related limitations appear consistently as the main source of performance instability. Studies of posture sensitivity, structural compliance and dynamic response show that robotic systems are more vulnerable than rigid machine tools to deflection, vibration and positioning error, especially under high-force cutting conditions [13], [17-18]. As machining loads rise, this structural weakness becomes visible through reduced dimensional accuracy and poorer surface quality [19-20], [29].

The literature does not, however, support stiffness as the sole determinant of machining outcome. In thermoplastic, polymer-based and other compliant materials, the practical penalty of robotic compliance appears less severe than in metallic machining [21-23]. Process planning contributes comparably. Feed rate, spindle speed, robot posture and toolpath strategy shape surface outcome because they govern local stiffness, engagement conditions and vibration behaviour [13], [20], [30], while simulation-assisted planning, posture optimisation and compensation methods reduce error [13], [16], [31-32]. Robotic surface quality is therefore governed by the combined effect of structural limitation and process control, rather than by stiffness alone.

Table 2 sets out the cutting conditions and surface roughness reported by the studies most relevant to interpreting the comparison.

Table 2. Reported cutting conditions and surface roughness in studies relevant to the comparison of CNC and robotic milling of UHMWPE

Study	Material / workpiece	Process / platform	Reported cutting conditions	Reported surface roughness (micrometres)	Evidence level
Piska and Urbancova [6]	UHMWPE implant inserts	CNC ball-end milling, dry	Cutting speed 70.3 to 282.6 m/min; feed rate 315, 450 and 630 mm/min; depth of cut 1 mm	Ra 2.49 to 2.61; Rz 18.68 to 19.84; Sa 3.63 to 3.68, on the as-milled surface before post-processing. Rq not reported	Direct
Ninggar et al. [8]	UHMWPE acetabular cup	CNC milling, dry	Spindle speed 7000 to 8000 rpm; feed rate 1300 to 1400 mm/min; step over 0.01 to 0.015 mm; depth of cut 0.55 to 0.65 mm	Optimum Ra 0.881 inner and 0.928 outer at 8000 rpm and 0.01 mm step over, with machining times of 1746.37 s and 942.21 s. Rq and Rz not reported	Direct
Basuki and Ismail [9]	UHMWPE biomaterial	CNC milling	Cutting speed held constant at 150 m/min; feed rate 0.025 to 0.2 mm/rev; depth of cut 0.05 to 0.2 mm	Minimum Ra below 2, obtained at feed rates of 0.05 mm/rev and below. Regression model $Ra = 2.811 + 41.8f - 1.507ap$. Rq and Rz not reported	Direct
Lestari et al. [10]	UHMWPE acetabular cup	CNC milling, dry	Spindle speed 6500 to 7500 rpm; feed rate 1000 to 2000 mm/rev as printed in the source; step over 0.01 to 0.1 mm	Measured Ra 0.577 to 1.758 across 27 runs. Response surface optimum Ra 1.72 at 7219 rpm, 0.069 mm step over and 1636 mm/rev. Rq and Rz not reported	Direct
Zakaria et al. [33]	UHMWPE, flat and curved surfaces	Robotic milling, six-axis KUKA KR 120 R2700	Spindle speed 6500 and 9500 rpm; feed rate 1500 and 1767 mm/min; depth of cut 0.1 mm	Flat, 6500 to 9500 rpm: Ra 2.331 to 1.656; Rq 3.044 to 2.075; Rz 11.765 to 7.509. Curved,	Closest direct evidence

Study	Material / workpiece	Process / platform	Reported cutting conditions	Reported surface roughness (micrometres)	Evidence level
				same speed change: Ra 1.669 to 1.209; Rq 2.246 to 1.559; Rz 8.778 to 5.877	
Antonelli et al. [21]	Additively manufactured polymeric components	Collaborative-robot contouring	Contouring finishing of 3D-printed polymer parts	Roughness values not extracted under conditions comparable to UHMWPE milling	Adjacent
Wan Jusoh et al. [32]	Polymeric foam	Simulation-driven robotic milling with SprutCAM	Parallel and equidistant finishing toolpath strategies	Surface roughness not reported. Machining time 73 s and 86 s against simulated 54 s and 62 s, deviations of 26.0 and 26.7 per cent	Adjacent
Wang et al. [13]	Complex parts, general robotic milling	Review of robotic milling	Not applicable	Not applicable	Contextual
Chen et al. [17]; Cvitanic et al. [18]	Robotic milling systems	Posture and stiffness optimisation	Not applicable	Not applicable	Contextual
Trzepiec et al. [22]; Prvulovi et al. [23]	Polymer-based materials	Low-force polymer machining	Not applicable	Not applicable	Contextual
Vadivel et al. [24]; Rooke et al. [25]	UHMWPE	Material behaviour	Not applicable	Not applicable	Contextual

Note: values are reproduced as reported in the cited sources. Not reported indicates that the descriptor was not given in the source. The feed rate unit for reference [10] is reproduced as printed in that publication. The studies were conducted with different cutting tools, workpiece geometries and measurement configurations, and the values are therefore not directly comparable across rows.

As shown in Table 2, the evidential basis is uneven. The CNC studies report Ra values between 0.577 and 2.61 micrometres for UHMWPE across a range of finishing conditions, with the lower part of that range obtained under optimised parameters on acetabular cup geometries [6], [8-10]. Against this, a single robotic study on UHMWPE is available. Zakaria et al. machined flat and curved UHMWPE surfaces on a six-axis KUKA KR 120 R2700 at a depth of cut of 0.1 mm, and reported Ra falling from 2.331 to 1.656 micrometres on flat surfaces and from 1.669 to 1.209 micrometres on curved surfaces as spindle speed increased from 6500 to 9500 rpm, with Rq and Rz following the same direction [33]. The remaining robotic entries provide adjacent rather than direct support. The study on polymeric foam reports machining time rather than surface roughness [32], and the collaborative-robot contouring study concerns additively manufactured polymer parts rather than UHMWPE [21].

Placing the reported values side by side makes the scale of the difference explicit. For UHMWPE, CNC finishing studies

report Ra between 0.577 and 2.61 micrometres depending on parameters and component geometry [6], [8-10]. The only robotic UHMWPE study reports Ra between 1.209 and 2.331 micrometres over its tested conditions, narrowing to between 1.209 and 1.656 micrometres at the higher of its two spindle speeds [33]. The robotic values fall inside the range reported for CNC machining of the same material, and the best robotic result lies below the as-milled CNC values reported by Piska and Urbancova [6]. Figure 2 presents these ranges. The overlap should not be read as equivalence. The studies differ in cutting tool, workpiece geometry, machine configuration and measurement setup, and none was designed as a controlled comparison. What the overlap does establish is narrower and still useful. The roughness penalty separating the two platforms in UHMWPE is not evident at the order-of-magnitude scale that metallic machining experience would lead one to expect, and the question of how large it actually is remains open rather than settled.

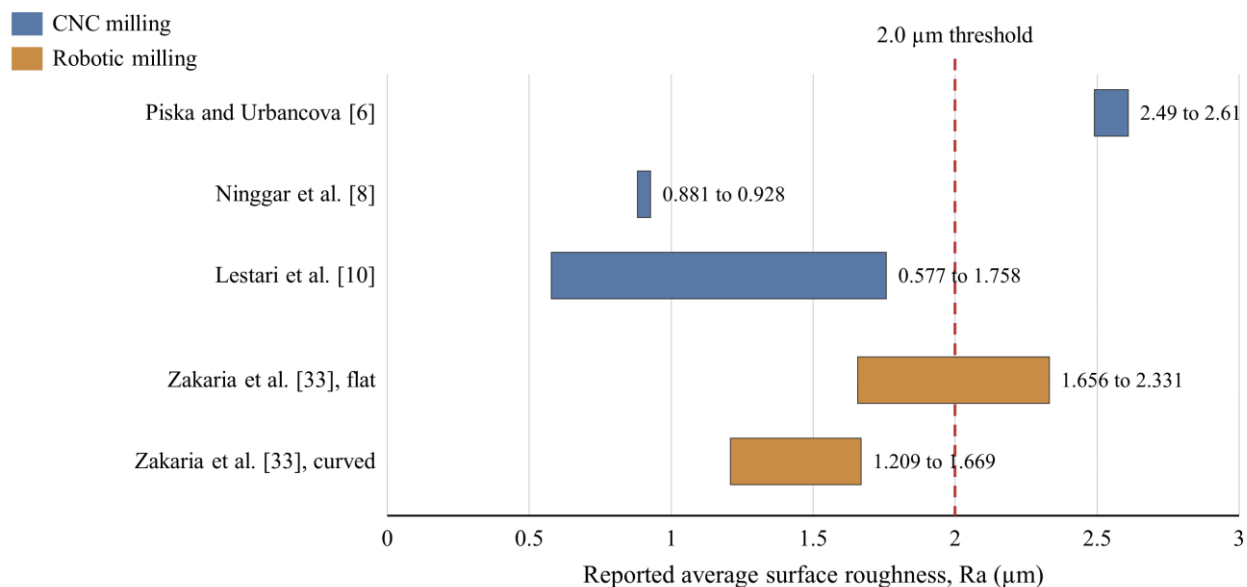


Fig. 2. Reported average surface roughness ranges for CNC and robotic milling of UHMWPE. Bars show the span of Ra values reported by each study. The studies were conducted with different tools, workpiece geometries and measurement configurations and are not directly comparable.

These ranges should be read against the roughness threshold adopted in the UHMWPE machining literature. An average roughness below 2 micrometres is the value against which Basuki and Ismail report their minimum result [9], and which Ninggar et al. and Lestari et al. both set as the target for acetabular cup machining, the former attributing it to ASTM requirements [8], [10]. Three of the four conditions reported by Zakaria et al. fall below that threshold, the exception being the flat surface machined at 6500 rpm at Ra 2.331 micrometres [33]. The relevant question is therefore not whether robotic milling can exceed CNC performance, but whether it can meet the same finishing threshold under low-force conditions.

The mechanism proposed for this overlap rests on cutting load rather than on structural rigidity. UHMWPE imposes a lower mechanical load on the machining platform than the metallic workpieces from which the compliance penalty was originally established, particularly during finishing with shallow engagement and moderate feed [23-25], so stiffness-related penalties persist but exert less influence on the final roughness. The viscoelastic recovery of the material after tool passage contributes a component of the measured texture that is independent of platform stiffness [24-26], which further compresses the difference the two platforms are able to produce.

Two of the studies in Table 2 were authored by members of the present research team. Reference [33], the robotic UHMWPE study designated as the closest direct evidence, and reference [32], the simulation-driven toolpath study, both include authors of this review. This is disclosed because reference [33] carries a disproportionate share of the argument. It is the only robotic UHMWPE dataset available, and the comparison presented here would not be possible without it. Its limitations should be weighed accordingly. It examines two spindle speeds and two surface geometries on a single robotic platform with one cutting tool, it does not include a CNC control machined under matched conditions, and it was not designed as a platform comparison. Reference [32] is weaker still as evidence for the present question, because its workpiece is polymeric foam rather than UHMWPE and it reports machining time and robot motion stability rather than surface roughness. Neither study establishes CNC to robot equivalence, and this review does not treat them as doing so.

Figure 3 summarises the resulting argument, linking the CNC benchmark for UHMWPE, the adjacent robotic evidence from low-force materials, and the material-specific mechanisms that may reduce the roughness gap between the two platforms.

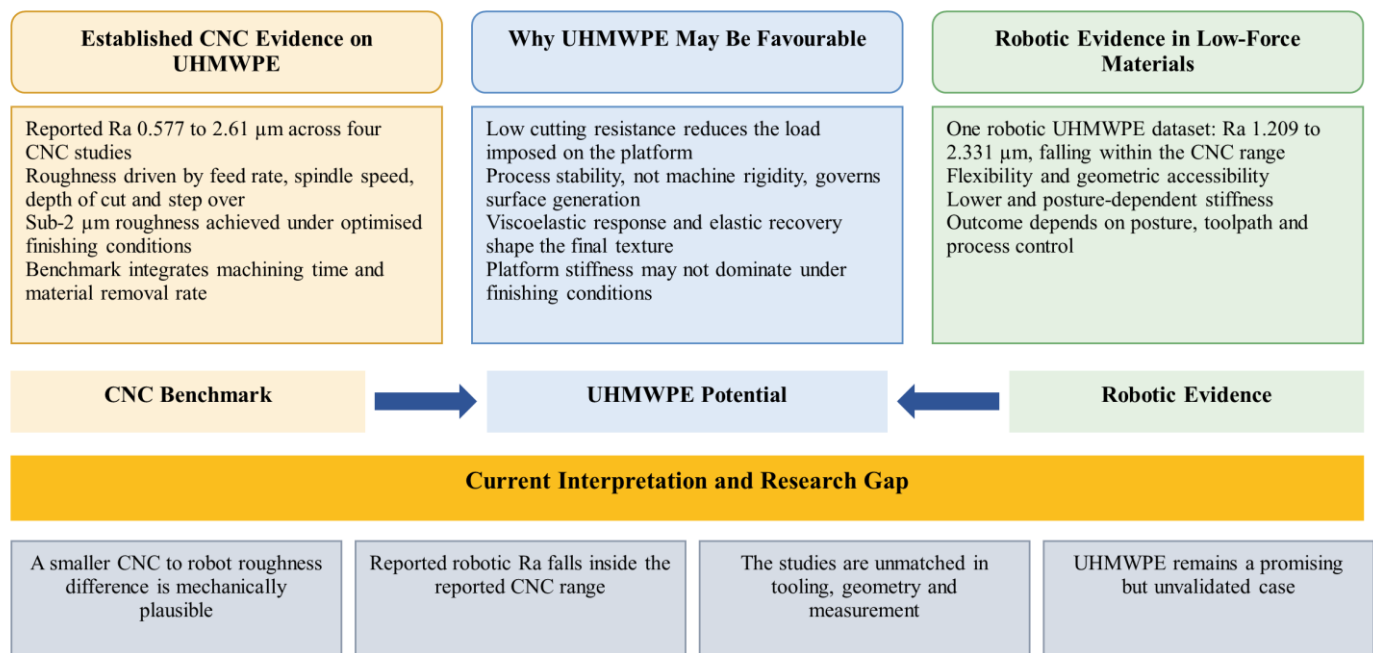


Fig. 3. Proposed analytical framework linking the CNC benchmark for UHMWPE, robotic evidence in low-force materials, and material-specific mechanisms to explain the potential reduction in CNC to robot surface roughness differences.

Taken as a whole, the available evidence supports a conditional rather than an absolute conclusion. UHMWPE can be interpreted as a material system in which robotic milling may approach CNC surface quality more closely than metallic machining experience would predict. That interpretation is mechanically reasonable and quantitatively consistent with the

values reported in Table 2, but it is not empirically verified, because it rests on two separate evidence streams and on mechanistic inference rather than on matched comparative experiments on the same workpiece and finishing objective [13], [21], [33]. UHMWPE should therefore be regarded as a

promising but unvalidated case for convergence in CNC and robotic surface roughness.

5. RESEARCH GAP AND FUTURE DIRECTIONS

The principal research gap is the absence of direct comparative studies between CNC and robotic milling using the same UHMWPE material under matched finishing objectives. The argument for reduced roughness differences is currently assembled from two neighbouring evidence streams, namely established CNC machining studies on UHMWPE and emerging robotic machining studies on thermoplastic or other low-force materials [6], [13], [21], [33]. This combined literature is informative, but it cannot determine whether robotic milling approaches CNC performance consistently under controlled and comparable conditions.

A second gap concerns the scope of surface evaluation. Most available studies report average roughness alone, because Ra is the most reported indicator in both conventional and robotic machining [6], [9-10]. Of the five UHMWPE studies synthesised here, only two report descriptors beyond Ra [6], [33]. For UHMWPE this is insufficient, since surface functionality depends on a broader topographical description including Rq, Rz and other texture-related indicators, particularly where tribological response and wear behaviour are important [2], [6-7]. Future comparative studies should adopt multi-metric surface characterisation rather than relying on a single parameter.

A third gap relates to manufacturing relevance. CNC studies on UHMWPE increasingly consider material removal rate, machining time and multi-response optimisation together with surface quality [8], [10], whereas equivalent multidimensional evaluation remains limited in the robotic context. Even where robotic milling appears favourable on roughness, its practical competitiveness cannot yet be assessed with confidence. A fourth concerns robot posture, local stiffness variation and engagement severity. Robotic compliance is configuration dependent, so the same nominal cutting parameters may not produce identical outcomes across different workspace positions, tool orientations or path directions [13], [17-18], and in UHMWPE recovery-related surface behaviour may further obscure platform-related differences.

On the present evidence, the most useful next step is a direct comparative study using the same UHMWPE material, comparable tool geometry and finishing conditions matched across CNC and robotic platforms. Such a design should employ a controlled experimental structure that accounts explicitly for posture and cutting direction, and should evaluate average surface roughness together with complementary descriptors such as Rq and Rz, alongside machining time, material removal rate, dimensional accuracy and process repeatability. Only through such experiments can the proposed reduction in CNC to robot surface roughness differences be validated under realistic manufacturing conditions.

6. CONCLUSION

This topical review examined whether UHMWPE represents a favourable case for reduced surface roughness

differences between CNC and robotic milling. Fourteen studies were synthesised under an explicit evidence hierarchy. The CNC studies reviewed report Ra between 0.577 and 2.61 micrometres for UHMWPE, with roughness governed by cutting parameters together with material-specific behaviour, particularly viscoelastic response and elastic recovery.

The single available robotic study on UHMWPE reports Ra between 1.209 and 2.331 micrometres, narrowing to between 1.209 and 1.656 micrometres at 9500 rpm [33]. These values fall within the range reported for CNC machining of the same material rather than an order of magnitude above it, which indicates that robotic milling should not be interpreted solely through assumptions derived from high-force metallic machining.

The evidence nevertheless remains insufficient to support direct equivalence between the two platforms. The studies compared differ in tooling, workpiece geometry and measurement configuration, and none was designed as a controlled comparison, so the present interpretation rests on established CNC evidence, one robotic UHMWPE dataset and mechanistic reasoning. UHMWPE can therefore be regarded as a promising but unverified case for reduced CNC to robot surface roughness differences. Future work should prioritise direct comparative studies under matched finishing conditions, supported by multi-metric surface evaluation and process-relevant performance indicators, so that the proposed material-driven interpretation can be validated and translated into practical manufacturing use.

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