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Functional tools micro-texturing for controlled chip formation in precision dry machining of PEEK

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Abstract

Precision machining of high-performance polymers, such as polyetheretherketone (PEEK), is increasingly required for biomedical and high-value engineering applications. However, dry turning of polymers is often limited by poor chip control, as conventional cutting insert geometries are primarily designed for metals and produce long, continuous chips that degrade process stability, productivity, and the quality of machined parts. This work investigates a functional modification of the tool rake face via laser-generated micro-grooves to influence chip flow without changing the overall tool geometry. Dry turning tests were carried out on PEEK using untextured and textured inserts. Chip morphology and tool-chip contact area were analyzed. Although complete chip breakage was not achieved during dry machining, the modified tools showed clear changes in chip flow, contact length, and chip geometry. The results highlight the limitations of conventional inserts for dry polymer machining and indicate that functional modifications of the rake face represent a promising direction for tool design to improve chip control and process stability in sustainable precision machining of polymers.

PEEK turning; chip control; textured tools; tool-chip contact

1. Introduction

Polyetheretherketone (PEEK) is increasingly used in biomedical and high-performance engineering applications due to its mechanical properties, biocompatibility, and chemical stability [1]. Machining remains a key manufacturing process for producing accurate and customized components. However, dry turning of PEEK is characterized by poor chip control. The material's ductile behavior promotes the formation of long, continuous chips that can wrap around the tool and workpiece, reducing process reliability [2].

The use of cutting fluids is often restricted in biomedical manufacturing due to contamination risks, while alternative cooling strategies, such as cryogenic cooling, introduce additional complexity at the process level [3]. In contrast, tool design solutions for chip control in polymer machining are still limited. Conventional turning inserts are typically optimized for metallic materials and rely on macroscopic chip breakers, which are generally ineffective when machining PEEK.

Surface modification of the tool rake face represents a possible way to influence chip flow without altering the overall tool geometry. Previous studies from the authors have shown that surface textures can affect tool-chip interaction by modifying contact conditions [4]. In this context, the present work aims to assess whether a local modification of the tool rake face can partially compensate for the limitations of standard insert designs by altering chip flow and contact behaviour under dry cutting conditions.

2. Materials and methods

Turning tests were performed on biomedical-grade PEEK (TECAPEEK™, supplied by Ensinger Plastics) using uncoated carbide turning inserts (Tungaloy™ VNMA 160402–330.5 TH10) with a nominally flat rake face (0° rake angle). A set of inserts was modified by laser texturing the rake face with linear micro-grooves oriented perpendicular to the cutting edge (see Figure 1). The texture was designed to introduce a local functional modification near the cutting edge, while keeping the global insert geometry unchanged. Two main design parameters were considered in this study: groove depth (G_d) and distance from the cutting edge (D), as seen in Figure 1. The groove depth, which controls the intensity of the tool-chip interaction, was set to 40 and 10 µm. The distance of the textured zone from the cutting edge was varied to 70, 100, or 130 µm, controlling when the chip engages the functional surface during its formation. While all textures shared the same pitch (P) and groove orientation with respect to the cutting edge.

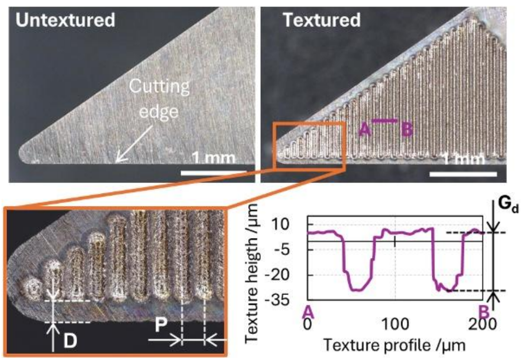

Figure 1. Untextured and textured inserts.

Turning tests were conducted on a lathe (Mori Seiki™ NL 1500 CNC) under dry conditions to isolate the effect of the tool surface modification. Consistent cutting parameters were maintained throughout all trials: cutting speed of 200 m/min, depth of cut of 0.5 mm, and feed of 0.1 mm/rev. After machining, chips were collected and analysed using optical microscopy (Keyence™ VHX-S770E/S750E) and scanning electron microscopy (FEI™ QUANTA 450 SEM) to evaluate their overall morphology, width, and surface features. Additional short-cutting tests were carried out to assess the tool-chip contact area by analysing the contact imprint left on the rake face.

The analysis focused on identifying changes in chip morphology and contact characteristics induced by the textured surface, rather than on achieving full chip segmentation.

3. Results and discussion

3.1. Chip morphology

In machining with the untextured insert, long, continuous chips were consistently produced. These chips showed limited curvature and a smooth back surface, indicating extended contact with the rake face (see Figure 2 a).

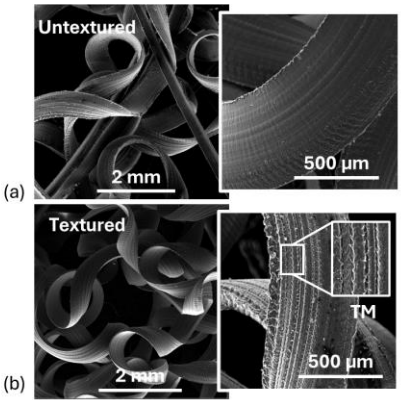

Figure 2. SEM images of the chip obtained with untextured (a) and textured (b) inserts. In the magnification, the texture marks left by the grooves are visible.

The introduction of micro-grooves on the rake face did not lead to chip breakage. However, chips produced with textured tools showed measurable differences compared to those obtained with the standard insert (see Figure 2 b). In particular, a reduction in chip width and an increase in chip curvature were observed. Texture marks (TM) corresponding to the groove pattern were visible on the back surface of the chips, confirming direct interaction between the chip and the modified rake face.

These observations indicate that the textured surface influenced chip flow, even though the deformation was insufficient to fracture the chip under dry cutting conditions.

3.2. Tool-chip contact behaviour

As visible in Figure 3, measurements of the tool-chip contact area showed a shorter tool-chip contact length (λ) and contact width (c) for textured inserts compared to the untextured geometry. This reduction suggests that the micro-grooves locally interrupted continuous contact between the chip and the rake face, promoting earlier chip detachment.

From a tool design perspective, this result is relevant because it shows that the standard insert geometry promotes extended contact, leading to less curved chips, which are therefore unfavourable for chip control in dry polymer machining. On the contrary, the textured insert, while still unable to break the chip, altered the functional behaviour of the tool by modifying how the chip interacts with the rake face.

3.3. Chip formation

The analysis of tool-chip contact shows that both the position and depth of tool textures influence chip formation. For deeper textures, grooves located closer to the cutting edge engaged the chip earlier, promoting greater curling. In contrast, deeper textures positioned farther from the cutting edge interacted with the chip later, producing wider chips with less pronounced curling. Shallower textures exhibited the same trend but with reduced effects: chip detachment from the rake face occurred later, regardless of the groove's distance from the cutting edge.

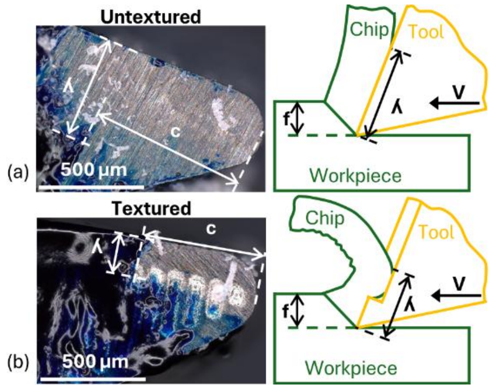

Figure 3. Chip-tool contact area and chip formation for untextured (a) and textured (b) inserts.

These results indicate that effective chip flow control is achieved when deeper textures are located near the cutting edge, as they reduce the tool-chip contact area, guide the material along the grooves, and enhance curling, facilitating chip detachment even under continuous chip formation through the functional role of the textured tool rake face.

4. Conclusion and future work

This work investigated the effect of a local modification to the insert rake face on chip formation during dry turning of PEEK. Although complete chip breakage was not achieved, textured tools clearly influenced chip morphology and tool-chip contact behaviour relative to untextured inserts.

From a precision engineering viewpoint, the results indicate that chip control in polymer machining should be addressed through micro-scale functional design of tool surfaces rather than through conventional insert geometries developed for metals. Local surface modifications of the rake face can influence chip flow and contact behaviour and represent a promising direction for further tool development.

Future work will focus on optimising texture geometry and position to enhance chip curvature and move towards reliable chip segmentation under dry cutting conditions.

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