Influence of cutting tool geometry on tool wear and generated forces during trochoidal milling operations of Inconel 718

From Knowledge to Competitiveness

Portugal-US Partnerships 2026 Summit

MIT Portugal Program

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Main objectives:

- Test the feasibility of trochoidal milling strategy on IN718 alloy;
- Determine optimal tool geometry for cutting IN718;
- Monitor the process' responses and find relations between these and sustained tool wear;
- Provide a benchmarking base for future process optimization and comparison with other tooling solutions.

Materials & Methods:

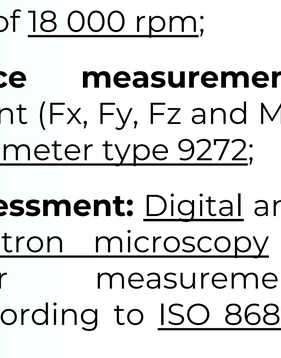
- **Workpiece material:** Inconel 718, with a tensile strength of 1412 MPa, yield strength of 1188 MPa, and a hardness value of 46 HRC;
- **Machining tools:** WC-Co TiAlSiN coated end-mills with 10 mm diameter and 5 cutting teeth – different helix and rake angles;
- **Machining center:** CNC 5 axis MAZAK CV5-500 with maximum spindle speed of 18 000 rpm;
- **Cutting force measurement:** Multicomponent (Fx, Fy, Fz and Mz) Kistler dynamometer type 9272;
- **Tool-wear assessment:** Digital and scanning electron microscopy – flank wear measurement performed according to ISO 8688-2;
- **Machined surface roughness:** measured using surface roughness tester Mitutoyo SJ-210 according to ISO 4288;

Machining parameters:

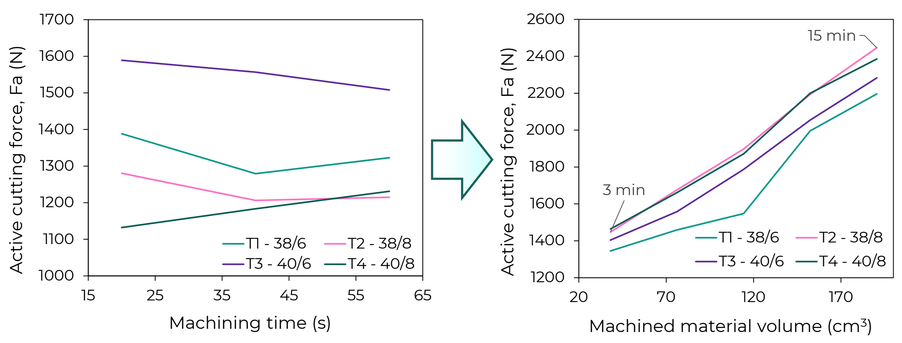
- Cutting speed ($\mathbf{V_c}$) = 120 m/min
- Feed-per-tooth ($\mathbf{f_z}$) = 0.07 mm/z
- Axial depth of cut ($\mathbf{a_p}$) = 19 mm
- Radial depth of cut ($\mathbf{a_e}$) = 0.5 mm

Tool helix (H) and rake (R) angle variations, in degrees (°):

- **T1** – 38H/6R
- **T2** – 38H/8R
- **T3** – 40H/6R
- **T4** – 40H/8R



Cutting force results:



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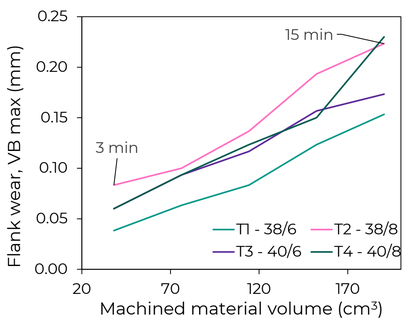
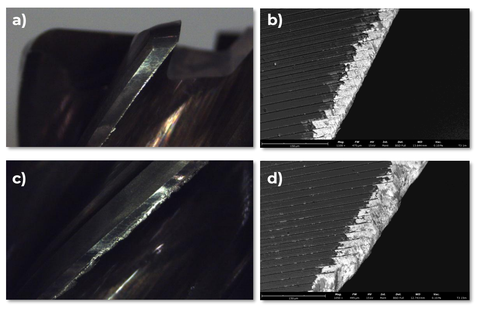
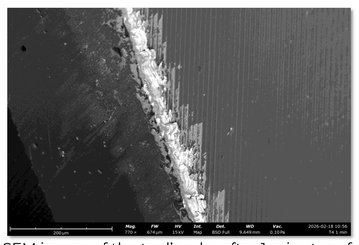


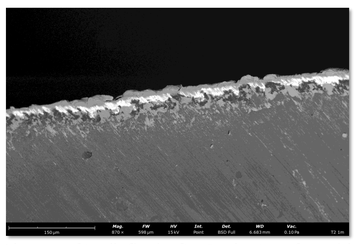


Tool wear: after 3 minutes of machining (a), and the corresponding SEM image (b); after 15 minutes of machining (c), and corresponding SEM image (d)

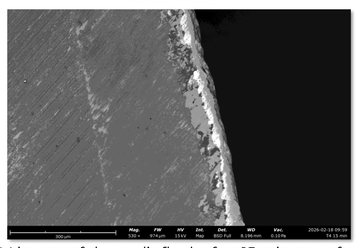
Tool wear mechanisms:



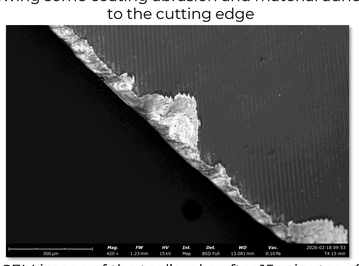
SEM image of the tool's rake after 1 minutes of machining showing material adhesion and coating delamination



SEM image of tool's flank after 1 minutes of machining showing some coating abrasion and material adhered to the cutting edge

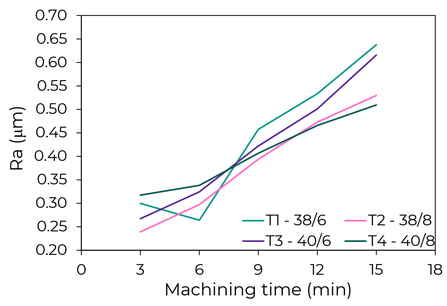


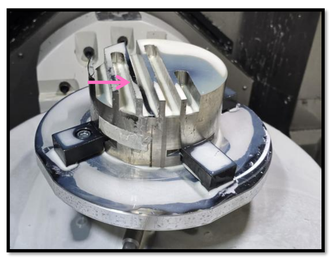
SEM image of the tool's flank after 15 minutes of machining showing mainly edge chipping as well as material adhesion

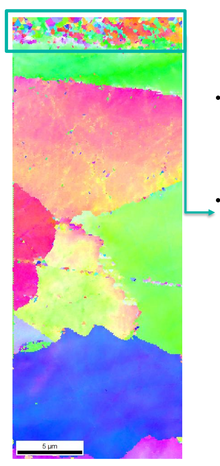


SEM image of the tool's rake after 15 minutes of machining and showing chipping and abrasion (both on substrate and coating)

Surface integrity results:







- Amorphous Inconel 718 layer - Thickness = 2.87 µm
- Surface machined with WC-Co, TiAlSiN coated inserts, using 50 m/min and fz = 0.02 mm/tooth

- Amorphous Inconel 718 layer - Thickness = 1.29 µm
- Surface machined with WC-Co, TiAlSiN coated tool, with T1 geometry, using 120 m/min and fz = 0.07 mm/tooth.

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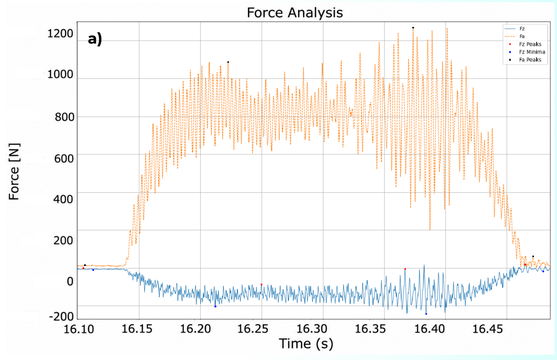
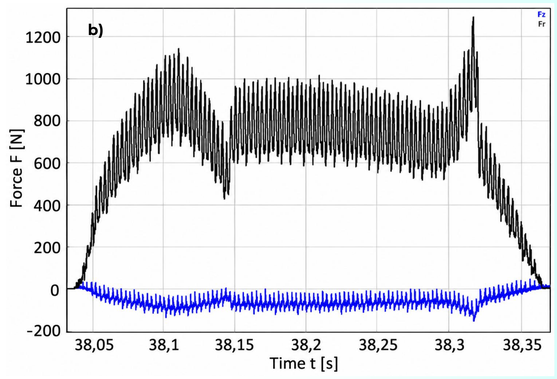
Simulation results:





Cutting force signal of a single trochoidal pass: Experimental values, with Fa being shown as orange and Fz being blue (a); Simulated values with *Toolyzer* software, with Fa being black and Fz blue (b)

Conclusions:

- Tested 4 different geometries, reaching considerable levels of MRR 12.7 cm^3/min;
- T2 and T4 tool exhibit higher values of Fa as well as VB (not for < 1 min. of cutting);
- Main wear mechanism are coating delamination, material adhesion and abrasive wear;
- EBSD analysis revealed a thinner layer of refined-grain microstructure for trochoidal milling;
- Lowest Ra values (machining direction) are obtained for T2 and T4 tools (~25% better than others);
- T1 geometry proved to be the best geometry in terms of sustained tool wear for IN718 trochoidal milling operations;
- Simulating T1 geometry in trochoidal milling operations yields satisfactory results, obtaining a 2.28% deviation from experimental Fa results, however, for Fz, resulted in an 11.36% deviation.

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