PRELIMINARY CUTTING FORCE AND TOOL WEAR STUDY FOR MICRO-PATTERNED TURNING INSERTS

Ryan A. Garcia[1], Tony L. Schmitz[1,2], Brian K. Canfield[3], Alexander Y. Terekhov[3], Trevor Moeller[4], and Lino Costa[4]
[1]Department of Mechanical, Aerospace, and Biomedical Engineering
University of Tennessee, Knoxville
Knoxville, TN, USA
[2]Manufacturing Science Division
Oak Ridge National Laboratory
Oak Ridge, TN 37830, USA
[3]Center for Laser Applications
University of Tennessee Space Institute
Tullahoma, Tennessee, USA
[4]Department of Mechanical, Aerospace, and Biomedical Engineering
University of Tennessee Space Institute
Tullahoma, Tennessee, USA

INTRODUCTION

This paper investigates the effect of micro-patterned features on the rake face of indexable inserts on cutting force and tool wear in turning. Micro-patterned inserts have been shown to lower the cutting forces during turning operations and thereby reduce the rate of wear of the tool in prior publications [1-2].

The decrease in cutting force has been attributed to decreasing the rake face friction, due to a smaller contact area between the tool and chip. In addition, the microscopic trenches provide locations for coolant micropools on the rake surface of the insert, which helps to further reduce friction. The smaller friction force causes less heat at the tool-chip interface which can reduce the wear rate.

Built-up edge on inserts can also affect wear rates. The built-up edge can act as a protective layer that is present on the surface. However, the built-up edge can damage the insert when the layer of built-up material breaks off; this can cause edge chipping. Built-up edge has been found to adhere best to a dimpled surface texture, rather than microscopic trenches. The trenches have caused the built-up edge to destabilize and not be retained on the insert surface [1].

MANUFACTURING PROCESS

In this study, microscopic trenches were patterned near the cutting edge on the rake face of turning inserts (Widia CCMW3252 THM INSERT) using an ultrafast laser (Amplitude Systèmes 20 W Tangerine) emitting 1030 nm wavelength laser radiation pulses, each with 0.3 picosecond pulse duration, at a rate of 100 kHz. The laser beam was focused on the rake surface using a 0.60 numerical aperture (NA) microscope objective (Leica Microsystems, GmbH H32× /0.60 ∞/1.80, Leitz Wetzlar). The insert was positioned and moved under the focused laser radiation using a set of nanopositioning stages (ANT95-3-V and ANT95-50-XY, by Aerotech) at a rate of 1000 µm/s, under a cover of flowing N_2 gas. Each trench, patterned 1000 µm long, 50 µm wide, and 10 µm deep, was formed in two passes by alternate line rastering (-X → +X, Step -Y, +X → -X, etc.), with line spacing of 4.5 µm (in Y) for a total of nine lines per trench. The laser energy per pulse was set to 25 µJ during the first pass, and 4 µJ during the second pass. A total of five inserts were patterned with sets of trenches 3.0 mm long and located 50 µm from the rake surface edge. The total number of trenches and machining time per pass varies was based on constant overall pattern dimension (3.0 mm) and spacing between trenches; see *Table 1*.

TABLE 1. Laser patterning details.

Insert #	# trenches	Trench spacing [µm]	Time per pass [s]
1	31	50	928
2	25	75	748
3	21	100	628
4	16	150	478
5	13	200	388

The laser patterned inserts were inspected with a Leica DVM6 digital microscope using a FOV 3.60 high-magnification objective. Leica LASX software was used to acquire 3D surface profiles of the patterned trenches and measure trench depths. A picture of insert #4 is shown in FIGURE 1. FIGURE 2 and FIGURE 3 show details of the trenches in insert #1.

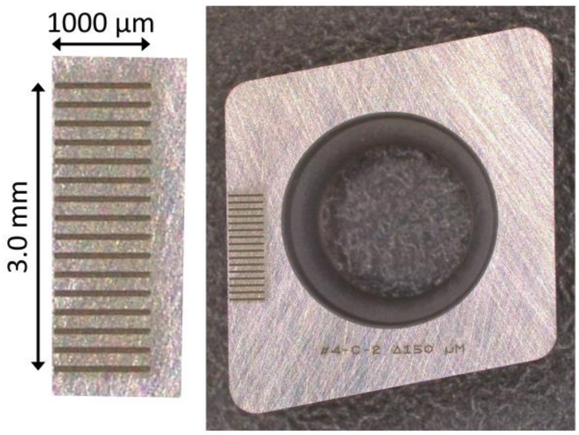

FIGURE 1. Insert #4.

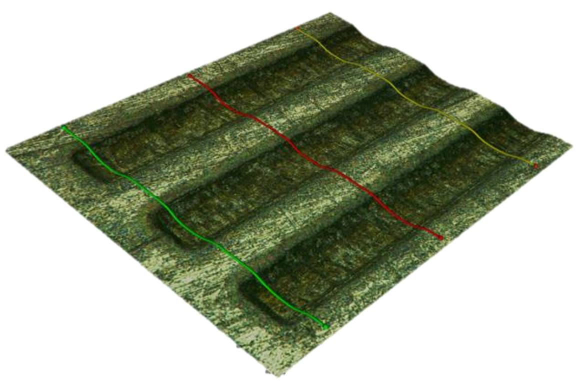

FIGURE 2. Multifocus image of trench detail for insert #1. Three profile paths are identified.

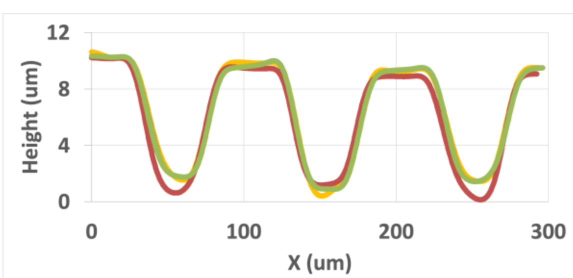

FIGURE 3. Example of trench depth profiles for insert #1, along the paths indicated in FIGURE 2.

TESTING PROCEDURE

Orthogonal cutting tests were performed using cutting edges with and without the micro-patterns. The micro-pattern was only present on a single cutting edge of the inserts, enabling testing to be conducted on the opposite edge of the insert with no pattern. This provided a direct comparison between the micro-pattern and regular insert edge on a single insert. The same insert was used to limit the variation in material composition from one insert to another. In addition, insert number 6 was not patterned and provided an unaltered rake face geometry. This insert served as the control test for the initial cutting force measurements.

The orthogonal cutting test were conducted on a Haas TL-1 CNC lathe. The normal and tangential direction cutting forces were recorded using a cutting force dynamometer (Kistler 9257B) for comparison between the cutting edges with and without micro-patterns. The cutting force directions are shown in Figure 4. The progression of flank wear width during the test cuts was also recorded. This was accomplished using a pair of Dino-Lite digital microscopes to record images of both the flank and rake faces of the insert at discrete intervals. The wear was measured using an Alicona InfiniteFocus SL to scan the worn insert and the Alicona wear measurement module to identify the maximum flank width.

Initial cutting force measurements have been performed, with full tool wear testing to be conducted as follow-on activities. Figure 5 shows the experimental setup that was used for the testing that was conducted.

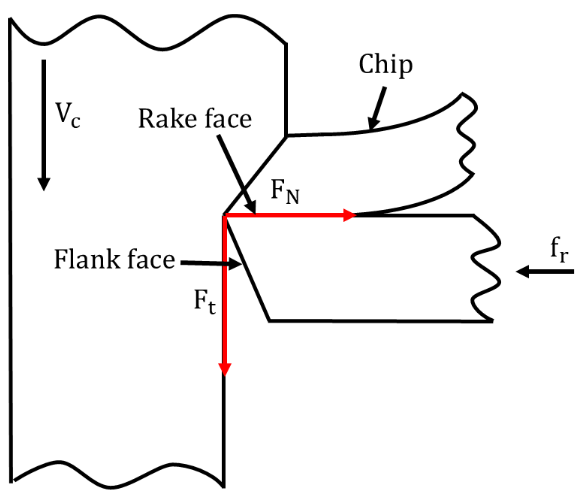

FIGURE 4. Diagram that shows the feedrate (f_r), cutting speed (V_c), normal cutting force (F_N), and tangential cutting force (F_t) directions.

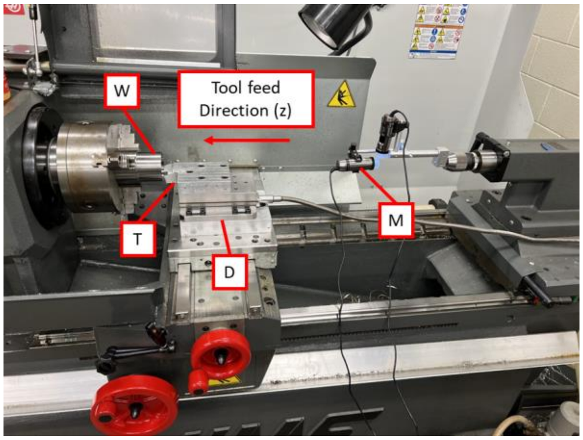

FIGURE 5. Photograph of orthogonal cutting setup including workpiece (W), dynamometer (D), cutting tool (T), Dino-Lite digital microscope (M).

The cutting speed that was used for all tests was 91.4 m/min (spindle speed of 443 rpm). The feed per revolution was 0.254 mm/rev and the length of cut was 6.35 mm. The length of cut is defined as the linear length of the SAE 304 stainless steel workpiece that was machined during each of the test cuts. The SAE 304 stainless steel tubes had a wall thickness of 2 mm and an outside diameter of 67.64 mm.

During each cutting test, Rapid-Tap cutting fluid was used as a lubricant to mitigate the adhesion of the 304 stainless steel work material to the uncoated carbide inserts. This was done so that there would not be damage done to the insert cutting edge and rake face from removing the chip between each of the test cuts. The Rapid-Tap cutting fluid was applied with a dropper bottle manually to the cutting edge prior to the start of each test.

CUTTING FORCE RESULTS

Cutting force measurements are reported in Figure 6. These results are the average force for both the tangential and normal directions. The error bars are the standard deviations that were calculated based on the variation in the time dependent force.

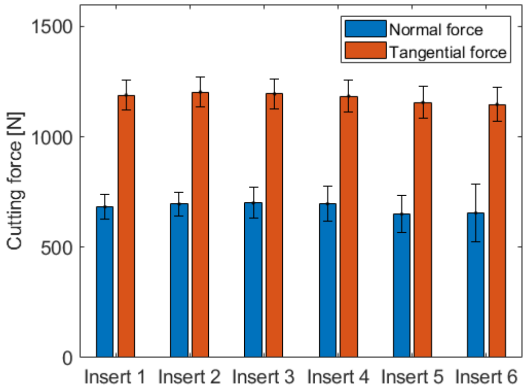

FIGURE 6. Cutting force data recorded during the initial round of test cuts.

The images that were recorded using the Dino-Lite digital microscopes are shown in Figures 7–14. Figures 7–10 are images of insert 6. Insert 6 did not have any pattern imprinted on the rake face. Figures 10–14 are images of insert 1 which had the patterned trenches present on the rake face. The parameters of the trenches for insert 1 are provided in Table 1.

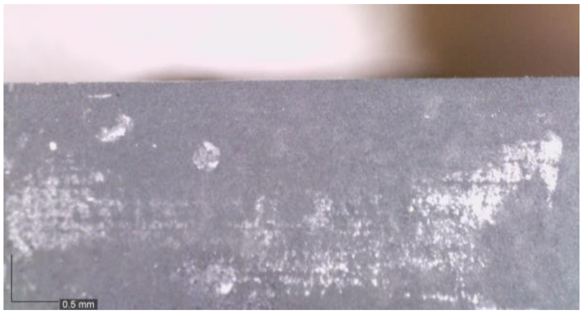
FIGURE 7. 64.4x image of the flank face of insert 6 prior to the initial test cut.

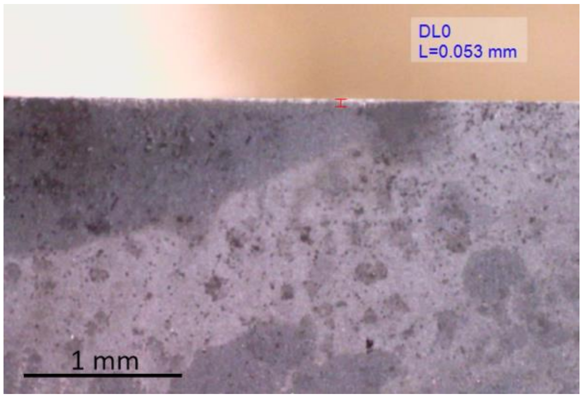

FIGURE 8. 64.4x image of the flank face of insert 6 after the first test cut; 53 μm of flank wear width was measured using the digital microscope.

FIGURE 9. 28.3x image of the insert 6 rake face prior to initial test cut.

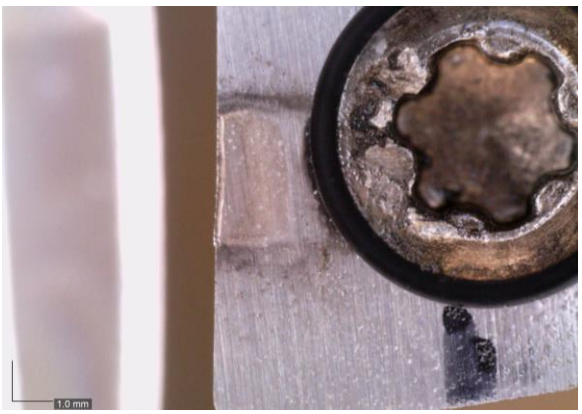

FIGURE 10. 28.3x image of the insert 6 rake face after the first test cut.

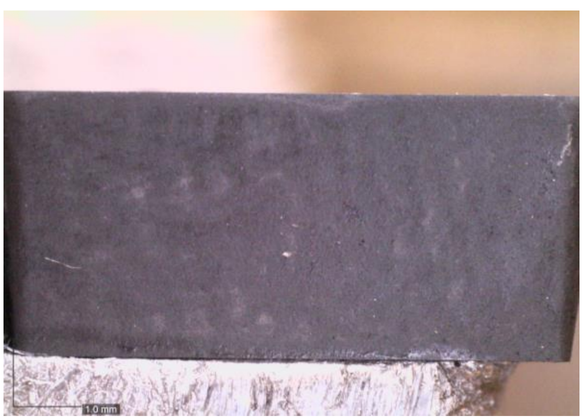

FIGURE 11. 46.4x image of the insert 1 flank face prior to the initial test cut.

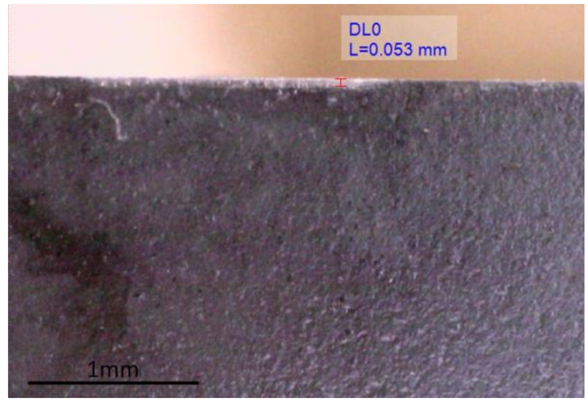

FIGURE 12. 46.4x image of the insert 1 flank face after the first test cut; 53 μm of flank wear width was measured using the digital microscope.

FIGURE 13. 50.1x image of the insert 1 rake face prior to initial test cut.

FIGURE 14. 50.1x image of the insert 1 rake face after the first test cut.

After the test cut was performed, the insert was scanned with the Alicona InfiniteFocus SL. As noted, the Alicona wear measurement module was used to determine the flank wear width. The scanned geometry is displayed in Figure 15 for insert 6 and Figures 17 and 19 for insert 1. The blue plane is the cross-section that the Alicona wear measurement module used to calculate the flank wear width by comparing the scanned insert before testing to the post-testing measurement. The results for insert 6 is shown in Figure 16. The results for insert 1 are shown in Figures 18 and 20.

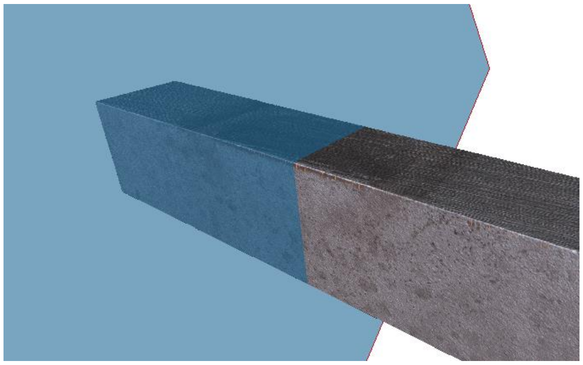

FIGURE 15. Alicona InfiniteFocus SL scanned geometry for insert 6.

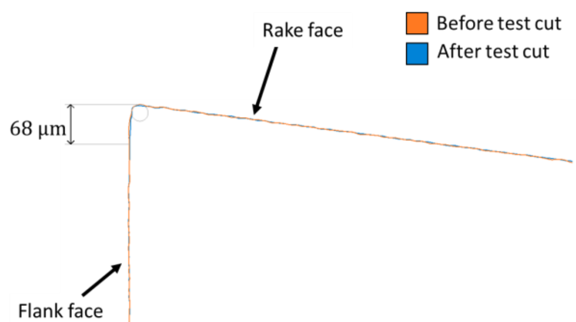

FIGURE 16. Alicona wear measurement module cross-section measurement for insert 6 with an edge radius of 12.66 μm.

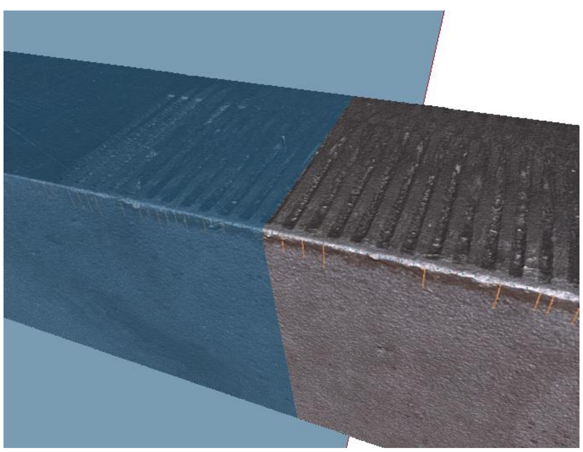

FIGURE 17. Alicona InfiniteFocus SL scanned geometry for insert 1 at the valley of the trench.

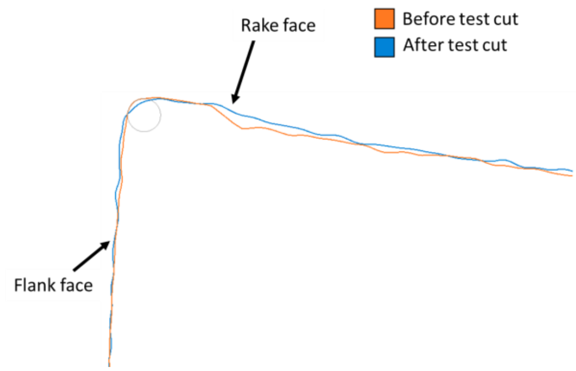

FIGURE 18. Alicona wear measurement module cross-section measurement for insert 1 at the valley of the trench with an edge radius of 10.28 μm.

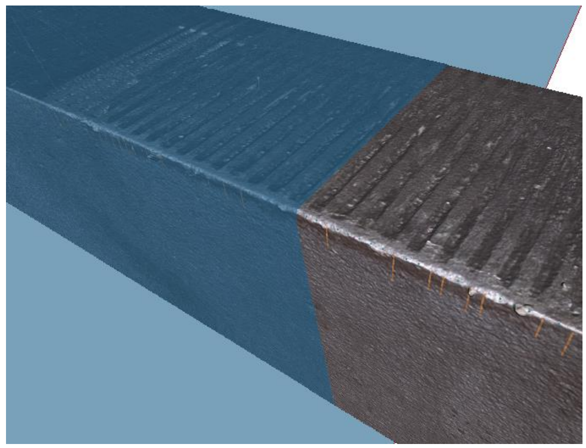

FIGURE 19. Alicona InfiniteFocus SL scanned geometry for insert 1 at the original rake face.

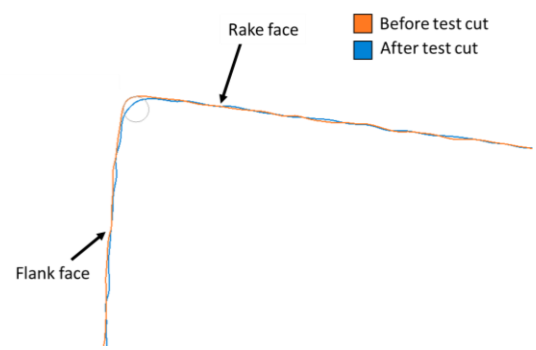

FIGURE 20. Alicona wear measurement module cross-section measurement for insert 1 at the peak of the trench with an edge radius of 10.28 μm.

CONCLUSIONS

The initial cutting test that have been conducted show that there is not a statistically significant difference in the cutting force between the patterned inserts and the unaltered insert. In fact, the smallest mean force values were obtained for the insert with no micro-patterns (insert 6).

Additional testing will be conducted to further evaluate the effectiveness of the micro-patterns to decrease the wear rate. Flood coolant will be applied in combination with the patterned insert features to see the effect of trapped coolant (micropools) on both cutting force and wear rate.

REFERENCES

[1] Özel, T., Biermann, D., Enomoto, T. and Mativenga, P., 2021. Structured and textured cutting tool surfaces for machining applications. CIRP Annals, 70(2), pp.495-518.

[2] Patel, K.V., Jarosz, K. and Özel, T., 2021. Physics-Based Simulations of Chip Flow over Micro-Textured Cutting Tool in Orthogonal Cutting of Alloy Steel. Journal of Manufacturing and Materials Processing, 5(3), p.65.