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EVALUATION OF CHIP-BREAKERS MANUFACTURED BY ULTRASHORT LASER PULSES IN CEMENTED CARBIDE TOOLS

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Abstract. *Chip-breaker is an obstacle placed on the rake surface of cutting tools to decrease the chip curl radius, promoting its control. Laser beams have been applied as an alternative route to make the structure flexible in relation to traditional techniques. The aim of this work is to evaluate the performance of two chip-breaker models manufactured by ultrashort laser pulses in uncoated cemented carbide tools. Turning tests were carried out in austenitic stainless steel (V304UF) with flat (reference) and chip-breaker tools, keeping the cutting conditions constant. Chip form, machining force and surface roughness parameters (Ra and Rz) were the output variables. The results showed that the chip-breakers successfully controlled the chip and caused a slight reduction in machining force and surface roughness values when compared to flat tool ones.*

Keywords: *chip-breaker, ultrashort laser pulses, micromachining, cemented carbide, turning process*

1. INTRODUCTION

When machining ductile materials, the crack that detaches chip from the workpiece does not extend along the primary shear plane. Thus, continuous and segmented types of chips are produced generating a variety of chip forms, generally long, that can damage the workpiece surface, modify the cutting tool geometry, leading to premature tool wear, productivity loss due to interruptions in the production to remove chips, besides posing real danger to the operator. The most popular approach to solve this problem is to use a chip-breaker, which is an obstacle placed on the rake face of the cutting tool; this modifies the surface, decreasing the chip curl radius and causing the chip break by bending (Trent and Wright, 2000; Kim *et al.*, 2009; Tschätsch, 2009; Machado *et al.*, 2015).

Chip-breakers are commonly manufactured by mechanical grinding or electrical discharge machining (EDM). However, these techniques are little flexible as to shape; furthermore, for the latter, any modification in the chip-breaker design involves changes in the EDM tool to machine the powders compaction die for sintering cutting tools with moulded chip-breakers (Mesquita and Marques, 1992; Miyazawa *et al.*, 1996; Eberle *et al.*, 2015). Thus, laser processing can be an alternative manufacturing route. According to Lorincz (2009), Korn (2009) e Makishi (2011), tools manufacturers are investing in CNC laser machines with seven axis to fabricate chip-breakers and to prepare edges of PCD and CVD-D tools, widely used in non-ferrous materials machining. They state to have achieved smaller and more controllable chips, besides longer tool life with chip-breakers manufactured by laser. Astakhov (2014) says that ultrashort laser pulses have the potential to replace EDM and grinding operations in chip-breaker and cutting edge preparation.

Femtosecond lasers are characterized by generating ultrashort pulses with durations ranging from tens to hundreds of femtoseconds (10^{-15} s), being shorter than the thermal vibration period of the material lattice. This implies reduced heat transfer to the material under irradiation and a minimal heat affected zone, preserving the surrounding material properties.

Moreover, the nonresonant interaction arising from the nonlinear interaction of the ultrashort pulses allows cutting any kind of material precisely (Liang *et al.*, 2003; Wang *et al.*, 2010; Samad *et al.*, 2012).

The aim of this work is to evaluate the performance of chip-breakers manufactured by ultrashort laser pulses in cemented carbide tools in turning austenitic stainless steel. Thus, the chip form, machining force and surface roughness were the output variables monitored.

2. EXPERIMENTAL PROCEDURE

Chip-breaker models with two different groove depths (named A and B models) were manufactured by focusing an ultrashort laser pulses on the rake face of TPUN 160304 uncoated cemented carbide cutting tools, BA55 by Brassinter. To machine the grooves, 30 fs pulses of an amplified Ti:Sapphire laser (Femtopower Compact Pro HR/HP manufactured by Femtolasers), with energy of 15 µJ, in a 4 kHz pulse train and centred at 785 nm were used. The laser pulses were focused by a lens of 38 mm of focus length. Chip-breaker model A received one laser beam pass with scanning velocity of 6 mm/min and model B, two passes with a velocity of 3 mm/min. The number of overlapped pulses per pass for the former condition was 336, while the latter was 672. The chip-breaker or ablated area was 0.75 x 2.5 mm; it was distant from the cutting edge around 250 µm. The process parameters were pre-established from Barbosa *et al.* (2015).

The chip-breaker models were characterized in a 3D Laser Microscope, model LEXT OLS4100 by Olympus, to evaluate the grooves depth. The microscope uses a low power light for scanning the samples, which allows the measurement without contact. After the machining tests, the tools integrity were also evaluated.

The cylindrical external turning dry tests were carried out in austenitic stainless steel V304UF bar (156 HV30) by Villares Metals, using a CNC lathe model GL 240M by Romi, to verify the performance of the chip-breakers at 160 m/min of cutting speed, 0.2 mm/rev of feed rate, 2 mm of depth of cut and along 15 mm of feed length. The tools were mounted on a CTGPL 2020 K16 tool-holder by Sandvik, allowing a semi-orthogonal cutting geometry with 0° inclination angle (λ_s), 6° rake angle (γ), 11° clearance angle (α) and 91° cutting edge angle (k_r). The cutting forces were monitored by a Kistler dynamometer, model 9121. Moreover, surface roughness parameters Ra and Rz were measured by a roughness tester, SJ-201 by Mitutoyo, with cut-off set at 0.8 mm, according to ISO 4288:1996. The machining test was also carried out with a flat cutting tool (reference) to compare the results. After the machining tests, the tools integrity were also evaluated.

3. RESULTS AND DISCUSSIONS

Figure 1 is a microscopic characterization of two chip-breaker models (A and B). Note that the edge of the chip-breaker grooves did not present signals of thermal damage, such as oxidation, due to the femtosecond laser processing. This is an important factor when etching brittle cutting tool materials, such as diamond tools.

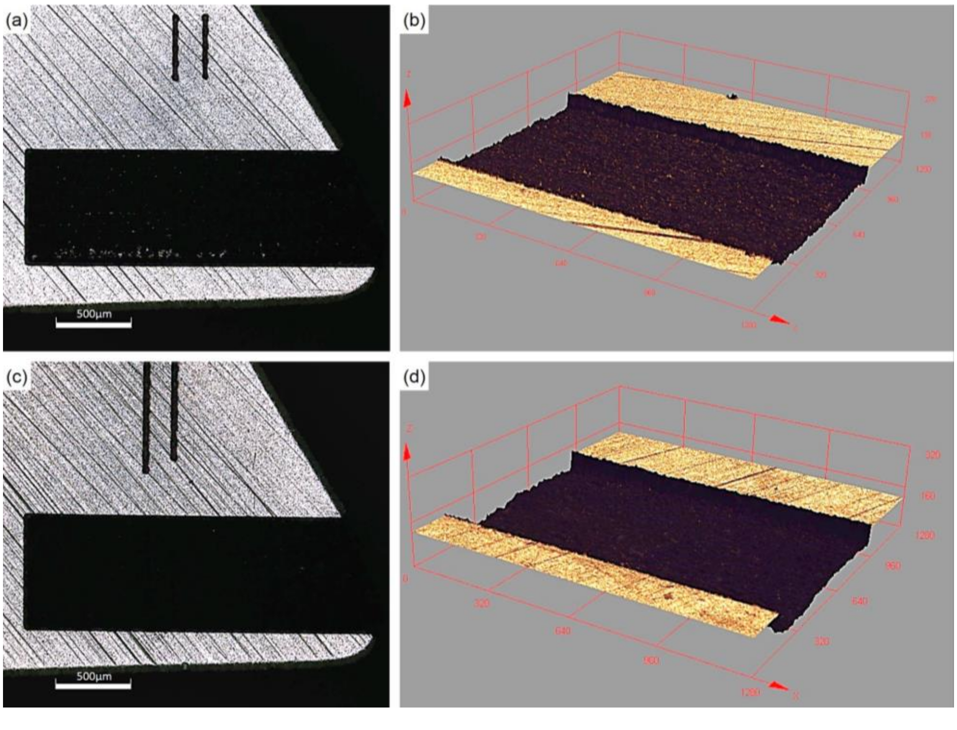

Figure 1. Chip-breaker microscopic characterization. (a) Model A; (b) Model B; (c) 3D profile of model A; (d) 3D profile of model B.

Eberle *et al.* (2015) pointed out a number of studies applying ultrashort laser pulses for cutting, edge preparation and chip-breaker fabrication in diamond cutting tools. They highlight the laser etched material properties, surface quality and superior flexibility of this technology in fabricating such structures. Furthermore, they present stunning images of 3D chip-breakers, manufactured by picosecond laser (10^{-12} s) using an ablation strategy of high fluence for roughing and low fluence for finishing.

Table 1 shows the average values obtained for the grooves depth. The analysis of the results shows that model B is twice as deep as model A.

Table 1. Chip-breaker models characterization.

Chip-breaker models	Depth [µm]
A	40±5
B	81±12

The result was expected since the model B was exposed to a laser beam for a longer time. It received two passes with half-scanning speed of model A, i.e., the double of overlap pulses per pass. Miyazawa *et al.* (1996) observed the same dependence on laser scan time for the groove depth in their experiments.

According to ISO 3685:1993, the turning tests generated a segmented chip type with long washer-type helical form for the flat tool and arc chip forms for chip-breaker tools, as shown in Fig. 2. It was also noted that the deeper chip-breaker model (B) produced a shorter arc chip than model A.

Figure 2. Chip forms. (a) Washer-type helical chip (reference tool); (b) Arc chip (chip-breaker model A); (c) Arc chip shorter than previously (chip-breaker model B)

The results show the chip-breaker models were successful in breaking by bending the chips generated in turning austenitic stainless steel, considered a difficult machinability material. Miyasawa *et al.* (1996) were also successful in producing chip-breaker by laser in a diamond tool when turning aluminium alloy.

Figure 3 shows the orthogonal components of machining force: cutting force (Fc); feed force (Ff) and passive force (Fp). A decreasing tendency of forces values can be observed from the flat tool (reference) to the deeper chip-breaker one.

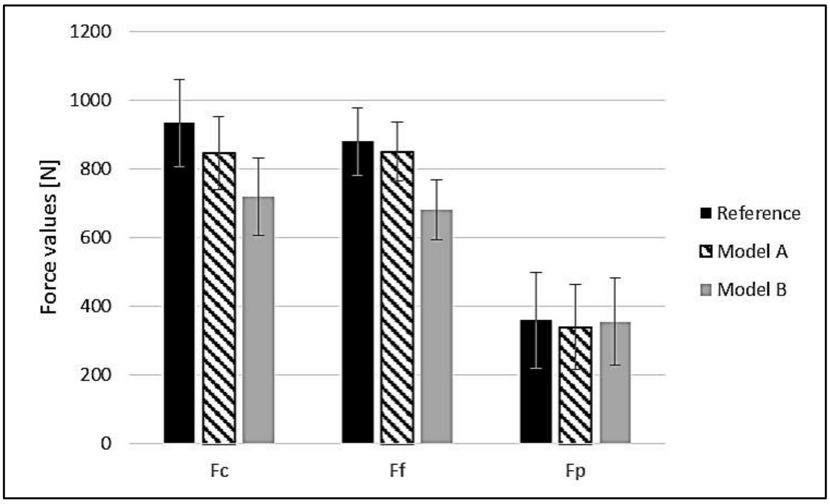

Figure 3. Results of cutting forces components

Hypothesis tests were carried out, considering small random samples (N=3), which it is supposed to represent a normal distribution. No significant difference was verified between reference and chip-breaker model A tools for Fc. However, there was a difference between reference and chip-breaker model B tools. Comparing both chip-breaker models for Fc, there was no difference. When comparing Ff, no statistical difference was observed between the reference and model A, yet there were differences among chip-breaker model B, reference and model A. Finally, there were no statistical differences among cutting tools for Fp. All the tests occurred for a significance level of 10%.

The results are in accordance with the literature. Mesquita and Marques (1992) state that the groove-type chip-breaker increases the effective rake angle, promoting less movement restriction and, consequently, decreasing cutting force components. Ståhl (2012) affirms that the chip-breaker modifies the chip-tool contact length due to rake angle changes. This can cause shear planes modifications influencing the cutting forces.

Figure 4 shows the machining force results, which is the resultant of cutting forces components. As can be observed, the chip-breaker caused a slight decrease in machining force when compared to the flat tool.

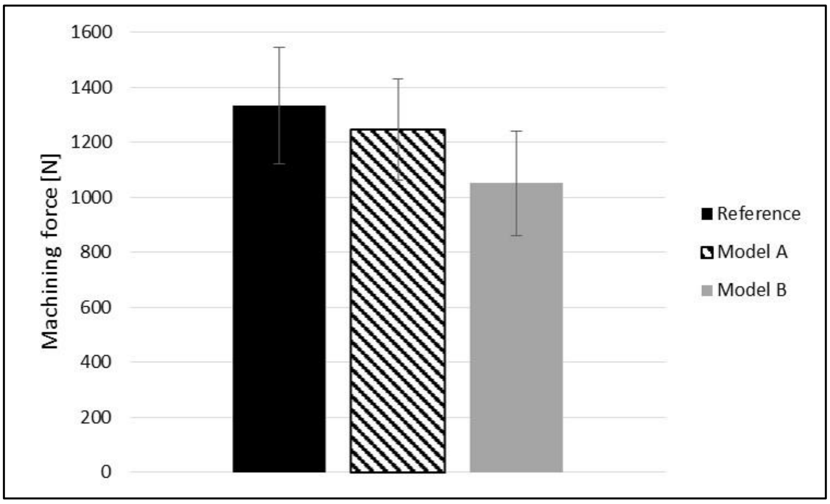

Figure 4. Results of machining force

Statistical analyses of the results for a significance level of 10% indicated that there were no differences among cutting tools. However, a tendency to drop in force values can be noted from the reference to the tool with chip-breaker model B. Hence, the significance can be reached if more tests will be carried out. The machining force for model B was 21% less than for the reference tool. Barbosa (2014) obtained similar machining force results (1120 N) when the same flat tool-workpiece pair was used for turning in approximate cutting conditions. The machining literature (Nakayama, 1962;

Boothroyd and Knight, 1989; Machado *et al.*, 2015) generally mentions that the chip-breaker does not greatly influence the cutting power and tool wear, although some statistical difference can be observed.

Surface roughness was also evaluated for Ra and Rz parameters, see Fig. 5. A slight drop in the values can be observed for the former and a sharper one for the latter. When the statistical analysis was carried out for small random samples (N=12) and 5% significance level, statistical difference was observed among the cutting tools assessed for both roughness parameters.

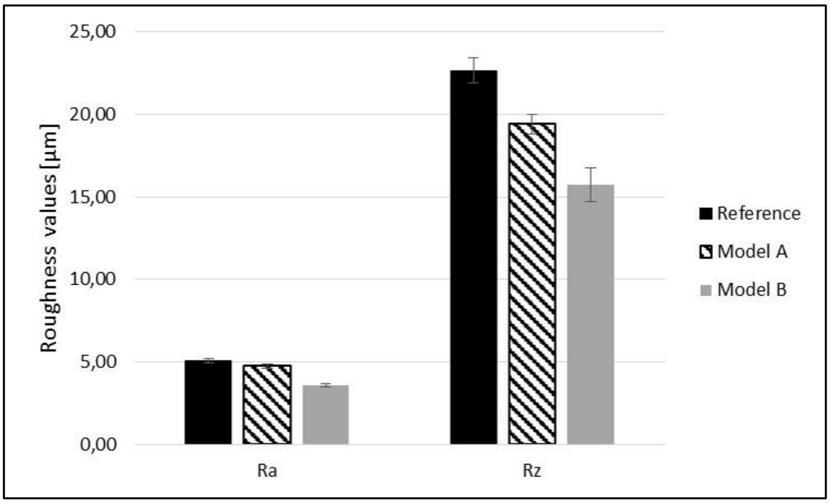

Figure 5. Results for surface roughness for Ra and Rz parameters

The results can be related to the smooth drop in machining force from the flat to the chip-breaker tool due to effective rake angle increase, causing decrease in the heights of peaks and valleys that characterizes the surface roughness (Boothroyd; Knight, 1989; Gadelmawla *et al.*, 2002). On the other hand, it is worth stressing that the passive force values did not show significant difference that could harm the surface finishing due to the chatter phenomenon (Venter *et al.*, 2016). The cutting tool with chip-breaker model B caused a decrease in Ra and Rz values in relation to the reference tool of 30%, respectively.

Figure 6 presents integrity images of rake face and flank for the cutting tools evaluated. The image of the rake face for the reference tool shows adhered workpiece material over the main cutting edge and oxidation marks. In chip-breaker model A, adhered material can be verified inside the groove and over the edge; there was also spalling of the tool portion between the main cutting edge and groove. The same observation applies to chip-breaker model B. The spalling is probably due to elevated cutting forces developed during the machining of austenitic stainless steel. Hence, the chip flow dragged the cutting tool fragments outside, transforming the design of the chip-breaker from groove to obstruction, but still being able to curl the chip and cause the break by bending. However, as previously mentioned, the chip-breaker caused the machining force to decrease and improved the workpiece surface roughness. When analysing the flank of the cutting tool, adhered material from the workpiece is verified on the main cutting edge besides oxidation marks for the three tools. The adhered material must not be mistaken for flank wear. Spalling is also observed for the chip-breaker cutting tools, being larger for model B. Although the chip-breakers have failed, they caused the machining force to decrease and improved the workpiece surface roughness, as aforementioned. These results are important to evaluate the cutting tools behaviour in a material of difficult machinability for further adjustments in chip-breaker design and laser parameters.

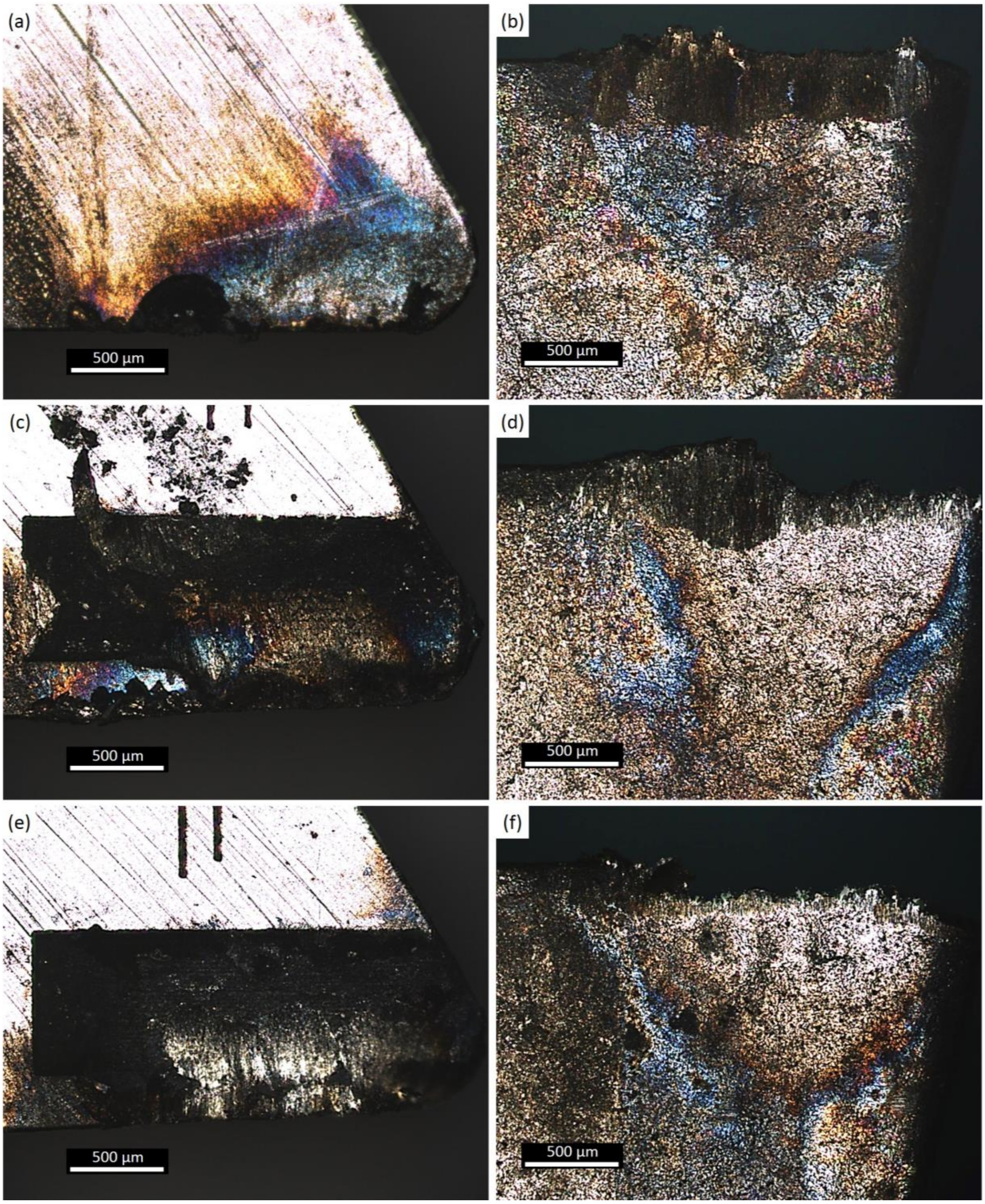

Figure 6. Cutting tools integrity. (a) Rake face of the reference tool; (b) Flank of the reference tool; (c) Rake face of chip-breaker model A; (d) Flank of chip-breaker model A; (e) Rake face of chip-breaker model B; (f) Flank of chip-breaker model B

4. CONCLUSIONS

The chip-breaker models were able to break the chips of austenitic stainless steel by bending, changing the shape from washer-type helical to arc, being shorter for chip-breaker model B. The machining force was reduced by 21% for chip-breaker model B in comparison to the reference tool, presenting statistical significance. Regarding surface roughness results, there was statistical significate difference among cutting tools; chip-breaker model B decreased the mean value by 30% for both Ra and Rz in comparison to the reference tool. Although the chip-breakers have spalled, they were successful in chip control. These results are an important contribution for further development of chip-breakers manufactured by laser, including applications in ultra-hard cutting tools.

5. ACKNOWLEDGEMENTS

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