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THE INFLUENCE OF THE CUTTING-EDGE MICROGEOMETRY OF REAMERS ON THE STAINLESS-STEEL MACHINING

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Abstract: *The process of reaming stainless steel (X5CrNi18-10) is difficult due the mechanical and chemical properties of the material. A small number of scientific papers address the subject of reaming in stainless steel. The main purpose of the experiments presented in this article is to foreground the influence of the cutting edges roundness to increase the finishing tools durability. This paper also studies the wear behavior of reamers during the machining process and the holes roughness evolution. The article contains details about the microgeometry and wear of the reamer and the holes surface quality.*

Key words: reaming process, reamer, cutting edge rounding, stainless steel, tool wear, microgeometry.

1. INTRODUCTION

One of the most difficult materials to machine is the austenitic stainless steel due to its high toughness and high ductility. Therefore, the cutting process leads to the formation of long continuous chips even in the case of reaming, where normally short chips are formed. The workpiece material sticks intensively to the cutting tool edge resulting in an aggressive wear, especially on the reamers' cutting corner. Furthermore, the build-up edge formation can tear off during cutting, and lead to the machining forces instability, which outcomes in holes with large geometry defects.[1]

In order to improve the reaming process of blind holes in stainless steel, the influence of cutting-edge microgeometry on wear evolution has been studied. According to a large number of researcher and especially to Denkena and Biermann [2], the microgeometry of cutting edge is a very important element in the evolution of tool wear and has many advantages like: higher edge stability and better metal coating adhesion on the cutting edge. The surface roughness and dimensional accuracy of the workpiece material is also affect by the cutting edge microgeometry according to T. Özel et al. [3].

Fig. 1. Chips stringy wrapped around reamer

One criteria responsible for the poor machinability of stainless steels is recognised

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as the work hardening [4]. In addition, the very strong material bond to the cutting tool during machining may cause the break of the tool, especially when the chips are stringy wrapped around (**Error! Reference source not found.**). Cutting force variations are much more pronounced when machining stainless steel compared to unalloyed steel [5]. Other general information regarding operating parameters while machining stainless steel are accessible in the academic literature [6]. In relation to machining operations with defined cutting edges, workpiece aspects of the surface integrity have also been published [7].

2. MATERIALS AND METHOD

2.1 Material

The deep drawing austenitic stainless steels euro norm 1.4301 with the follow chemical composition X5CrNi18-10 (**Error! Reference source not found.**), has a very high corrosion resistance, lower than 0,10mm/year.

Table 1

Chemical composition of X5CrNi18-10 according to DIN EN 1.4301

Chemical Composition		
Country (Region)	European Union	
Standard	EN 10088-2	
	EN 10088-3	
Steel Grade (Material Number)	X5CrNi18-10 (1.4301)	
C ≤	0,07	0,07
Si ≤	1,00	1,00
Mn ≤	2,00	2,00
P ≤	0,045	0,045
S ≤	0,015	0,030
Cr	17,5-19,5	17,5-19,5
Ni	8,0-10,5	8,0-10,5
N ≤	0,10	0,10

Thus, it is widely used in food industry to make transport items and preserve drinks. The good resistance to atmospheric corrosion, make it also suitable for more sever environment, such as marine components. Furthermore, it is well known for excellent weldability, good glazing aptitude and very good drawability. Therefore, this type of stainless steel is utilized in manufacturing of: sinks, tableware, household, food industry, heat exchangers, in mechanical industry through moulded parts and a various number of machine parts. The austenitic stainless steels euro norm 1.4301 is considered a basic alloy material and by adding alloying elements it derives in to other stainless steel alloys [8].

2.2 Microgeometry preparation and measurement

After the grinding process, two wet-sandblasting strategies were applied according to Voina et. al. [9], to achieve cutting edge rounding of 10µm (Strategy 1) and 15µm (Strategy 12). The sandblasting machine used to create the microgeometry of the tool, was a Graf Compact 2 Plus. It uses a mixture of water with a concentration of 15-20% blasting agent type Edelkorund Rosa 240/280. The microgeometry of the edges was measured on the Alicona Infinite Focus microscope equipped with the software Edge Master version 7.

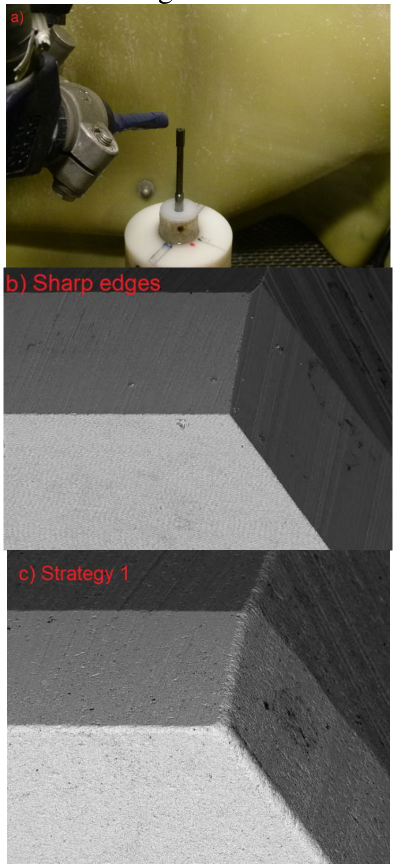

Fig. 2 a) Wet-sandblasting setup, b) Reamer sharp cutting edges, c) Microgeometry resulted after strategy 1, d) Microgeometry resulted after strategy 2

2.3 Machine setup and cutting parameters

Durability tests were performed on the three axes CNC milling machine, Tajmac MCFV 1060. The CNC machine was equipped with an HSK-A taper hydraulic chucks (ISO 12164-1 / DIN69893-1) with increased clamping force and reduction sleeves. A constant spindle speed of 1989 rot/min (cutting speed of 50m/min), feed speed of 1591mm/min (feed per rotation of 0,8mm) and cutting depth of 0.2mm/diameter were used as cutting parameters. The cutting fluid concentration was ~10% universal emulsified and with an internal cooling pressure of around 40bar.

The machining tests were conducted to achieve finished holes with a tolerance of the final diameter of ø8H7 and workpiece surface roughness $R_a \leq 1$ and $R_z \leq 6$ µm. To obtain holes with these specifications, a two-step machining route has been employed: core drilling made with a carbide ø7,8mm coated drill (DIN 6537L) followed by a reaming process in the most widely used stainless steel (X5CrNi18-10).

The reamer type used in this application was a solid carbide TiAlN coated monobloc reamer, with internal cooling, cutting direction right-hand and diameter of 8mm, manufactured in tolerance H7. These are straight-fluted reamers, which are generally applied in blind holes and due to their straight fluted geometry and central internal cooling can evacuate the chips from the hole against the direction of the feed (Figure 3).

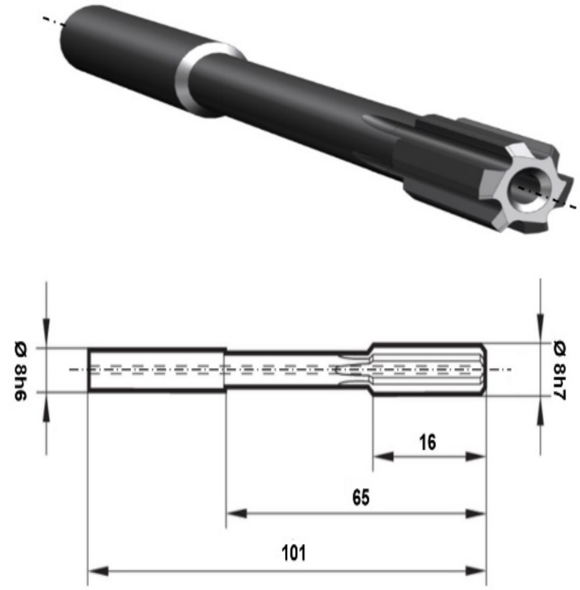

Fig. 3 The reamer design [10]

2.4 Tests trials and measurements

Following the drill cycle, the reaming process was performed with fast feed tool retraction. After each 50 holes equivalent to one machining cycle, the tests were stopped to take off the chips which were stringy wrapped around reamer and to verify the quality of holes surfaces with an MahrSurf PS1 electronic roughness tester. The measurement length was L_c=6 mm, according to EN ISO 4288 (min. L_c=4 mm) starting from a depth of 14 mm towards the entrance of the hole. For each hole, 3 measurements were made on different radial positions and the arithmetic mean value was taken into consideration.

As a criterion for stopping the durability tests, the roughness values of R_a > 1µm and R_z > 6µm were selected together with bore limit gauge.

Dimensional accuracy was checked using a Ø8,0H7 gauge every time when the machine was stopped (after every 50 holes) by choosing five bores as follows: the first and the last holes of the reaming cycle and another three bores randomly between them.

The tool wear was studied using a scanning electron microscope at the following intervals: after machining 100 holes and at the end of the test when the limit of 600 holes was reached.

3. RESULTS AND DISCUSSIONS

The minimum durability threshold has been set at 600 holes. Both standard reamers with sharp cutting edges and those with rounded cutting edges have reached this limit. The values in each roughness measurement interval represents the arithmetic mean of three consecutive measurements. Analyzing the stopping criteria such as the roughness and optic wear of the tools, a significant difference has been noticed between the tools with the prepared cutting edges and the standard ones.

In terms of bores roughness, the following results were interpreted: the R_a roughness is kept within the same limits for all tools in the first 200 holes. After this limit, the R_a roughness made by the reamers with standard sharp edges has a constant increase up to 0,6 µm (Figure 4), while the R_z, according to Figure 5, has an increase from 1,75 µm up to 3,6 µm at the end of the tests.

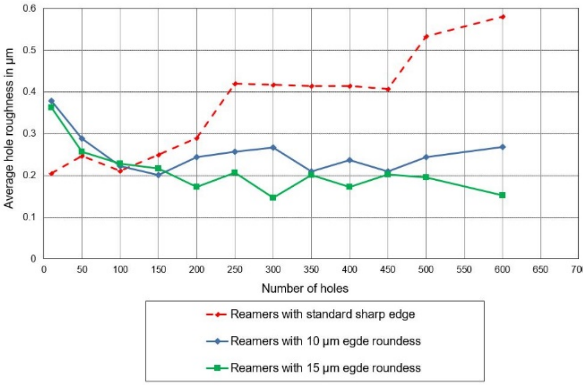

Fig. 4 R_a roughness evolution

While the reamers with standard edges are producing surfaces with a R_a and R_z increasing values tendency, the other two, with 10 microns edge roundness and 15 µm roundness have the tendency to improve the quality of the surface. After a running-in wear of approximative 100 holes, the reamers with 10 µm and 15 µm edge roundness have the predisposition, to keep the machined surface at a relatively constant value of R_a =0,22 / R_z =2,25 µm and R_a =0,19 / R_z =1,9 µm respectively. Also, the variation during the tests were significantly lower than in the case of the standard sharp edge reamers (300% increase values for R_a and 200 % for R_z).

The optic wear of the tools was studied using SEM microscopy. The analysis was made after reaming 100 and 600 holes with each type of tool.

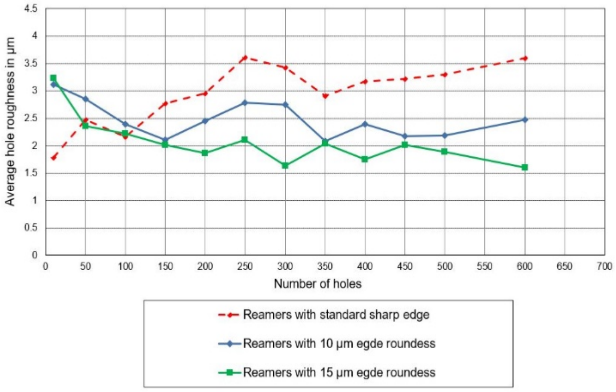

Fig. 5 R_z roughness evolution

The results reveal an accentuated wear of standard reamers on the rake face starting from the first 100 bores (considered in our case the running-in wear). The coating has been removed on a large surface in the reamer corner on the chip formation area, and on the entire length of the minor and major edges. The build-up material is observed on the cylindrical leading surface of the fluted land using the HDASB detector (Figure 6).

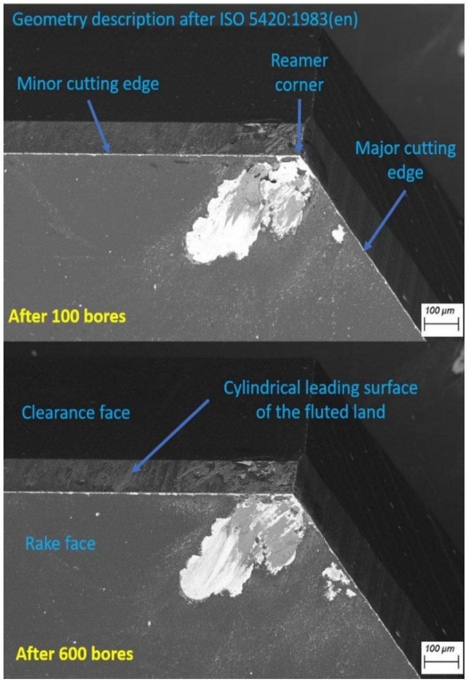

Fig. 6 Geometry description and wear evolution of standard reamers

In the case of reamers with rounding edge of 10 microns (Figure 7), the wear after 100 bores is inferior than in the case of standard reamers (Figure 6) concerning the coating removal on the edges and it remains relatively constant until the end of the tests. However, the cylindrical leading surface present an extension of wear after the first 100 bores. Although it starts to appear later, the second wear formation area on the rake face is larger at the end of the trials. At 600 bore the wear expands on the cylindrical face surface but remains constant on the rake face.

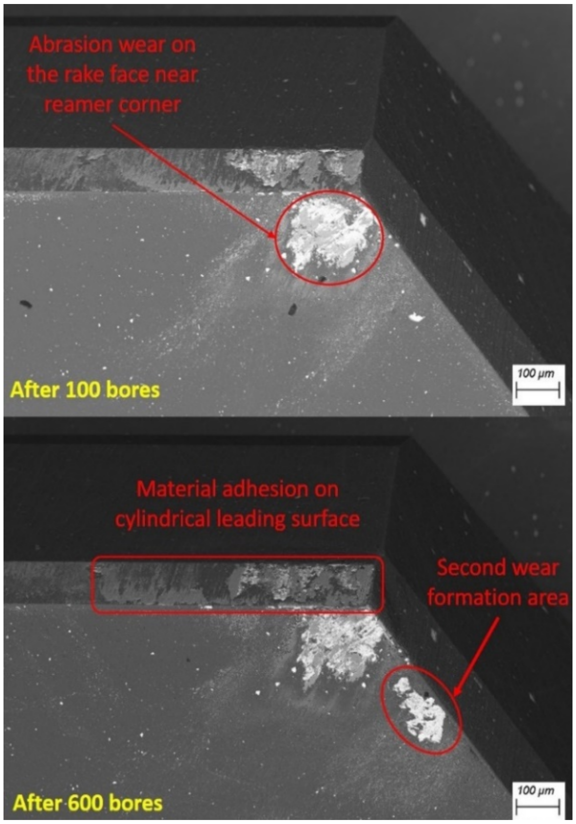

Fig. 7 Wear evolution on the reamers with 10μm edge roundness

The most significant reduction in wear during the tool life (durability) tests was observed on the reamers with a rounding edge of 15 microns (Figure 8). The surface area of wear on the rake face near the corner decreased compared to the previous examples. The minor edge shows no traces of coating abrasion outside the chip formation area. After 600 bores, there is a slight increase in wear on the cylindrical leading surface. The second distinct wear zone is not yet defined at the end of the tests although the coating is starting to be brighter on SEM images, meaning that the coating is thinner or its stats to peel off.

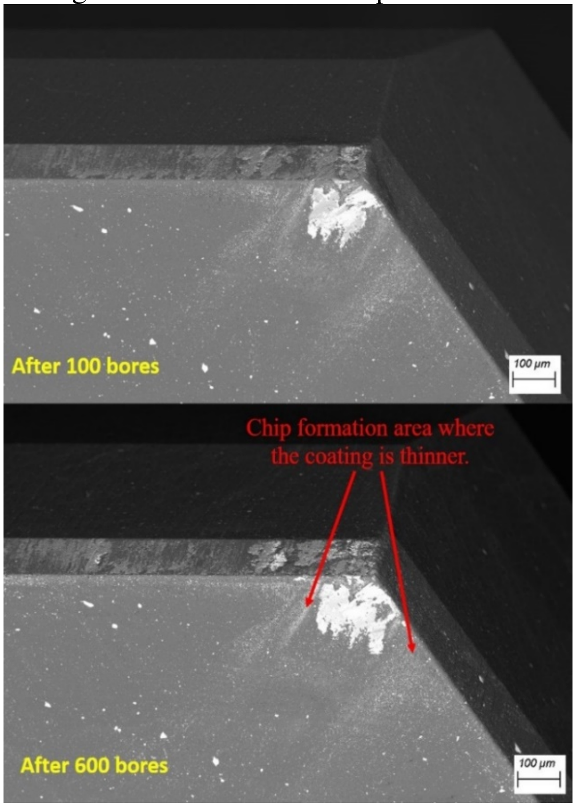

Fig. 8 Wear evolution on the reamers with 15μm edge roundness

4. CONCLUSIONS

Durability - All tested tools have reached the minimum set threshold of 600 reamed holes. The durability of all reamers in stainless steel can exceed this limit. Depending on the evolution of the tool wear and the roughness of reamed holes, it is possible that the standard reamers with sharp edges could have an inferior durability than those with rounded edges. The rounded edges give the reamer stability during the process concerning the surface quality.

Tool wear - A decrease is observed in the case of reamers with prepared microgeometry on the most important areas of tool geometry especially on the rake face and cutting edges, except the cylindrical leading surface where the wear and material adhesion is more preponderant due to the work hardening of the machined material.

Chips stringy wrapped around reamer - A smaller volume of chips was found on the reamers with sharp edges compared to those whose edges are rounded but only at the beginning of the tests.

In conclusion the reamers with a 15 µm cutting edge roundness are the best solution for machining this type of austenitic stainless steel.

5. REFERENCES

[1] I J. L. Endrino, G. S. Fox-Rabinovich, and C. Gey, *Hard AlTiN, AlCrN PVD coatings for machining of austenitic stainless steel*, Surf. Coatings Technol., vol. 200, no. 24, pp. 6840–6845, 2006, doi: https://doi.org/10.1016/j.surfcoat.2005.10.030.

[2] B. Denkena and D. Biermann, *Cutting edge geometries*, CIRP Ann., vol. 63, no. 2, pp. 631–653, 2014, doi: https://doi.org/10.1016/j.cirp.2014.05.009.

[3] T. Özel, T.-K. Hsu, and E. Zeren, *Effects of cutting-edge geometry, workpiece hardness, feed rate and cutting speed on surface roughness and forces in finish turning of hardened AISI H13 steel*, Int. J. Adv. Manuf. Technol., vol. 25, no. 3, pp. 262–269, 2005, doi: 10.1007/s00170-003-1878-5.

[4] L. Jiang, Å. Roos, and P. Liu, *The influence of austenite grain size and its distribution on chip deformation and tool life during machining of AISI 304L*, Metall. Mater. Trans. A, vol. 28, no. 11, pp. 2415–2422, 1997, doi: 10.1007/s11661-997-0198-z.

[5] I. Korkut, M. Kasap, I. Ciftci, and U. Seker, *Determination of optimum cutting parameters during machining of AISI 304 austenitic stainless steel*, Mater. Des., vol. 25, no. 4, pp. 303–305, 2004, doi: https://doi.org/10.1016/j.matdes.2003.10.01.

[6] R. Edwards, *Cutting Tools*, 1st ed. Leeds, United Kingdom: Maney Publishing, 1993.

[7] M. Imran, P. T. Mativenga, A. Gholinia, and P. J. Withers, *Comparison of tool wear mechanisms and surface integrity for dry and wet micro-drilling of nickel-base superalloys*, Int. J. Mach. Tools Manuf., vol. 76, pp. 49–60, 2014, doi: https://doi.org/10.1016/j.ijmachtools.2013.10.002.

[8] P. After, C. Rolling, and F. Annealing, *Cr-Ni-Mo austenitic stainless steel ACX 240 EN designation ASTM designation X2CrNiMo17-12-2 composition*, pp. 1–2.

[9] I.-D. Voina, S. Sattel, G. Contiu, A. Faur, and B. Luca, *Reamers cutting edge preparation for improvement the GGG 40 machining*, in MATEC Web of Conferences, 2018, vol. 178, p. 1014.

[10] Gühring KG, *HR 500 Exclusive Line high-performance reamers Catalog*, pp. 8–10, 2017.

INFLUENŢA MICROGEOMETRIEI ALEZOARELOR ÎN PRELUCRAREA OŢELULUI INOXIDABIL

Rezumat: *Procesul de alezare a oțelului inoxidabil (X5CrNi18-10) este unul dificil din cauza proprietăților mecanice și chimice ale materialului. Un număr mic de lucrări științifice abordează subiectul alezării găurilor în oțeluri inoxidabile. Scopul principal al experimentelor prezentate în acest articol este evidențierea influenței rotunjirii muchiilor aşchietoare asupra creşterii durabilității alezoarelor. În această lucrare se studiază suplimentar uzura sculelor pe parcursul aşchierii şi evoluția rugozității găurilor finisate. Articolul conține detalii despre microgeometria, uzura alezorului respectiv calitatea suprafeței găurilor.*

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