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THE MACHINABILITY OF NICKEL-BASED ALLOYS IN HIGH-PRESSURE JET ASSISTED (HPJA) TURNING

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Preliminary note – Prethodno priopćenje

Due to their mechanical, thermal and chemical properties, nickel-based alloys are generally included among materials that are hard to machine. An experimental study has been performed to investigate the capabilities of conventional and high-pressure jet assisted (HPJA) turning of hard-to-machine materials, namely Inconel 718. The capabilities of different hard turning procedures are compared by means of chip breakability. The obtained results show that HPJA method offers a significant increase in chip breakability, under the same cutting conditions (cutting speed, feed rate, depth of cut).

Key words: machinability, chip shape, high-pressure jet assisted turning

INTRODUCTION

Cutting of nickel-based alloys is a topic of high interest for today's industrial production and scientific research. Nickel-based alloys are among the most commonly used materials in aerospace industry (engines), power production (power plant generators), environmental protection and waste management (flue gas desulphurization plants), chemical industry (cauldrons, heat exchangers, valves, pumps). They are characterized by good corrosion resistance and/or excellent high temperature strength. The specific properties, adjusted to the respective application area, are essentially dependent on the chemical composition, possible cold-shaping and the type of heat treatment. In accordance with their most important alloying elements, nickel alloys can be classified under five main groups, Figure 1 [1].

There are several criteria for material machinability evaluation, and the most frequently used ones are: tool life (influencing the machining time and production costs), cutting forces (influencing energy consumption), cutting temperatures (influencing tool wear), machined surface quality and chip shape [2].

The varying chemical compositions and crystalline structures of nickel-based alloys have a direct effect on their machinability. Nickel-based alloys are well known to yield very poor machining performance [3].

Due to their mechanical, thermal and chemical properties, nickel-based alloys are generally included among materials that are hard to machine. With respect to their machinability, nickel-based alloys can be divided into five machinability-groups [4].

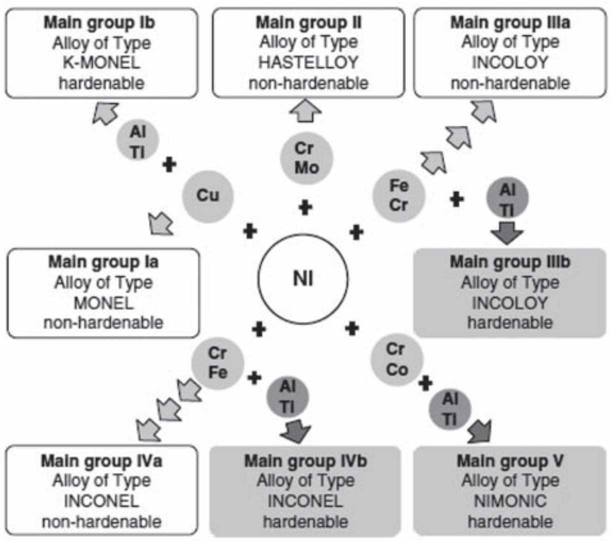

Figure 1 Classification of nickel alloys [1]

Inconel 718, which falls under machinability group 3, is also called „super alloy". This alloy is the most commonly employed nickel super alloy and represents 25 - 45 % of the annual volume production [5]. The poor thermal conductivity of Inconel 718 raises temperature at the tool–workpiece interface during machining, thus, it accelerates the undesired tool wear and results in shortening cutting tool life. Different assistance methods have been developed to replace the "conventional cutting process". One of them is high-pressure jet assistance (HPJA), which aims at upgrading conventional machining using the thermal and mechanical properties of high-pressure jet of water or emulsion directed into the cutting zone [6]. This machining alternative offers reduced costs, avoidance or reduction of health and environmentally hazardous elements.

This study mainly focuses on the evaluation of the chip shape, while machining Inconel 718 under high

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pressure, and conventional cooling conditions in the longitudinal turning process. The shape of chip is generaly very important for the quality of machining process and machining tests were conducted at conventional and various high pressure levels of cooling/lubrication fluid. Especially advantageous are chip forms that do not inhibit the machining process. These may not damage the tool system, the machine tool and the surface of the processed component.

EXPERIMENTAL PROCEDURE

In machining, the chip formation is largely influenced by heat and friction generated in the contact zone between the rake face of the tool and the machined surface material. In turning of hard-to-machine materials, the thermal influence can lead to high temperatures and structural alterations of the workpiece material, causing the change of mechanical material properties. The thermal impact mainly depends on the cooling and lubrication capability as well as the maximum temperature reached in the cutting zone. Conventional cooling is not efficient enough to prevent extreme thermal conditions in the cutting zone, especially when cutting advanced materials.

High pressure jet assisted (HPJA) turning is a process where cooling lubrication fluid (CLF) is delivered into the cutting zone region under extremely high pressure of up to p = 300 MPa and at a lower volume flow rate than in the conventional case, providing improved lubrication, cooling and chip breaking effects. This is an innovative method of lubricating and/or cooling the cutting zone during machining.

The experimental work was carried out at the Laboratory for Machining, the Faculty of Mechanical Engineering in Ljubljana. The experiments were conducted in a longitudinal turning process on the conventional lathe, fitted with a Hammelmann high-pressure plunger pump of 200 MPa pressure and 8 l/min capacity.

The fluid used was the Vasco 5 000 CLF from Blaser Swisslube Inc., a 5,5 % emulsion without chlorine on the basis of vegetable oil mixed with water (pH 8,5 - 9,2). The jet was directed normally to the cutting edge at a low angle (about 5 - 6°) with tool rake face at the distance of 22 mm.

All experiments were carried out using the nickel-based alloy Inconel 718 supplied as bars (145 mm diameter x 300 mm long) with hardness between 36 and 38 HRC. Structural analysis and mechanical tests were carried out in the laboratory for testing materials at Technical University of Chemnitz, Germany. Figure 2 shows the microstructure of the tested material [7]. Table 1 shows the chemical composition and Table 2 the mechanical and physical properties of alloys used in the study.

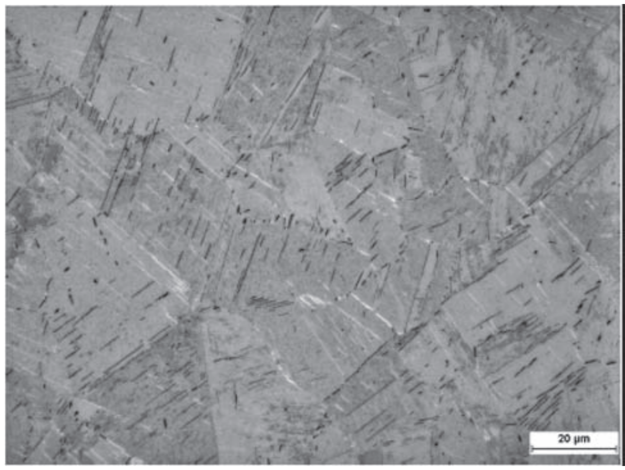

Figure 2 Microstructure of Inconel 718 [7]

Inconel 718 was machined with coated carbide cutting tools – SANDVIK SNMG 120408 - 23 with TiAlN coating. Inserts had positive geometry with the rake angle of 13°. Standard sapphire orifices of 0,25 and 0,4 mm in diameter, commonly used in waterjet cutting applications are mounted with a custom made tool clamping device that enables accurate coolant jet adjustments.

EXPERIMENTAL RESULTS

Machining experiments were conducted in dry, conventional and HPJA conditions. In HPJA machining of Inconel two pressures (50 and 130 MPa) were applied. The diameter of the nozzle was D_n = 0,25 mm. The CLF flow at 130 MPa was approximately 2,6 l/min, while the lowest flow rate was defined as 10 times lower than in case of conventional cooling; this was 0,6 l/min at pressure of 50 MPa. The cutting speeds used were in an interval ranging from 12,7 m/min to 127 m/min while all other cutting parameters were kept constant (feed rate f = 0,2 mm/rev, and depth of cut, a_p = 2 mm).

In dry cutting of Inconel, burned, golden colour chips were formed regardless of the cutting parameters. Besides, very high temperature in the cutting zone was observed. The chips turned red during cutting and the insert was worn immediately. The results have shown that dry cutting conditions are not appropriate for this material at such depth of cut.

Figures 3 to 5 present some chip shapes regarding the cooling and cutting conditions in Inconel 718 turning.

Table 1 **Chemical composition of Inconel 718 / wt.%**

Ni	Cr	Fe	Co	Mo	Al	C	Si	Nb-Ta	Ti
50 - 55	17 - 21	18	1	2,8 - 3,3	0,3 - 0,7	0,08	0,35	4,8 - 5,5	0,7 - 1,15

Table 2 **Mechanical properties of Inconel 718**

Tensile strength / MPa	Yield strength / MPa	Elastic modulus / MPa	Hardness / HRc	Density / g/cm^3	Melting point / °C	Thermal conductivity / W/mK
1 310	1 110	206	36-38	8,19	1 300	11,2

As expected, an increase in the pressure yielded a considerable decrease the size of chips. This effect can be enhanced with an increase in the cutting speed and pressure, Figure 6. The best chip breakability in the whole range of cutting speed is obtained at the highest pressure.

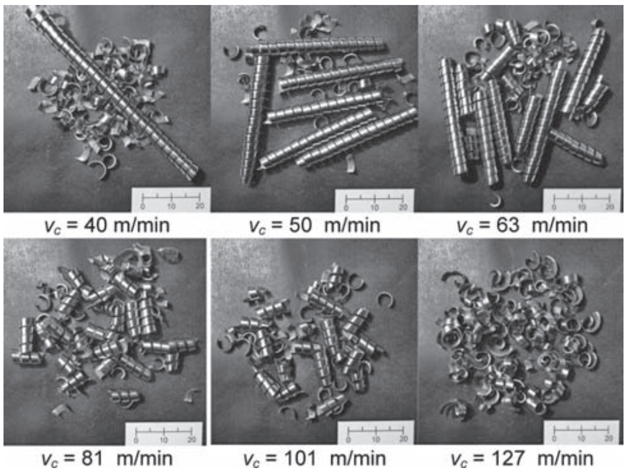

Figure 3 Chip shapes regarding the cutting speed (f = 0,2 mm/rev, a_p = 2 mm)

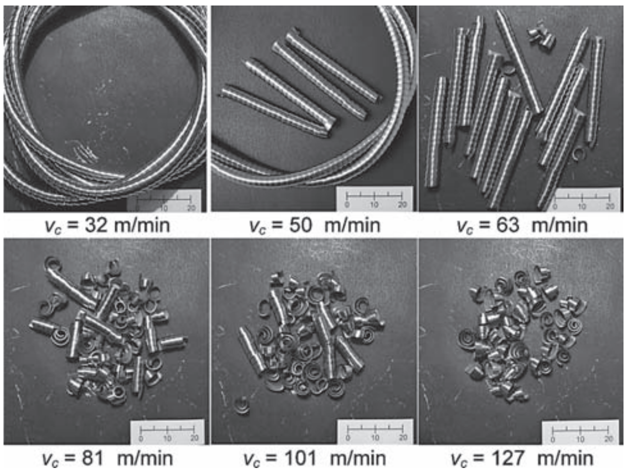

Figure 4 Chip shapes regarding the cutting speed (f = 0,2 mm/rev, a_p = 2 mm, p = 50 MPa, D_n = 0,25 mm)

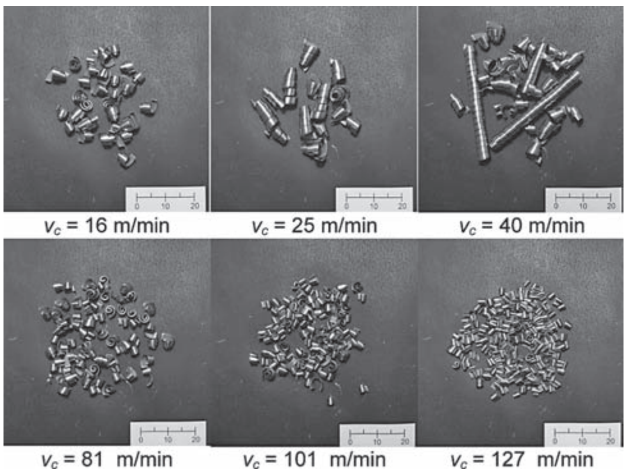

Figure 5 Chip shapes regarding the cutting speed (f = 0,2 mm/rev, a_p = 2 mm, p = 130 MPa, D_n = 0,25 mm)

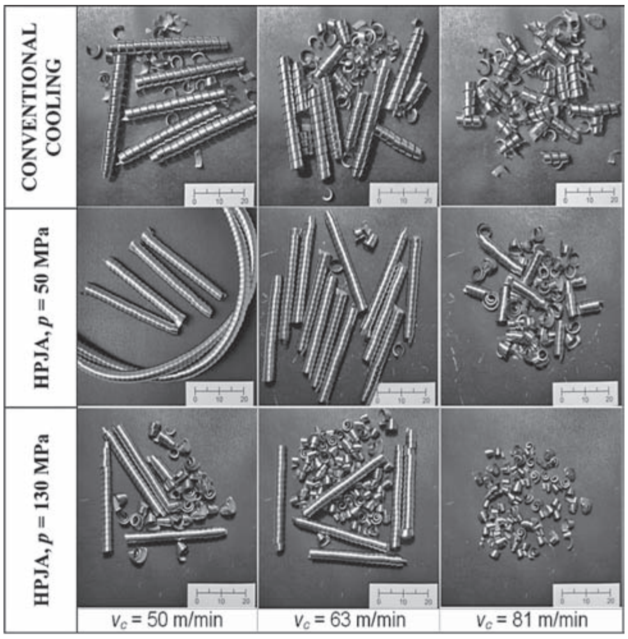

Figure 6 The influence of pressure on chip shapes for different cutting speeds (f = 0,2 mm/rev, a_p = 2 mm)

CONCLUSION

The presented research is based on an experimental comparison of Inconel 718 machinability in two turning operations using coated carbide cutting tools. In the first case, conventional cooling is performed, and in the second case, HPJA conditions are employed. Dry machining of Inconel 718 with carbide tools is not possible. The machining capabilities of conventional and HPJA method are compared with respect to chip breakability. The major concluding remark regarding the HPJA advantages over conventional cooling in the turning of Inconel 718 is a significant increase in chip breakability, while CFM consumption is up to ten times lower and tool life several times longer. With increasing pressure and cutting speed, chip breakability can be even further improved.

According to the experimental results, HPJA method could be defined as an efficient alternative lubrication solution for machining nickel-based alloys with coated carbide cutting tools.

REFERENCES

[1] J. L. Everhart, Engineering Properties of Nickel and Nickel Alloys, Plenum Press, London, (1971)
[2] M. Sekulić, M. Hadžistević, Z. Jurković, M. Gostimirović, Metalurgija 49 (2010) 4, 339-342.
[3] E. O. Ezugwu, Z. M. Wang, A. R. Machado, Journal of Materials Processing Technology 86 (1998) 1-3, 1-16.
[4] F. Klocke, Manufacturing Processes 1-Cutting, Springer, (2011)
[5] I. A. Choudhury, M. A. El-Baradie, Journal of Materials Processing Technology 77 (1998) 1-3, 278-284.
[6] C. Courbon, D. Kramar, P. Krajnik, F. Pušavec, J. Rech, J. Kopač, International Journal of Machine Tools&Manufacture, 49 (2009) 14, 1114-1125.
[7] D. Kramar, High-pressure cooling assistance in machining of hard-to-machine materials, PhD Thesis, Faculty of Mechanical Engineering, Ljubljana, 2009.

Note: The responsible translator for English language is Ksenija Mance, a Senior Lecturer at the Faculty of Engineering, Rijeka, Croatia