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Učinki kemične sestave orodja na njegovo delovanje pri struženju Inconela 718 s keramičnimi vstavki

The Effects of a Tool's Chemical Composition on Its Performance when Turning Inconel 718 with Ceramic Inserts

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Raziskovali smo učinke kemične sestave rezalnega orodja na obrabo in dobro trajanja orodja. Izvedli smo serijo preizkusov z uporabo keramičnih orodij na osnovi silicij-nitrita (Si, Al, O, N) in ojačanih z dodatki (Al_2O_3+SiC_w), z dvema različnima geometrijskima oblikama (kvadrat in krog) in tremi različnimi kakovostmi ISO. Pri keramičnem orodju sta veliki vsebnosti aluminija in germanija povzročili oblikovanje roba, medtem ko sta obrabo zarez pri keramičnem orodju ojačanem z dodatkom povzročili veliki vsebnosti bakra in kisika. Z uporabo štirih različnih orodij dveh kakovosti smo ugotovili najboljše delovanje pri rezalni hitrosti 200 m/min. Dejstvo, da je keramično orodje, kvadratne oblike, ojačano z dodatkom podvrženo plastičnim deformacijam, lahko pripišemo veliki vsebnosti kisika v sestavi rezalnega orodja.

(Ključne besede: rezalna orodja, kemične lastnosti, superzlitine, obraba orodij)

The effects of a cutting tool's chemical composition on wear and tool life are investigated. A series of experiments was carried out using silicon-nitrite-based (Si, Al, O, N) and whisker-reinforced ceramic tools (Al_2O_3+SiC_w) that have two different geometries (square and circular) and three different ISO qualities. For the ceramic tools, a high level of aluminum and germanium caused built-up edge (BUE) formation, while notch wear is considered as a cause of high copper and oxygen levels in whisker-reinforced ceramic tools. Four different tools with two qualities showed the best performance at a cutting speed of 200 m/min. The fact that the whisker-reinforced square-type ceramic tools are subjected to plastic deformation is attributed to the high oxygen level in the cutting tool's structure.

(Keywords: cutting tools, chemical properties, superalloys, tool wears)

0 INTRODUCTION

Inconel 718, a nickel-based super-alloy, has been widely used in the aircraft and nuclear industries due to its exceptional thermal resistance and the ability to retain its mechanical properties at elevated temperatures over 700°C ([1] to [3]). Nickel-based super-alloys are classified as difficult-to-cut materials due to their high shear strength, work hardening tendency, highly abrasive carbide particles in the microstructure, a strong tendency to weld and form a built-up edge, and a low thermal conductivity ([4] and [5]). They have a strong tendency to maintain their strength at the high temperatures generated during machining [6].

The short tool life and surface quality problems during the machining of nickel-based super-alloys are the main subjects that must be investigated. Residual stresses formed at the workpiece surface during machining negatively affect the mechanical strain and corrosion properties of the workpiece ([2] and [5]).

The main factors that affect the performance of a cutting tool while machining super-alloys are ([6] and [7]): (i) high hardness, (ii) wear resistance, (iii) chemical inertness and (iv) fracture toughness. Ceramic tools are suitable with regard to the first three properties, even at high cutting speeds. With the introduction of sialon materials, Inconel 718 can be machined using whisker-reinforced aluminum-silicon-carbide tools at higher cutting speeds. However, their fracture toughness is much lower than that of other tool materials, such as carbide inserts.

The cutting speed is an important factor that influences the tool wear and tool life when cutting nickel-based alloys. Nickel-based super-alloys can be machined successfully at high cutting speeds between 200 m/min and 750 m/min ([1], [8] and [9]). In previous studies, whisker-reinforced ceramic tools were found to be very suitable for the machining of Inconel 718 ([9] and [10]). In this study, for the machining of Inconel 718 with ceramic inserts, cutting-speed experiments of tool wear are carried out to investigate the effects of the tool's chemical structure on tool wear and tool life.

1 MATERIALS AND METHOD

1.1 Test specimens

The workpiece material used in the experiments was a cylinder with a size of Ø50×500 mm mm. The diameter and volume of the Inconel 718 workpiece material after the machining were measured as 408 mm and 273 cm^3, respectively. The chemical composition and mechanical properties of the Inconel 718 workpiece materials used in the experiments are shown in Table 1 and Table 2. Typical SEM analyses and the metallurgical structure of the machined workpiece material are shown in Fig. 1.

1.2 Machining parameters

The cutting-tool inserts were chosen as the square and round types that are widely used in manufacturing industry, having two different geometries and three different ISO qualities. The materials and properties of the cutting tools used are shown in Table 3. These inserts are tested by cutting Inconel 718 under a constant feed rate of 0.20 mm/rev, a constant depth of cut equal to 2 mm and different cutting speeds of 150 m/min, 200 m/min, 250 m/min and 300 m/min, taking into consideration ISO 3685 and the manufacturer's recommendations. For each experiment, 273 cm^3 workpiece material was cut and the mean flank wear values were measured.

An OKUMA LB-45II type CNC turning machine was used for the machining experiments. The general specifications of the machine tool can be seen in Table 4.

2 RESULTS AND DISCUSSION

A reference flank wear value of V_B = 0.3 mm was chosen as the wear criterion, according to ISO 3685 [11]. The cutting tool was rejected and further machining stopped based on one or a combination of the following rejection criteria, based on ISO Standard 3685 for tool-life testing:

- Average flank wear = 0.3 mm.
- Maximum flank wear = 0.4 mm.
- Nose wear = 0.5 mm.
- Notching at the depth-of-cut line = 0.6 mm.
- Excessive chipping (flaking) or catastrophic fracture of the cutting edge.

The whisker-reinforced aluminum insert ($Al_2O_3 + SiC_w$) KYON 4300 SNGN and the silicon-nitrite-based ceramic KYON 2100 SNGN insert remained below the reference value at 150 m/min, as seen in Fig. 2. The other two round-type inserts

Table 1. *Chemical composition of Inconel 718 (wt. %)*

C	Mn	Si	P	S	Cr	Ni	Co	Mo	Nb+Ta	Ti
0.040	0.08	0.08	<0.015	0.002	18.37	53.37	0.23	3.04	5.34	0.98
Al	B	Ta	Cu	Fe	Ca	Mg	Pb	Bi	Se	Nb
0.50	0.004	0.005	0.04	17.80	<0.01	<0.01	0.0001	.00001	<.0001	5.33

Table 2. *Mechanical properties of Inconel 718*

Temperature (°C)	Yield Strength MPa	Tensile Strength MPa	%Elongation	%Contraction
RT(Room Temp)	807.08	673.20	23.3	42.1
648 °C	641.70	555.10	22.2	30.8

Table 3. *Geometry and material of the cutting tool inserts*

	Material	Grade	Catalog No	Tool holders	Approach angle	Rake Angle (Degree)
Ceramic tools	Sialon ceramic	KYON 2000	RNGN 12 07 00	CRSN R 2525 M12-MN4	75^o	– 7
	Sialon ceramic	KYON 2100	SNGN 12 07 12	SSBC R 2525 M 12	75^o	+5
	Whisker-reinforced ceramic ($Al_2O_3 + SiC_w$)	KYON 4300	SNGN 12 07 12	SSBC R 2525 M 12	75^o	+5
	Whisker-reinforced ceramic ($Al_2O_3 + SiC_w$)	KYON 4300	RNGN 12 07 00	CRSN R 2525 M12-MN4	75^o	– 7

Table 4. *General specifications of the CNC turning machine tool used in the experiments*

Phase number	3
Frequency	50 Hz
Load capacity	60.9 kW
Serial number	0046
Chuck	N15 A11
Cylinder	Y2050 Re
Max. revolution number	2800 rpm.
Max. pressure	3 MPa

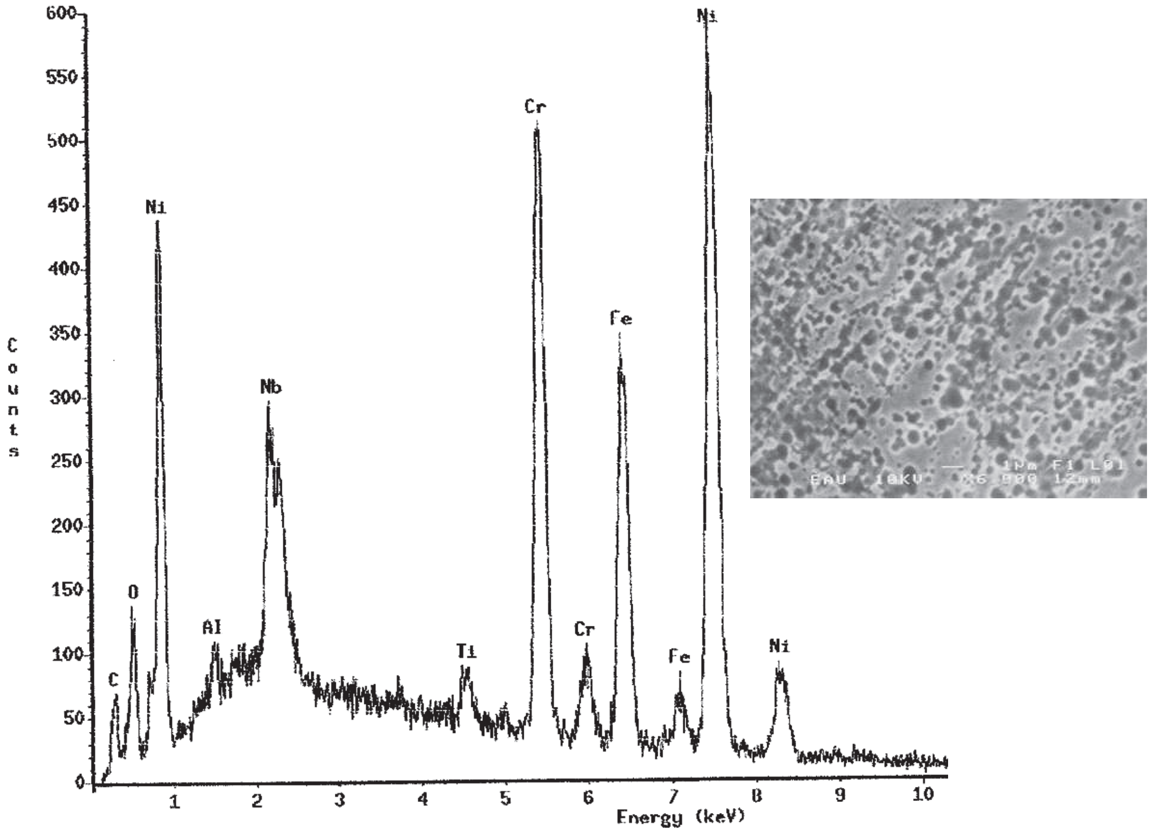

Fig. 1. *Typical SEM (scanning electron microscope) analysis and metallurgical structure of the machined workpiece material*

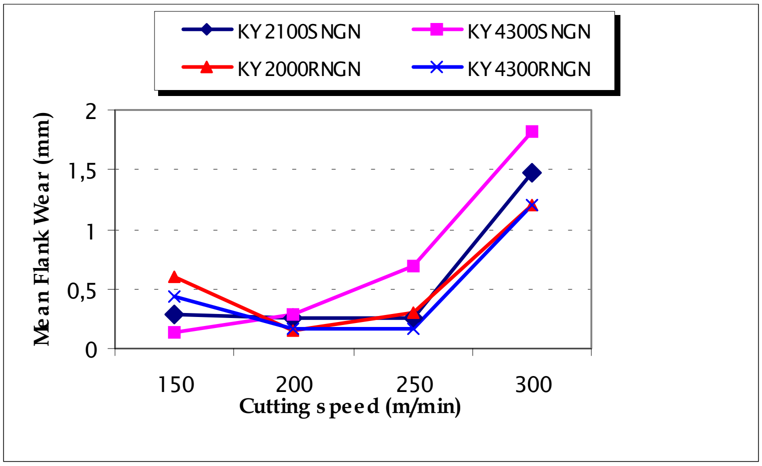

Fig. 2. *Relationship between the mean flank wear (VB) and the cutting speed (V) when machining Inconel 718 (f = 0.2mm/rev, d = 2 mm)*

exceeded the reference case and they were not suitable for cutting Inconel 718 at this cutting speed (Fig. 2). The EDS (electron-dispersion spectroscopy) analyses were obtained using a scanning electron microscope in order to determine the chemical elements present in the cutting tools (Fig.3, Fig. 4, and Table 5). From the EDS results we can see that the composition contains mainly Si, Al and C for the KYON 2100 SNGN tool, and that this cutting tool is subjected to general BUE and crater wear. The KYON 4300 SNGN cutting tool, having Al, O and Si in its structure, showed better performance at low cutting speeds, as shown in Fig. 2. The other inserts, KYON 2000 RNGN 12 07 00 and KYON 4300 RNGN 12 07 00, did not show a satisfactory performance. The KYON 2000 RNGN ceramic tool showed excessive wear compared to the other inserts (Fig. 2 and Fig.5). From the EDS analysis of this cutting tool, one can see that the levels of Si and Al are very high (Fig. 3), which contributes to the notch formation.

From Fig. 2 it is clear that the round-type cutting inserts wore out more quickly than the square-type inserts at low cutting speeds. This can be attributed to the tool geometry, and when the cutting speed increased the tool-wear value decreased. Generally good agreement was observed between these experimental results and the existing literature studies ([6], [7] and [10]).

All the inserts wore out beyond the reference value at a cutting speed of 300 m/min. At this speed, the round-type cutting inserts exhibited better performance than the square-type tools.

As a result, the KYON 4300 SNGN insert resisted only at low cutting speeds. At high cutting speeds both the KYON 4300 RNGN and KYON 2000 RNGN inserts showed good performance compared to the other inserts. The recommendation for tool inserts for the cutting of Inconel 718 was the KYON 4300 square type at low cutting speeds and the KYON 2000 round type at high cutting speeds. The

Table 5. *Element analysis of ceramic cutting tools under SEM equipment*

KYON 4300 RNGN 12 07 00

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Zr-L	0.0319	1.320	4.42	4.21	+/- 1.87
Ti-K	0.0174	0.890	3.09	1.55	+/- 0.83
V -K	0.0072	0.889	1.21	0.64	+/- 1.36
W -M	0.3776	1.212	23.81	45.75	+/- 2.95
Cr-K	0.0954	0.857	15.03	8.17	+/- 1.87
Ni-K	0.1893	0.807	24.91	15.28	+/-10.63
Fe-K	0.0420	0.832	5.99	3.50	+/- 3.70
Nb-L	0.1674	1.248	21.53	20.90	+/- 2.53
As-L	0.0000	1.476	0.00	0.00	+/- 0.00
Ta-M	0.0000	1.285	0.00	0.00	+/- 0.00
Total			100.00	100.00	

KYON 4300 SNGN 12 07 12

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Zr-L	0.0000	1.393	0.00	0.00	+/- 0.00
Ti-K	0.0000	0.829	0.00	0.00	+/- 0.00
V -K	0.0000	0.818	0.00	0.00	+/- 0.00
W -M	0.7437	1.049	62.21	77.99	+/- 2.36
Cr-K	0.0000	0.781	0.00	0.00	+/- 0.00
Ni-K	0.0448	0.711	7.95	3.18	+/- 4.77
Fe-K	0.0017	0.746	0.33	0.13	+/- 1.88
Nb-L	0.1459	1.282	29.51	18.70	+/- 1.78
As-L	0.0000	1.133	0.00	0.00	+/- 0.00
Ta-M	0.0000	1.065	0.00	0.00	+/- 0.00
Total			100.00	100.00	

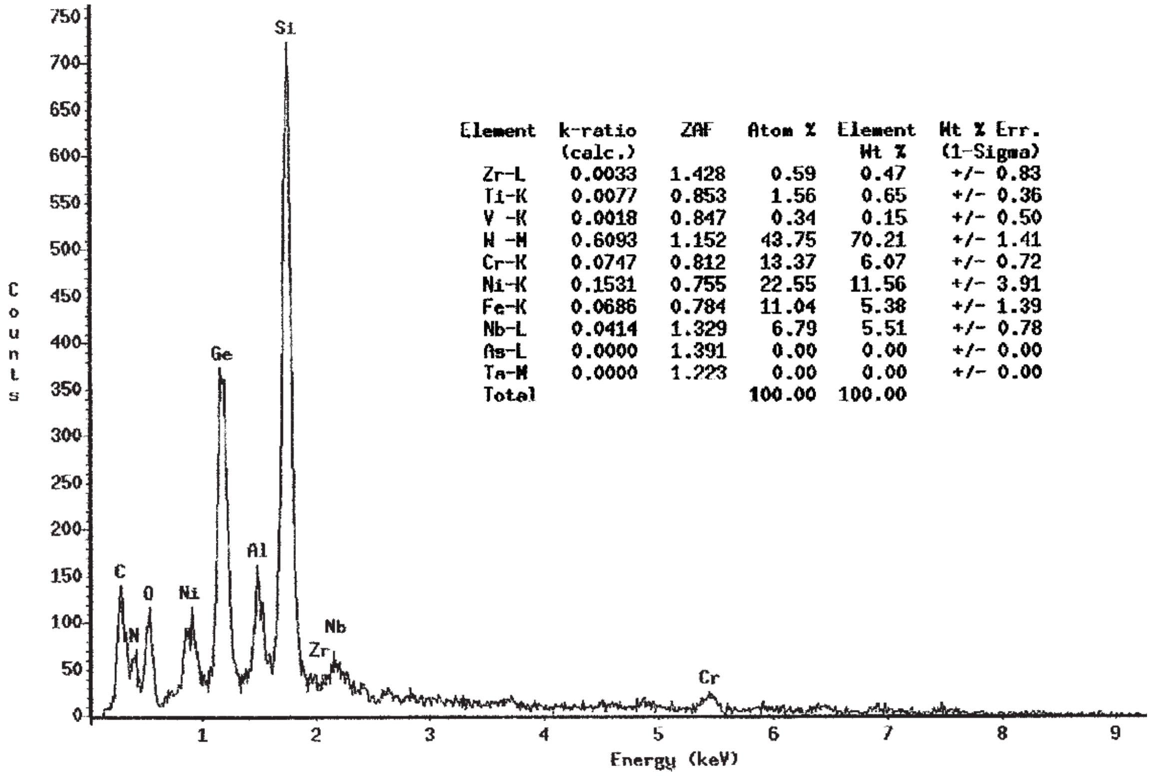

Fig. 3. *Element analysis of KYON 2000 RNGN ceramic cutting tool*

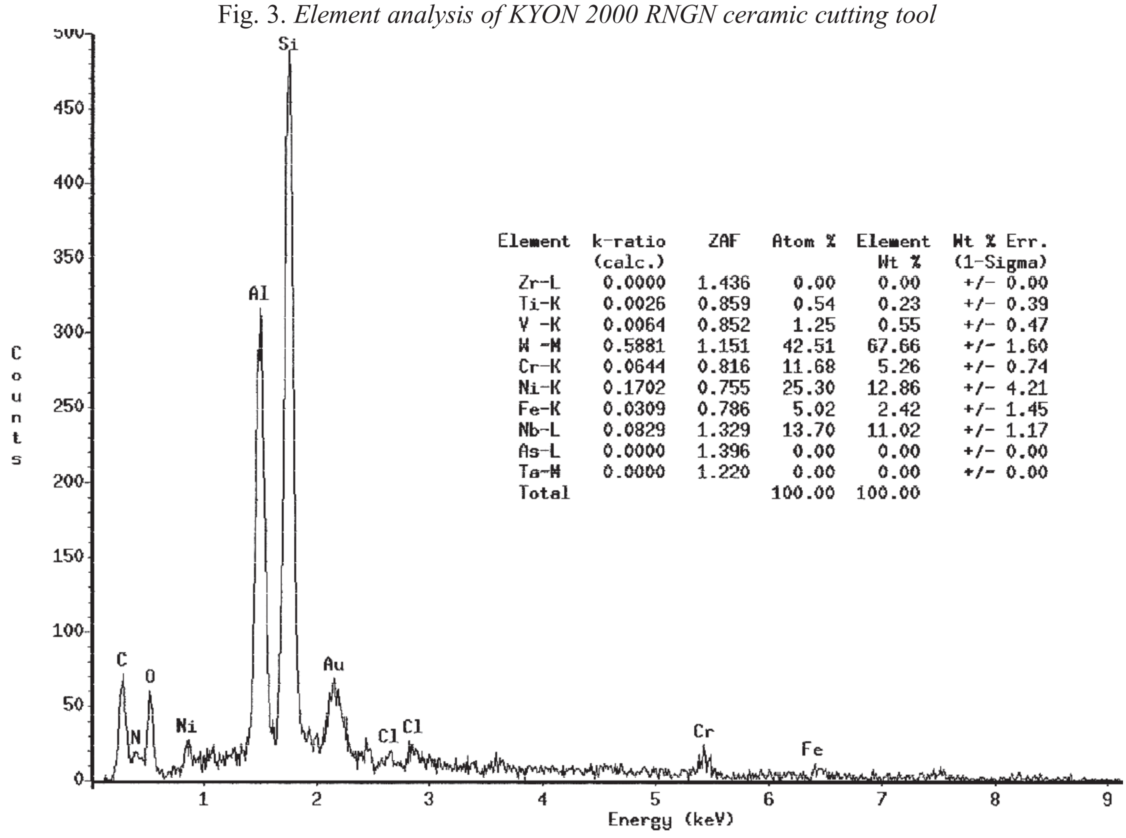

Fig. 4. *Element analysis of KYON 2100 SNGN ceramic cutting tool*

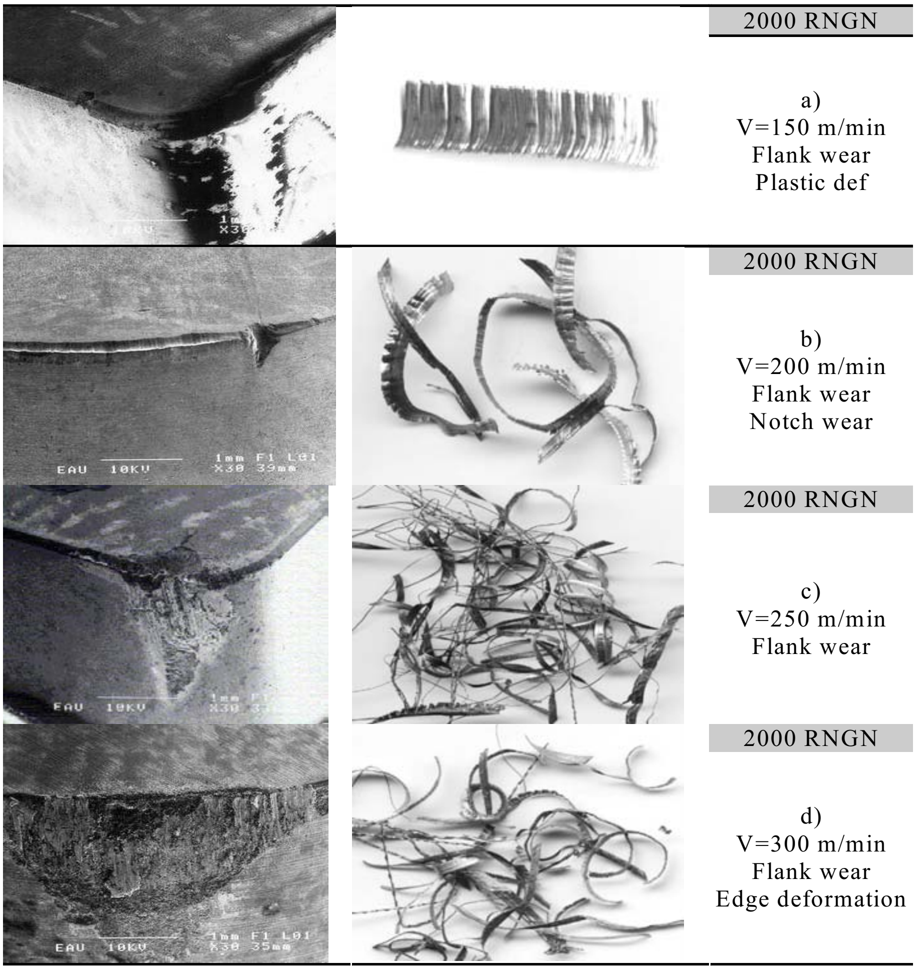

Fig. 5. *Typical wear types and chip formation of the ceramic tools under test*

KYON4300 SNGN insert was not suitable for cutting Inconel at high speeds.

3 CONCLUSIONS

Generally speaking, flank wear, cratering, notching and plastic deformation are the wear mechanisms observed with ceramic inserts when machining Inconel 718. The dominant wear mechanisms seen for round-type inserts are notch wear, while flank wear and cratering are the major wear types for the square-type inserts. Based on the experimental results, the optimum cutting speed was found to be 250 m/min, with the tool life being negatively affected above this speed. The major wear types for the ceramic inserts are flank wear, chipping and plastic deformation.

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