Study of Tool Wear and Tool Life During Turning of Inconel 718

Saumya S. Adhikari+, Barun Haldar*, A. B. Chattopadhyay+, Santanu Das*1

* Deptt. of Mechanical Engg., Kalyani Govt. Engg. College, Kalyani-741235, West Bengal

+Dept. of Mechanical Engg., IIT Kharagpur, Kharagpur-721302, West Bengal

e-mail : Sdas_me@rediffmail.com, santanu_das@hotmail.com

1. Author for correspondence

ABSTRACT

Among the nickel based heat resistant superalloys (HRSA), Inconel 718 is well known for its extensive use in the aircraft and nuclear industry due to very high temperature resistance, ability to retain mechanical properties even at high working temperature and high corrosion resistance. However, Inconel 718 is classified as a difficult-to-machine material. In this paper, experimental investigations, machining characteristic in turning Inconel 718 with uncoated carbide and coated (TiAlN) carbide tool inserts are highlighted. Experiments have been done by varying cutting velocity under dry , soluble oil and cryogenic environment. Machining results indicate that under any machining conditions, coated carbide tool inserts show significantly better performance than uncoated carbide tool inserts in machining Inconel 718.

INTRODUCTON

The evaluation history of civilization has been linked with the workability of human beings with the advanced material like alloys, super alloys etc. Nickel and the nickel-based alloys constitute a family of alloys with increasing importance in many industrial applications. Inconel 718 has a great significance in aircraft, nuclear, power plant, medical, chemical etc. industries [1] due to their advanced characteristics like as high hot hardness, high strength-to-weight ratio, excellent corrosion resistance, which are also essential for the economic exploitation of aerospace engines [2, 3]. World spends a several billion dollars every year for cutting tools [4]. 8o, it is very essential to pick out the economic machining conditions for machining a defined material.

The challenges for machining Inconel 718 are corresponding to its inherent properties such as [5,6], high shear strength, high work-hardening capacities, low thermal conductivity and specific heat leading to high cutting temperature [7] up to 1200 °C, gummy and tendency to weld and form built up edge, very strain rate sensitive and readily work harden, causing further tool wear, highly abrasive carbide particles contained in the microstructure cause abrasive wear, due to their high strength, the cutting forces attain high values, excite the machine tool system and may generate vibrations which affect the surface quality, and dimensional instability characteristics [8].

A well equipped cutting tool for machining Inconel 718 should have[9] good wear resistance, high hot hardness, high strength and toughness, good thermal shock properties, adequate chemical stability at elevated temperature.

Objective of the present work is to study the wear characteristics of the uncoated carbide and coated carbide tool inserts while turning Inconel 718 rods with different cutting velocities at constant feed and depths of cut under different environment, such as dry , wet with soluble oil (1:20) and liquid nitrogen (cryogenic).

EXPERIMENTAL INVESTIGATIONS

Experimental procedure and conditions

Turning tests on Inconel 718 rods (ϕ125 X 600 mm) have been conducted on NH-22, 11kW, HMT (India) make center lathe at different cutting velocities (V_c) maintaining constant feed and depth of cut under dry, wet (1:20 soluble oil) and cryogenic cooling environments. TiAlN-coated carbide and uncoated carbide tool inserts have been used in the machining tests to study the tool wear patterns with the passage of machining time. The chemical composition of Inconel 718 is shown in table 1. Table 2 shows the detailed experimental conditions employed during present study. Figure I shows the specially designed liquid nitrogen nozzle which has been fitted on the tool post.

Tablel: Chemical composition of Inconel718 used in present work

Constituent	Fe	Cr	Nb	Mo	Ti	Al	C	Si	Mn	Co	Cu	S	P	Ni
Chemical Composltlon wt.(%)	19.150	17.840	5.300	3.050	1.050	0.540	0.030	0.030	0.020	0.010	0.010	0.007	0.005	52.95

Table 2 : Experimental Conditions

Machine Tool	NH 22 HMT make Lathe, 11 KW (15hp)	
Work piece details	**Material**	Inconel 718 (specimen supplied by Midhani)
	Size	ϕ 125 × 600 mm
Cutting Tool (inserts)	**Material**	Coated (TiAlN) carbide - SNMG 120408 - M1 CP 250 (ISO M20) Uncoated carbide -SNMG 120408-M1 CP 883 (ISO M20)
	Geometry	-6, -6, 6, 6, 15, 75, 0.8 (mm)
	Tool Holder	PSBNR 2525 M12 (ISO specification)
Process Parameters (for wear test)	Cutting Velocity, V_c : 45, 60 and 80 m/min Feed, S_o : 0.2 mm/ rev (constant) Depth of cut, t : 1.5mm (constant)	
Environment	Dry, Wet (soluble oil) and Cryogenic (liquid N_2) condition	

Figure 1 : Photographic view of liquid nitrogen delivery nozzle injecting Liquid Nitrogen during turning of Inconel 718

Discussion on Experimental Results

During machining, the cutting tool inserts has been withdrawn at regular intervals to examine the wear pattern and measure the wear feature like average flank wear (V_B), maximum flank wear (V_M), Notch Wear (V_N) and average auxiliary flank wear (V_S). Photographs of flank and rake face of the tool inserts are taken in an inverted type metallurgical microscope (Olympus Japan, Model : MG).

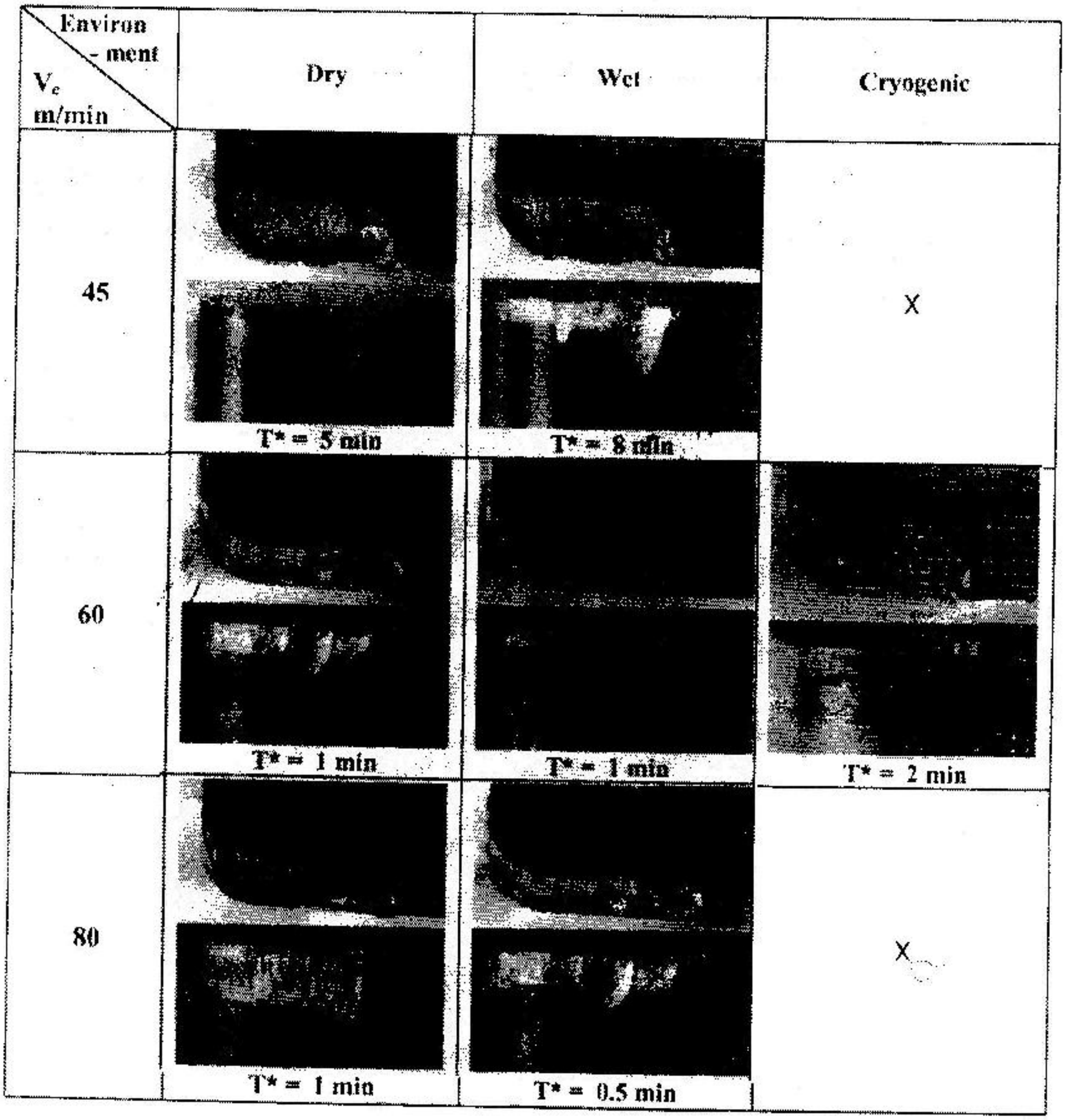
A cutting tool is rejected and future machining stopped based on one or a combination of the following rejection criteria :

Average Flank Wear (V_B) $\geq$ 0.3 mm

Maximum Flank Wear (V_M) $\geq$ 0.7 mm

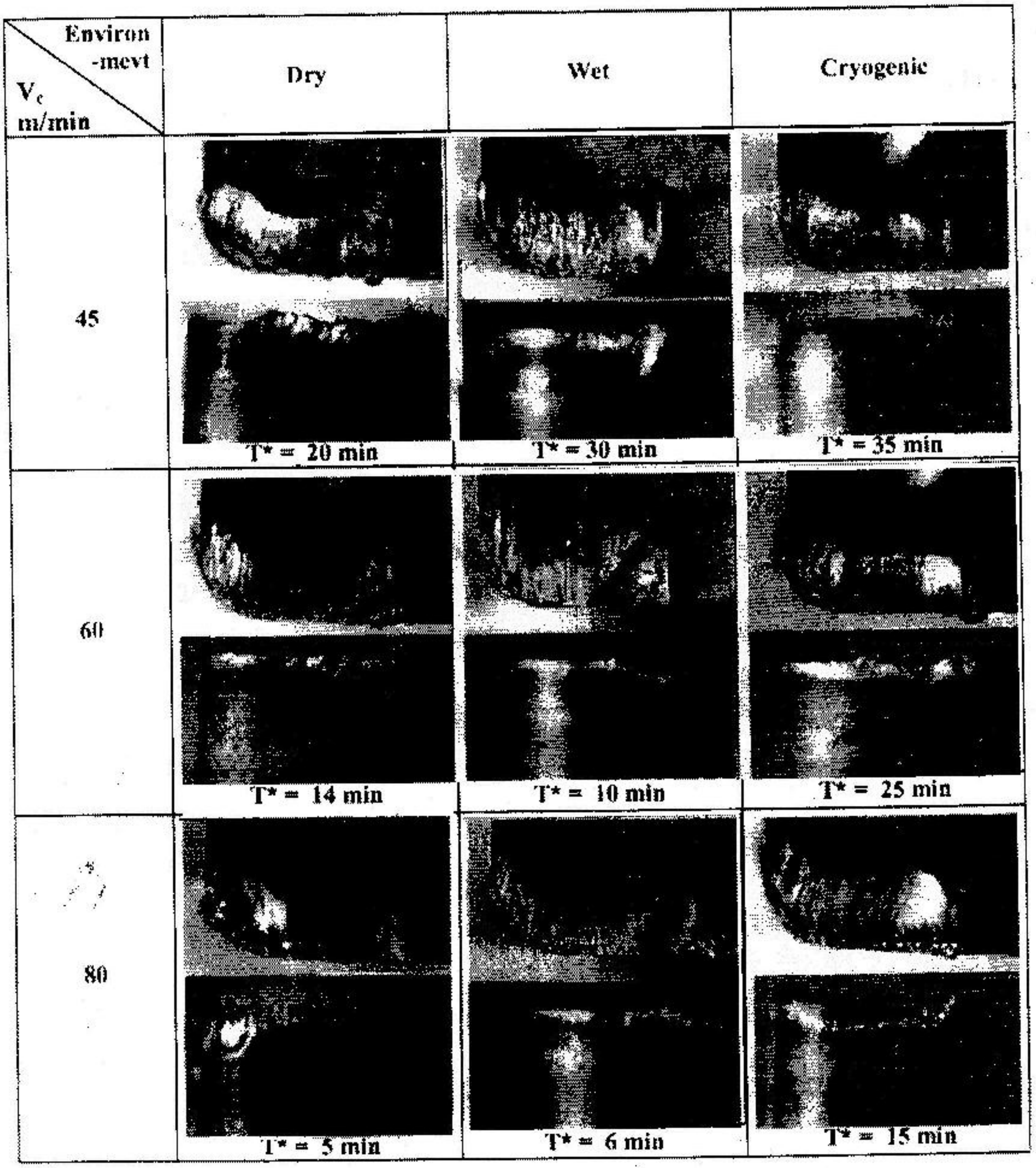
Excessive chipping (flanking) or catastrophic fracture of the cutting edge

Figure 2 : Photographic views (where upper half of each photograph is rake surface and lower half is principal flank surface) of tool wear of uncoated carbide tool inserts at the end of Tool life (T*).



The uncoated carbide tools failed while machining with in a short time by intense crater and flank wearing can be seen in fig 2 (a). High cutting tool temperature due to high specific energy required by Inconel 718, poor thermal conductivity of work material and shorter chip tool contact length as well as strong adhesion at the chip tool interface accelerate the crater wear formation. On the other hand, hard inclusions, work hardening and abrasive nature of Inconel 718 seemingly caused large flank wear. Inconel

Figure 3 : Photographic views (where upper half of each photograph is rake surface and lower half is principal flank surface(of tool wear of coated carbide inserts at the end of Tool life (T*).



718 is hard and also poses high hot hardness; high work hardening makes the machined surface of the Inconel 718 further hard. As a result, excessive stress appears on the cutting edge at its outer end causing deep and wide notch at the flank with in short time even when V_c is low i.e. 45 m/ min only.

Adverse flow of the work material through this notch worsens and situation further leading to complete tool-failure. It is evident from fig. 2(b) that V c is raised to 60 and 80 m/min, the tool failed almost with in a minute by sever wear at the principal flank and the round tool-tip even before large notch appears.

Compared to uncoated carbide, the TiAlN coated tool performed remarkably better and survived much longer in machining the Inconel 718. Fig. 3(b) clearly depicts that rate of growth of tool wear decreased by several folds when the carbide tool is coated (TiAlN). While at moderate Vc, i.e. 45m/min, the coated tool has attained lesser amount of wear even after 20 to 29 min, but, the amount of wear attained the uncoated one is only 5 to 8 min.

It clearly appears from the fig. 3(a) that unlike the uncoated tool, the coated one can effectively machine the Inconel alloy when V_C is increased to 60 ancl 80 m/min in spite of having high wearing rate with increased V_C. This indicates that the coated tool particularly TiAlN coated carbide insert work satisfactorily in machining Incone 1718 at low to medium speeds.

Fig. 2(a) and (b) are showing comparative wear patterns of tool inserts at the end of the tool life under different conditions. In general, large scale crater and edge chipping along with BUE are clearly seen. However, in cryogenic conditions, due to better control of temperature under inert atmosphere, adhesion has been reduced to a considerable extent, there by showing the higher tool life than the dry and wet conditions.

The growth of flank wear in the uncoated tool with the progress of machining the Inconel 718 under dry and with soluble oil have been monitored and shown in fig. 2(a). This figure visualizes that the tool has to be withdrawn after 5 min due to excessive Notch wear, V_N, while during machining at low speed, i.e. 45 m/min. Both the average flank wear V_B and maximum wear V_M gradually and uniformly increase with time. Use of soluble oil enables to continue up to 8 min by reducing notching wear through growth rate of V_B and V_M remain almost unchanged.

Fig. 3(a) indicates that life of the uncoated tool gets exhausted with in a minute while dry machining of the alloy at elevated speed i.e. 60 m/min. Application of soluble oil has not improved the situation.

It appears from fig.3(b) that the coated tool survives much longer than the uncoated tool under the same machining condition. Both V_B and V_M have developed slowly and V_N has been almost absent. Use of soluble oil at such low speed machining of Inconel 718 visibly has reduced V_B and V_M , but induces notch wear, V_N, which finally has been the cause of tool failure. When V_C was raised to 60m/min, both V_B and V_M grew faster in dry machining by the coated tool reasonably for high sliding speed and temperature. But the growth of flank wear is decreased sizeably when soluble oil was employed. It is clearly evident from fig.3(b) that at V_C =80 m/min, even the coated tool attains flank wear very rapidly. Use of soluble oil has not reduced the wear that significantly. But application of liquid nitrogen jets have reduced wear substantially and have raised tool life remarkably, expectedly through more effective cooling and thereby reducing the thermally sensitive wearing processes like adhesion and diffusion.

Fig 2(a) : Tool wear curves of uncoated carbide tool inserts under different conditions

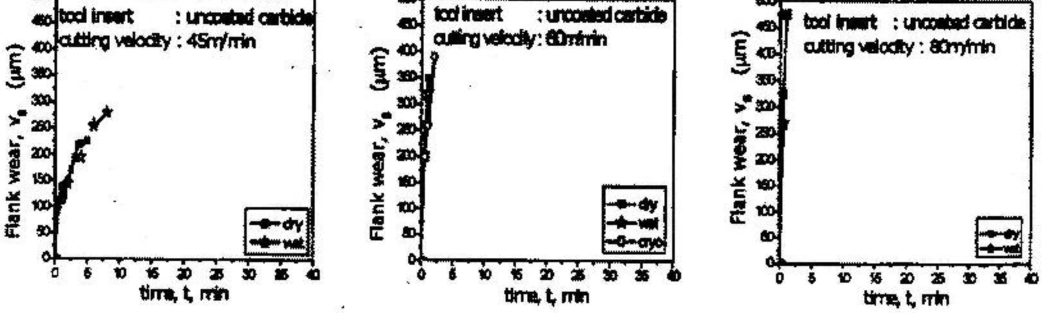


Fig. 2(b) : Tool wear curves of coated carbide tool inserts under different conditions

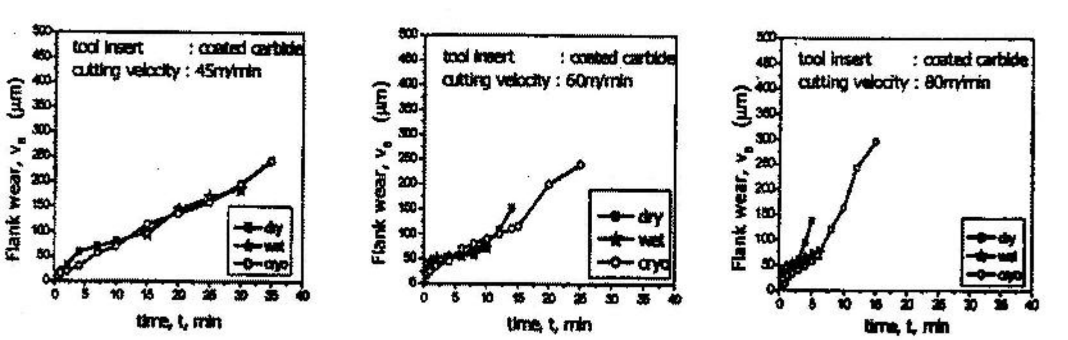


Fig 3(a) and 3(b) are showing the comparative pattern of plots explaining the growth of the flank wear with the proceeding of machining time for Uncoated and Coated carbide tool inserts. From the figures it is clear that the flank wear reaches its extreme value (fig. 3 (a)) very soon for the uncoated carbide, where as it takes much time (fig 3(b)) in case of coated carbide inserts. For both the carbide inserts, intense flank wear is not the only reason behind the rejection of tool insert, as fracture due to intense notching and grooving has been seen (fig. 2 (a), (b)) taking place on the flank surface of the insert.

CONCLUSIONS

Based on the experimental observations on turning of Inconel 718 with coated carbide tool inserts, the following conclusions can be drawn:

- TiAlN coated tool perfonns well with reasonable tool life at low and moderate cutting velocities.
- The wear resistance and tool life of the coated tool have increased substantially due to application of liquid nitrogen jets.

REFERENCES

1] Choudhury, I.A.; El-Baradie, M.A.; *Machinability ofnickel-base super alloys: a general revie*; Journal of Materials Processing Technology 77 (1998).

[2] Ezugwu, E.O.; Bonney, J; *Effect of high-pressure coolant supply when machining nickel-base*, Inconel 718, alloy with coated carbide tools; Journal of Materials Processing Technology (2004).

[3] Rahman, M; Seah,W.K.H.; Teo,T.T.; *The machinability of Inconel 718*; Journal of Materials Processing Technology 63(1997)199-204.

[4] Chattopadhyay, A.B.; Ray, K.K.; and Dutta, A.K; *On the high performance ceramic toolsf or achining steel*; National conference on Advances in Manufacturing Systems, ASM-03, 8-291h March, 2003, Production Engg. Dept., Jadavpur University, Kolkata.

[5] Dudzinski, D.; Devillez, A.; Moufki, A. ; Larrouque're , D.; Zerrouki, V. ; Vigneau, J.; *A review of developments towards dry and high speed machining of Inconel 718 alloy*; International Journal of Machine Tools & Manufacture 44 (2004) 439-456.

[6] Wang , Z. Y.; Rajurkar, K.P.; Fan , J.; Lei, S.; Shin, Y.C.; Petrescu, G.; *Hybrid machining of Inconel 718*,. International Journal of Machine Tools & Manufacture 43 (2003).

[7] Arunachalam, R.M. ; Mannan, M.A. , Spowage, A.C.; *Residual stress and surface roughness when facing age hardened Inconel 718 with CBN and ceramic cutting tools*; International Journal of Machine Tools & Manufacture 44 (2004) 879-887.

[8] Subhas, B.K.; Bhatt. R; Ramachandra, K; Balakrishna,H.K; *Simultaneous Optimization of Machining Parameters for Dimensional Instability Control in Aero Gas Turbine Components Made of Inconel 718*; Journal for Manufacturing Science and Engineering, November 2000, Vol.122/1.

[9] Ezugwu, E.O. ; Bonney, J.; Yamane, Y.; *An overview of the machinability aeroengine alloys*; Journal of Materials Processing Technology 134 (2003).