A Review on Tool Wear Mechanisms in Milling of Super Alloy

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Abstract: Super alloys have vast range of applications in gas turbine engines of aircraft due to their ability to withstand all the mechanical properties at elevated temperature. Super alloys are difficult to cut material which involves large amount of cutting forces while its machining. These large cutting forces lead to frequent tool wear which consumes tool replacement time and cost. This work deals with the review of various tool wear mechanism in cutting of super alloys for proper selection of tools for particular material.

Key words: BUE, Crater wear, Flank wear, notch wear.

INTRODUCTION

Super alloys have vast range of applications like Gas turbine Engine, Reciprocating engines etc. Inconel718 is a Nickel based super alloy which is used in high temperature applications like combustion chambers of Gas Turbine Engines and Steam Turbine Engines, [4]. The applications involving Inconel718 undergo large fluctuating thermal stresses. If Inconel718 material with high surface roughness is used in such part, the material may fail to its earliest as high surface roughness act as minute notches which increases the stress concentration on the surface. In order to achieve good surface quality lower values of feed rate and depth cut is required which affect productivity to the greater extent and also at high speed cutting force increases simultaneously.

Super alloys

It is an alloy based on group VII elements (Nickel, cobalt, or iron with high percentage of nickel added) to a multiplicity of alloying elements are added. The defining feature of a super alloy is that it demonstrates a combination of relatively high mechanical strengths and surface stability at high temperature [12].

Nickel-Iron-base alloys

This type of super alloys possess high toughness and ductility and are used in applications where this properties are required e.g. turbine discs and forged rotors. Their cost is low due to substantial amount of iron added. There are three groups of nickel iron based super alloy. Nickel-Iron based super alloys are known for their high toughness and ductility and are been used in many such applications where these properties are required at elevated temperatures and pressures. (I)Precipitation-hardened alloys (ii) Low-coefficient-of-thermal expansion (iii) Modified stainless steels

Cobalt-base super alloys

Cobalt-base super alloys have superior high corrosion resistance hence it is used in applications where hot corrosion is required. These alloys sustain this property at many range of temperatures from moderate to high. They are used in GTEs in vanes and other stationary components because of their stress ruptured properties and hot corrosion resistance. The microstructure of cobalt based super alloys consist of a small FCC gamma matrix with a number of strengthening faces. They have high thermal fatigue resistance and welding ability.

Nickel-base super alloys

These super alloys have high temperature and strength combination. The capability of sustaining high temperature in nickel base super alloys is due to the precipitation of high volume fraction of the Ni3.They are known for high strength and creep resistance at elevated temperatures.

Tool Wear

During the machining process, the cutting tools are loaded with the heavy forces resulting from the deformation process in chip formation and friction between the tool and work piece. The heat generated at the deformation and friction zones overheats the tool, the chip and partially the work piece. All the contact surfaces are usually clean and chemically very active; therefore the cutting process is connected with complex physical-chemical processes. Wear on the tool, which occurs as the consequence of such processes, is reflected as progressive wearing of particles from the tool surface. A summarized picture of the basic causes, mechanisms, types and consequences of the wear is presented in Figure 1 [7].

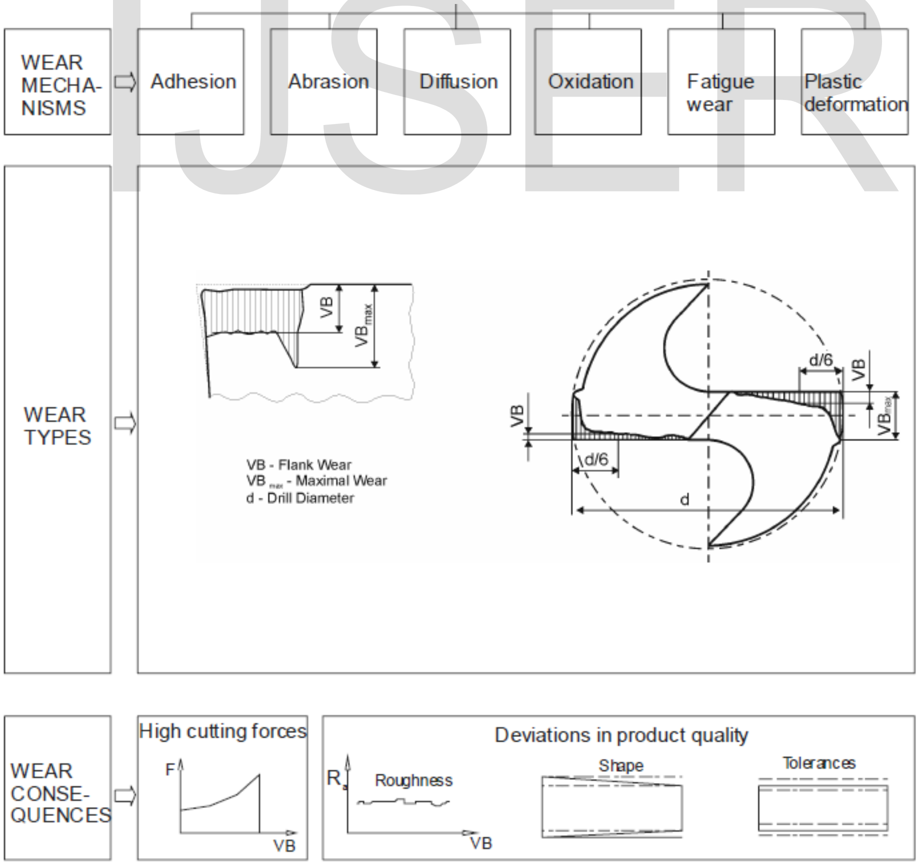

Fig. 1. An overview of the causes, mechanisms, types and consequences of the tool wear [7]

Tool wear is generally considered to be a result of mechanical (thermo-dynamic wear, mostly abrasion) and Chemical (thermo-chemical wear, diffusion) interactions between the tool and work piece. The temperature at the contact zone might raise or exceed the level of the resistivity of the cutting materials, which results as increased crater wear, chipping of the cutting edge or even catastrophic damages to the tool tip.

Types of wear include:

1. **Flank wear** in which the portion of the tool in contact with the finished part erodes. Can be described using the Tool Life Expectancy equation.
2. **Crater wear** in which contact with chips erodes the rake face. This is somewhat normal for tool wear, and does not seriously degrade the use of a tool until it becomes serious enough to cause a cutting edge failure.
3. **Built-up edge** in which material being machined builds up on the cutting edge. Some materials (notably aluminum and copper) have a tendency to anneal themselves to the cutting edge of a tool. It occurs most frequently on softer metals, with a lower melting point. It can be prevented by increasing cutting speeds and using lubricant. When drilling it can be noticed as alternating dark and shiny rings.
4. **Glazing** occurs on grinding wheels, and occurs when the exposed abrasive becomes dulled. It is noticeable as a sheen while the wheel is in motion.
5. **Edge wear**, in drills, refers to wear to the outer edge of a drill bit around the cutting face caused by excessive cutting speed.

LITERATURE SURVEY

Literature survey on flank wear

Choudhary and El Baradie [4] studied machinability using different cutting tools like cemented tungsten carbide tool, ceramic tool, cubic boron nitride was performed. It was concluded that resistance towards depth of cut, notch wear was equal to salon and silicon carbide.

Miroslav Janos and Ivan Mrkvica[14] carried out with different combinations of feed and cutting speed. The most optimal cutting conditions were found out by measuring the milling time till vertical wear was reached and the cutting inserts used were not able to machine. By using optimum cutting parameters cutting tool material and geometry of tool machining of Inconel 718 was made economical and effective.

J.P.Costes et al [8]analyzed the studies made for the wear of CBN tools, a description of the modes of degradation is given: during machining, the work piece, under high temperatures and stresses, plasticized itself superficially, so the alloy spread on the contact area between the insert and the work piece (rake and flank faces). They concluded that the dominant wear mechanisms of the CBN cutting tool during the cutting process are adhesion, then diffusion and finally abrasion.

Zhaopeng Hao et al [13]analyzed Tool wear mechanism in dry machining Inconel718 with coated cemented carbide tools. CCD and scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectrometer (EDS) were used to study tool wear mechanism. According to analysis of tool wear mechanism, tool flank wear model was established. The optimal temperature in machining Inconel718 with PVD-coated (TiAlN) tool was obtained through the established model.

Oguz Colak [15] carried out experiment using Taguchi L18 with three different cutting speed and feed rate and two different depth of cuts. Cutting forces components and tool flank wear were the main parameters seem for optimization. High pressure cooling helps in good surface finish but results in decreased cutting force components.

Literature survey on Built up Edge

M. A. Hadia et al[19] studied tool wear mechanism and tool life in ball nose under Minimum Quantity of Lubricant (MQL) condition for Inconel718 during end milling. Main aim was to focus on comparison of up-milling and down-milling operation using Physical Vapour Deposition (PVD) and using coated carbide inserts. This experiment reveals that tool wear increases with increase in DOC, feed rate and cutting speed. Significant pitting and notch wear were the major failure mode typically located near the DOC line that affecting tool performance.

H.R. Krain et al [11] studied effects of changing operation parameters on tool life, productivity and wear pattern. Experiments were conducted to find out the influence of feed rate and immersion ratio on tool life with proper tool material and geometry. Further experiments were done using reduced number of operating parameters to examine the influence of tool material and geometry.

E.O Ezugwo et al [6] carried out machining of different super alloys using different tools like CBN and PCD was observed. Conventional coolant application is not enough as formation of vapour blanket enables it to reach the interface. Machining of high speed aerospace alloys can be achieved by combination of appropriate tool material and machining technique.

S.A. Khan et al [16] experimented finish turning of Inconel 718 using low concentration PCBN inserts. At the lowest cutting speed (150m/min), average tool life using the round insert was approximately 5 times longer in comparison to the C-type tool, with severe grooving and built up edge (BUE) formation observed on wear scar micrographs in all experiments with the latter. As cutting speed was increased to 300m/min, the presence of grooving and BUE diminished, leading to comparable performance between the C-type and round tools.

Waseem Akhtar et al [21] studied review of the tool wear mechanism in the machining of nickel based super-alloys .It has revealed about the tool wear mechanisms in the machining of these alloys. Adhesion wear was found to be the main phenomenon leading to the cutting tool wear in this study. At medium cutting speeds, adhesion of the work piece material onto the tool surface in the form of BUE or BUL caused tool failure by attrition phenomenon.

Irfan Ucun et al [20] studied the effects of the coating material and MQL system were examined in the milling of Inconel 718 nickel under micro conditions. As a result of the experimental study, flank wear was observed due to the abrasive wear mechanism, which is the most frequently observed wear type. Local fractures on the cutting edges and sides of the cutting tools as a consequence of fatigue and BUE formation were observed.

Literature survey on notch wear

T.Kitagawa et al [3] performed cutting experiments and numerical analysis up to a cutting speed of 600m/min for investigating temperature and wear of cutting tools. Experiment revealed that feasibility of high speed end milling depends on transient temperature rise or time lag, owing to a shortcut distance of the tool edge per single revolution, existence of helix angle and temperature drop through the use of coolant.

Miroslav zetek et al [22] did an experiment dealing with measuring the tool wear on the flank face VB, on monitoring the cutting forces and work piece quality. For longer tool life all the parameters should possess optimum values this article presents the important factors during the optimization process. Relation between edge radius and cutting tool life is evident. In terms of reliability it was found desirable to have linear tool wear without maxim tool wear and notches or other defects. This increased the overall safety, reliability and cutting tool efficiency, and this is desirable when machining super alloys.

Kejia Zhuang et al [23] observed the wear mechanism of alumina based ceramic cutting tools during dry turning of Inconel718 is experimentally investigated. Based on the observation of tool wear, an attempt by employing the hardened layer beneath the work piece surface is made to explain the occurrence of notch wear. Consequently, predictive model of notch wear depth considering the influence of work hardened layer is developed. Series of cutting tests are used to validate the proposed notch wear model, and the result indicates that the proposed model is feasible.

M.S.Kasim et al [18] investigated tool wear using a ball-type end mill. Notch wear and flaking near the depth of the cut zone were the predominant types of tool failure for the four round cutting tools and were initiated by pitting caused by the repetitive cyclic load. The combination of notch wear and flaking caused the cutting edge to fail abruptly.

A. Shokrania et al [17] annealed Inconel718 with dimensions 100mm x 150mm x 50mm is used in this paper. Cutting tool for machining trials is disposition (PVD) TiAlN coated solid carbide end mill. Most effective approach was studies for machining and nickel based alloys for penetrating a small amount of cryogen in to the cutting zone. It was found that cryogenic cooling produces a better surface finish than dry machining. Cryogenic cooling significantly reduced the tool life to the coated solid carbide end mills.

Seref Aykut et al [9] Cutting forces (Fx, Fy and Fz) which are formed on symmetric face milling of cobalt based super alloy by using TiN/TiCN/TiAlC PVD coated and uncoated tool hard metal insert are measured experimentally. Chip morphology and tool wear were compared by using PVD coated tool and uncoated tool hard metal inserts which are obtained depending on feed rate, cutting speed and cutting depth.

Literature survey on Crater wear

Jorge A. Olortegui-Yume and Patrick Y. Kwon [10] Steady-state turning experiments were carried out with multilayer coated inserts consisting of TiN/Al2O3/TiCN deposited on a carbide substrate. The delamination in the coatings of MLCTs earlier was not observed in the MLCTs despite of the fact that similar machining conditions have been employed. This study indicates that the multilayer coating studied resists crater wear mainly because of the obstruction of depth growth by means of a second layer(Al2O3) with a low dissolution potential into steel.

S.K. Choudhury and Ganga Raju [5] this paper presents the effects of spindle rotational speed and feed rate on the crater wear along the lip of a drill. Crater wear has been recommended for acceptance as a performance index owing to the relative ease with which it can be measured and the fact that, at higher speeds, crater wear is more significant than flank wear.

Literature survey on glazing

M. M. Hamdy and R. B. Waterhouse [1] investigated the fretting wear of Ti-6Al-4V and Inconel718 with A sphere-on-flat configuration. Glaze formation on Inconel718 occurs at 540°C at both amplitudes of slip but only at an amplitude of 40 µm at 280 °C. The wear rate and coefficient of friction decrease when the glaze is present. Glaze forms on the alloy Ti-6Al-4V at temperatures of 200 °C and above but tends to break down at 600 "C owing to creep of the underlying material. R.B. Waterhouse [2]observed that in nickel-based alloy, Inconel 718, developed glaze oxide when fretted at 540°C in air, as indicated by a low coefficient of friction and wear rate. The glaze type oxide forms a spinel type structure on nickel alloys which results in low fretting wear at high temperature.

CONCLUSION

This paper dealt with various types of tool wear mechanisms involved in machining of super alloys. Tool wear mechanisms like Flank wear, Crater wear, Built up edge, Glazing and edge wear is discussed in this work.

REFERENCES

M. M. Hamdy and R. B. Waterhouse, "The fretting wear of ti-6ai-4v and aged Inconel 718 at elevated temperatures", *Wear*, *71* ,pp. 237 – 248,1981

[1] R.B. Waterhouse, "Fretting at high temperatures", TRIBOLOGY international August 1981,pp 203-208, 1981

[2] T. Kitagawa, A. Kubo, K. Maekawa, " Temperature and wear of cutting tools in high-speed machining of Incone1718 and Ti-6A1-6V-2Sn", wear 202, pp.142-14,1997

[3] I.A. Choudhury, M.A. El-Baradie, "Machinability of nickel-base super alloys: a general review", Journal of Materials Processing Technology 77, pp. 278–284, 1998

[4] S.K. Choudhury , Ganga Raju, "Investigation into crater wear in drilling" , International Journal of Machine Tools & Manufacture 40 ,pp. 887–898, 2000

[5] S.A. Khanna, S.L. Soo, D.K. Aspinwall, C. Sage, P. Harden, M. Fleming, A. White,R. M'Saoubi," Tool wear/life evaluation when finish turning Inconel 718 using PCBN tooling", 5th CIRP Conference on High Performance Cutting 2012,pp 283-288, 2012

[6] S. Dolinšek, J. Kopač, "Mechanism and types of tool wear; particularities in advanced cutting materials'', Journal of Achievements in Materials and Manufacturing Engineering, volume 19, issue 1 ,November 2006

[7] J.P. Costes, Y. Guillet, G. Poulachon, M. Dessoly, “Tool-life and wear mechanisms of CBN tools in machining of Inconel 718”, International Journal of Machine Tools & Manufacture 47, pp.1081-1087,2007

[8] Seref Aykut , Eyup Bagci , Aykut Kentli, Osman Yazıcıogˇlu , “Experimental observation of tool wear, cutting forces and chip morphology in face milling of cobalt based super-alloy with physical vapour deposition coated and uncoated tool”, Materials and Design 28 ,pp. 1880–1888,2007

[9] Jorge A. Olortegui-Yume and Patrick Y. Kwon, “Crater Wear Evolution in Multilayer Coated Carbides During Machining Using Confocal Microscopy”, Journal of Manufacturing Processes Vol. 9/No. 1,2007

[10] H.R. Krain, A.R.C. Sharman, K. Ridgwa, “Optimisation of tool life and productivity when end milling Inconel718”, Journal of Materials Processing Technology 189, pp.153–161, 2007.

[11] Blaine Geddes, Hugo Leon, Xiao Huang, 2010, “Super alloys Alloying and Performance”, United States of America,pp.18-35

[12] Zhaopeng Hao , DongGao , YihangFan , RongdiHan, “New observations on tool wear mechanism in dry machining Inconel718”, International JournalofMachineTools&Manufacture51,973–979,2011

[13] Miroslav Janos, Ivan Mrkvica, “Milling Possibilities of Material Inconel718”, Manuf. and Ind. Eng., 11(4), ISSN 1338-6549 Faculty of Manuf. Tech. TUKE,2012

[14] Oğuz Çolak, “Investigation on Machining Performance of Inconel 718 under High Pressure Cooling Conditions” Strojniški vestnik - Journal of Mechanical Engineering 58 11,pp. 683-690, 2012

[15] S.A. Khana, S.L. Soo, D.K. Aspinwall, C. Sage, P. Harden, M. Fleming, A. White,R. M’Saoubi,” Tool wear/life evaluation when finish turning Inconel 718 using PCBN tooling”, 5th CIRP Conference on High Performance Cutting 2012,pp 283-288, 2012

[16] A. Shokrani, V. Dhokia, S.T Newman, R. Imani-Asrai, "An Initial Study of the Effect of Using Liquid Nitrogen Coolant on the Surface Roughness of Inconel718 Nickel-Based Alloy in CNC Milling", Procedia CIRP 3,pp. 121 – 125, 2012

[17] M.S. Kasim , C.H.CheHaron , J.A.Ghani , M.A.Sulaiman , M.Z.A.Yazid , “ Wear mechanism and notch wear location prediction model in ball nose end milling of Inconel718” , Wear 302 ,pp. 1171–1179, 2013

[18] M. A. Hadia, J.A. Ghania, C.H. Che Harona, M. S. Kasim, “Comparison between up-milling and down-milling operations on tool

wear in milling Inconel 718", Procedia Engineering 68,pp. 647 – 653, 2013

[19] Irfan Ucun , KubilayAslantas , FevziBedir , "An experimental investigation of the effect of coating material on tool wear in micro milling of Inconel 718 super alloy", Wear 300 ,pp. 8–19,2013

[20] Waseem Akhtar, Jianfei Sun, Pengfei Sun, Wuyi Chen, Zawar Saleem, "Tool wear mechanisms in the machining of Nickel based super-alloys: A review", Front. Mech. Eng. 2014, 9(2): 106–119, 2014

[21] Miroslav Zetek, Ivana Česáková, Vojtěch Švarc, "Increasing Cutting Tool Life when Machining Inconel718", Procedia Engineering 69,pp. 1115 – 1124, 2014

[22] KejiaZhuang, DahuZhu, XiaomingZhang, Handing, "Notch wear prediction model in turning of Inconel718 with ceramic tools considering the influence of work hardened layer" ,Wear313,pp 63–74, 2014