A STUDY ON STEPS INVOLVING DEFORMATION IN METAL MACHINING WITH WORN TOOL WITH ADHESION ON HIGH STRENGTH MATERIALS

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ABSTRACT:

The subject of friction is important in all engineering applications wherever solid surfaces are in sliding contact with each other. This is particularly true in metal working processes where the sliding pair of surfaces is metals and where plastic deformation of the softer of the two metals usually takes place under conditions of high normal pressure. In orthogonal metal cutting processes frictional drag apparently is encountered on the rake face between chip and tool and as the tool wears, additional frictional drag also occurs between flank of the tool and the work piece. Friction at these contact regions affects the chip formation process, power consumption, metal removal rate, quality of machined surface and active life of the cutting tools. The material selection consisted of large grained and small grained material both in a hardened and non-hardened state. During the turning experiments, forces were recorded and the chips produced were collected. Longitudinal cross sections of the chips were investigated in an optical microscope. A stereomicroscope was used to investigate the chip macrostructure as well as the contact length between tool and chip. Considerable things in metal machining process have been studied in the present work.

Keywords: *Tool frictional forces, tool worn, chip formation, high strength alloys.*

1.0 INTRODUCTION

In almost all manufacturing of metallic components the process that gives the component its final shape is a machining operation. The aerospace industry is no exception and a lot of machining is performed in the making of components to be used in aircraft engines. As the materials used in such applications have to withstand high temperatures and still retain high strength, machining of these alloys is very hard. As a consequence a lot of resources are put into the research of this problem.

In the early years of the jet engine, austenitic stainless steels where used for the turbine blades. These materials soon proved to be limiting the development of the turbines, as improving turbine efficiency meant increasing operating temperatures. This called for a new type of material, one which would be more tailored to meet the need for better mechanical properties at high temperatures. This demand led to the development of a class of materials known today as the super alloys.

The development of these materials continues to this day with optimization of chemical composition and production methods, because these materials have to work in, what is described in the journal

Flight from 1948 as "…the most arduous instances of high-temperature operation." Something that is still (and possibly more than ever) true in this age of environmental awareness and subsequent demands for increased fuel efficiency.

In order to do this successfully super alloys are required to have a broad spectrum of properties such as high temperature strength and high resistance to creep, oxidation and fatigue just to name a few. These extraordinary properties require extraordinary materials, something that is reflected in the prefix "super" in super alloys and which will be explained deeper in the following sections.

2.0 Mechanisms and Methodology

Strengthening mechanisms

Nickel based and nickel-iron based super alloys are primarily strengthened in two ways; precipitation hardening and solid solution hardening. For temperatures below 0.5Tm grain size hardening according to Petch-Hall is also effective; however at higher temperatures larger grains is to be preferred as they give better creep resistance by reducing the amount of grain boundaries in the material.

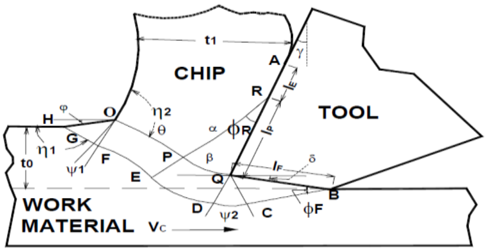
The main strengthening mechanism in nickel based super alloys is precipitation hardening. The hardening effect comes from the fact that dislocation movements through precipitates are hindered by the ordered structure of the precipitates. For a dislocation to pass through the precipitate the order of the atoms must be broken which means that a thermodynamically less attractive state is achieved by the creation of APB (anti phase boundary) which means that more energy is needed to move a dislocation through the precipitate. To restore order dislocations have to travel in pairs, referred to as super dislocations, where the first dislocation destroys the order and the second restores it. In some cases it is not even enough for two dislocations to cooperate but even more have to move together.

Machining

By virtue of its flexibility, machining is used to form almost all metallic materials into geometries useful for engineering, ranging in scale from micrometers to several tens of meters. Machining spans several processes that all have one thing in common; the material is removed from the pre-shaped starting material called the *work piece* by cutting in the form of chips. Some commonly known and widely used processes fitting this description is turning, milling and drilling.

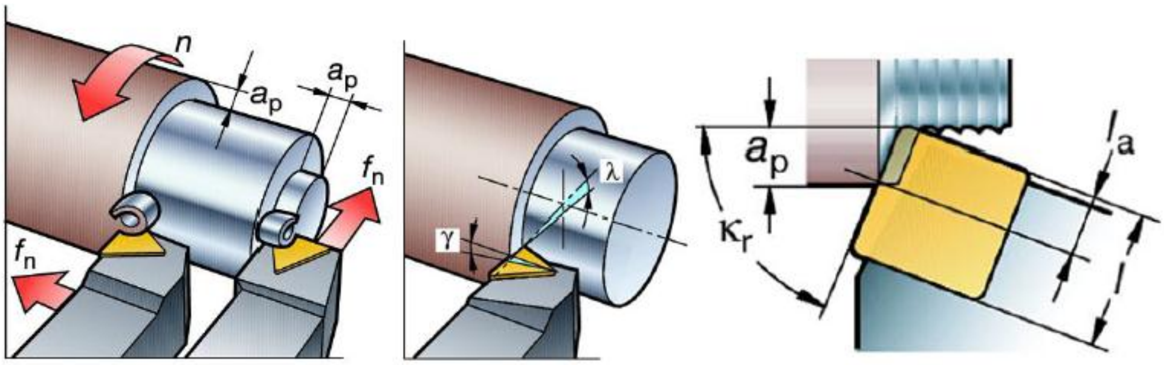
The importance of quantitatively estimating the technological performance of machining operations such as tool life, forces, power and surface finish attracts growing attention from the international machining research community due to the ever increasing applications of machining technologies in a wide variety of modern industries. This performance information is required for the selection and design of machine tools and cutting tools, as well as the optimization of cutting conditions for the efficient and the effective use of machining operations, so that the product quality and the operational safety in automated machining systems is assured. The machining performance is known to vary significantly with the progression of overall tool wear, including major flank wear, crater wear, minor flank wear, nose wear and groove wear at minor cutting edge.

This is because the tool wear formed at different tool faces alters the original tool geometry/configuration thus resulting in unexpected machining performance.



Cutting parameters

In dealing with turning, there are several parameters that control the process and affect the tool life, surface finish and the material removal rate. The optimum selection of the processing parameters is therefore a combination that results in the best possible compromise between the three previously mentioned variables depending on the demands placed upon the part being produced. Below is a listing of the essential parameters with a short description of their definition and the units that will be used throughout this work.



A gradual build-up of forces as the cutting edge length is increased gradually.

Initial contact with the work piece is made further from the relatively weaker tip of the insert.

The surface layer, which often is harder, perhaps by scales from the previous forming process, heat treatment or work-hardening from the previous cutting pass, is spread over a larger length of the cutting edge. This reduces notch wear.

The greater contact length promotes better heat conduction into the work piece and more even heat distribution in the cutting insert.

INSERTS

Cutting inserts (here after called inserts) are the components that are in contact with and cut away material from the work piece to produce the desired component geometry within specified tolerances. This imposes requirements on dimensional stability and this dictates the characteristics of the insert regarding both its geometry and material.

Hot hardness measures how well a material retains hardness at elevated temperatures (see figure above). A higher hot hardness allows for higher cutting speeds.

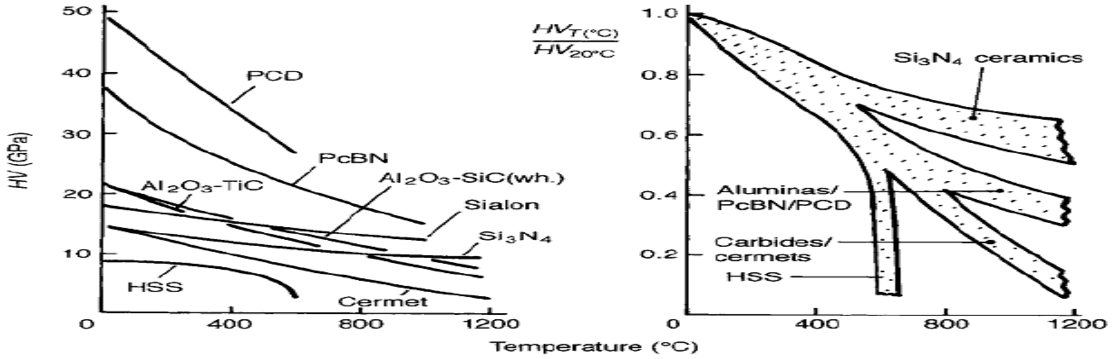


Figure: Hardness of tool materials plotted against temperature. The left graph shows absolute hardness values and the right hardness relative to room temperature hardness.

Cutting fluids

Cutting fluids are often employed in metal cutting operations to reduce cutting forces by providing lubrication and to reduce tool, work piece and machine temperatures. This increases tool life and improves surface finish and the use of the correct cutting fluid is sometimes even necessary in order to have an efficient cutting operation. Other notable effects include flushing away chips from the cutting zone and to protect the work piece from corrosion.

However, cutting fluids also have drawbacks, such as higher machining costs, stemming from both the cost of acquisition and subsequent disposal of the fluid and the cleaning of the finished component. This can account for more than four times the cost of the cutting inserts in the case of aeronautical materials.

Thus economic incentives combined with growing environmental concerns and demands for higher productivity (often leading down the high speed machining route) has increased the interest of manufactures of aeronautical components towards reduction (such as Minimum Quantity Lubrication - MQL) of cutting fluid use and dry machining.

Wear and wear mechanisms

When discussing wear mechanisms it is important to keep in mind that the factors controlling wear depend on a multitude of properties, regarding not only the tool material, but also the work material, the process, the process parameters and the resulting temperatures and forces. Trent et al summarizes this well:

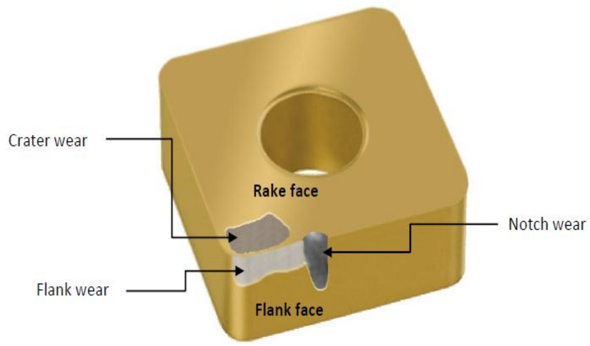
"Wear resistance is not a unique property of a tool material which can be determined by one simple laboratory test, or correlated with one simple property such as hardness."

Abrasion

Abrasion is the wear on a surface in sliding contact with another surface. Harder materials scratch less hard materials and if a material contains hard particles such as carbides or nitrides, these can have a higher hardness than the tool material, which leads to abrasive wear of the tool. This is one of the reasons for the development and use of harder tool materials and the use of coatings, especially when cutting materials with high hardness or with hard particles or inclusions.

Adhesion and diffusion

In metal cutting the conditions for metal bonding of the work piece material to the tool is particularly favourable. The newly cut metal is shielded from the external atmosphere which prevents oxidization and the high temperatures combined with high contact forces helps to weld the two materials together. This adhesion of the work material to the tool can be in the form of a built-up edge (BUE) or as small particles or layers. These deposits of work material are often rejoined to or pushed on by the chip flowing past them and in the process of breaking off they might peel off some of the tool material resulting in adhesive wear of the tool.



Schematic illustration of different kinds of wear.

Crater wear occurs on the rake face of the tool and is due to the high temperatures in this region, allowing diffusion between the work material and the tool. The high temperatures also affect the tool material yield strength, and for high cutting speeds it is possible that the tool is sheared. This produces a rapid crater wear and is often followed by tool fracture. This type of shearing crater wear is more common for high strength, high melting point materials such as super alloys.

Flank wear

Flank wear is the wear occurring at the flank face, below the cutting edge of the tool. The cause for this is the tool rubbing against the work material, and this sliding contact produces wear by abrasion and adhesion.

Notch wear

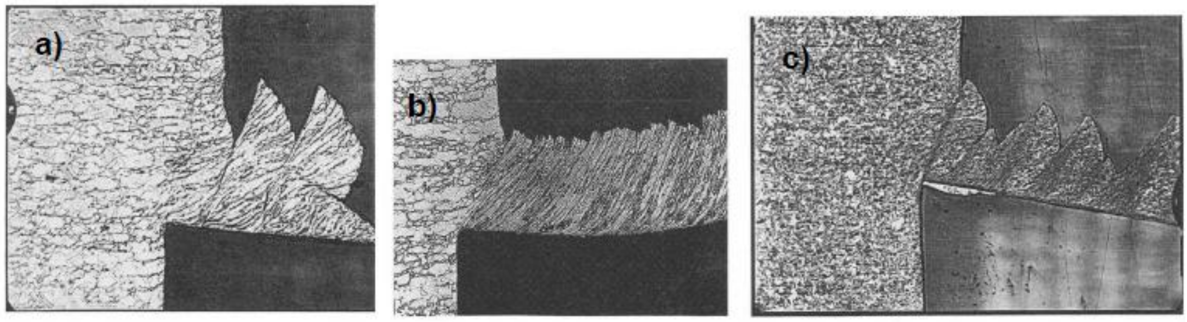
Notch wear is a localized form of wear at the depth of cut line. This type of wear is common for work hardening materials such as super alloys and austenitic steels and is thought to be caused by oxidation of the tool material as well as contact with the previously cut surface, which is harder and may include oxides and burr.

Deformation

From the general description of the machining process it can be understood that in order to form chips with a tool severe plastic deformation of the material is required. This section will describe how and where this deformation takes place and by which deformation mechanisms the material is deformed.

3.2.1 Models for chip formation

In classical chip formation theory all deformation of the material being machined into a chip takes place in one plane. This shear plane is seen as extending from the tip of the tool to the surface of the work piece (see figure 4). One also specifies the shear plane angle as the angle between the shear plane and the surface of the work piece. From this it is possible to calculate the chip velocity which will be different from the cutting speed as the feed and chip thickness is not the same as long as the shear plane angle is not 45°.



Chip morphologies. a) discontinuous chip produced at low speeds b) continuous chip c) segmented chip

4.0 CONCLUSIONS

By studying some of the before researches and the process of machining the friction formation and the forces acting while chip breaking was observed. Main consideration factors discussed in the paper for further investigation of metal cutting process. Worn behaviour of inserts and process also discussed with wear properties.

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