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EDS Analysis of Flank Wear and Surface Integrity in Machining of Alloy 718 with Forced Coolant Application

Henrik Jäger[a, b,*], Nageswaran Tamil Alagan[a], Jonas Holmberg[a, c], Tomas Beno[a], Anders Wretland[d]

[a] *University West, Department of Engineering Science, 461 86, Trollhättan, Sweden*
[b] *Swerea-KIMAB AB, 164 40, Stockholm, Sweden*
[c] *Swerea-IVF AB, 431 22, Mölndal, Sweden*
[d] *GKN Aerospace Engine Systems AB, 461 81, Trollhättan, Sweden*

* Corresponding author. Tel.: +46 (0)8 440 48 05. *E-mail address:* henrik.jager@swerea.se

Abstract

There has been extensive research on forced coolant application, usually known as high pressure coolant, in machining heat resistant super alloys. This technology has shown to improve the tool life, chip segmentation, surface integrity and reduce the temperature in the cutting zone. A number of studies have been done on hydraulic parameters of the coolant. This study has been focused on residues on the flank face of the insert and residual stress on the workpiece surface generated by regular and modified cutting inserts. To identify any residual elements, analysis were done by energy dispersive X-ray spectrometer, EDS, on regular as well as modified inserts in combination with forced coolant application on both rake and flank face. The investigations have shown that the temperature gradient in the insert has changed between the regular and modified cutting inserts and that the tool wear and surface roughness is significantly affected by the modified cutting tool.

Keywords: EDS; Heat zone; Surface roughness; Residues; Facing; Forced coolant application; Residual stress

1. Introduction

Heat resistant super alloys, HRSA, constitutes an area of high and continuous interest within industrial sectors such as aerospace, offshore and energy applications in general where the energy conversion is based on gas turbines. Such applications can increase their fuel efficiency by burning fuel at higher and higher temperatures which in turn sets the requirements for the materials to be used and consequently will impact their machinability. This has created a market situation with more focus on HRSA, also for components that traditionally have been made from other alloys.

Of all the nickel-based alloys, Alloy 718, also known as Inconel 718, is the most commonly used and shows excellent high temperature strength and resistance to creep and corrosion. Despite over 45 years in use it is still regarded as a difficult material to machine, even with today's standard of machining technology. Thus, it exhibits high temperatures in the cutting zone and thereby creates excessive tool wear. Most heat is generated in the primary shear zone and in combination with the low thermal conductivity of Alloy 718, the heat is concentrated at the cutting edge line. Heat is also generated in the secondary shear zone, where interaction between the tool and the chip produces heat due to friction. Several techniques exist to lower the cutting zone temperature, effectively prolonging tool life.

In 2015 Tamil Alagan et al. investigated two types of modified cutting tool geometries. The first cutting tool geometry, named Gen I, Fig. 1a, had its surface area increased about 12% compared to that of a regular insert. The second insert, named as Gen II is an advancement of the Gen I, Fig. 1b, to improve the coolant reachability closer to the cutting edge. Both inserts have increased tool life based on improving heat dissipation in the cutting zone [1] [2].

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2. Insert coolant interaction

Since 1952, research in coolant applications for machining processes have been focused on methods such as high pressure coolant, flood cooling, minimum quantity lubrication (MQL), liquid nitrogen, CO_2, compressed air etc. The media acting as coolant has always been investigated on hydraulic parameters like pressure, nozzle diameter, flow rate, flow distance etc. Studies have been performed on temperature in the cutting zone, chip segmentation, cutting forces, tool life, tool wear types, machining time, tool-chip contact length and surface integrity of the work piece material, with and without the use of coolant [3] [4] [5].

The physical interaction of coolant, cutting insert and workpiece in the cutting zone can be considered as an envelope to form a system boundary. When studying the effects of the coolant, other than hydraulic parameters are influencing the machining process, leading to a new perspective from a thermodynamical and fluid mechanical point of view.

In thermodynamics, conduction occurs whenever a temperature gradient exists in a solid medium and heat will flow from a region of higher temperatures to one with lower temperatures [6]. In the machining process, heat generated in the primary shear zone is transferred by conduction from the work piece into the chips and the cutting tool.

From a fluid mechanical perspective, there is a boundary layer formation. Compared to dry machining, machining with coolant adds additional physical phenomena to the process. In particular when coolant fluid touches the hot zone in the contact area between cutting tool and workpiece and the temperature of the zone is significantly higher than the boiling point of the coolant. An insulating vapor layer may occur that will restrict the coolant from reaching the hot surface which will reduce the heat transfer significantly. This is known as the "*Leidenfrost effect*". In machining with coolant, the vapor layer will act as a barrier, preventing new coolant from getting close to the cutting edge.

One of the reasons of using the forced coolant application in the machining process is to deliver the coolant closer to the cutting edge by increasing pressure and compressing the vapor layer. From the last decades, the forced coolant was experimented at various pressure ranges to reach the coolant closer to the cutting edge with limited awareness of the effects of the insulating vapor film.

In 2015, Tamil Alagan et al. investigated the effects of an increased surface area of the insert, with the intension to improve heat dissipation and create means for the coolant to reach closer to the cutting edge, Fig. 1a and Fig. 1b. The overall results have shown reduced tool wear leading to increased tool life [1] [2].

The current work represents a continuation of the previous research, with focus on regular inserts compared to Gen II and corresponding workpiece analysis. The inserts are investigated by EDS analysis with respect to traces of the workpiece material adhered onto the surface of the insert, as well as coolant residues on their flank face due to the heat generated in the cutting zone. Surface roughness and residual stress measurements are done on the surface generated.

3. Experimental setup

The insert nomenclature and experimental conditions are referred from the previous articles [1] [2]. Facing operation is done on a cast ring of Alloy 718 in a machining center [1] [2].

3.1. Insert design

The inserts used for analysis are from the previous research conducted by Tamil Alagan et al. in 2015 [1] [2]. One insert is a regular insert, RCMX 120400 and the other inserts are Gen I and Gen II, Fig. 1a and Fig. 1b. Both are uncoated cemented carbide tools of grade H13A.

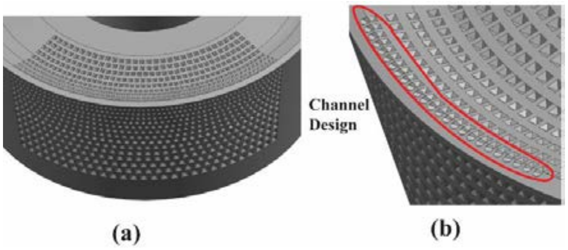

Fig. 1. (a) First generation insert, Gen I (b) Second generation insert, Gen II

3.2. Cutting fluid, cutting tool and workpiece analysis

The cutting fluid had a concentration of around 5% of synthetic emulsion. A sample of coolant, tap water and emulsion concentrate was collected and tested for traces of calcium and sulphur. In addition it was discovered that lubrication oil leaked out from the machine tool and was dissolved in the coolant while circulating in the coolant supply system. This has increased the Ca and S concentration in the coolant leading to its trace in the EDS analysis.

3.3. Analysis of specimens

Inserts were analyzed using a Field Emission Scanning Electron Microscope (FESEM) equipped for energy dispersive electron spectroscopy (EDS) photographed with 30x zoom. A back-scatter (BS) detector was used and for EDS analysis the detector was calibrated using a Cobalt reference sample. EDS mapping was performed on the flank surface where most wear was visible. The surface roughness was measured using surface interferometer with Sensofar S Neox equipment. The roughness measurements were performed over a 300 x 600 µm surface in the radius of the cut and a surface of 1.0 x 1.25 mm for measurements on the finished surface with a resolution of 0.25 µm. The result was filtered using a spatial median denoise filter for the low frequencies and a robust Gaussian filter for the high frequencies. The arithmetic roughness value, S_a, is the parameter that describes the roughness over a surface compared to the traditional R_a that instead describes the roughness measured over a single profile [7]. In this investigation the S_a was used to describe the surface roughness.

The residual stress measurements were performed using a Stresstech G2R XStress 3000 lab-XRD equipped with a Mn X-ray tube (λ:0.2103 nm). The modified $\sin 2\psi$ method was used with 5 psi angles (40°...-40°) and the 151.88° diffraction peak. The residual stress was calculated assuming elastic strain