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Hard coatings to improve the machining of nickel based materials

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Abstract

Difficult-to-machine materials like nickel based alloys have become a key material in many branches of industry, above all in the aerospace industry. The reasons for this mainly lie in the combination of properties such as high strength at increased temperatures, a high degree of chemical resistance and high wear resistance. However, these advantages are offset by a major disadvantage: the machining, in particular milling, is very difficult. Only relatively low cutting speeds can be used and tool life is usually short. Developing tool and technology solutions aimed at obtaining an enhancement of the machining techniques used for milling of difficult-to-cut materials.

The results of research, in particular with regard to the development of hard coatings in conjunction with suitable substrate materials, cutting edge preparation and finishing systems show an improvement in the performance of cutting nickel based alloys. Best results were reached by stable oxynitridic and embedded nanoscale structures. Combinations of these coating structures with optimized coating composition and improved coating adhesion were used to develop coatings with higher strength and hardness as well as an improved stability at higher temperatures. Related to ultra-fine graded solid carbide materials, sharp cutting edges (4 µm) and polished tools, hard coated tools were used for HPC milling of nickel based materials at cutting speeds up to 150 m/min. Various cutting analyses show the applicability of the developed coatings and the corresponding process chain to improve the efficiency of cutting processes.

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Keywords: Nickel alloy; difficult-to-machine, wear, cutting edge, surface modification, PVD-coating

1. Introduction

Difficult-to-machine materials like nickel based alloys have become a key material in many branches of industry, above all in the aerospace industry. The reasons for this lie mainly in the good combination of properties such as high strength at increased temperatures, low density, high degree of chemical resistance and high wear resistance. However, these advantages are offset by a major disadvantage: the machining, in particular milling is very difficult and therefore very expensive since only relatively low cutting speeds can be used and tool life is usually short [1].

The prime causes of problems when working with nickel based alloys are high thermal stresses at the cutting edges as a result of low thermal conductivity through the chips and the workpiece, the low E modulus, which can lead to serious deflection and consequently cause vibration or chatter, and the high strength of the material at high temperatures.

A great number of R & D projects are therefore devoted to developing tool and technology solutions aimed at obtaining a significant improvement in the performance of the machining techniques used for milling of difficult-to-machine materials [2, 3]. Research activities for productivity improvement in machining these alloys based on the optimization of cutting tool material and geometry, cutting edge preparation and hard coating systems [4, 5]. These parameters in combination with optimized machining conditions allow a great potential for wear reduction and high performance cutting of difficult-to-machine materials.

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2. Investigation of machining nickel based materials

2.1. Objectives

The objective of extensive studies of machining of nickel based materials was to develop solutions along the process chain: cutting edge preparation - coating - finishing obtaining a significant improvement in the performance of milling difficult-to-machine materials. An optimized process chain in combination with suitable cutting tool material and geometry are crucial for economic and process-stable manufacturing.

A further objective of investigations was the development of cutting strategies for improved machining of nickel based alloys. Depending on process forces and temperatures as well as the tool wear, the cutting parameters can be adjusted to improve process efficiency, e.g. to increase the cutting speed.

2.2. Procedure

To achieve the objectives, PVD-hard coatings with specific requirements were developed. Relevant properties are the thermal and mechanical stability, the thermal protection of the substrate, the reduced friction and a very good coating adhesion. Process simulations were used to calculate process conditions like cutting temperatures and forces and to determine cutting strategies with reduced load.

Hard coating systems and process simulation were used to optimize the milling of the nickel based alloy Inconel 718 with carbide ball nose end mills. To achieve the objectives of an improved machining process, different boundary conditions and processes were taking into account regarding the following procedure of investigations (see Fig. 1.):

- Determination of process characteristic
- Influence of the substrate material
- Development of PVD hard coating systems
- Substrate-pre and coating post-treatment
- Application test

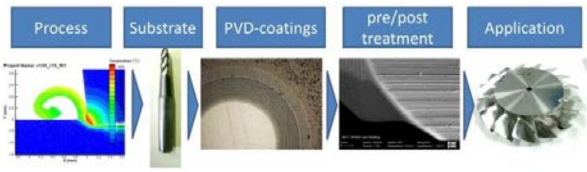
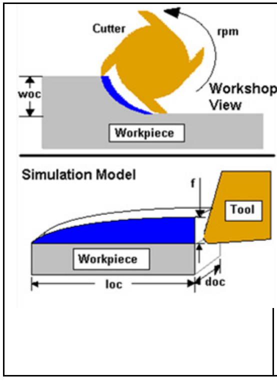


Fig. 1. Procedure of investigations.

2.3. Process simulation

Process characteristics were determined by simulation of the cutting process. For the simulations the software tool AdvantEdge by the company Third Wave Systems (TWS) was used. This software was developed especially for the simulation of cutting processes. The simulation model and the cutting conditions given in Fig. 2 were used to calculate cutting forces and temperatures.



<u>cutting tool:</u>
∅ 5.6-8.5 mm, 4 cutting edges
cutting angle: 8° - 12°
clearance angle: 12°- 15°
cutting edge radius: 4-8 µm
<u>Material</u>
cutting tool: carbide H10F
work piece : Inconel 718
<u>process parameters</u>
cutting speed: 100-200 m/min
tooth feed: f_z =0.04-0.08 mm
cutting width: a_e= 0.1-0.3 mm
cutting depth: a_p= 1-4 mm

Fig. 2. Model of simulation (left) and variation range of used cutting parameter (right).

During the process simulation, process and tool conditions were varied to determine their influence on the cutting process. Based on the calculated cutting forces and temperatures cutting tool geometry (macro and micro geometry) and cutting parameters for further investigations were defined according to a reduced thermal and mechanical load.

2.4. Substrate material

To determine the suitable substrate material, different carbide materials with different properties were used and tested. In cooperation with industrial partners tools with optimized geometry according to simulation results were produced. Main properties of the carbides are:

- Cobalt content : 10.0% to 12.0%
- Other carbides: 1.0% to 1.5%
- Average grain size: 0.5 µm to 1.2 µm
- Hardness: 1380 to 1780 HV 30
- Transverse rupture strength: >4000 N/mm²

2.5. Coating development and post treatment

An Arc-PVD-process was used to develop hard coatings with a high thermal and mechanical stability and with optimized coating adhesion. Coating deposition was done on commercial Arc PVD machines from the company PLATIT AG (Switzerland). To improve coating properties like coating adhesion, hardness and friction, coatings with different structures were used. Of special interest are coatings with:

- Oxynitridic structures (high thermal stability)
- Nanocomposites (high mechanical strength)
- Multilayer structure (high crack resistance)

Tool pre- and coating post-treatment processes were also used for cutting edge preparation and to reduce coating roughness (droplet minimization) and to minimize friction effects during the process. Pre-treatment (cutting edge grading and cutting edge rounding) and post-treatment (film polishing) were both done by stream finishing with the OTEC DF-3 tool.