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Wear characterisation and tool performance of sintered carbide inserts during automatic machining of AISI 1045 steel

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ABSTRACT

This paper presents tool condition monitoring (TCM) of dry turning processes on automatic lathes, and describes the information generated by different measuring systems applied to the single point turning situation. The outputs measured were correlated with the state and wear rate of the cutting tools.

Semi-finishing and rough-shaping tests have been carried out at different cutting speeds. Uncoated sintered carbide inserts have been used in both processes, while TiC–TiN coated inserts have only been used in the semi-finishing processes. The behaviours of the utilised power, the tool-holder shank vibrations and the surface roughness vs. pass number were studied. The main criteria used for the wear assessment, were the roughness checks on work pieces in the semi-finishing processes, the electrical input by the lathe motor together with the vibrations level in the rough-shaping processes.

The life of the tool inserts was assessed for each test, and Taylor's equation was determined for the three types of inserts used.

The parameters investigated show that the results are directly influenced by degree of the tool wear and also give indications when the tool insert has reached the end of its life.

Coated inserts permit approximately 50% longer machining time, a higher wear mark width and a reduced applied power consumption, compared with uncoated inserts. The end of tool life in the semi-finishing processes, when compared to the rough-shaping processes, refers to the higher power range used in the latter.

The established relationships can be used in the evaluation of a tool insert's life and subsequently give rise to clear indications of the opportunity for higher productivity.

1. Introduction

Determination of the life of tool inserts is still a major concern, even though current production techniques are carefully designed and are based on decades of experience, research and development. In metal turning, the ideal situation is characterised by regular and uniform tool insert wear. The adoption of cutting parameters well below the ones potentially achievable, nevertheless, can result in a better continuous control of the cutting operations, and in a reduction of waste. The development and the widespread use of hard metal coated tool inserts, in recent decades, has also given rise to a substantial increase in the chip volume removed per unit of machining time.

Sandwik Automation (1992a,b) reported on automatic TCM systems as applied to some machine tools—including computer controlled (CNC) lathes, in which the correlation of cutting power (or force) and wear mark width increase, provides information and warning signals to the operator. This information output, however, is insufficient for monitoring cutting tool conditions. Beiss and Kutsch (1996), on the other hand, studied the machinability of materials and the derived costs vs. cutting speed relationships, with the aim of achieving minimum machining costs. Machinability – expressed as the material's response to the chips removal using cutting tools – is major aspect of the economics of parts production by machine tool operations. Its study therefore needs an examination of other parameters connected with tool wear. Paravicini Bagliani (2005), for example, carried out tests on several steels, to develop a machinability control factor (MCF) to assist in forecasting the machinability of a steel by using regular measurement. Theoretical and experimental work has also been carried in recent years, to investigate the relationship between carbide tool insert wear as related to operating conditions. The results of recent experimental studies of metal cutting processes reported by Luo et al. (2005) indicate that cutting speed can influence the life of a tool insert to a greater extent than feed rate. This information is based on simulations of cutting mechanics and an empirical model, but not on practical tests. Tool wear, is also a criterion often employed to evaluate aspects of a material's machinability, and there is a wide

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Table 1
Work piece chemical compositions (values in %).

Carbon	0.46
Manganese	0.64
Silicon	0.27
Phosphorus	0.029
Sulphur	0.020
Fe	Bal.

literature which studies the influence of the metallurgical characteristics on this.

Measurements and evaluation of mechanical vibrations and shocks have demonstrated their usefulness in machining monitoring, as reported by several authors: Abrami (1981), for example, reported on the benefit of vibration measurements and analysis, in controlling the condition of machine tools; Brock (1984) gives indications of the usefulness of mechanical vibration measurements in his study dedicated to these. Procedures for monitoring machine tool vibrations are set out in the ISO 13373-1 norm (2002), whereas Heyns (2007) reviews vibration measurements for TCM in various fields of application. Rogante (1998) reports a study on the vibrations of machine tools, and advises on the measurement of these. Salgado and Alonso (2006) have recently applied a new non-parametric technique of time series analysis to this problem. That is, the use of single spectrum analysis (SSA), to study the vibration signals produced in turning processes, with the aim of obtaining tool wear information. SSA can be also considered for applications in TCM, however, this single method alone is insufficient for monitoring tool conditions.

Surface roughness is a prime indicator of surface quality on machined parts, and it is the result of a combination of process parameters including tool geometry, cutting conditions and tool wear. Dhar et al. (2007) reported that surface roughness in turning processes is usually due to the following factors: regular feed marks left by the tool-nose on the machined surface; irregular distortion of the auxiliary cutting edge at the tool-nose as a consequence of chipping or fracturing; wear vibration in the machining system; and the eventual built-up of edge formation.

Each of the above mentioned papers uses one measuring system applied to the single point turning situation. In the present TCM study, conducted in accordance with UNI-ISO 3685 standards (1981), three measuring systems have been considered – the applied power of the lathe dc motor, the vibration levels of the tool-holder shank and the surface roughness of the work pieces – with the intention of obtaining better information on tool life assessment and better understanding of tool wear processes, in dry machining of steels using CNC lathes.

2. Experimental setup

2.1. Work piece material

The work piece material used was AISI 1045 (UNI C45) normalised medium carbon steel. Hot rolled steel bars – all from the same cast – were used. These had a maximum tensile stress of 65 kg/mm^2 and a tested hardness of ∼191 HB; the latter value being within in the range of 180–200 HB as prescribed by the UNI-ISO 3685 standards (1981). The corresponding specific cutting force was 300 kg/mm^2. The bar lengths used were 310 mm for the semi-finishing, and 173 mm for the rough-shaping processes. The initial diameter of the bars was 118 mm, well above the minimum initial diameter of 100 mm prescribed by the above standard. The minimum diameter of the bars reached during the tests, was fixed of 62 mm. The chemical composition of the work pieces is listed in Table 1, and it is in accordance with the requirements of the same standards. The work piece was replaced when length/diameter ratio reached a value of 10, also in accordance with the above standards.

Table 2
Tool inserts geometry.

Parameters	Semi-finishing tests	Rough-shaping tests (1st series)	Rough-shaping tests (2nd series)
Insert shape	Triangular, 60°	Square, 90°	Square, 90°
Chip-breaker	Double-sided	Double-sided	Single-sided
Cutting edge length (mm)	22	12	12
Thickness (mm)	4.76	4.76	4.76
Nose radius (mm)	0.8	0.8	0.8
Back rake angle	−6°	−6°	−6°
Front clearance angle	6°	6°	6°
End cutting edge angle	45°	15°	15°
Side cutting edge angle	0°	15°	15°
Side rake angle	6°	6°	6°
Side clearance angle	0°	0°	0°

2.2. Cutting inserts and tool-holder geometry

Tool inserts (Impero, Italy) with and without coating, were used in the turning processes. These all had a nose radius of 0.8 mm and in accordance with UNI 7736 standards (1977). Tungsten, titanium and tantalum sintered metal carbides were selected as material components of the inserts used, as they are currently those most popular for chip removal processes. Titanium carbide, in particular, has a superior adhesion and edge strength giving improved reliability; and also has high resistance to flank and crater wear, over long unmanned machining time.

The semi-finishing tests were carried out using triangular inserts with an ISO designation of TNMG220408 and the following characteristics: density 12.35 kg/dm^3; hardness = 1520 Hv; bending resistance = 165 Hbar. The chemical composition of these inserts was (wt%): WC = 71; TaC = 12; Co = 9; TiC = 8. The tool holder used in these tests had an ISO designation of PTGNR2525-22.

A first series of rough-shaping tests was carried out using square inserts with an ISO designation of SNMM120408 and with the same material composition and characteristics, as the inserts employed in the semi-finishing tests.

A second series of rough-shaping tests was carried out using square coated inserts with an ISO designation of SNMM120408. The chemical composition of the body was (wt%): WC = 69.5; TaC = 12; Co = 10.5; TiC = 8; and the 3–5 μm thick coating of TiC–TiN was made with a Chemical Vapour Deposition (CVD) technique. This vapour deposit prevents the occurrence of welding which causes chipping at the top cutting edge of the tool insert. The tool holder used in the rough-shaping tests has ISO designation of PSBNR2525-12.

The geometry of the cutting inserts is given in Table 2.

2.3. Cutting conditions

In all the tests the cutting depth and feed rate were chosen according to the UNI-ISO 3685 standards (1981), and took into consideration the need to obtain effective chip control. Cutting speed and feed rate generally determine the surface finish, the power requirements and the removal rate of the material. Lim et al. (1999) have shown that the rate of decrease of high speed steel tool wear due to the TiN-coatings depends mainly on cutting speed and the feed parameters. These parameters have therefore been kept constant throughout each test period.

The semi-finishing tests were carried out at the following cutting speeds (m/min): 125, 140, 160 and 180. A cutting depth of 2 mm and a feed rate of 0.22 mm/rev were used.

The first series of rough-shaping tests was carried out using the following cutting speeds (m/min): 90, 100, 112, 125 and 140.