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Tool life evaluation of cutting materials in hard turning of AISI H11

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Abstract. The aim of this experimental study is to evaluate the tool life of each cutting material used in dry hard turning of AISI H11, treated at 50 HRC. This steel is intended for hot work, is free from tungsten on CrMoV basis, insensitive to temperature changes and has a high wear resistance. It is employed for the manufacture of the moulds and inserts, module matrices of car doors and helicopter rotor blades. The tests of straight turning were carried out using the following cutting materials: carbides (H13A and GC3015), ceramics (mixed CC650 and reinforced CC670) and cermets (CT5015 and GC1525). Experimental results enable us to study the influence of machining time on flank wear *VB* of these cutting materials and to determine their lifespan for this cutting regime (depth of cut $a_p = 0.15$ mm, feed rate $f = 0.08$ mm/rev and cutting speed $V_c = 120$ m/min). It arises that mixed ceramic (insert CC650) is more resistant to wear than cutting materials. Its tool life is 49 min and consequently, it is the most powerful.

Key words: hard turning, AISI H11, tool life, response surface technology.

1. INTRODUCTION

Concerning cutting tools used in manufacturing process, the tool life is directly controlled by the constitutive material [1]. Practically the lifespan is evaluated by the measure of the flank wear. If it increases quickly, the lifespan becomes very short and vice versa. In finish turning, tool life is measured by the machining time taken by the same insert until the flank wear reaches its allowable limit of 0.3 mm. Wear is an important technological parameter of control in the machining process. It is the background for the evaluation of the tool life and surface quality [2–5].

Flank wear is usually observed in the flank face of a cutting insert. Among the different forms of tool wear, flank wear is the important measure of the tool life as it affects the surface quality of the work piece. The nature and the rate of growth of flank wear with machining time are the most important criteria for judging the life of each tool. Abrasion and adhesion are the two wear mechanisms for flank wear. The flank wear is usually due to crack development and intersection by hard asperities or wear particles acting as small indenters on the cutting face. In many cases, this action caused broken chips of irregular shape from the flank face and which in turn abrades the tool material and creates the scar mark in the flank face of the tool [6].

Yallese et al. [7] have shown that for the 100Cr6 steel, the machined surface roughness is a function of the local damage form and the wear profile of the CBN tool. When augmenting V_c, tool wear increases and leads directly to the degradation of the surface quality. In spite of the evolution of flank wear up to the allowable limit $VB = 0.3$ mm, arithmetic roughness R_a did not exceed 0.55 µm. A relation between VB and R_a in the form $R_a = ke^{\beta(VB)}$ is proposed. Coefficients k and β vary within the ranges of 0.204–0.258 and 1.67–2.90, respectively. It permits the follow-up of the tool wear.

The aim of the present study is to evaluate flank wear and to determine the lifespan of each cutting material on AISI H11 hardened steel. Machining tests were carried out under dry conditions with the following materials: H13A, GC3015, CT5015, GC1525, CC650 and CC670 (these are “Sandvik Coromant grades”) [1].

A model, predicting the lifespan T of mixed ceramic CC650 was developed. To calculate the constants of this model, the softwares Minitab 15 and Design-Expert 8 analysis of variance (ANOVA), multiple linear regression and response surface methodology (RSM), were exploited. The analysis of variance ANOVA is a computational technique that enables the estimation of the relative contributions of each of the control factors to the overall measured response. RSM is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which response of interest is influenced by several variables and the objective is to optimize the response [8–10].

2. EXPERIMENTAL PROCEDURE

The material used for the experiments is grade AISI H11 steel, a hot work steel, which is widely used in hot form forging. It is employed for the manufacture of the module matrices of car doors, helicopter rotor blades, shells, moulds and inserts of high pressure die casting strongly requested with high lifespan. Its chemical composition is given in Table 1.

Table 1. Chemical composition of AISI H11

Composition	wt, %
C	0.35
Cr	5.26
Mo	1.19
V	0.5
Si	1.01
Mn	0.32
S	0.002
P	0.016
Other components	1.042
Fe	90.31

Table 2. Characteristics of used inserts

Cutting materials	Designation	Chemical composition
Uncoated carbide H13A	SNMG120408-MR	Tungsten carbide
Uncoated cermets CT5015	SNMG120408-QF	Carbide with titane basis
Coated carbide GC3015	SNMA120408-KR	Coating CVD TiCN-Al_2O_3- and TiN
Coated cermets GC1525	SNMG120408-PF	Coating PVD TiCN and TiN
Mixed ceramic CC 650	SNGA120408 T 010 20	Al_2O_3 (70%) + TiC (30%)
Reinforced ceramic CC670	SNGN120408 T 010 20	Al_2O_3 (75%) + SiC (25%)

The workpiece used for experiments was of 300 mm length and 75 mm in diameter, hardened to 50 HRC.

The lathe, used for machining operations, was from TOS TRENCIN company; model SN40C, spindle power 6.6 KW.

The cutting inserts used were uncoated carbide H13A, coated carbide GC3015, uncoated cermets CT5015, coated cermets GC1525, reinforced ceramic CC670 and mixed ceramic CC650. These inserts were removable, of square form with eight cutting edges. Their characteristics are listed in Table 2.

The toolholders (designation CSBNR2525M12 and PSBNR2525M12) have a geometry of the active part, characterized by the following angles: major cutting edge angle $\chi = 75°$, relief angle $\alpha = 6°$, rake angle $y = -6°$, inclination angle $\lambda = -6°$.

An optical microscope model Hund (W-AD) was adapted to measure flank wear of different tools.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Effect of machining time on flank wear *VB*

The tests of long duration of straight turning on AISI H11 steel treated at 50 HRC were carried out. The purpose of these operations was to determine the

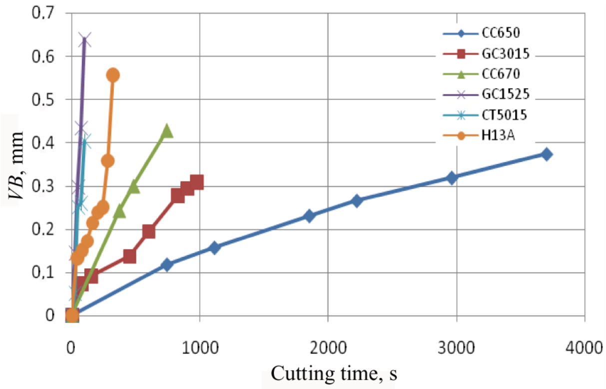

Fig. 1. *VB* of cutting materials vs machining time *t*.

wear curves as a function of machining time and therefore the tool life of various cutting materials used. Figure 1 shows the evolution of the flank wear VB versus machining time at $f = 0.08$ mm/rev, $a_p = 0.15$ mm and $V_c = 120$ m/min.

According to the curve of mixed ceramic $Al_2O_3 + TiC$ (CC650) and for a machining time of 740 s (12.33 min), the flank wear *VB* of this insert reaches a value of 0.118 mm. At the end of machining $t = 3700$ s (61.67 min), the flank wear is 0.374 mm. This change represents an increase of 217%. The tool life of this insert is 49 min.

A first operation of turning by the insert CC670 leads to a value of wear *VB* of 0.243 mm. This exceeds its allowable value and reaches 0.429 mm for the second operation of machining. By examining the shape of this curve, the tool life of this insert is only 8 min. In these cutting conditions, the tool life of whisker ceramic does not exceed the rate of 17% of that of the mixed ceramic.

For machining done by the uncoated cermets CT5015, the wear *VB* is 0.404 mm, which means that the edge of this tool is severely damaged. Its tool life is less than 1.5 min.

The flank wear of the coated cermets GC1525 exceeds its allowable value and reaches 0.460 mm. According to its curve, its tool life is 1 min.

The first machining test done with the coated carbide GC3015 generates a flank wear of 0.074 mm. For a machining time of 975 s (16.25 min), its wear *VB* is 0.309 mm, which defines the lifespan of this tool 16 min.

At $t = 120$ s (2 min), the flank wear of uncoated carbide H13A is 0.172 mm. Its *VB* exceeds the allowable value and reaches 0.358 mm for a machining time of 280 s (4.67 min). Tool life of H13A is 4.5 min.

3.2. Tool life of cutting materials

Figure 2 illustrates the tool life of each cutting material. The lifetimes of coated carbide GC3015, composite ceramic $Al_2O_3 + SiC$ (CC670), uncoated carbide H13A, uncoated cermets CT5015, and coated cermets GC1525 are respectively 16, 8, 4.5, 1.5 and 1 min.

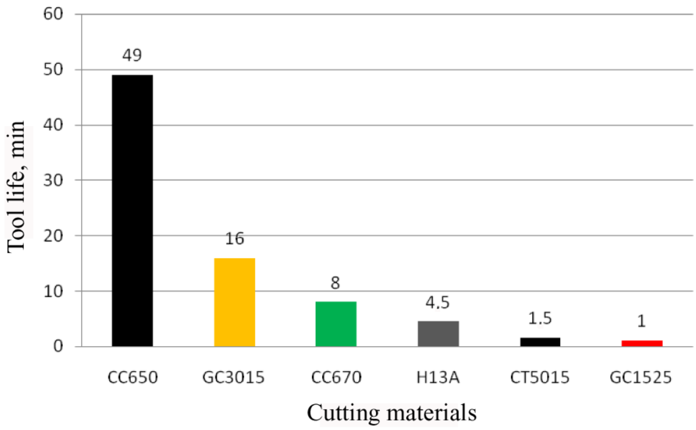

Fig. 2. Tool life of cutting materials.

These values represent 32.65, 16.33, 9.18, 3.06 and 2.04% of the tool life of mixed ceramic Al_2O_3 + TiC (CC650). These results prove that the mixed ceramic Al_2O_3 + TiC is more efficient than other grades used.

3.3. Lifespan T of CC650

Mixed ceramic Al_2O_3 + TiC was more efficient than other cutting materials in terms of wear resistance. This is why we felt it necessary to analyse the behaviour of this nuance in terms of tool life T. Based on the 2^2 factorial design, a total of 4 tests were carried out. The range of each parameter is set at two different levels, low and high. Results are given in Table 3.

Mathematical model of tool life T of CC650 is

$$T = 95.9 - 0.354V_c - 65.6f, \quad (1)$$

where f is the feed rate; $R^2 = 98.09\%$.

3.4. 3D Surface plot for tool life T of the CC650 insert

The 3D Surface of CC650 tool life T vs cutting speed V_c and feed rate f is plotted in Fig. 3.

This figure was obtained using RSM according to its mathematical model.

Table 3. Lifespan T of CC650

Test No.	f, mm/rev	V_c, m/min	T, min
1	0.08	120	49
2	0.16	120	42
3	0.08	180	26
4	0.16	180	22.5

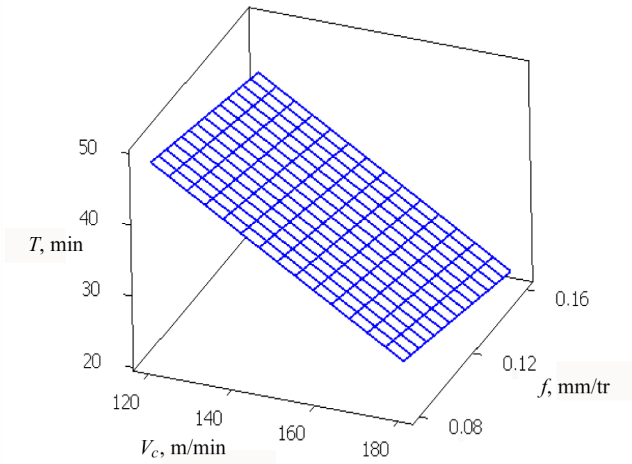

Fig. 3. 3D Surface plot for tool life T of CC650 vs V_c and f.

4. MICROGRAPHS FOR FLANK WEAR *VB* OF THE CC650 TOOL

For the considered regime ($V_c = 120$ m/min, $a_p = 0.15$ mm and f = 0.08 mm/rev), flank wear VB of the mixed ceramic CC650 spreads regularly. Figure 4 shows the micrographs for VB of CC650 insert.

Figure 5 shows the micrographs for VB of CC650 insert at the cutting regime $V_c = 120$ m/min, $a_p = 0.15$ mm and $f = 0.16$ mm/rev.

When the Al_2O_3 + TiC mixed ceramic (insert CC650) is machined at cutting speed of 180 m/min (severe cutting conditions), its lifetime becomes shorter due to the rapid spread of the flank wear VB. This is due to the rise of temperature in the

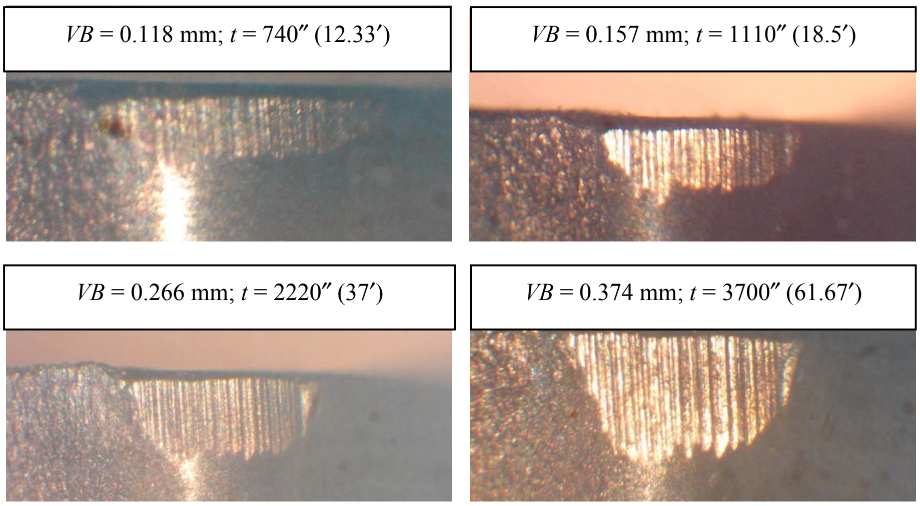

Fig. 4. Micrographs for VB of CC650 at a_p = 0.15 mm; f = 0.08 mm/rev and V_c = 120 m/min.

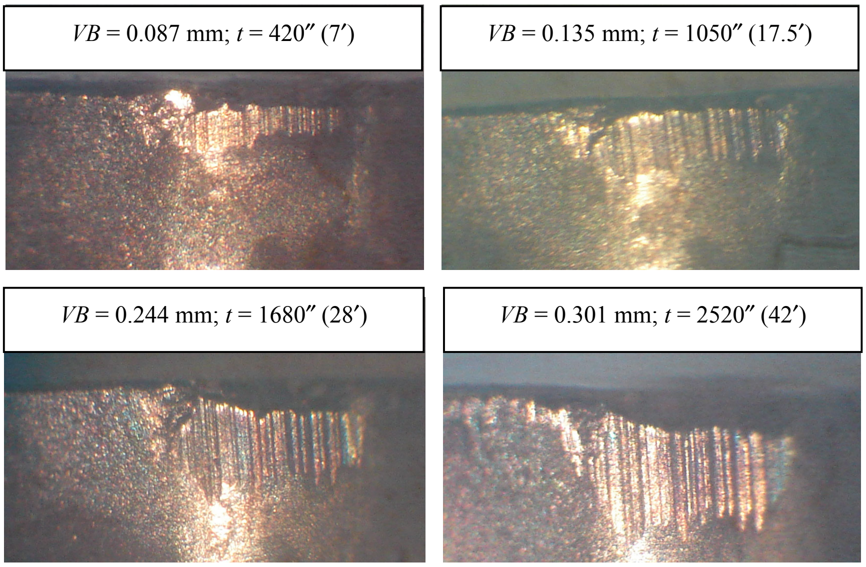

Fig. 5. Micrographs for VB of CC650 at a_p = 0.15 mm; f = 0.16 mm/rev and V_c = 120 m/min.

cutting zone which triggers the different wear mechanisms. The lifetimes of this tool are respectively 26 and 22.5 min for these two feed rates 0.08 and 0.16 mm/rev.

Figure 6 shows the micrographs for VB of CC650 insert at this cutting regime ($V_c = 180$ m/min, $a_p = 0.15$ mm and $f = 0.08$ mm/rev).

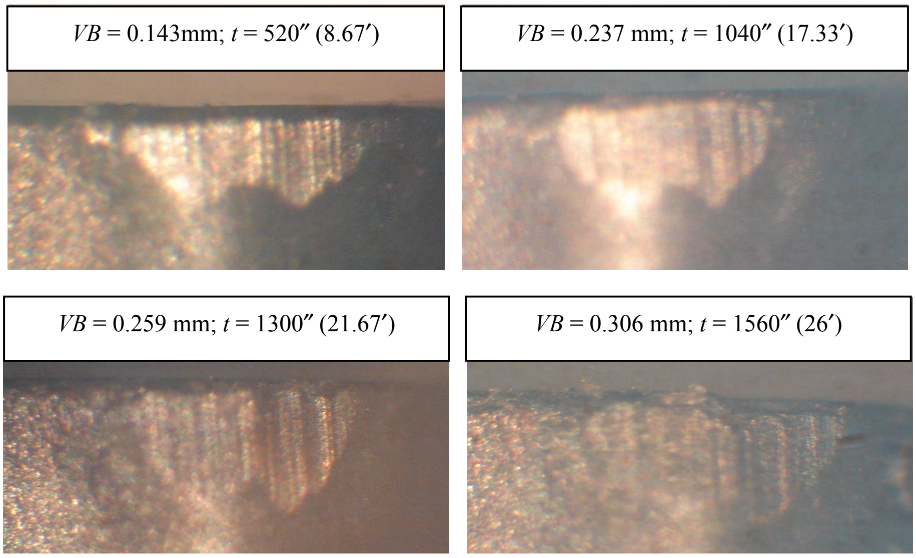

Fig. 6. Micrographs for VB of CC650 at a_p = 0.15 mm; f = 0.08 mm/rev and V_c = 180 m/min.

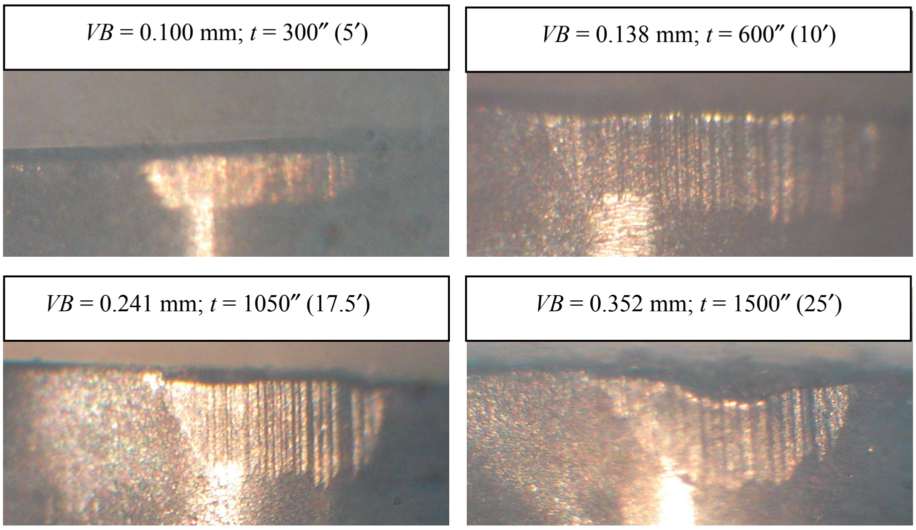

Fig. 7. Micrographs for VB of CC650 at $a_p = 0.15$ mm; $f = 0.16$ mm/rev and $V_c = 180$ m/min.

Figure 7 shows the micrographs for VB of CC650 insert at the cutting regime $V_c = 180$ m/min, $a_p = 0.15$ mm and $f = 0.16$ mm/rev.

5. CONCLUSIONS

The following conclusions can be derived from this experimental study of dry hard turning of AISI H11 steel, treated at 50 HRC, machined by the following cutting materials: the carbides (H13A and GC3015), the ceramics (mixed CC650 and reinforced CC670) and the cermets (CT5015 and GC1525).

1. The tool life of the uncoated cermets CT5015 and the coated cermets GC1525 is less than 2 min. The tool life of the uncoated carbide H13A is 4.5 min. The tool life of the reinforced ceramic CC670 is only 8 min. However, the tool life of the coated carbide GC3015 is 16 min. As for the mixed ceramic, its tool life is 49 min.
2. Cutting speed influences tool life T of CC650 more significantly than the feed rate.
3. This experimental study confirms that in dry hard turning for the cutting regime tested, the mixed ceramic is the most powerful tool in terms of wear resistance and lifespan.

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Lõikeriistamaterjalide püsivus terase AISI H11 treimisel rasketes tingimustes

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Eksperimentaalse uurimistöö eesmärgiks oli hinnata erinevate lõikeriistamaterjalide püsivust tööriistaterase AISI H11 (kõvadus 50 HRC) rasketes tingimustes kuivtreimisel. Volframivaba kuumtööriistateras CrMoV on kulumiskindel ja temperatuurimuutuste suhtes mittetundlik. Seda tööriistaterast kasutatakse pressvormide, matriitside, autouste ja helikopterite rootorilabade vormimiseks jms tootmiseks. Tööriistaterase AISI H11 treimiskatsed viidi läbi, kasutades alljärgnevaid lõikeriistamaterjale: kõvasulamid (margid H13A ja GC3015), lõikekeraamika (mitmefaasiline keraamika CC650, sardkeraamika CC670) ning keraamilis-metalsed komposiidid (kermiste margid CT5015 ja GC1525). Eksperimendid võimaldasid uurida lõiketöötluse põhiaja mõju eelnimetatud lõikeriistamaterjalide kulumisele tagatahul ja määratleda püsivusaeg töötlemisel kindlas režiimis (lõikesügavus $a_p = 0,15$ mm, ettenihkekiirus $f = 0,08$ mm/pööre ning lõikekiirus $V_c = 120$ m/min). Selgus, et kulumiskindlaimaks ja suurima püsivusega (49 minutit) materjaliks osutus mitmefaasiline keraamika CC650.