TURNING OF ANNEALED AISI H13 HOT WORK DIE STEEL

Breno Antunes Gonzaga
Universidade Federal de Minas Gerais, Departamento de Engenharia Mecânica, Av. Antônio Carlos, 6627 – Pampulha, Belo Horizonte MG, CEP: 31.270-901.

Alexandre Mendes Abrão
Universidade Federal de Minas Gerais, Departamento de Engenharia Mecânica, Av. Antônio Carlos, 6627 – Pampulha, Belo Horizonte MG, CEP: 31.270-901.
e-mail: abrao@ufmg.br

Abstract: *AISI H13 hot work die steel is widely employed in the metalworking industry due to its high toughness and high resistance to wear and cracking at elevated temperatures. In spite of its importance to the manufacturing sector, published literature on the machining of such material in the annealed state is poor, with most of the research work concentrated on its hard machining. This paper is focused on continuous dry turning of annealed AISI H13 hot work die steel (230 HV) employing coated carbide tools, aiming to identify the tool material and cutting parameters which will promote longest tool life, highest metal removal rate and best workpiece surface finish. The experimental work was carried out using the following cutting conditions: cutting speed from 100 to 300 m/min, feed rate from 0,3 to 0,5 mm/rot and a constant depth of cut of 1 mm. The results indicated that, in general, best performance was obtained using intermediate cutting speed and feed rate, thus leading to longer tool life and maximum metal removal.*

Keywords: *hot work die steel, turning, coated carbide tools.*

1. Introduction

Tool steels comprise a large number of work materials widely used for the manufacture of parts as distinct as shear blades and punches. The addition of elements which promote the production of stable hard carbides, such as manganese, chromium, molybdenum, tungsten and vanadium, make tool steels harder and more wear resistant than plain carbon steels and capable of operating at higher temperatures. The principal materials in this category are high speed steels and hot and cold work die steel and information is given below regarding their composition (Bolton, 1989):

High speed steels can be divided into tungsten high speed steels (AISI T1, T2, T6, etc.) and molybdenum high-speed steels (AISI M2, M10, M47, etc.). The amount of tungsten in the former group is around 18% and the amount of molybdenum in the latter group varies from 3.75% to 9.5%. Molybdenum is chemically equivalent to tungsten but has approximately half the atom mass.

Hot work steels are classified into hot work chromium (typically AISI H13, H14, etc.), tungsten (AISI H21, H25) and molybdenum (AISI H42 only) steels. AISI H13 contains 5% Cr, AISI H21 9% W and AISI H42 5% Mo. Finally, cold work steels are high carbon (the D series: AISI D2, D3, D7, etc.) containing 12-13% Cr and 1.5-2.35% C and are designed to be dimensionally stable on heat treatment. Additionally, Kalpakjian (1995) includes in the tool steels group shock resisting steels (S series), mould steels (P series), water hardening (W series) and special purposes (L and F series) steels.

High amounts carbon and alloy elements are highly recommend in steels designed to be used as tools, however, they are detrimental to the material's machinability. Chromium, tungsten, molybdenum and vanadium usually present in tool steels make these materials difficult to machine. Moreover, carbide particles size and shape and their distribution in the steel matrix strongly affect their machinability. For instance, tool steels containing small, spheroid and thoroughly distributed carbide particles in a ferrite matrix have their machinability drastically improved. In contrast, tool steels containing less than 0,75% carbon present large carbide grains scattered in a broad area, which results in poor machined surface finish and short cutting tool life. The hardness of the ferrite matrix, which increases as these alloy elements are added, is another factor to be considered.

In addition to the cutting parameters (cutting speed, feed rate, etc.), ASM (1995) states that the microstructure features of the steel, such as the ferrite matrix properties and carbide distribution, considerably affect the performance of H13 steel under machining operations, best results being obtained with a matrix made of lamellar and spheroid pearlite. On the other hand, Shaw (1984) asserts that the mean ferrite path, i.e., the mean spacing of adjacent carbide particles along a straight line, must be taken into account: the longer the path, the lower the hardness, irrespectively of the particle shape.

Hardened tool steels are best machined using coated carbide cutting tools (ISO grade K), ceramics and polycrystalline cubic boron nitride (PCBN) tools due to their superior wear resistance (König et al., 1984). While coated carbide tools can be used to turn annealed tool steel at cutting speed up to 350 m/min, the upper limit for uncoated carbides is 75 m/min (Che Haron et al., 2001).

Trent (1989) adds that thanks to the retention of hardness to higher temperatures than other tool materials combined with excellent abrasion resistance and resistance to reaction with ferrous work materials, hardened tool steels are efficiently machined using PCBN tools.

Cutting forces when machining hard materials are not extremely higher than when cutting in the annealed state due to the relatively small amount of plastic deformation of the chip (limited by crack initiation and resulting in a saw-tooth type of chip) and also because of the low contact area between chip and tool, which reduces the friction force (Nakayama et al., 1988). Nevertheless, cutting forces are reported to be approximately 30 to 80% higher than when machining materials of lower hardness.

Aspinwall et al. (1985), Bordui (1988) and Ohtani et al. (1986) compared the performance of different tools while cutting tool steels hardened from 18 to 62 HRC. Despite the increase in the cutting force as workpiece hardness was elevated, the tool life of PCBN inserts also increased within certain limits.

When turning hardened AISI H13 steel (49-52 HRC) with PCBN tools, Dewes and Aspinwall (1996) found that using a cutting speed of 400 m/min, feed rate of 0,5 mm/rot and depth of cut of 0,5 mm, the cutting tool would take 164 minutes to reach the tool life criterion, being able to remove 52 cm^3.

Silva et al. (1997) carried out face milling experiments on AISI H13 steel (48 HRC) using carbide and silicon nitride cutting tools. The results indicated that the hardmetal was superior to the ceramic with regard to tool life, metal removal rate and surface finish. Moreover, the carbide inserts provided less scatter in the Ra and Rmax results as tool wear progressed. The poor performance of the silicon nitride tools was attributed to their low fracture toughness, which resulted in tool chipping and spalling during cutting.

The machining of hardened steels using PCBN and ceramic tools has been extensively investigated in the last 20 years aiming the substitution of grinding operations. However, this is not true for annealed tool steels, which published literature is scarce. Therefore, the principal aim of this paper is to investigate the machinability of AISI H13 tool steel in the annealed condition when turning using coated carbide inserts.

2. Experimental procedure

Bars of AISI H13 hot work die steel (ϕ75 x 265mm) with an average hardness of 230 HV were used as workpiece material. All the testes were conducted using ISO grade P15-K15 coated carbide inserts named VRA. Additional tests were also carried out under selected cutting conditions using a second coated carbide tool called UC 6010 (ISO grade P30) in order to compare the performance of both materials. Nevertheless, the inserts possessed the same geometry, ISO coded CNMG 120408. The tools were mounted on a holder code PCLNR 2020 K12, which ensured the same cutting geometry.

The experimental work was carried out on a CNC lathe (3500 rpm e 5,5KW). Tool wear was monitored on a toolmaker’s microscope equipped with digital micrometers and surface roughness was evaluated using a portable roughness meter (Mitutuoyo Surftest 301) set to a 0,8 mm cut-off. Table (1) presents the cutting conditions tested for the VRA tool material. A tool life criterion of VB_B = 0,5 mm was established (ISO 3685, 1993) and in addition to cutting time, the volume of removed material was also recorded. Once finished the tests with the VRA tool, the cutting condition which provided best results was identified and the test was repeated for the UC6010 tool material.

Table 1. Cutting conditions tested for VRA coated carbide insert.

Cutting speed v_c (m/min)	Feed rate f (mm/rot)	Depth of cut a_p (mm)
100	0,3	1,0
200	0,3 0,4 0,5	
300	0,3	

3. Results and discussion

Figure (1) shows the tool life curves against cutting time when turning with the VRA insert at cutting speeds of 100, 200 and 300 m/min with a feed rate of 0,3 mm/rot and a depth of cut of 1 mm. As expected, increasing cutting speed the tool wear rate is elevated. For a cutting speed of 100 m/min the tool life criterion was not reached after 18minutes of cutting, therefore, the test was interrupted. The same trend is observed in Fig. (2), where the curves for volume of metal removed are presented, however, it can be seen that highest metal removal is obtained using an intermediate cutting speed. An elevation in cutting speed results in both higher metal removal and tool wear rates, the latter as a result of higher cutting temperatures.

Figures (3) and (4) show, respectively, tool wear against cutting time and metal removal when turning with the VRA tool for three values of feed rates (0,3 – 0,4 and – 0,5 mm/rot) and constant cutting speed and depth of cut. It can be seen that only after 8minutes the trends for each feed rate value are defined, suggesting that the tool life criterion of VB_B=0,3 mm recommended by ISO 3685 standard (1993) would not be adequate in the present case since it could not indicate any appreciable differences regarding tool life when machining at feed rates of 0,4 and 0,5 mm/rot (for cutting time) or at feed rates of 0,3 and 0,4 mm/rot (for metal removal).

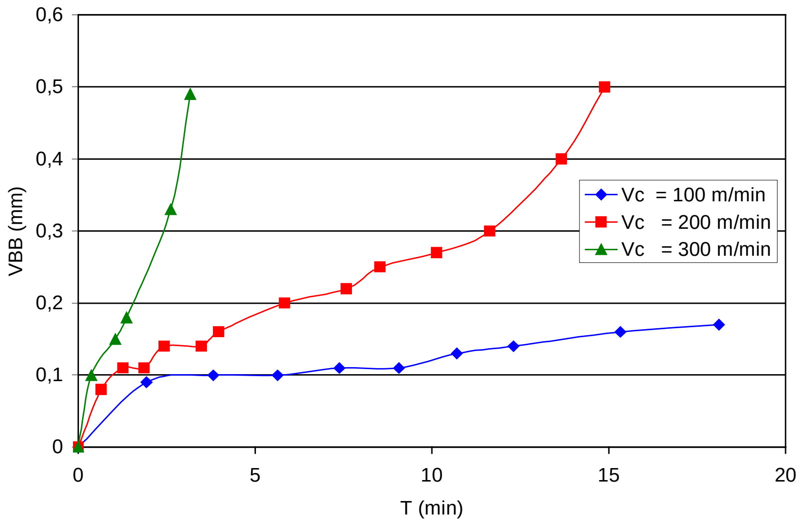


Figure 1. Tool wear against cutting time for the VRA tool (f=0,3 mm/rot e a_p=1mm).

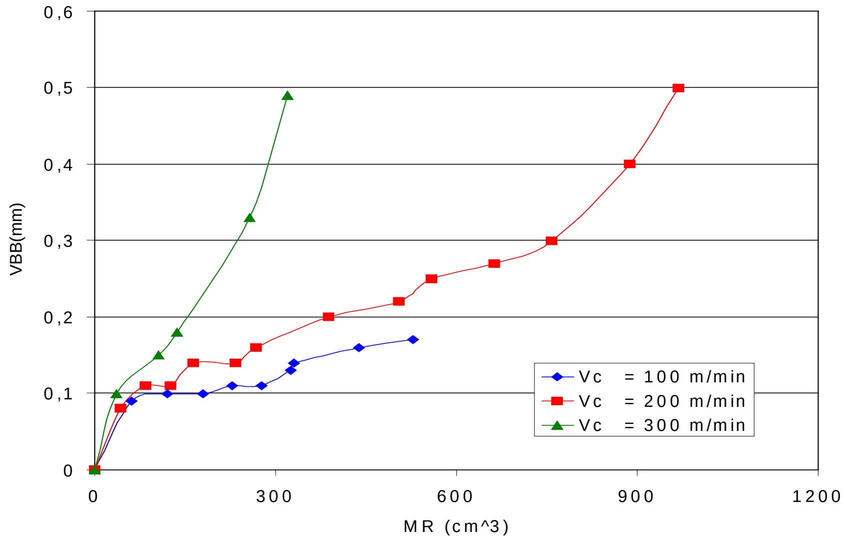


Figure 2. Tool wear against metal removal for the VRA tool (f=0,3 mm/rot e a_p=1mm).

As can be noticed in Fig. (3), an increase in feed rate results in higher tool wear, however, this is not observed for metal removal, see Fig. (4). In this case, a feed rate of 0,5 mm/rot provides a slightly larger metal removal throughout the test, being outperformed by f=0,4mm/rot only at the end of the experiment. In contrast, the lowest feed rate (f=0,3 mm/rot) reached the tool life criterion giving the lowest amount of removed metal.

Figure 5 represents tool life and metal removal against cutting speed for the VRA tool using a feed rate of 0,3 mm/rot and depth of cut of 1 mm, whereas Fig.(6) shows tool life and metal removal against feed rate for the same tool material (v_c=200 m/min and a_p=1mm). In both cases it can be noticed that for a tool life criterion of VB_B=0,5 mm, tool life is reduced as either cutting speed or feed rate are increased. In contrast, maximum metal removal is achieved employing intermediate cutting speed and feed rate values (v_c=200 m/min and f=0,4 mm/rot, respectively).

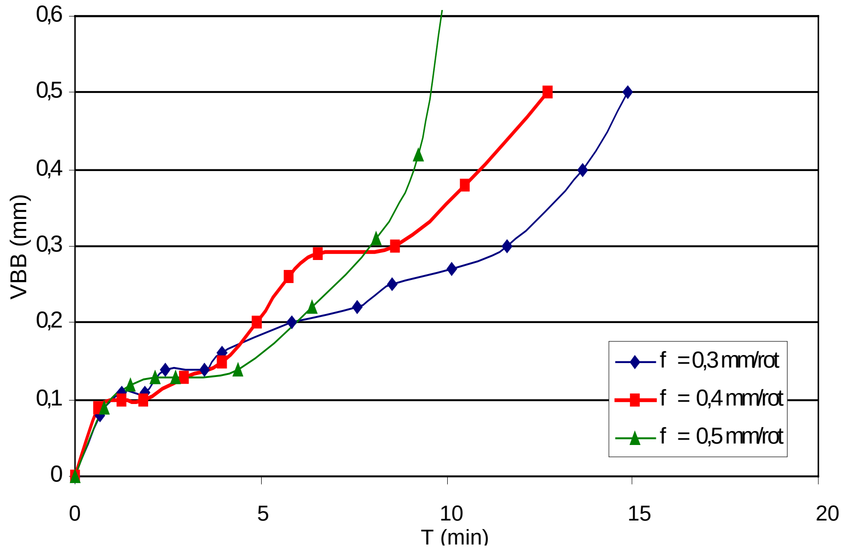


Figure 3. Tool wear against cutting time for the VRA tool (v_c=200 m/min and a_p=1mm).

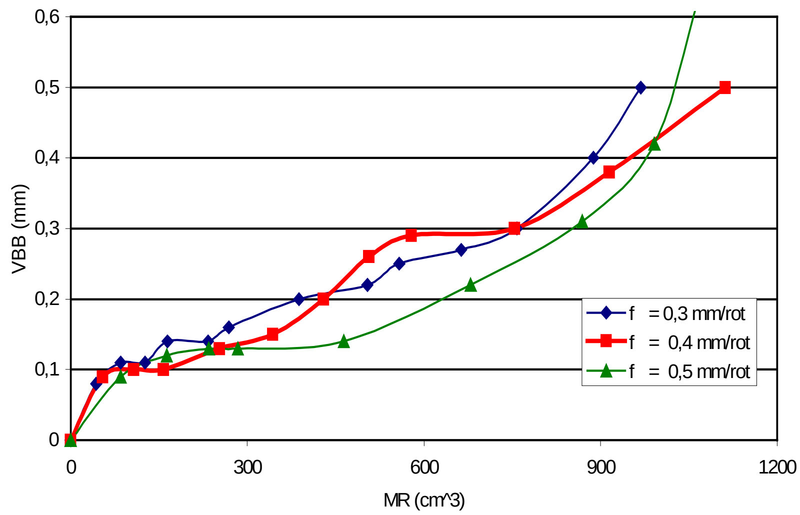


Figure 4.Tool wear against metal removal for the VRA tool (v_c=200 m/min and a_p=1mm).

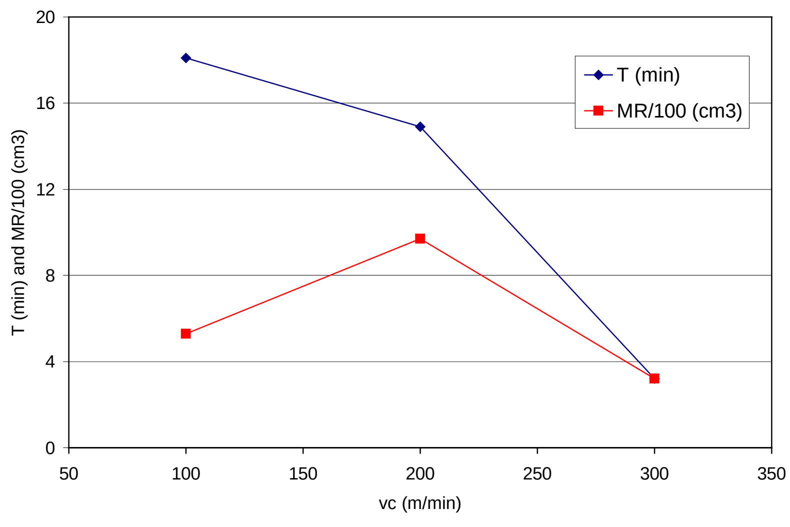


Figure 5. Tool life and metal removal against cutting speed for the VRA tool (f=0,3 mm/rot e ap=1mm).

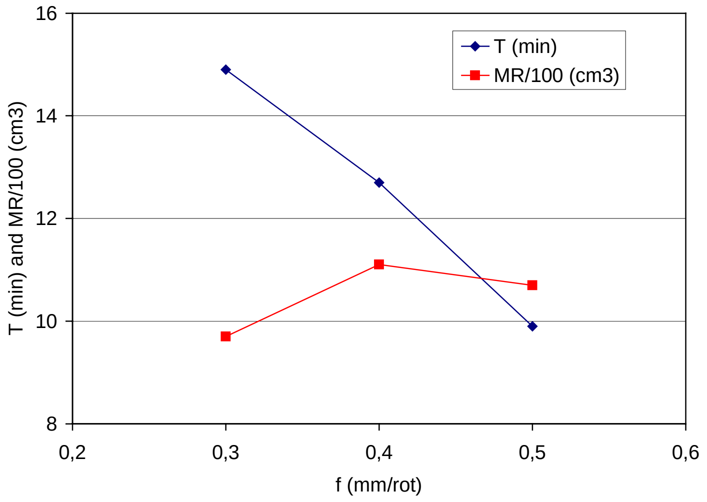


Figure 6. Tool life and metal removal against feed rate for the VRA tool (v_c=200m/min and a_p=1mm).

Figures (7) and (8) compare the performance of VRA and UC6010 tools under the cutting parameters which provided best results for the former tool material (cutting speed of 200 m/min, feed rate of 0,4mm/rot and depth of cut of 1 mm). The results indicate that the UC6010 cutting tool possesses superior wear resistance compared to VRA with regard to both cutting time, see Fig.(7), and metal removal, see Fig. (8), thus allowing the removal of 1423 cm^3 against 1112 cm3 before VB_B=0,5 mm.

Figures (9) and (10) compare the surface roughness values produced after turning the annealed hot work die steel. They show, respectively, the evolution of the average (Ra) and maximum (Rt) values against cutting time for the following cutting conditions: v_c=200 m/min, f=0,4 mm/rot e a_p=1mm. In both cases it is plain that UC6010 is capable of producing better surface finish. This is not unexpected since UC6010 presented superior wear resistance, see Fig. (7). Comparing these findings with the theoretical roughness values (Ra=6,4 μm and Rt=25 μm) it can be observed that UC6010 produced a surface finish better than predicted, whereas the results given by VRA were within the expected range. This is not true for the maximum roughness values, which results were not as good as those for Ra.

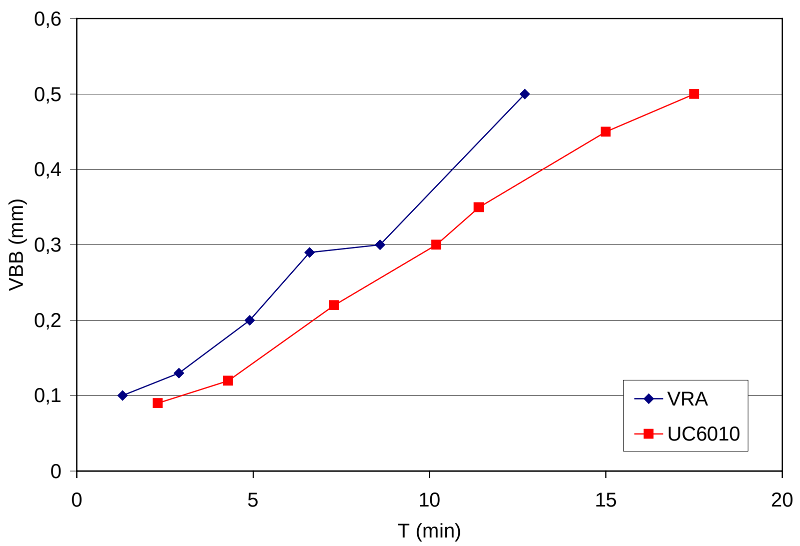


Figure 7. Tool wear against cutting time for VRA and UC6010 tools (v_c=200 m/min, f=0,4 mm/rot e a_p=1mm).

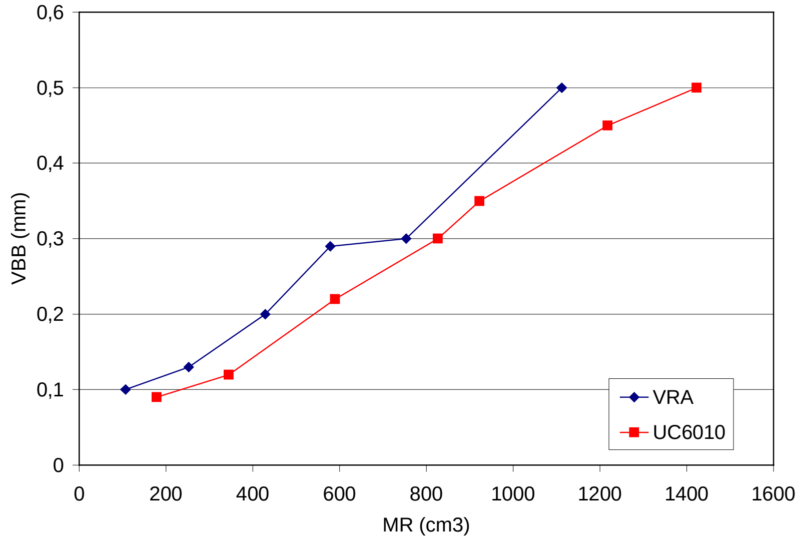


Figure 8. Tool wear against metal removal for VRA and UC6010 tools (v_c=200 m/min, f=0,4 mm/rot e a_p=1mm).

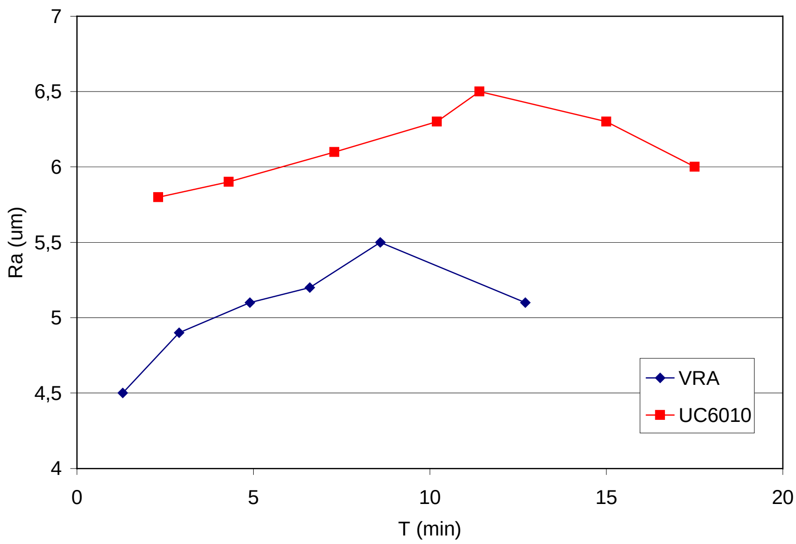


Figure 9. Average surface roughness (Ra) against cutting time for VRA and UC6010 tools (v_c=200 m/min, f=0,4 mm/rot e a_p=1mm).

As far as the swarf produced is concerned, in general the chip breaker presented a satisfactory performance, with the chips form varying from ribbon to helical as cutting speed is decreased or feed rate is increased. When comparing the tool materials under the same cutting parameters (v_c=200m/min, f=0,4mmrot and a_p=1 mm), both produced helical chips, however the swarf produced by the UC6010 insert was short, whereas that generated using the VRA tool was long, as can be seen in Fig. (11).

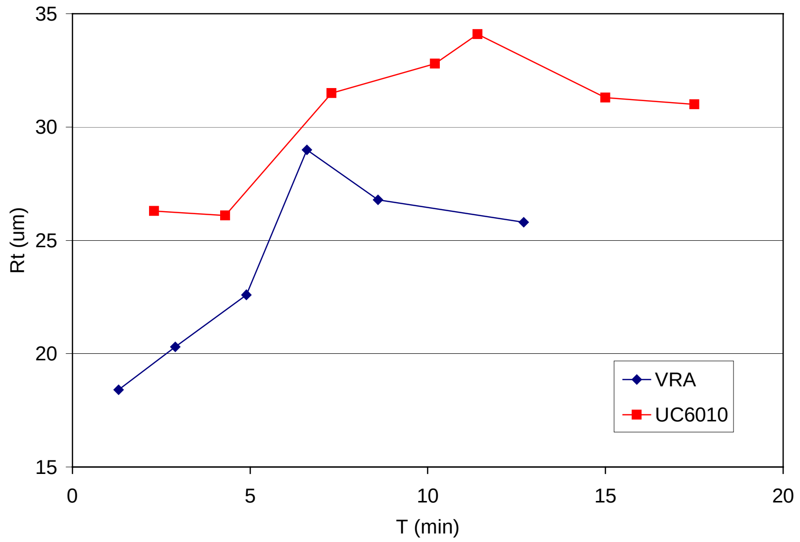
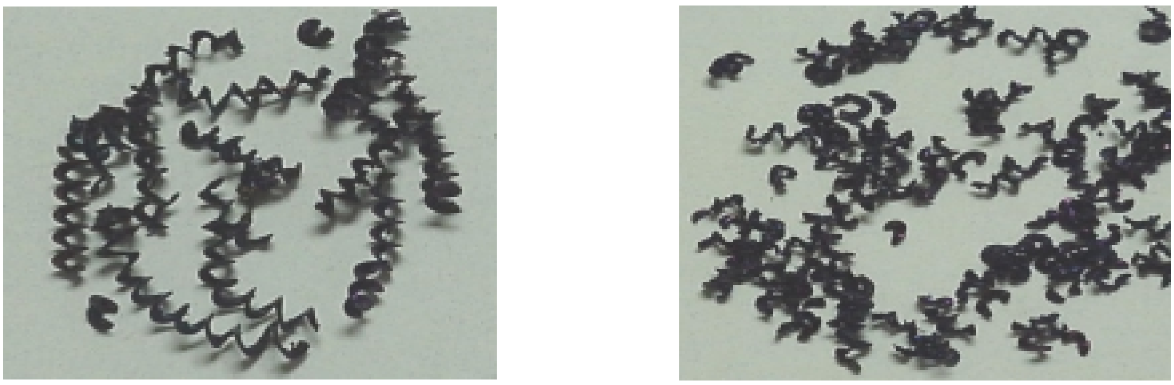


Figure10. Maximum surface roughness (Rt) against cutting time for VRA and UC6010 tools (v_c=200 m/min, f=0,4 mm/rot e a_p=1mm).



(a) VRA (b) UC6010

Figure 11. Swarf produced when cutting at v_c=200m/min, f=0,4mm/rot and a_p=1mm using: (a) VRA and (b) UC 6010 tools.

4. Conclusions

After continuous dry turning annealed AISI H13 hot work die steel (230 HV) with coated carbide tools, the following conclusions can be drawn:

- An increase in cutting speed results in higher tool wear rates, however, employing an intermediate cutting speed of 200 m/min, highest metal removal is obtained before reaching the tool life criterion;
- Similarly, the tool wear rate increases with feed rate and f=0,4 mm/rot gives best results with regard to metal removal;
- Using intermediate cutting conditions (v_c=200 m/min, f=0,4 mm/rot and a_p=1mm) the UC6010 coated carbide tool outperformed the VRA coated carbide when evaluating tool life, metal removal, surface finish and swarf control;

5. Acknowledgements

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