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Thermomechanical Treatment Influence on the Cutting Behaviour of the HSS Tools

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Abstract The paper shows the cutting behavior of the three high-speed steels, which were thermomechanical treated. The performed studies highlight that unconventional treatment (thermomechanical) applied to the high-speed steels improves their technological properties. To benefit from this improvement, the deformation degree applied at studied steel must be up to 70% (ideal between 50-70%). Thermomechanical treated steels were used in the manufacturing of various types of cutting tools, which were subsequently tested in the cutting process. The volume of processed results being great, the paper presents the cutting behavior of the disk-type of milling cutters (disk cutter). Through geometry and shape this type of tool is suitable to be processed by thermomechanical treatment. In tests were used both normal cutting regimes and hard (specific to this steels). The performances of cutting tools made through the thermomechanical treatment are superior to those conventionally manufactured. Specifically, regardless the cutting speed or time, the cutting tools from first category are worn less than those classics.

Keywords High-speed Steel, Thermomechanical Treatment, Cutting Behavior, Cutting Tools, Wear

1. Introduction

The manufacturing of high-speed steel (HSS or HS) in the early 1900s concomitant with the applying of quenching to high temperatures was an important step in the cutting tools evolution. The developing of new materials for cutting tools did as the utilization of high-speed steel to be diminished, not abandoned. The high-speed steel field was not explored and exploited at full capacity, reason for that was initiated the research presented in this paper. Due to a price/quality acceptable ratio, a good hardness and toughness, high-speed steel tools will be produced. In the worldwide there are many attempts to improve the tools performance, using the unconventional processes. In the case of HSS, through cryogenic treatment the tool performances can be increased with 44%, in certain cutting conditions Da Silva[1]. For the long tools with small diameters, a good work piece surface roughness can be achieved, provided the tooth passing frequency used in the milling process Mendes de Aguinar[2]. By the applying a laser treatment for the tool surface is obtained a good layer hardness, thus as, the tool do not lose its working stability and to make the tool surface more resistant to action in external conditions. For the tool wear not only the hardness of the processed material has a vital role, but also the microstructure and thermal characteristics of the tool material (metallurgical powder) Klocke[3]. Under the action of the vibrations applied during welding, the material behavior is better: the density of the material deposited increases, tensions and friction of the basic material go down Luca[4]. The unconventional treatment demonstrated more improvement in the wear resistance and hardness compared with conventional heat treatment Sri Siva[5].

The previous researches have shown that applying a thermomechanical treatment (TMT or thermomechanical treatment – plastic deformation fallowed by the HSS specific heat treatment) improves both the hardness and toughness. The research program was conducted in three stages. In the first stage were determined certain mechanical and technological characteristics of the studied high-speed steels, whose were applied thermomechanical treatments. The second stage studied the thermomechanical treatment influence on the hardness and wear of these. The last stage of the research that is presented in this paper, determined the cutting behavior of the HSS tools obtained through the thermomechanical treatment. The chemical composition of the steels studied is presented in table 1. The symbolization in various standards of the studied steels is given in table 2.

Table 1. Chemical composition of the studied high-speed steels

High-speed steel type	Chemical composition [%]					
	C	Cr	Mo	W	Co	V
HS6-5-2C	0.84-0.94	3.8-4.5	4.7-5.2	6.0-6.7	≤ 0.6	1.7-2.0
HS2-9-1-8	1.05-1.15	3.5-4.5	9-10	1.2-1.9	7.5-8.5	0.9-1.3
HS3-3-2	0.95-1.03	3.8-4.5	2.5-2.8	2.7-3.0	≤ 0.6	2.2-2.5

Table 2. Symbolization in various standards of HSS

DIN	EN	Werkstoff	Bohler	AISI/SAE
HS6-5-2C	HS6-5-2C	W.1.3343	S600	M2
HS2-9-1-8	HS2-10-1-8	W.1.3247	S500	M42
HS3-3-2	-	W.1.3333	-	-

Theapplying of thermomechanical treatment to the high-speed steels had a positive effect on the mechanical and technological properties. More specifically, the steel microstructure, the hardness, toughness and bending resistance increased. These properties are essential for cutting tools, reason for that they also have been studied.The effectuated studies have shown that the applying of an additional deformation to the high-speed steels, improves the properties, if the deformation degree is between 50-70% Catana[6]. The thermomechanical treatment applied to the high-speed steels was of high temperature (deformation temperature between 900-1100^oC) and the plastic deformation was performed with deformation degree between 50-70%. The thermomechanical treatment of the studied steels had next steps:

- heating until the plastic deformation temperature (maximum temperature 1050-1100^oC depending of the steel types);
- plastic deformation by repression for obtaining the deformation degree and geometrical shape;
- reheating at the quenching temperature (maximum temperature 1220-1230^oC depending of the steel types) followed by air jet cooling.

The tempering was made by the classical method. Last step was the machining that was performed by grinding for sharpening and to obtain the final geometrical shape. Through this process were realized the cutting tools of disk cutter (disk-type of milling cutter) category, because this method is economic efficient only for the tools with large dimensions (diameter) and complex geometry (see fig. 1).

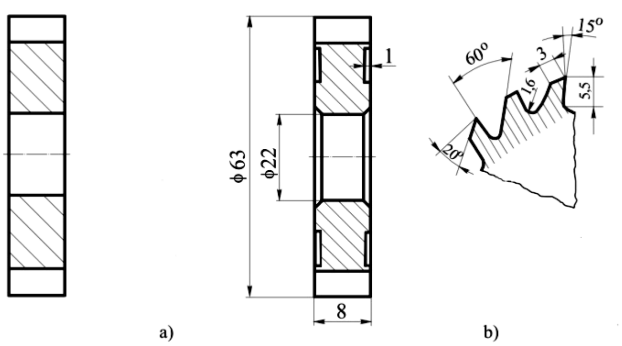

Figure 1. Dimensions and geometry of the disk cutter: a) disk cutter dimension, b) details of the tooth geometry

2. Theoretical Considerations

The disk cutters obtained by thermomechanical treatment were tested to the cutting behavior. The comparison was made with the disk cutters obtained by classical method Catana[7]. The test conditions were heavy and normal. All cutting tests (trials) effectuated were conducted in according with the manufacturer testing standards, available for this tool type.

The heavy testing conditions were:

- cut (chipped) material C 45 (EN/DIN), of 500 mm length and hardness of 182 HB;
- cooling fluid, composed of the emulsified oil in water (5% oil), the flow rate of 5 litres/minute.

To obtain the relevant results, the tests were performed on the tools with different diameters, widths and teeth numbers. The behavior of all these tools in cutting was better than similar tools but obtained by conventional methods. The volume of the test results being large, the paper presents only the results effectuated for a disk cutter with the diameter of 63 mm, 8 mm width a teeth number of 16. The milling cutters materials were of HS6-5-2C, HS2-9-1-8 or HS3-3-2 high-speed steels. It also should be noted, that the disk cutters were obtained by the thermomechanical treatment as it was described above. The dimension and geometry of the disk cutter were shown in figure 1.

For the performed tests were kept constant the following parameters:

- cutting depth t = 9.5 mm;
- feed per tooth f_d = 0.09 mm.

These values were determined based on the information defined by the manufacturer of tools. The standards also required the values of the cutting speed: v_p = 20 … 28 m/min. For the tested tools type (ϕ = 63 mm), the milling machine spindle speed was:

$$v_p = \pi \cdot D \cdot n / 1000 \Rightarrow n = 1000 \cdot v_p / \pi \cdot D \text{ [rev/min]}, \quad (1)$$

where: *D* is the disk cutter diameter. For v_p=28 m/min, the value for n is 141 rev/min. Was adopted n = 118 rev/min (rpm) (spindle speed existing on the milling machine), that corresponding to v_p = 23.35 m/min, speed that is in the mentioned interval.

The feed value was:

$$v_s = tn \cdot f_d \cdot n = 16 \cdot 0.09 \cdot 118 = 169.92 \text{ [mm/min]}, \quad (2)$$

where: *tn* is the teeth number. Was adopted v_s = 150 mm/min (s = 1.27 mm/rev), because existing on the milling machines. The trial aim is to determine the wear value on the back edge, to make a comparison between the behavior of face disk cutters obtained by the thermomechanical treatment and the classic. After behavior trial should not be observed the breaches, wear marks or other defects. After the tests, the disk cutter must be used further at cutting. The wear width on the back edge does not exceed 0.2 mm.

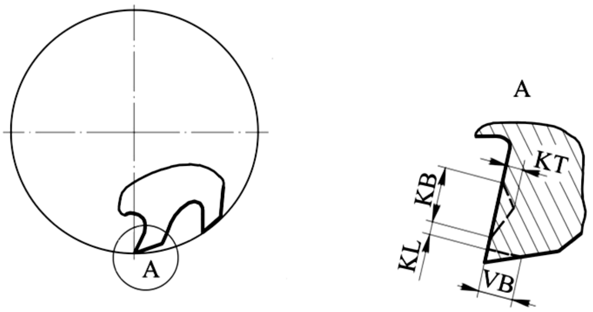

Figure 2. Wear types of cutting part

The figure 2 shows the types of wear that may occur at cutting tools:

- VB – wear width on the back edge;
- KB – crater width;
- KL – distance from the milling tooth peak to the crater origin;
- KT – crater depth.

The wear measurement was performed after with the milling cutters were chipped a distance of 6 meters or 12 meters. For a more accurate results at how the milling teeth are worn, the measurement was performed every two teeth, more precisely to the odd teeth. The cutting process parameters used in the heavy test are presented in table 3.

Table 3. Heavy regime parameters

Parameter Regime	v_p [m/min]	s [mm/rot]	t [mm]
A	23.35	1.27	9.5
B	29.68	1.56	9.5
C	37.60	1.57	9.5

3. Experimental Results

The results of the performed trials are presented in figure 3. Although the cutting test was performed on a length greater than that provided in the manufacturer standards, to the tested milling cutters there was no appearance the breaches (pinching) or broken teeth neither to the disk cutters obtained by thermomechanical treatment neither to those obtained by the classical method.

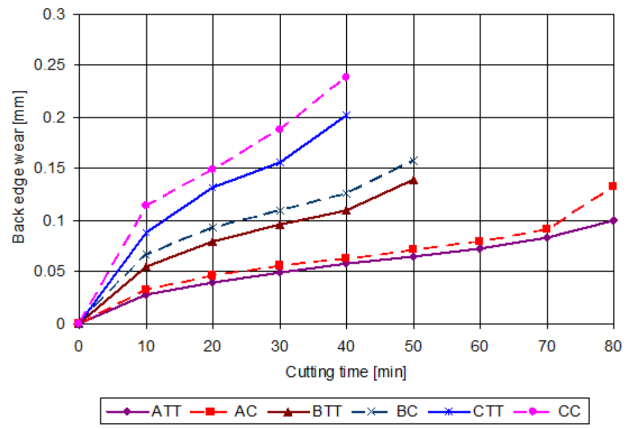

Figure 3. Variation in time of the wear, depending of speed for the HS6-5-2C: A, B, C – cutting regime, TT – thermomechanical treatment, C – classical process (ATT – thermomechanical treated disk cutter, tested in regime A)

A first conclusion is that the thermomechanical treatment did not cause the high-speed steel brittleness, that leading to the mechanical and technological properties deterioration of the HS6-5-2C steel. The analyze of figure 3 shows that independent of the cutting speed used during the behavior tests, the teeth wearing is lower at the disk cutter obtained by plastic deformation.

The figure 4, 5 and 6 show the evolution of the wear depending of the cutting speed.

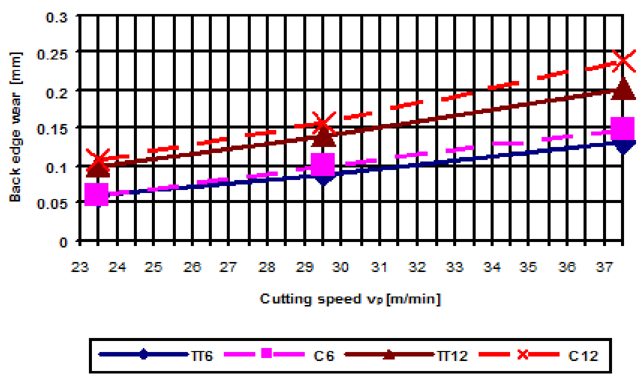

Figure 4. Evolution of wear depending of speed for HS6-5-2C: 6, 12 meters testing distance

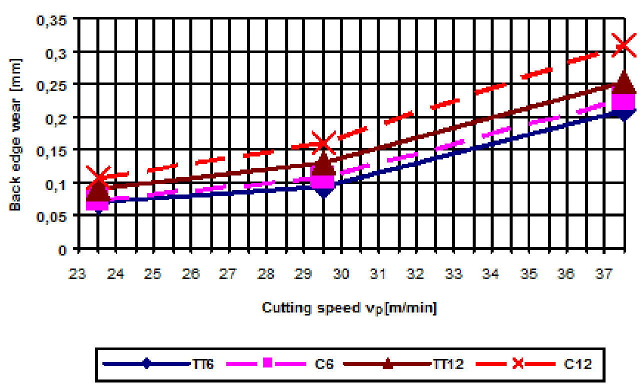

Figure 5. Evolution of wear depending of speed for HS3-3-2: 6, 12 meters testing distance

The above figures show that for the disk cutters obtained by thermomechanical treatment, the back edge wear is lower than those produced by the classical method. The figure 6 shows that for the HS2-9-1-8 steel, the wear values are close of the wear values for the HS6-5-2Csteel. Perhaps this wear evolution is influenced of the high percent of Co, which produce cobalt carbides, compensating in this mode, the W lower percent.

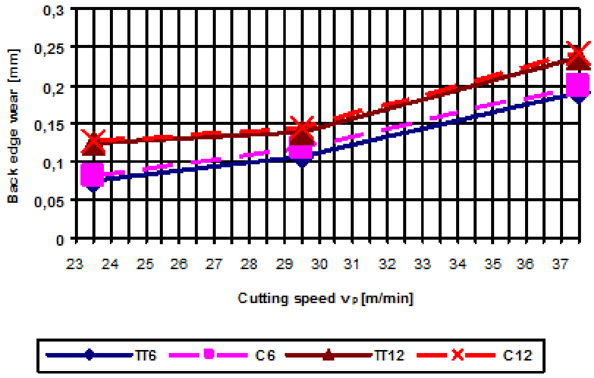

Figure 6. Evolution of wear depending of speed forHS2-9-1-8: 6, 12 meters testing distance

For the lower cutting speeds the wear differences are reduced, but when the cutting speed increases, the differences between wears are greater. Because the testing conditions described above were heavy, same trials are made for the cutting normal conditions for such tool types and processing. The parameters of the normal cutting regime are shown in table 4.

Table 4. Normal cutting regime parameters

Parameter Regime	vp [m/min]/[rpm]	sd [mm]	t [mm]
A	11.70/60	0.06	1.4
B	14.60/75	0.06	1.4
C	18.60/95	0.06	1.4
D	23.35/120	0.06	1.4

The trial aim was to completion of the information about the cutting behaviour of the disk cutters of the studied steels obtained by the thermomechanical treatment. The results of these tests are shown in figure 7.

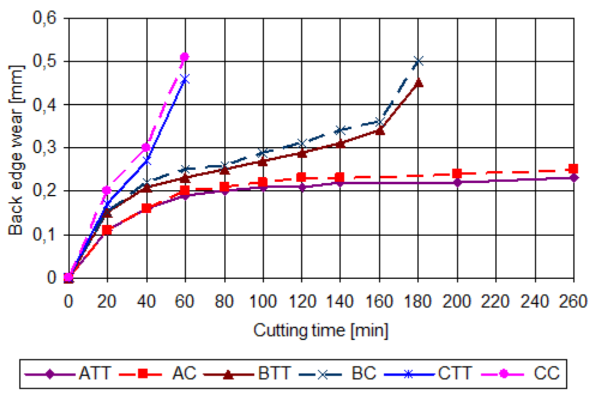

Figure 7. Variation in time of the wear depending of speed for HS6-5-2C: A, B, C – cutting regime, TT – thermomechanical treatment, C – classical process

The wear study is made using the same disk cutters type, previously presented. The cut (chipped) material was a C 45 steel with 175 HB, the cooling fluid flow rate was of 3 l/min. The tests were done for the each cutting speed through wear measuring on the back edge, at every 20 minutes. The figure 7 shows that at the trial beginning the wear is almost identical for the two types of disk cutters and as the cutting time increases, the differences between wears are greater. The wear differences between steel grades are presented better in figure 8. For studied steel grades in the case of classical cutting tools the wear is greater than those obtained by thermomechanical treatment.

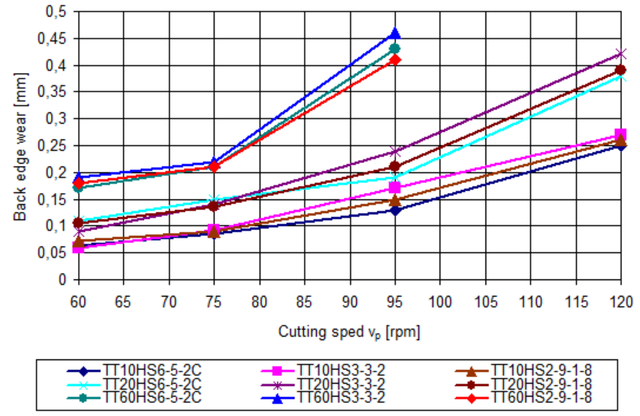

Figure 8. Wear evolution depending of cutting speed: 10, 20, 60 test time [min], TT – thermomechanical treated

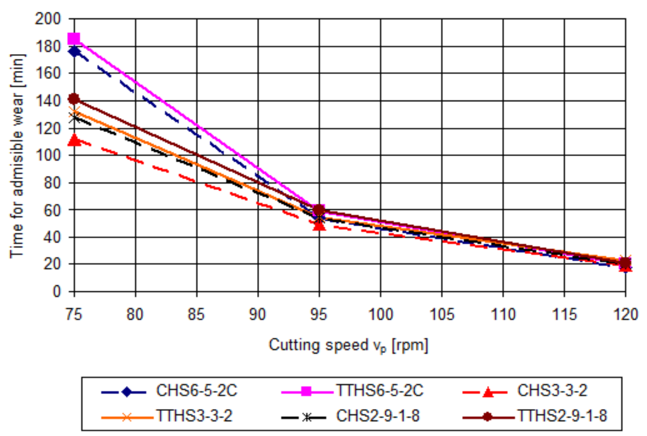

Figure 9. Durability (tool life) variation depending of speed for studied steels: TT – thermomechanical treatment, C – classical process

The figure 8 analysis shows that for small testing speeds the wears are close for all high-speed steel grades. In the case of great value of speeds, the differences between wears begin to be accentuated. The small values of wear are for the HS6-5-2C and than for the HS2-9-1-8. If the cutting speed is 75 or 95 rpm and the trial time of 60 minutes the small wear is for the HS2-9-1-8.

According to the manufacturer recommendation of the disk cutters, it is considered that the tools have reached to the admissible wear value, when its value on the back edge is of 0.4 mm. For this case, it was considered as the admissible back edge wear, the h_α = 0.45 mm value, for which is built the chart of the figure 9. The figure 9 shows which high-speed steel grade has the highest durability. This is HS6-5-2C and the second place is occupied by the HS2-9-1-8.

The tests as those previously presented were performed and for the disk cutters with diameters of 80, 100 and 125 mm. The cutting process parameters necessary for tests were calculated with (1) and (2). The tests show that, the disk cutters obtained by thermomechanical treatment have a smaller wear, in comparison with those obtained by classic method.

4. Conclusions

The general conclusion is that the cutting tools behavior obtained by thermomechanical treatment is superior to those produce by classical methods (processing entirely by cutting). Also, the paper presents the cutting behavior of cutting tools obtained by thermomechanical treatment applied at different high-speed steel grades. Comparing the evolution of the two disk cutters categories (obtained by classical and thermomechanical processes) can draw the following conclusions:

- the disk cutters realized by thermomechanical treatment are worn less than those classical, regardless of the rotation speed or cutting time;
- at the high cutting speeds, specific for this material, the differences are becoming more clearly, of course in favor of those thermomechanical treated;
- when the tools are new, the durability of the disk cutters obtained by thermomechanical treated is between 8.70 and 9.50% (depending of the cutting speed and the steel grades) higher than the classical disk cutters;
- the thermomechanical treated disk cutters maintain, better their cutting properties, after regrinding, in comparison with those classical (this test is not presented in paper);
- the best results in tests are obtained for the HS6-5-2C steel fallowed by the results of HS2-9-1-8 steel.

The applying of the thermomechanical treatment for the studied high speed steels determines superior mechanical and technological properties, reason which influences in better the tools behavior obtained of materials, thus processed. A disadvantage of the thermomechanical treatment applying is that become profitable for certain tools types, more precisely for the tools with large dimensions and complicated geometries.

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