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Effect of Cryogenic Treatment on HSS Tool

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Abstract— *Studies on cryogenically treated high speed steel tools show microstructural changes in the material that can influence tool lives and productivity significantly. Results in the literature show tool life improvements from 92% to 817% when using the cryogenically treated HSS tools in the industry. However, the real mechanisms which guarantee better tool performance are still dubious. This implies in the need of further investigation in order to control the technique more scientifically. This work aims to verify the effect of cryogenic treatment on M2 high speed steel tools after using either laboratories or shop floor tests in an automotive industry. Sliding abrasion and hardness tests were also carried out as well as microstructural analysis*.

***Keywords*— HSS Tool, Cryogenic treatment, High Speed Steel**

I. INTRODUCTION

The need to develop more and more resistant tool materials able to cut increasingly resistant workpiece materials and the demand of the technological development for higher productivity and lower costs have caused many tool materials with excellent properties such as cemented carbide, cermets, ceramics and ultra hard materials (CBN, PCBN and PCD) to emerge. High speed steel (HSS) can also be included in this list since this tool material is fairly well used in the industry to date, although being developed more than a century ago. Its main applications are for drills, taps, milling cutters, broaches and also bits where the economical cutting speed is too low to think about carbide tool.

With the time, since their creation, the properties of the HSS tools were considerably improved. The perfect combination of alloying elements and the domain of heat treatment processes conferred to this material excellent hardness and wear resistance properties allied to good toughness. As a result of technological advance a great variety of HSS tools are actually available, including coated and powder metallurgy tools. In recent decades interest in low temperature effects have been demonstrated particularly during heat treating cycles of tool steels. Some literature data indicates that the lives of tools and other steel components may increase significantly after being submitted to subzero (below 0 ◦C) temperatures. The results can be surprisingly good, depending on the application. Reports of 92–817% increases in tool lives after they have being treated at −196 ◦C are found [2].

II. LITERATURE SURVEY

The articles found in the literature about this subject vary tremendously from mere promotional information until full scientific publication. The lack of common sense in the literature regarding to the metallurgical aspects that cryogenic treatment confers better wear resistance and consequently higher tool lives as well as contradictory results that are also encountered [3–5] The latter kind of articles may offer metallurgical details and the mechanisms that will guarantee improved properties of the tools. The first users of this technique [6] applied temperatures in the range of −80 to −100 ◦C for periods of about 30 min–1 h, and the improvement on tool life was credited to the transformation of retained austenite (softer) into martensite (harder) and the production of a more stable structure. In general the addition of alloying elements lowers the Ms (temperature of the beginning of martensite transformation) and Mf (final transformation temperature) lines in a way that the latter dwells at subzero temperatures. The conventional heat treatment normally uses cooling conditions only until room temperature, which may leave some retained austenite on the microstructure. This fact must be considered during heat treatment of tool steels. For the eutectoid steel the Mf temperature is of approximately of −50 ◦C, therefore after quenching some percentage of retained austenite will be present [8]. Lately this structure can be transformed into martensite if the material is submitted to reheating or to a stress field, causing distortion on its body. This non-tempered martensite may cause cracks, particularly in complex shape tools made of highly alloyed steels [9]. The subzero treatment will transform a great deal of this retained austenite by reaching the Mf line, giving more dimensional stability in the tool microstructure. Barron [10] has attributed the improvement of the wear resistance of these tools to another mechanism besides the transformation of the retained austenite into martensite. He verified that the tool steels submitted to conventional heat treatment presented only a small amount of retained austenite, but those submitted to cryogenic treatment showed better performance during machining. This new mechanism would be time and temperature dependent due to the long period (8 h or more) during which the tools would have to stay at cryogenic temperatures. Before the cryogenic treatment the microstructure showed relatively large carbides (20 m) dispersed in the matrix. After the cryogenic treatment, carbide particles as small as 5 m were found. The carbide refinement could in such a way contribute to the improvement of the wear resistance of the tool. Barron thus attributed this achievement both to austenite transformation and to the presence of hard and small carbide particles well distributed among the larger carbide particles within the martensite

III. EXPERIMENTAL PROCEDURE

Fig. 1 shows a flowchart with the resume of the activities developed in this work in order to compare the cryogenically. treated tools with the conventionally treated ones, highlighting the tests carried out in the laboratory and at the shop floor of a car manufacturer industry.

2.1. CUTTING TOOLS

The cutting tools used in the machining tests are:

A and D: Lathe tool of M2 high speed steel with the dimensions of 10 mm × 10 mm × 102 mm.

B and E: Twist Drills of M2 high speed steel with 7.5 mm of diameter.

C and F: Special milling cutter of M2 high speed steel with a 3m TiN coating.

The first two tools (A and B) were laboratory tested while the last tool (C) was tested at the shop floor of a car manufacturing industry. The tools came from the same batch to avoid possible performance variation due to variation caused by the manufacturing process.

2.2. CRYOGENIC TREATMENT

The tools were cryogenically treated at Cryo Quality Ltd. Company using equipment that could completely control the thermal cycle in terms of temperature and time. A recommended thermal cycle for this tool material was used, consisting of a cooling to a temperature of −196 ◦C followed by three cycles of heating to temperatures in the order of +196 ◦C for tempering, lasting a total of 43 h. Fig. 2 illustrates this thermal cycle.

The following steps were taken for the cryogenic treatment, after the tools were conventionally quenched and tempered: • Step 1: Cooling to −196 ◦C (4 h at a rate of 1 ◦C/mim);

Step 2: Cold stabilization at −196 ◦C (20 h);

Step 3: Heating to +196 ◦C (8 h at a rate of 1 ◦C/mim);

Step 4: Hot stabilization at +196 ◦C (2 h);

Step 5: Cooling to room temperature (1 h average);

Step 6: Stabilization at room temperature (2 h);

Step 7: Heating to +196 ◦C (1 h average).

Steps 5–7 were repeated three times. Before the cryogenic treatment the tools have previously been submitted to conventional thermal treatment to obtain the secondary hardness (conventional quenching and tempering). This sequence was chosen following the work developed by Yun et al. [16]. According to them the cryogenic treatment in M2 high speed steel can be applied either after quenching and tempering or straight after the quenching. Their results with tools cryogenically treated straight after the quenching were apparently better than those obtained with the tool cryogenically treated after quenching and tempering. Regardless the rout the materials can usually have their properties improved with cryogenic

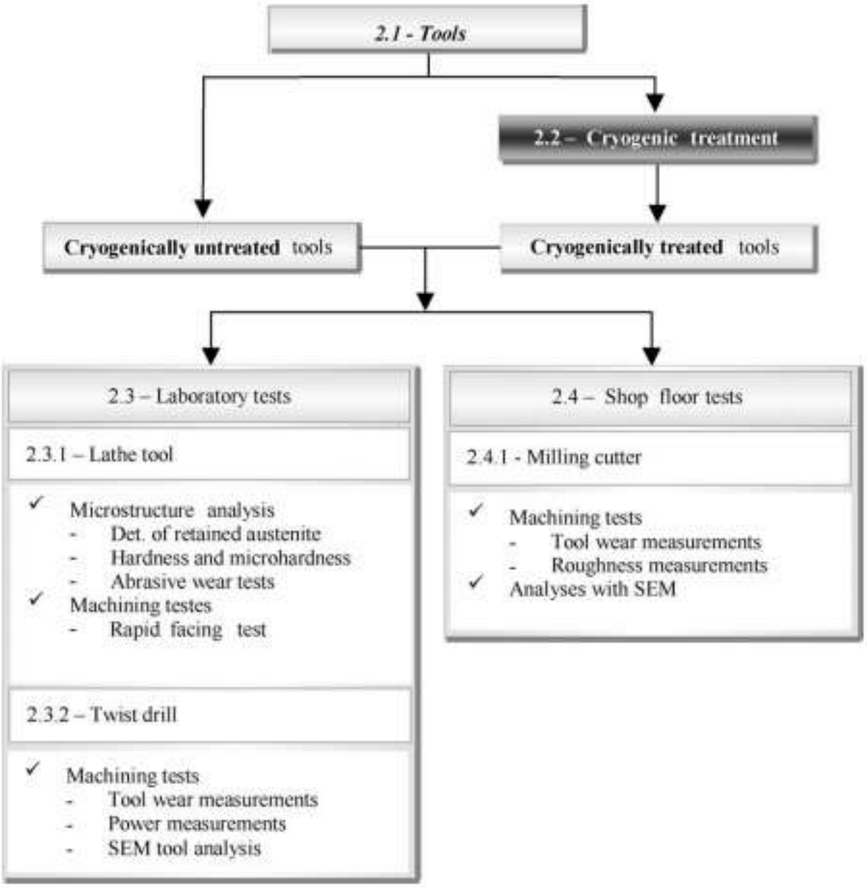

FIG 1 EXPERIMENTAL TEST CARRIED OUT

Shop floor tests (special shaper milling cutter) presents the values of the average flank wear of the right and left milling cutters (new tools) after machining 200 workpieces for the teeth nos. 1 and 2. The cryogenically treated tools present higher average flank wear than the untreated tools. This fact was also observed when using resharpened tools. Although the wear of the cryogenically treated tools were higher than the untreated ones the surface roughness generated by the two tools were very similar (Ra varying from 0.99 to 1.63m for the surface generated by the treated new tools and from 0.98 to 1.41 m for the new untreated tools).

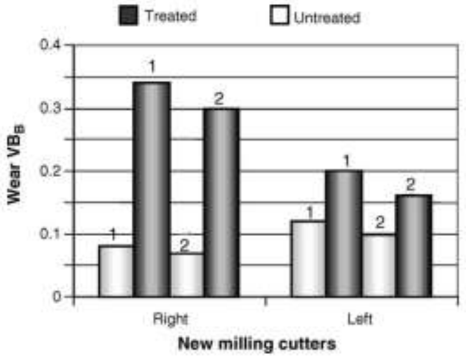

FIG .2 FLANK WEAR OF MILLING CUTTER

IV. CONCLUSION

Based on the results obtained in the present investigation the following conclusions can be drawn: 1. The hardness and the microhardness of the M2 HSS samples were not significantly affected by the cryogenic treatment. 2. The samples cryogenically treated showed a fraction very close to 0% of retained austenite. This means that practically the 25% in volume of the retained austenite observed in the untreated sample were transformed into martensite by the cryogenic treatment. 3. A superior performance of the cryogenically treated tools compared to the untreated ones was observed in the Brandsma rapid facing test. This difference reached 44% in some cutting conditions. 4. The difference on the percentage of retained austenite of the cryogenically treated and untreated samples did not alter the abrasive wear rate at the conditions used here for the sliding abrasion tests. This is possibly due to the ability of the austenite of the untreated samples to harden during plastic deformation either by workhardening or by its transformation into martensite. These phenomena may compensate the gain obtained by precipitation of fine carbides in the cryogenically treated samples. 5. The cryogenic treatment increased the performance of the M2 HSS twist drills. The gain observed during drilling steels adopting catastrophic failure as the end of tool life criterion varied from 65% to 343% depending on the cutting conditions used. 6. Shop floor tests with cryogenically treated coated HSS milling cutters presented worse performance than untreated tools when shaping the top surface of the teeth of gear rings. 7. Overall the cryogenic treatment had favourable influences on the performance of the tools tested. This means that depending on the application the cryogenic treatment may be a good alternative for having productivity enhancement. Optimization of the parameters involved in the whole thermal cycle must, however, precede the application.A conclusion section must be included and should indicate clearly the advantages, limitations, and possible applications of the paper. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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