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REGULAR ARTICLE

Effect of the Number of Tempering Cycles on the Improvement of the Durability of a High-Speed Steel Cutting Tool

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The high-speed steel Z80WCV 18-04-01 is highly valued in intensive machining for its exceptional characteristics such as high hardness and heat resistance. Composed of carbon, chromium, tungsten, and vanadium, this steel is particularly suitable for manufacturing cutting tools such as lathe tools, milling cutters, drills, and taps. The cumulative tempering process plays a crucial role in enhancing these properties, directly influencing the performance and durability of turning tools. This research aims to evaluate the effects of different tempering treatments on Z80WCV 18-04-01 high-speed steel turning tools, focusing on hardness, toughness, and microstructural changes, tempering involves heating the steel to a specific temperature below its critical point and then cooling it, which modifies its internal structure to achieve desired mechanical properties. By varying the tempering temperature and duration, researchers can tailor the steel's hardness and toughness to optimize performance in cutting applications. Understanding these changes is essential for developing tools that can withstand the demanding conditions of industrial machining processes, the microstructural analysis will provide insights into how the steel's grain size, carbide distribution, and phase composition evolve with different tempering treatments.

Keywords: Hardness, Resistance, Cutting tools, Lathe tools, Toughness.

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1. INTRODUCTION

Heat treatment of cutting tools is a critical step in their manufacturing process aimed at optimizing their performance and durability under severe cutting conditions. This process typically involves operations such as controlled heating, holding at specific temperatures, and proper cooling to achieve desired microstructures and mechanical properties.

Recent studies have explored various aspects of heat treatment applied to tool steels. For instance, research such as that conducted by [1] has examined the influence of heat treatment parameters on wear resistance and the durability of cutting tools. Similarly, analyses have investigated the effects of heat treatments on dimensional stability [2] and resistance to deformation of tools in high-speed cutting environments. Research on heat treatments can significantly impact the durability of cutting tools in specific working environments [3], such as those involving high temperatures or high speeds.
The coatings are promising materials for wide application, for example, as protective coatings against rapid tool wear [4, 5]. Tal to wood, plastics, and composites, makes them versatile tools suitable for various applications.

They are widely used in sectors such as aerospace, automotive, shipbuilding, manufacturing, and construction. Their ability to produce precise and uniform chamfers meets the rigorous quality standards of these industries [6].These studies highlight the crucial importance of precise control over heat treatment parameters to achieve finely tuned microstructures and optimal mechanical properties. Integrating this knowledge into the design and manufacturing of cutting tools plays a decisive role in the competitiveness and efficiency of modern machining processes.

Conventional heat treatment of micro-alloyed steels includes quenching and tempering. Tempering at different temperatures and durations can provide a beneficial combination of microstructure and precipitates [7, 8]. Multiphase microstructures and various carbide types further meet the requirements for excellent mechanical properties in high-speed tool steels [9-11].

The precipitation of fine particles during tempering plays a crucial role in enhancing the strength and toughness of ultra-high-strength micro-alloyed steels. Numerous studies on carbide precipitation evolution under different tempering times, studied the precipitation evolution in tool steels during multi-tempering at 680 °C for 100 hours. They observed that M3C carbides initially transformed from M-A particles, followed by precipitation of MC carbides. The M3C particles gradually refined and rounded, while M23C6 carbides coarsened with increasing tempering time. Moon et al. [12] clearly demonstrated the sequence of carbide precipitation in tool steels. They also found that the precipitation sequence during tempering at 650°C was: MC + M3C →

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MC → MC + M7C3 + M23C6, the evolution of different carbides in tool steels after tempering and found that M23C6 exhibited higher thermal stability compared to M7C3 [13]. The carbide precipitation sequence can be summarized as follows: M3C → M7C3 → M23C6. Conversely, Asadabad et al. [14] reported that some M23C6 carbides transformed into M7C3 in tool steels. Janovec [15] reported that Cr content determines the precipitation transformation sequence in Cr steels. With the addition of 1 wt % Cr, the precipitation sequence in Cr-Mo-V steels was proven to be M23C6 → M7C3 [16]. In medium to high Cr steels, Jia et al. identified four types of precipitates, M2X, M3C, M23C6, and M7C3, with M7C3 showing lower thermal stability compared to M23C6 [17-19].

2. EXPERIMENTAL METHOD

2.1 Tool Drawing

The drawing below depicts a slitting tool, which consists of two parts: an active part and a fastening part. Our tool also includes two angles: a cutting angle and a clearance angle. The dimensions are shown on the drawing. After each wear of the active part, it must be sharpened, meaning the cutting angle and the clearance angle. The tool has a specific lifespan.

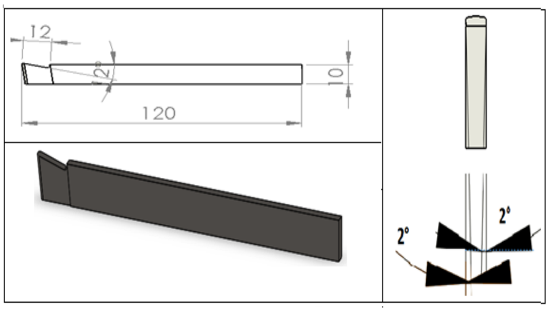

Fig. 1 – Cutting tool

2.2 Chemical Composition

Cutting tools made of high-speed steel maintain their high hardness up to a temperature of 650°C. High-speed steel is characterized by its high hardness.

Table 1 – Chemical composition of steel Z80WCV 18-04-01

Number of pieces	Heat treatments	HRC
1	Quenching	66
1	Quenching and 1 temper	63
1	Quenching and 2 temper	64
1	Quenching and 3 temper	64.5
1	Quenching and 4 temper	65

2.3 The Description of the Microstructure

Describing a globular perlite structure with carbides in a steel such as Z80WCV 18-04-01 involves identifying the microstructural phases and their distinctive characteristics. Here is a general description of this microstructure.

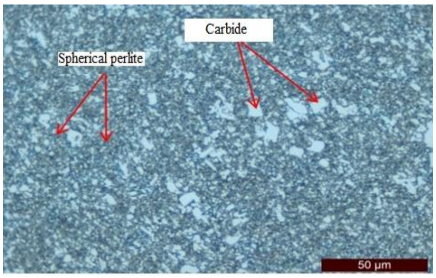

Fig. 2 – Raugh material

Perlite is a microstructure composed of alternating lamellae of ferrite and cementite, resulting from a eutectoid transformation during the cooling of a hypoeutectoid steel. In the case of globular perlite, the ferrite and cementite lamellae take on a globular form rather than a lamellar one.

Carbides are hard intermetallic phases primarily composed of carbon and a metallic element. In the case of Z80WCV 18-04-01 steel, one can expect the presence of tungsten (W), chromium (Cr), and vanadium (V) carbides. These carbides form during the solidification and cooling of the steel due to the segregation of alloying elements.

3. RESULTS AND DISCUSSION

3.1 Hardness

The table. 2 shows that:

- Hardness (HRC) varies between 63 and 66 for
- different heat treatments applied.
- The highest hardness in the quenched state is approximately 66 HRC.
- Applying a single tempering process after quenching results in a hardness decrease (63 HRC).
- The second and third tempers have only a minimal effect on hardness, maintaining it around 64 HRC (secondary hardening).
- The fourth temper shows a slight increase in 65HRC

Table 2 – Hardness after quenching and the tempering.

Designation	%C	%Si	%Mn	%Cr	%w	%Fe	%V
Wt.%	0.79	0.39	0. 19	3.69	17.851	75.39	0.984

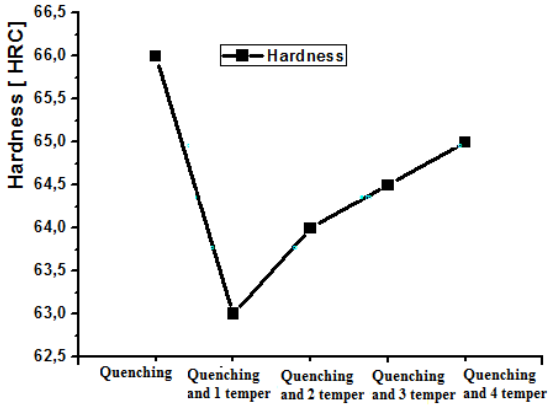

Fig. 3 – Hardness curve as a function of heat treatment

In Fig. 3, we have plotted hardness as a function of the treatments applied. We observe that hardness decreases from 66 to 63 HRC (in the case of the first temper), and from this point onward, it begins to increase until reaching 65 HRC.

3.2 The Lifespan and Number of Machined Parts

The results of our study on the lifespan of cutoff tools at each income level, essential tools in various mechanical construction parts manufacturing processes. Cutoff tools play a crucial role in the precise shaping of parts. To assess their performance, we analyzed the different heat treatments applied to the tools, namely quenching followed by multiple tempering cycles (ranging from one to four cycles). These heat treatments were the sole parameter we considered to influence their lifespan, measured by the number of parts cut before the tool needs to be sharpened. The results of this study, detailed in the following table, provide valuable insights for enhancing the efficiency and longevity of cutoff tools, thereby contributing to more reliable and cost-effective production.

In Table No. 3, we summarized our results. We mentioned that, among the tool samples, one tool underwent quenching and a single tempering cycle and machined 700 pieces. Another tool underwent a second tempering cycle and cut 1000 pieces, while a tool subjected to four tempering cycles cut 1600 pieces.

Therefore, the conclusion drawn is that the number of tempering cycles on our tools has a significant influence. The tempering treatment factor yields good results. If regler was intended to be translated as conclude or determine, it's appropriately used as conclude in this context see Table No. 3 below.

Table 3 – Results of lifespan according to the number of machined piece

The sample size of the cutting tools	Heat treament	The average number of machined piece
1	quenching and 1 tempering cycle	700
1	quenching and 2 tempering cycle	1000
1	quenching and 3 tempering cycle	1400
1	quenching and 4 tempering cycle	1600

The results obtained clearly indicate that the number of machined parts is proportional to the number of tempering cycles. There is a gradual increase in the tool lifespan with each additional tempering cycle undergone, maintains better cutting performance and increased wear resistance, allowing it to remain effective over a longer period of time. Additionally, the number of machined parts also increases as the cumulative number of tempering cycles increases. This means that the cutoff tool is capable of sustaining its cutting capability for a greater amount of work before showing signs of wear or loss of effectiveness. The best results were achieved with the tool that underwent 4 cumulative tempering cycles, showing significant machining time and a high number of machined parts. This confirms that this heat treatment has significantly enhanced the durability and performance of the high-speed steel tool. These findings underscore the importance of cumulative tempering cycles in enhancing the cutting performance of high-speed steel, thereby prolonging tool life and increasing overall productivity.

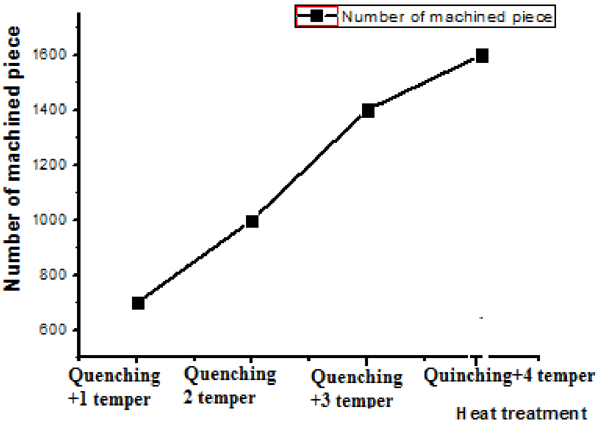

Fig. 3 – Number of machined pieces according to tool

4. CONCLUSION

The material studied is the high-speed steel Z80WCV 18-04-01, widely used for cutting tools due to its excellent mechanical properties and wear resistance. After quenching followed by an initial tempering at 560 °C for 1 hour, the microstructure of the steel primarily consists of tempered martensite, which is very hard but partially softened and stabilized by the tempering process. Primary carbides are still present. A second tempering at 560°C for 1 hour further transforms the martensite into tempered martensite, enhancing its stability and ductility, with reduced but persistent presence of residual austenite and very fine carbides. Following a third tempering at 560 °C for 1 hour, the majority of the structure comprises tempered martensite, offering a good combination of hardness and toughness, with some persistent islands of residual austenite. A fourth tempering at 560 °C for 1 hour results in a structure entirely composed of tempered martensite, ensuring excellent toughness with moderate hardness and an absence of residual austenite, indicating high material stability.

Hardness test results show that the hardness (HRC) varies between 63 and 66 for the different heat treatments applied. The highest hardness in the quenched state is 66 HRC. Applying a single tempering after quenching decreases the hardness to 63 HRC. The second and third temperings have minimal effect on hardness, maintaining it around 64 HRC (secondary hardening). The fourth tempering shows a slight increase in hardness to 65 HRC.

In conclusion, this study demonstrates the significant impact of heat treatments on the tested tool samples.

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Вплив кількості циклів загартування на підвищення довговічності ріжучого інструменту зі швидкорізальної сталі

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Швидкорізальна сталь Z80WCV 18-04-01 високо цінується при інтенсивній обробці завдяки своїм винятковим характеристикам, таким як висока твердість і термостійкість. Ця сталь, що складається з вуглецю, хрому, вольфраму та ванадію, особливо підходить для виготовлення ріжучих інструментів, таких як токарні верстати, фрези, свердла та мітчики. Кумулятивний процес відпустки відіграє вирішальну роль у покращенні цих властивостей, безпосередньо впливаючи на продуктивність і довговічність токарних інструментів. Це дослідження має на меті оцінити вплив різних процедур відпуску на токарні інструменти для швидкорізальної сталі Z80WCV 18-04-01, зосереджуючись на твердості, в'язкості та мікроструктурних змінах. Відпуск передбачає нагрівання сталі до певної температури, нижчої за її критичної точки, а потім охолодження, яке змінює його внутрішню структуру для досягнення бажаних механічних властивостей. Змінюючи температуру та тривалість відпуску, дослідники можуть підбирати твердість і міцність сталі для оптимізації продуктивності при різанні. Розуміння цих змін має важливе значення для розробки інструментів, які можуть витримувати складні умови промислових процесів механічної обробки. Аналіз мікроструктури дасть уявлення про те, як розмір зерна сталі, розподіл карбіду та фазовий склад змінюються з різними обробками відпуску.

Ключові слова: Твердість, Опір, Ріжучий інструмент, Токарний верстат, В'язкість.