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MECHANICAL PROPERTIES OF CHROMIUM STEEL DRILLS IN THE CONTEXT OF DURABILITY AND SAFETY OF USE

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Zbigniew Bałaga[1] – *orcid id: 0000-0002-7004-7037*, e-mail: zbigniew.balaga@pcz.pl
Michał Opydo[1] – *orcid id: 0000-0002-3632-4504*, e-mail: michal.opydo@pcz.pl
Agata Dudek[1] – *orcid id: 0000-0001-9115-028X*, e-mail: agata.dudek@pcz.pl
Barbara Lisiecka[2] – *orcid id: 0000-0002-0945-3423*, e-mail: barbara.lisiecka@ipo.lukasiewicz.gov.pl
[1]Faculty of Production Engineering and Materials Technology, Czestochowa University of Technology, Av. ArmiiKrajowej 19, 42-201Częstochowa, **Poland**
[2]Łukasiewicz Research Network, Institute of Industrial Organic Chemistry, Explosive Techniques Research Group, Zawadzkiego 1 Street, KrupskiMłyn, 42-693, **Poland**

Abstract: This article presents the research results on the influence of heat treatment of chromium steel, used in the production of drill bits, on their mechanical properties and operational safety. The analyses revealed that the steel used in manufacturing the studied drill bit underwent hardening and tempering processes, which affected its structure and hardness. The presence of tempered martensite and manganese sulfides was observed, which, although not having a destructive impact on the steel's properties, may limit the formation of undesirable iron sulfides. Additionally, a layer with reduced hardness was identified on the working surface of the drill bit, suggesting the possibility of tool overheating during operation. During the tool's use, complex mechanical stresses, such as torsional, compressive, and bending stresses, may accumulate in areas prone to damage, especially at the interface between the tooth and the drill bit shank. The article emphasizes the importance of proper tool usage, including adjusting pressure and drilling angle and maintaining optimal operational conditions to ensure safety and durability. The research findings aim to enhance workplace safety and improve the performance of cutting tools in materials engineering.
Keywords:heat treatment, chromium steel, drill bit, operational safety, stresses

1. INTRODUCTION

Safety in materials engineering, particularly regarding the use of cutting tools like drills, is a critical issue for both work efficiency and the health protection of machine operators. Drills, being one of the most fundamental tools in machining processes, must possess appropriate mechanical properties to ensure high drilling efficiency and safe operation under various working conditions (Bansal, 1990; Bryant and White, 2000;Uhl et al., 2023;Holm, 2005; Raju, 1998; Wang& Shih, 2011).
The research in this study focuses on analyzing the impact of heat treatment on chromium steel used in the production of the tested drill and its influence on mechanical properties

and operational safety (Hu et al., 2024). Processes such as hardening and tempering are designed to enhance hardness and wear resistance (Botti et al., 2017; Uhl et al., 2022; Zhang et al., 2023; Momeni et al., 2017); however, they can also alter the material structure, potentially leading to tool failure during use in extreme scenarios (Spasova et al., 2022, Jantunen, 2002).

This work specifically investigates the drill steel's microstructure, which shows the presence of tempered martensite and manganese sulfides (MnS) that may influence the mechanical properties of the drill. The identified changes in hardness across the drill surface indicate a possibility of overheating during use, which can reduce strength and compromise safety. Such structural changes could weaken the drill, particularly in regions subject to stress concentration, such as the junction between the cutting edge and the drill's core (Spasova et al., 2022; Susmel, 2022; Jiang et al., 2024; Liu et al., 2019; Bagni et al., 2015, Leitner et al., 2017).

The safe use of cutting tools requires careful attention to the materials, production process, and appropriate working conditions, including control over applied pressure, rotational speed, and drilling angle (Wang et al., 2021). Improper drill use, such as excessive overheating or applying excessive pressure, can damage the tool and elevate accident risks. Furthermore, maintaining the proper condition of the drill holder and avoiding undesirable vibrations –which can create additional stresses on the tool–is essential for ensuring safety during drilling (Uhl et al., 2021; Kessai et al., 2022; Botti, 2020; Lindenmann et al., 2021).

Heat treatment issues are also of great importance for other areas, both industrial (Ulewicz et al., 2013; Wrońska et al., 2019) and military (Krysiak et al., 2020). The obtained material properties can be further improved using special coatings (Radek, 2009) and possibly superalloys (Szczotok et al., 2017). The characteristics of special coatings can be shaped to a vast extent using laser processing, both in tribological (Radek&Antoszewski, 2009; Radek et al., 2021) and corrosion aspects (Scendo et al., 2012; Scendo et al., 2013). The obtained effects are of great importance, among others, for the railway industry (Radek et al., 2019; Radek et al., 2020), the machinery industry (Żórawski et al., 2008; Markovic et al., 2021), the energy sector (Fialko et al., 2019) and construction (Orman et al., 2022). However, the issue of waste management, especially that contaminated with heavy metals (Radzymińska-Lenarcik&Ulewicz, 2019), remains an open issue. To fully master the problems, the industry undoubtedly needs very well-educated engineering staff (Radek et al., 2023).

In materials engineering, the conducted research is a vital step in enhancing the durability of cutting tools and their safety. Understanding the link between heat treatment, material structure, and the mechanical properties of drills facilitates the development of more effective tools that are not only more durable but also safer to use under various machining conditions and different types of workpiece (Liu et al., 2024, Jiang et al., 2024).

2. RESEARCH RESULT

The tests were conducted on a concrete drill bit with a length of 1000 mm and a diameter of 10 mm, featuring an SDS+ shank. During operation, the drill bit cracked in the working part, approximately 20 mm from the end of the shank designed to be mounted in the drill chuck (Fig. 1).

To determine the type of steel used in the production of the tested drill bit, a chemical composition analysis was performed using a Bruker Q4 Tasman spark spectrometer. The results revealed that the steel used for the drill bit is chemically similar to 40Cr steel, although it was found to have a higher carbon content than the range permitted by the standard (Table 1). The sulfur content was also exceeded.

Fig. 1. Macro image of the drill bit damage location

Table 1
Chemical composition of 40Cr steel as recommended by the standard and as determined by spectrometer analysis, wt. %

Permissible chemical composition according to the standard									
C	**Si**	**Mn**	**Cr**	**Mo**	**Ni**	**Cu**	**P**	**S**	**Fe**
0.37-0.44	0.17-0.37	0.50-0.80	0.80-1.10	max. 0.15	max. 0.30	max. 0.30	max. 0.035	max. 0.035	rest
Tested chemical composition									
0.519	0.224	0.579	0.829	0.0029	0.017	0,022	0.012	0.058	rest
Standard deviation									
0.0039	0.014	0.0011	0.0012	0.00005	0.0081	0.0004	0.0005	0.0005	-

To determine the cause of the fracture in the tested drill bit, we analyzed the structure of the steel from which the drill bit was made, along with the fracture surfaces at the breakpoint, using the Keyence VHX-6000 light microscope and the JEOL JSM-6610LV scanning electron microscope, equipped with an Oxford EDS chemical composition analyzer. The steel exhibited a martensitic structure (Fig. 2) with visible precipitates. The chemical composition analysis of these precipitates revealed the presence of manganese sulfides, as shown in Fig. 3.
Microstructural analysis of the material plays a crucial role in assessing its durability and resistance to damage during operation. The microstructure of chromium steel, including the distribution of phases and the presence of inclusions or cracks, directly influences the fracture and wear mechanisms of the drill bit. Specifically, microstructural defects, such as grain size variation or the presence of heterogeneous phases, can weaken the material, increasing the risk of drill bit failure under challenging working conditions. Therefore, a thorough microstructural analysis enables a better understanding of damage mechanisms and optimization of the drill bit production process, which directly affects their safety and operational efficiency.

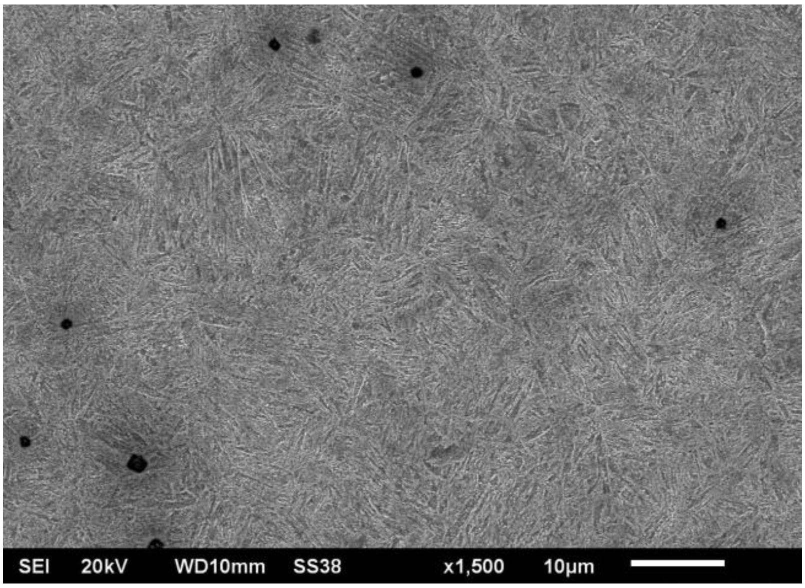
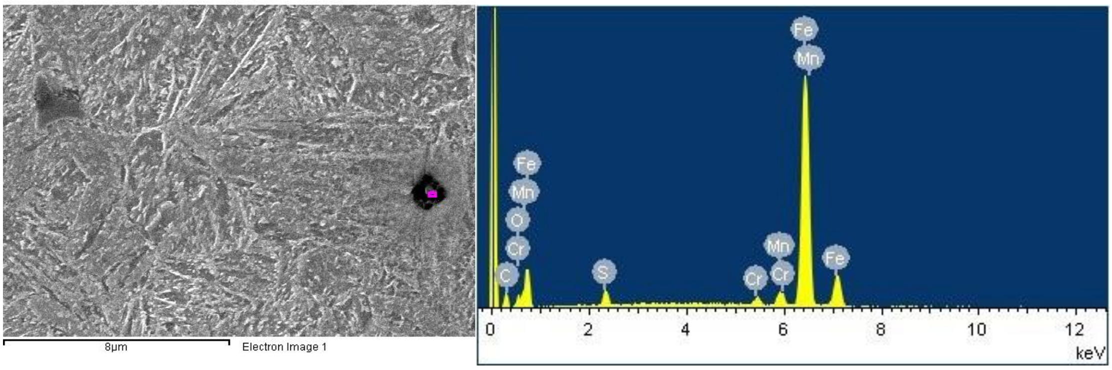


Fig. 2. Microstructure of the steel used for manufacturing the drill bit (mag. 1500x)



Fe	Mn	S	Cr	O
90.90	4.28	1.94	1.54	1.30

Fig. 3. Chemical composition analysis of precipitates in the steel microstructure (mag. 7500x), wt. %

Examinations of the fracture surfaces on both sides of the broken drill bit revealed that the fractures were of a fatigue nature, with visible microcracks (Figures 4 and 5). Additionally, during microscopic observations, a very thin layer approximately 5 μm thick was observed on the fracture surface, differing from the drill bit's internal microstructure (Figure 6). Chemical composition analysis using a scanning electron microscope did not reveal significant differences in elemental composition compared to other examined microareas. To determine the mechanical properties of the tested drill bit, microhardness measurements were performed using the Vickers method. The measurements were carried out using a Shimadzu HMV-G microhardness tester, applying a load of 980.7 mN (HV0.1). The tests were performed on the cross-sectional area of the drill bit at various locations, including near the working surface of the drill, around the cutting edge, and the spiral groove that facilitates chip removal during drilling, as well as in the core of the drill bit. The obtained values are presented in Table 2.

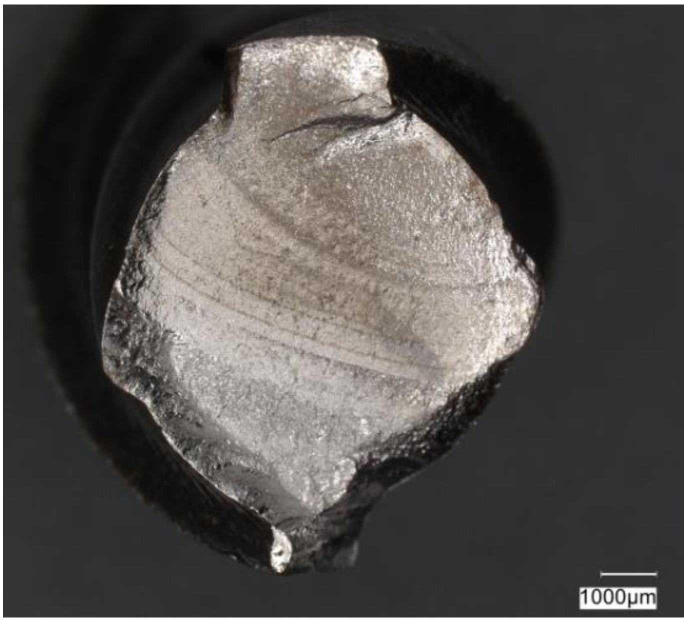


Fig. 4. View of the fracture surface at the point of drill bit failure

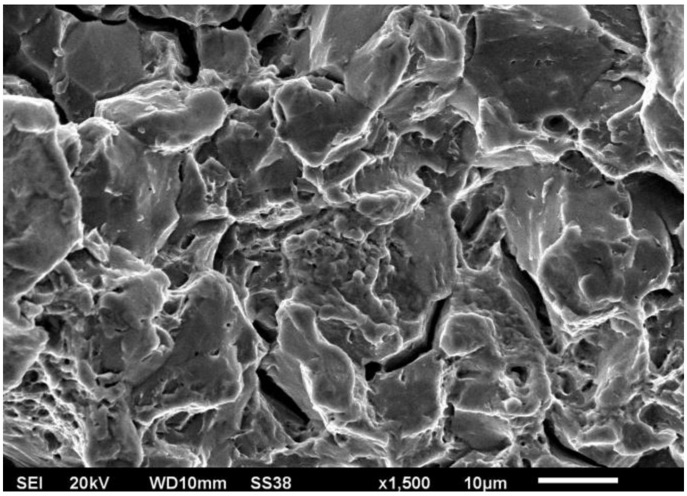


Fig. 5. Displays the fracture surface at the drill bit failure point, highlighting visible microcracks (mag. 1500x)

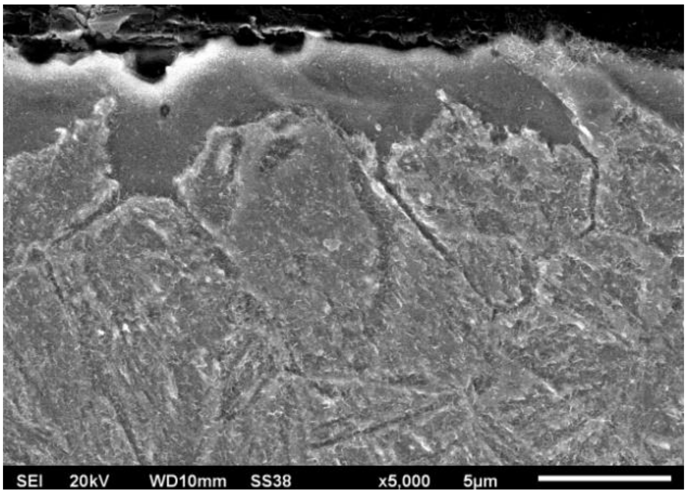


Fig. 6. Microstructure near the surface of the drill bit (mag. 5000x)

Table 2
Microhardness measurement results

Drill surface HV0.1	Drill core HV0.1
450.5	486.7
Standard deviation	**Standard deviation**
12.3	8.1

3. SUMMARY

The conducted studies have shown that the shank of the tested drill bit is made of chromium steel, which underwent heat treatment, including hardening and tempering. The material structure revealed the presence of tempered martensite and manganese sulfide (MnS) precipitates. Although these sulfides do not have a detrimental effect on the steel's properties due to their high melting point, they play a role in limiting the formation of unwanted iron sulfides.

A thin layer, several micrometers thick, was observed on the working surface of the drill bit. During metallographic sample preparation, this layer did not etch in the same way as the core of the drill bit. The chemical composition of this layer was similar to that of the steel used, suggesting its homogeneity with the base material. Microhardness measurements revealed that the hardness near the surface of the drill bit (450,5 HV0.1) was lower than that of the core (486,7 HV0.1), which may indicate the possibility of tool overheating during use. This phenomenon could result from improper temperature management, leading to a reduction in the hardness of the martensitic surface layer.

In terms of drill bit usage, temperature control is a crucial factor in ensuring operational safety, especially in avoiding tool overheating. The operator should adjust the feed force and drill feed rate according to the hardness of the material being drilled to prevent tool damage. Additionally, during drilling, especially with longer drill bits, it is important to maintain the correct drilling angle (perpendicular to the surface) and ensure the drill holder is in good condition. It is important to avoid situations where the drill holder in the power tool allows for vibrations, which could induce additional stresses in the tool.

During the drilling process, the drill bit is subjected to significant mechanical challenges that can lead to damage. Specifically, attention should be given to the complex stress state, which includes:

- Torsional stresses, arising from the torque generated by the rotational movement of the drill bit,
- Dynamic compressive stresses, caused by the impact of the drill bit on the material being drilled, as well as stresses induced by excessive pressure on the tool,
- Bending stresses can occur if the drilling angle is incorrectly positioned.

The analysis of the fatigue fracture characteristics in the tested drill bit and the location of crack propagation in the area where the cutting edge meets the core suggests that the failure may have resulted from the accumulation of various stresses. The most vulnerable area for these phenomena is the corner where the cutting edge joins the core of the drill bit, where stress concentrations, microstructural damage due to tool overheating, and the hardness difference between the surface and core of the drill bit occur.

The results of these studies are crucial for the design of drill bits and ensuring their safe operation, particularly in the context of machining materials that require precise temperature and stress management during drilling. The use of modern heat treatment methods, such as laser treatment or induction processes, can bring further benefits in optimizing the mechanical properties of chromium steel used in drill production. These technologies allow for more precise control of treatment parameters, which can result in materials with improved hardness, higher wear resistance, and greater stability under harsh operating conditions. In practice, the introduction of such innovative methods can significantly enhance the durability of drill bits, thereby reducing operational costs and increasing efficiency in industrial processes. Thanks to these technologies, it becomes possible to design tools with higher resistance to extreme temperatures, pressures, and mechanical loads, which is crucial in industries that require high reliability.

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