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Effect of Cryogenic Treatment on the Wear and Corrosion Resistance of the ELMAX tool Steel

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Abstract

In our research, we investigated how the wear and corrosion resistance properties of ELMAX tool steel change during cryogenic treatment. The tool steel was heat treated in two different ways: con-ventionally, and using cryogenic treatment. From the two differently heat treated workpieces, 3 spe-cimens each were subjected to wear and corrosion tests. Based on the obtained results, it can be sta-ted that both the wear resistance and corrosion resistance improved as a result of the cryogenic tre-atment. These properties can clearly determine the usability of the material in many applications.

Keywords: *heat treatment, cryogenic treatment, wear, corrosion.*

1. Introduction

Tool steels are fundamental pillars of modern industry, as they play a crucial role in the manufacturing of machines, tools, and equipment due to their high hardness, strength, and wear resistance.

These optimal mechanical properties are determined by the material's chemical composition and the carefully selected heat-treatment procedures, which transform the internal structure of the steel to meet specific requirements.

The heat treatment of tool steels is a complex process aimed at modifying the microstructure in such a way that the steel attains the desired properties. One of the most commonly applied procedures is the combination of quenching and tempering [1]. During quenching, the steel is heated to a high temperature (austenitic state), followed by rapid cooling, producing a hard but brittle martensitic structure. This is then followed - often in multiple steps - by tempering operations, which fine-tune the microstructure, optimizing hardness, toughness, and corrosion resistance according to the intended industrial application.

To further optimize conventional procedures, recent research has shifted toward the use of deep cryogenic treatment between quenching and the first tempering step. This operation specifically targets the refinement of the martensitic structure by minimizing the amount of retained austenite. As a result of deep cryogenic treatment, the strength and wear resistance of the steel improve.

Tempering after cryogenic treatment promotes carbide precipitation and increases martensite stability, enabling further enhancement of hardness and wear properties. Deep cryogenic treatment presents both new possibilities and new challenges in maximizing the often contradictory requirements of tool steels (e.g., toughness vs. wear resistance).

The goal of our investigation is to present and compare in detail the effects of two different heat-treatment procedures on the properties of a specific tool steel, ELMAX. The comparison focuses on the following two processes:

- Conventional procedure: Quenching followed by three tempering cycles;
- Cryogenic procedure: Quenching, cryogenic treatment, then three tempering cycles.

By comparing the results, the study illustrates the differences between the characteristics achievable by the two technologies.

Armed with these comparative results, it becomes possible to improve the efficiency of industrial production by providing guidance for selecting the appropriate heat treatment technology.

2. Material grade

The tool steel examined in this study is Uddeholm ELMAX SuperClean, distributed in Hungary by voestalpine High Performance Metals Hungary Kft [2].

Table. 1. *Chemical composition of ELMAX* [2]

Element	Content (weight %)
C (carbon)	1.7
Si (silicon)	0.8
Mn (manganese)	0.3
Cr (chromium)	18.0
Mo (molybdenum)	1.0
V (vanadium)	3.0

ELMAX is a powder-metallurgy tool steel developed by the Swedish company Uddeholm in the early 2000s.

Its purpose was to combine the advantages of traditional high-wear-resistance tool steels with the corrosion resistance of stainless steels.

Thanks to powder-metallurgy technology, it features a homogeneous microstructure and excellent properties, including high wear resistance, good machinability, and dimensional stability. It was originally developed for injection molding and extrusion tools, but today it is widely used, for example, in the production of premium kitchen knives, as well as tactical and survival knives [3].

3. Conducted Tests and Heat Treatments

To evaluate the properties, hardness measurements, wear and corrosion tests were carried out.

The specimen preparation was performed in the laboratory of Polyax Ltd. Hardness was measured using an Ernst AT130 D hardness tester.

Wear testing was conducted on polished specimens using the abrasion apparatus available in our university's materials testing laboratory (Fig. 1). Three tests were performed per specimen, each lasting 5 minutes.

The abrasive ball was made of Al_2O_3 with a diameter of 20 mm. The rotational speed of the ball

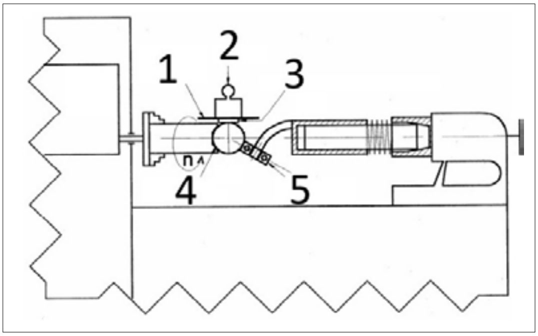

Fig. 1. Schematic of the abrasion apparatus [4]
1: Rigid plate mounted on a pivot rod, 2: Load, 3: Specimen, 4: Abrasive ball, 5: Ball bearing

drive was 570 rpm. The applied load was 72 g, which included the pivot rod and additional load. No lubricant was used during the test.

Wear marks on the polished surfaces were examined using an Olympus BX53M microscope.

For corrosion testing, ASTM G31-21 [5] and its supplementary standard ASTM G1-03(2017)e1 [6]. were used as guidelines. During the tests, three specimens each were immersed in a 6% $FeCl_3$ solution for 72 hours. Corrosion resistance was evaluated based on the mass loss rate.

The specimen dimensions were identical for all tests, on the order of tenths of a millimeter: 16.0 × 10.0 × 2.5 mm.

3.1. Heat Treatments

The heat treatments were carried out at the heat treatment facility of Titán 94 Ltd (Fig. 2). Quenching, cryogenic treatment, and the first tempering were performed in a Schmetz IU72/IF 2RV vacuum furnace, while the subsequent two tempering cycles were conducted in a nitrogen gas protected tempering furnace.

The heat treatment cycle diagram is shown in Fig 3. For the conventionally treated specimens, all parameters were identical except for the cryogenic treatment.

Notable parameters include the austenitizing temperature of 1080 °C, cryogenic treatment at −150 °C, and tempering temperatures of 200-, 210-, and 180 °C, respectively.

4. Results

4.1. Hardness

The workpiece from which the specimens were machined was received in a softened state.

The average hardness values are summarized in Table 2:

Table 2. *Averaged hardness values*

	Softened	After Heat Treatment
Conventionally treated	257 HB	58 HRC
Cryogenically treated	257 HB	59 HRC

The results confirm the expected increase in hardness.

4.2. Wear Resistance

The formula used to determine the wear coefficient is:

$$K = \frac{V_v}{S \times N} \left(\frac{mm^3}{Nm} \right) \quad (1)$$

where:
- K: wear coefficient,
- V_v: lvolume loss,
- S: wear path length,
- N: applied load.

The evaluation methods and formulas applied are described in more detail in the literature [4].

The wear coefficient values determined from the abrasion tests are summarized in Table 3.

Table 3. *Averaged wear coefficients*

Average Wear Coefficient	
Conventional	10.066 × 10^{-6} mm³/Nm
Cryogenically treated	4.853 × 10^{-6} mm³/Nm

The obtained results also support the assertion that significant differences in wear properties can be observed even among steels with very similar hardness [7].

4.3. Corrosion Resistance

The mass loss rate (*mlr*) was determined using the following equation:

$$mlr = \frac{\Delta m}{A \times t} \left(\frac{g}{m^2 h} \right) \quad (2)$$

where:
- Δm is the mass loss caused by corrosion,
- A is the surface area of the specimen exposed to the ferric chloride solution,
- t is the exposure time in the corrosive medium

The calculated values are summarized in Table 4.

Table 4. *Averaged corrosion mass loss rates*

Corrosion Mass Loss Rate, g/(m²h)	
Conventional	0.577
Cryogenically treated	0.372

These results highlight the wide range of properties achievable through different heat treatment procedures.

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Fig. 2. *Heat treatment facility of Titán 94 Ltd.*

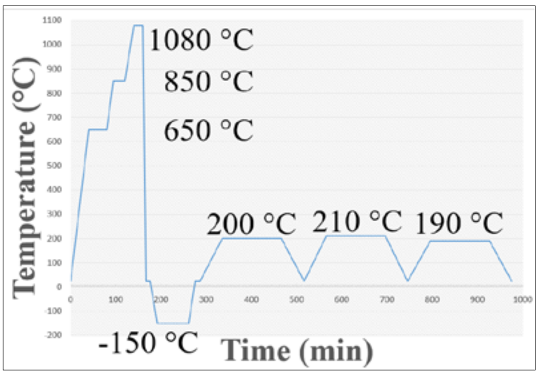

Fig. 3. *Heat treatment diagram of the cryogenically treated specimens.*

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