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INFLUENCE OF HEAT TREATMENT REGIMES ON THE HARDNESS OF Cr-Si ALLOYED STRUCTURAL STEEL FOR CONSTRUCTION OF FORGINGS PARTS

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Abstract: Track links used in agricultural machinery are subjected to harsh service conditions with cyclic loading, impact stresses and abrasive wear. Hence, the appropriate regime of heat treatment should be selected for obtaining the required combination of hardness, strength and durability. This paper investigates the influence of different heat treatment regimes on the hardness of forged track link components from 38HS steel. The specimens were heat treated under three sets of conditions and then tested for hardness and hardness distribution in the material. The results obtained were analysed in order to establish the influence of heat treatment parameters on the final properties of the steel and to determine the regime that offers the most favourable hardness characteristics for demanding operating conditions. The study presented contributes to the knowledge of the influence of the conditions of heat treatment on the mechanical properties of components made of 38HS steel used in tracked agricultural machinery.

Key words: 38HS steel, heat treatment, hardness testing, forging, agricultural machinery

1 INTRODUCTION

As part of this research, the influence of tempering temperature on the hardness of 38HS steel, which is used for the production of components subject to

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high operational loads, such as ridges agricultural machinery tracks, was investigated. For the purposes of the experiment, three identical samples made of 38HS steel were prepared.

Metals and their alloys represent the most important technical materials due to the wide range of possible mechanical and physical properties, the most prominent of which are: tensile strength, toughness, hardness, plasticity, magnetism, the possibility of physical and chemical processing, as well as good thermal and electrical conductivity. However, the continuous progress of various technologies requires the development of new materials with improved or new properties that are necessary for the reliable performance of given functions.

Today, thanks to the comprehensive development of science, and in particular, physical metallurgy and metallography, heat treatment has taken on even greater importance and the behaviour of metals during heat treatment can be predicted with certainty. Therefore, we can know very precisely what structure and mechanical properties will be obtained when the metal is subjected to certain heat treatment regimes. This is made possible by extensive theoretical knowledge, empirical data, as well as sophisticated engineering software packages.

Heat treatment is of great importance in almost all branches of industry, and its application is reflected in: the automotive industry, mechanical engineering, tool production, forging industry, agriculture, etc. This means that millions of tons of steel are heat treated in the form of plates, profiles, pipes, wires, etc. Responsible parts of machines are almost always subjected to heat treatment, so ball bearings, gears, engine blocks, cutting tools of machine tools and other parts are almost always treated with some form of heat treatment.

It is important to note that heat treatment, in addition to mechanical properties, can also improve physicochemical properties: magnetism, corrosion resistance, fire resistance and thermal stability of steels intended for operation at high temperatures, as well as many other useful properties.

Tempering is carried out immediately after quenching in order to achieve improvement. The tempering time depends on the dimensions of the steel part. The tempering parameters should be such as to enable the reduction of internal stresses, homogenization of the structure, increase of plasticity and transformation of the martensite formed by quenching, and thus the formation of a stable structure (bainite). After heating, the furnace is turned off, and the part remains in it and thus cools to room temperature [1].

In an research of the performance of hollow track bolts, Zasypkin et al. compared the mechanical properties of 38HS and 30HGSN2A steels. Their results indicate the limited durability of 38HS steel under cyclic bending conditions, which indicates the importance of choosing an adequate heat treatment regime for components exposed to high loads [2].

Zasypkin et al. state that the application of high-temperature thermomechanical processing (HTMT) significantly improves the characteristics of steel, but at the same time emphasize that in order to achieve optimal durability, it is necessary to carefully design the technological process, including the release phase [2].

As Ivković et al. determined by analysing cast steel, the tempering temperature plays a decisive role in the formation of the final relationship between tensile strength and ductility. The results show that increasing the temperature to 600°C provides better toughness compared to tempering at 450°C, which is essential for the working conditions of components such as track ridges [3].

The paper entitled “Effect of rapid tempering at high temperature on

microstructure, mechanical properties and stability of retained austenite of medium carbon ultrafine bainitic steel" by J. Wang et. al. studied the effect of rapid tempering on various properties of ultrafine bainitic steels, which provides a good support for the development of the tempering process for this type of steel [4].

Kolahi-Aval and Mintz [5] demonstrated that tempering of ferrite-pearlite steels can lead to a deterioration in impact transition temperature (ITT) because the embrittling effect of grain boundary carbide coarsening outweighs the toughening effect of yield strength reduction.

In contrast to ferrite-pearlite grades, fully pearlitic steels exhibit a marked improvement in impact behaviour upon tempering, as the reduction in yield strength becomes the controlling factor in the fracture process [6].

In the production of forgings intended for the track system components of agricultural machinery, selecting an appropriate heat treatment regime is a significant technological challenge, given that these components are subjected to variable mechanical loads, impacts, and abrasive wear during operation. The use of 38HS steel an alloy containing chromium and silicon-allows for the achievement of varying hardness levels through quenching followed by tempering. However, the selection of the tempering temperature requires careful consideration; excessive hardness can be detrimental to components subjected to impact loads, while an excessive reduction in hardness may negatively affect wear resistance. Consequently, it is necessary to examine how different heat treatment regimes influence the material's hardness key indicator of its suitability for the intended operational conditions.

The aim of this research is a comparative experimental analysis of the influence of tempering temperature (460 °C, 500 °C and 610 °C) on the hardness of forgings made of 38HS steel, with constant parameters of hardening and holding time. The contribution of the work is reflected in the experimental data that serve as the basis for the selection and optimization of the heat treatment parameters of these components.

2 MATERIALS AND METHODS

Material 38HS (according to the GOST standards, often used in our industry for the production of highly loaded machine parts) is an alloy steel that is primarily used for components exposed to high static and dynamic stresses. Also used in medium-sized cars, excavators or tractors. This steel is difficult to weld. Its chemical composition is shown in Table 1.

Table 1. *Chemical composition*

Chemical element	***C***	***Si***	***Mn***	***P***	***S***	***Cr***	***Ni***	***Mo***	***Al***	***Cu***	***V***	***W***	***Ti***
Amount, %	*0.34-0.42*	*1.1-1.4*	*0.3-0.6*	*Max 0.35*	*Max 0.35*	*1.3-1.6*	*Max 0.30*	*Max 0.11*	*≥0.02*	*Max 0.30*	*Max 0.05*	*Max 0.2*	*Max 0.03*

Table 2. *Mechanical properties*

State	***Rm, MPa***	***Rp0.2, MPa***	***A, %***	***Z, %***	***Impact energy, J***
Normalized	*930*	*735*	*12*	*50*	*69*
Q+T	*994*	*1189*	*21*	*54*	*72*

The data on the chemical composition and mechanical properties of 38HS steel, presented in Tables 1 and 2, were obtained from the material test certificate for the specific production batch from which the test specimens were manufactured. This certificate is part of the internal technical documentation of the company that facilitated the experimental research.

When looking closely at the alloying elements in Table 1, it is clear why this steel has such specific properties after quenching and tempering:

- Carbon (C: 0.34-0.42%): Places this material in the category of medium-carbon steels. This percentage is carefully balanced, it provides sufficient conditions for the formation of hard martensite in the structure during quenching, while on the other hand leaving the material with sufficient ductility so that the part does not crack at the first impact load in service.
- Silicon (Si: 1.1-1.4%): It is found in a fairly high percentage for this class of steel. Its main role is phase stabilization and raising the yield strength of the material. Silicon significantly slows down the softening of the steel during tempering, which directly explains why we were still able to maintain such high hardness values at high temperatures (such as 460°C and 500°C).
- Chromium (Cr: 1.3-1.6%): This is the key alloying element responsible for hardenability. Chromium allows the part to be hardened equally on both the surface and the deeper cross-section of the track link. In addition, chromium forms stable carbides that dramatically increase resistance to abrasive wear when in contact with the ground.
- Aluminium (≥0.02%) and titanium prevent austenite grain growth during heating in the furnace, allowing the structure to remain fine-grained and tough, which further ensures a product from brittle fracture.
- Trace elements (V, W, Ti): Although present in small quantities, they act as structure modifiers.

All three samples were subjected to the austenitization procedure at a temperature of 860°C. The holding time at the given temperature was 3 hours, followed by rapid cooling in water for 12 minutes, which achieved the maximum initial hardness of the martensitic structure.

After quenching, the samples are subjected to an annealing process to transform the martensite into a relaxed martensite, thus achieving a balance between the strength and toughness of the material. Firing was performed at three different temperatures: 460°C, 500°C and 610°C. The duration of the release process for all samples was uniform and amounted to 5 hours, after which the samples were cooled at room temperature.

The goal of this experiment is to define the optimal heat treatment regime through a comparative analysis of the measured hardness after loosening at the specified temperatures, which ensures the best ratio of mechanical characteristics required for the demanding working conditions of the track link.

Enhanced hardening 38HS steel for heat improvement demonstrating its properties after hardening in water and tempering. It is abrasion-resistant, suitable for large and variable loads. For heavy-duty, high wear and torsion resistant parts, medium-sized heavy duty machines such as friction discs, cams, clutch discs, gears, camshafts, studs, axles, screws and even suction valves

Typical heat treatment for this steel consists of quenching and tempering

(Q+T). Therefore, this steel was chosen for experimental investigations. Mechanical properties of steel in both normalized and quenched heat-treated states found in literature are shown in Table 2. 38HS also features spring steel properties with low tempering - high strength, wear resistance, elasticity and plasticity.

In this experiment, the hardness of 38HS steel was investigated after heat treatment (tempering) at different temperatures. The Brinell method was used for the experiment. Before the pressing itself, it was necessary to adequately prepare the surface of the samples. The surface is ground to remove oxide layers, roughness and any irregularities that could affect the accuracy of the measurement and the clarity of the print edges. After the preparation, it was started to make the prints on the hardness measuring device. By pressing the ball into the material (Figure 1) under a defined load, impressions were obtained, the diameter of which was measured using a hand-held optical instrument with a microscope (Figure 1). The obtained values of the diameter of the impression were then used to read the final hardness (HB) directly from the corresponding tables on the machine.

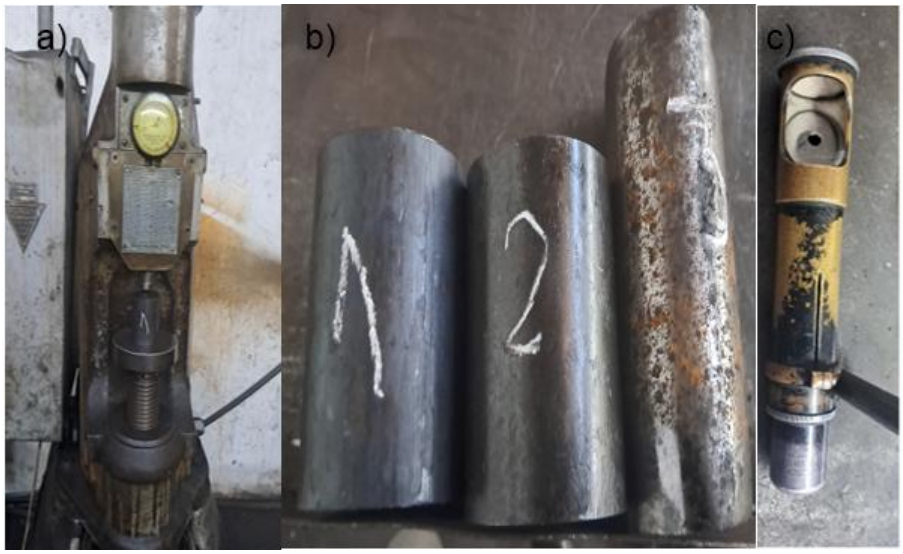


Figure 1. *a) Device for ball prints; b) Steel part for experiment c) Instrument with a microscope*

Hardness measurements were carried out on a standard Brinell hardness testing. The testing parameters were set using a hardened steel ball indenter with a diameter of D = 5 mm under a nominal test load about of F = 30 kN. The dwell time under maximum load was held constant at 15 seconds. For each test indent, two mutually perpendicular diameters of the impression were measured using an integrated optical microscope with a measurement resolution of 0.01 mm (Figure 1c). The mean indentation diameter was subsequently used to determine the resulting Brinell hardness number. For greater statistical reliability, two individual indentations were recorded for each heat treatment temperature regime, as reported in Table 3.

3 RESULTS AND DISCUSION

The measurement was performed on samples that underwent heat treatment at three different temperatures, with two measurements for each temperature for greater reliability, table 3.

Table 3. *Experimental results of Brinell hardness (HB) testing*

Heat-treatment	***Point***	***HB***
Q+T (at 460°C)	*1*	*450*
	2	*477*
Q+T (at 500°C)	*1*	*400*
	2	*418*
Q+T (at 610°C)	*1*	*340*
	2	*320*

When looking at the figures in the table, a completely expected and metallurgically logical trend is clearly visible: as we raise the tempering temperature, the hardness of the material gradually decreases. However, what is crucial for us is how the steel structure itself behaves at each of these levels:

- Regime at 460°C (Hardness 450-477 HB): Here we measured quite high hardness values. This unequivocally confirms that the structure is still dominated by low-tempered martensite, which has not yet started to flow significantly. In practice, this regime brings exceptional surface strength, which makes it an ideal choice for positions where wear resistance is the primary and most important requirement.
- Regime at 500°C (Hardness 400-418 HB): At this temperature, we record a decrease in hardness, which is a clear signal that a more serious process of carbide coagulation has begun in the material. At the same time, there is a significant release of internal stresses that remained after the rapid cooling during quenching, so the material slowly loses its brittleness and transitions to a tougher phase.
- 610°C regime (Hardness 320-340 HB): As expected, here we record the lowest hardness values in the entire experiment. However, it is at 610°C that 38HS steel achieves its absolute optimum and ideal balance between strength and toughness. The structure heat-treated in this way is crucial for parts that are subjected to heavy impact and dynamic loads in real operation, because in this way the risk of sudden brittle fracture is completely avoided.

Higher temperatures result in higher ductility and toughness, while temperatures closer to 300°C result in higher hardness and strength. This is achieved by the redistribution of carbon atoms in the material which changes its microstructure and mechanical properties. Therefore, it can be said that the process of tempering is an important step of heat treatment process. It helps to adjust the mechanical properties to meet the specific performance demands while preserving the stability and integrity of the material [6].

In Figure 2, the complete cyclograms of the applied heat treatment processes (the quenching and the tempering stages that followed) are methodically shown for the three experimental regimes. The diagram shows that the first hardening step was a

uniform austenitization at 860°C with a 180 min hold time, followed by an intensive water quenching to obtain a fully martensitic matrix in the whole component. The second stage is the tempering cycles performed at 460 °C, 500 °C and 610 °C, respectively, with a constant soaking time of 300 min followed by a controlled air cooling to the room temperature to finish the structural relaxation.

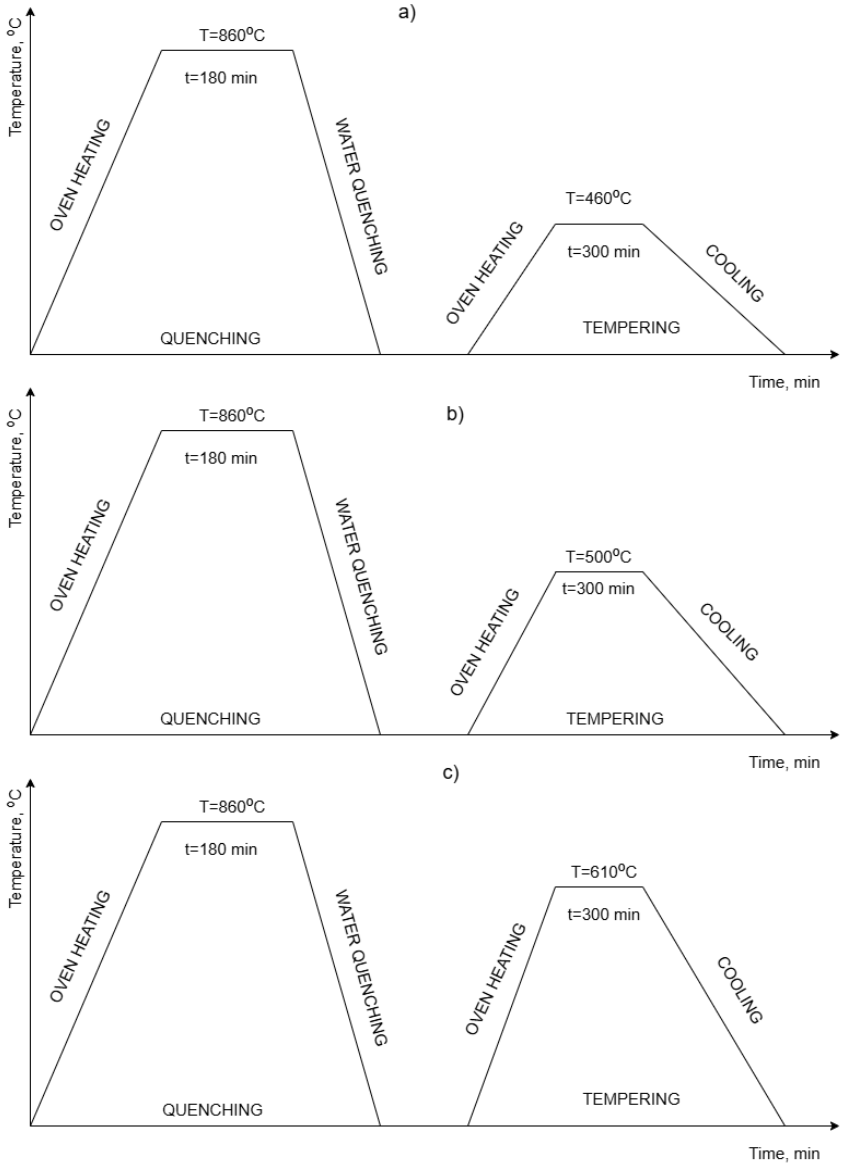


Figure 2. *Schematic representation of the heat-treatment regime: a) tempering temperature at 460°C; b) tempering temperature at 500°C; c) tempering temperature at 610°C*

4 CONCLUSION

Through a detailed analysis of the obtained hardness test results, we have come to the conclusion that the tempering regime at a temperature of 500°C is by far the most optimal choice compared to the other two tested regimes.

Although the sample tempered at a lower temperature of 460°C offers maximum surface strength and wear resistance, its toughness is significantly reduced. This makes it very susceptible to sudden brittle fracture under the influence of high impact loads, to which the track link is constantly exposed during vehicle operation. On the other hand, the high tempering temperature of 610°C did bring excellent toughness, but at the cost of an excessive drop in the hardness of the surface layer, which would dramatically accelerate the wear and tear of the material in the field.

Therefore, the heat-treated regime at 500°C establishes the most important, ideal balance between hardness and toughness. In this way, the customer's very strict requirements regarding the durability, safety and overall reliability of this agricultural machinery component in real field conditions are fully met.

Future research in this area should definitely be directed towards examining the effects of different cooling media, as well as longer holding times of the material at tempering temperatures. This would allow us to further fine-tune and define the stability limits of the mechanical properties of 38HS steel under variable operational loads.

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