VSB TECHNICAL UNIVERSITY OF OSTRAVA | FACULTY OF MECHANICAL ENGINEERING

MM Science Journal | www.mmscience.eu
ISSN 1803-1269 (Print) | ISSN 1805-0476 (On-line)
Special Issue | TEAM 2024
Transdisciplinary and Emerging Approaches to Multidisciplinary Science
11.9.2024 – 13.9.2024, Ostrava, Czech Republic
DOI: 10.17973/MMSJ.2024_12_2024131

MM SCIENCE JOURNAL

TEAM2024-00044

THE INFLUENCE OF QUENCHING AND TEMPERING ON THE HARDNESS AND MICROSTRUCTURE OF 42CrMo4 STEEL

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Abstract
This article deals with the effect of quenching and tempering on the hardness and microstructure of 42CrMo4 steel. All investigated samples were water quenched from an austenitizing temperature of 820 °C. After quenching, the samples were tempered at 610 °C, for 30 minutes and for 60 minutes. After the heat treatment, the cross-sectional hardness of the samples was measured. The hardness was measured using the Vickers tester and a test force of 98,1 N (HV10). The highest average hardness was achieved after quenching with values of 657,3 HV10 on the surface and 487,6 HV10 in the core. Samples that were tempered for 30 and 60 minutes showed an average surface hardness of 364,3 HV10 and 330 HV10 and an average core hardness of 332,3 HV10 and 303,3 HV10, respectively. The microstructure was investigated by the use of light optical microscope.

Keywords:
Quenching and Tempering, 42CrMo4 Steel, Hardness, Microstructure

1 INTRODUCTION

42CrMo4 steel is widely used in industry due to its exceptional combination of mechanical properties, including wear resistance, strength and toughness. Its versatility enables application in various industries, especially in those where parts are exposed to high loads [Gai 2023]. Recent research analyzes various aspects of the processing of this steel, including heat treatment processes, hydrogen diffusion and susceptibility to hydrogen-induced fractures, contributing to a better understanding of its characteristics and potential weaknesses under specific conditions.

The heat treatment of 42CrMo4 steel was investigated in detail, and its influence on the behavior of the material was presented in the paper dealing with tensile behavior of 42CrMo4 steel [Imdad 2023]. This paper analyzes the tensile properties of steel under different heat treatment conditions, including annealing, normalizing and quenching and tempering, which is essential for understanding the mechanical performance of steel under realistic conditions.

Similar studies, such as [Zafra 2020a], investigate the effect of tempering temperature on hydrogen diffusion, which is important to prevent hydrogen-induced embrittlement.

Hydrogen diffusion and its effects on the mechanical properties of 42CrMo4 steel under various heat treatment conditions have been presented in several studies. The paper [Zafra 2020b] studies the influence of tempering temperature and plastic deformation on the ability of steel to retain hydrogen, which is crucial for understanding the phenomena that lead to the fracture of the material. Furthermore, the study [Zafra 2020c] investigates hydrogen-induced embrittlement in the heat-affected zone of hardened and tempered 42CrMo4 steel, providing important insights into the material's susceptibility to degradation due to hydrogen. Fracture resistance and toughness of hardened and tempered 42CrMo4 steel, especially in the heat-affected zone, was investigated in the paper [Zafra 2021]. This paper studies the micromechanisms of fracture in the presence of hydrogen and provides valuable information on the resistance of the material to the occurrence of fractures, which is a key factor in assessing the reliability of steel under extreme conditions.

Material fatigue has also been the subject of considerable research. In the paper [Lanzutti 2020], the fatigue properties of 42CrMo4 steel after mechanical treatment and hot forging process were analyzed. This research highlights the influence of mechanical surface treatments on the fatigue life of steel, which is crucial for its application in dynamically loaded components, such as those in the automotive and mechanical industries.

The monotonic behavior of steel 42CrMo4 in the normalized and quenched and tempered state was thoroughly investigated in [Basan 2008]. This research analyzes how different heat treatment conditions, such as normalizing and quenching and tempering, affect the tensile properties and ductility of steel. Similar research, such as [Imdad 2023], also studied the influence of heat treatment on the tensile behavior of steel.

Fatigue crack growth in 42CrMo4 steel under different heat treatment conditions is discussed in detail in the paper [Lesiuk 2018]. This research shows how heat treatment, particularly the quenching and tempering processes, affects the resistance of steel to fatigue cracking, which is critical for the long-term reliability of the material in industrial applications. These results are in line with research such as those from the article [Lanzutti 2020], which also examines the influence of heat treatment and mechanical processing on fatigue properties.

Phase changes and cooling of 42CrMo4 steel under the influence of different quenching agents were investigated in [Sakkaki 2020]. In this research, the influence of different quenching agents on the microstructure and mechanical properties of steel is analyzed, suggesting alternative quenching approaches to improve specific steel characteristics.

The study [Salas Vicente 2021] deals with the prediction of the hardness of nodular cast iron after quenching and tempering procedures. Using the Hollomon-Jaffe parameter as a predictive tool, the authors investigated the relationship of tempering temperature and time with the mechanical properties of material, providing a model for heat treatment optimization. This enabled a more precise control of the properties of ductile iron in industrial applications.

In the article [Janjusevic 2009] the effect of tempering temperature and time on the mechanical properties of HSLA steel, using the Hollomon-Jaffe equation to predict hardness was investigated. A similar approach is applied in the present research, where the change in hardness of 42CrMo4 steel after different heat treatment regimes is experimentally analyzed. The article emphasizes the importance of tempering optimization to achieve a balanced combination of steel strength and toughness.

The investigations analyzed above provide a comprehensive insight into the behavior of 42CrMo4 steel under various heat treatment conditions, its resistance to hydrogen-induced degradation, and its mechanical properties under dynamic loads.

The aim of the present study is to determine the type of tempering for steel 42CrMo4, i.e. the duration of tempering to achieve optimal hardness.

2 RESEARCH METHODOLOGY

Experimental procedures were carried out in the laboratories of the Đuro Đakovic company, using high-quality furnaces for heat treatment. Bosio EUP-40/1200 furnace was used for austenitizing and Nabertherm furnace for tempering process.

The Bosio EUP-40/1200 furnace allows an operating temperature of up to 1100 °C, with a maximum temperature of 1200 °C. Heating is provided by heaters located in the floor and on the sides of the furnace. Extremely efficient thermal insulation enables quick reaching of working temperatures, while thermocouples ensure precise temperature control. The furnace can work in a protective atmosphere, which enables high control of the heat treatment process. Fig. 1 shows the Bosio EUP-40/1200 furnace. The Nabertherm furnace, also with a maximum temperature of 1200 °C, is ideal for everyday laboratory use. All heating elements are ceramic and easily replaceable, which contributes to the long-term reliability of the furnace. The design of the lifting door ensures safe operation of the operator. The furnace is equipped with a temperature limiter to prevent overheating. Fig. 2 shows a Nabertherm furnace.

Fig. 1: Bosio EUP-40/1200 furnace.

Fig. 2: Nabertherm furnace.

The researched steel 42CrMo4 was austenitized at 820 °C for 45 minutes, after which it was quenched in water. The tempering process was carried out in two steps, both at a temperature of 610 °C. The first tempering lasted 30 minutes, and the second 60 minutes. With this process, the goal was to achieve an optimal balance between the hardness, strength and toughness of the material.

The chemical composition of 42CrMo4 steel is shown in Tab. 1.

Tab.1: Chemical composition of 42CrMo4 steel.

C	0,38-0,45
Si	0,17-0,37
Mn	0,50-0,80
Ni	≤0,3
Cr	0,9-1,2
Mo	0,15-0,25
P	≤0,035
S	≤0035

3 RESULTS AND DISCUSSION

The hardness of the base material before quenching was measured by the HV10 method and ranged from 274 to 302 HV10, with an average value of 288,6 HV. The measured hardness of the base material is shown in Tab. 2.

Tab. 2: Hardness of the material before heat treatment (HV10).

1. measurement	302
2. measurement	286
3. measurement	290
4. measurement	291
5. measurement	274
Average value	288,6

By quenching, significantly higher hardness was achieved, which was highest on the surface of the sample (657,3 HV10), while the average hardness at a distance of 24 mm from the quenched end was 487,6 HV10 (shown in Tab. 3 and in Fig. 3).

Tab. 3: Hardness after quenching (HV10).

Distance from the quenched end, mm	1. measur.	2. measur.	3. measur.	Average
0,5	656	656	660	657,3
2	595	597	600	597,3
4	597	605	608	603,3
6	628	625	623	625,3
8	645	643	641	643
10	622	623	618	621
12	614	592	595	600,3
14	616	619	608	614,3
16	517	519	520	518,6
20	501	541	504	515,3
24	496	469	498	487,6

Quenching increased surface hardness by about 369 HV10, and core hardness by about 199 HV10.

To obtain the microstructures, after mounting, grinding and polishing, the nital (a solution of nitric acid and alcohol) was used for the etching. The light optical microscope was used.

The magnification was 200x.

Figures 4 a), b) and c) show the microstructure of steel in the quenched state starting from the surface, through the transition zone to the core.

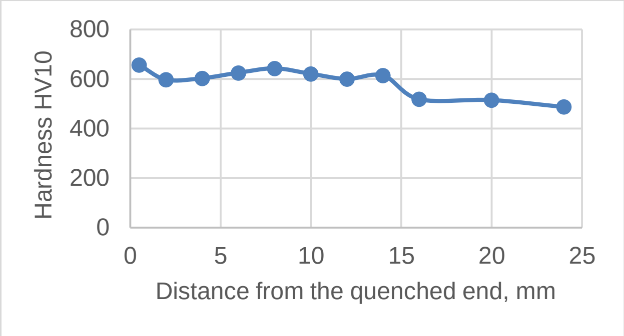


Fig. 3: Jominy hardness after quenching.

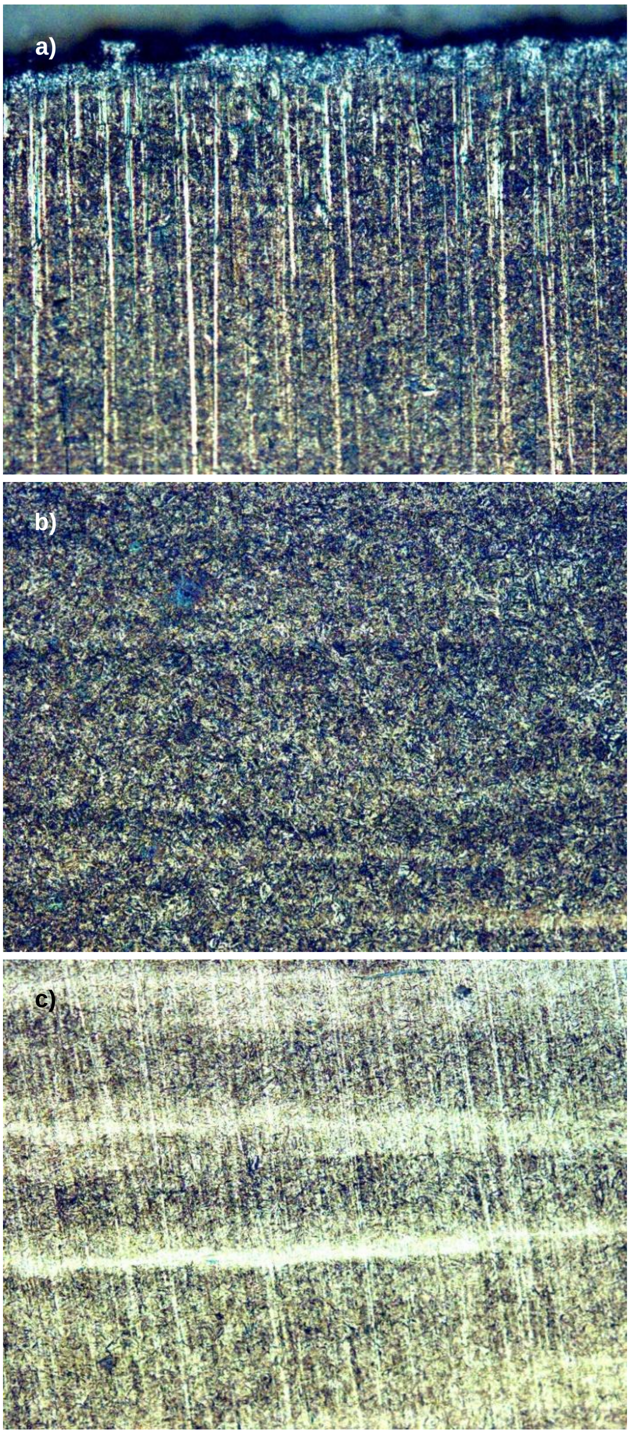


Fig. 4: Microstructure after quenching; a) surface; b) transition zone; c) core.

After quenching, two tempering procedures were carried out. Both treatments were carried out at a temperature of 610 °C. The first tempering lasted 30 minutes, and the second tempering lasted 60 minutes. The test results after the first treatment are shown in Tab. 4.

Tab. 4: Hardness after tempering at 610 °C/30 minutes (HV10).

Distance from the quenched end, mm	1. measur.	2. measur.	3. measur.	Average
0,5	364	364	365	364,3
2	351	352	345	349,3
4	356	356	362	358
6	362	362	362	362
8	371	368	370	369,6
10	346	350	350	348,6
12	371	370	372	371
14	359	377	376	370,6
16	367	368	368	367,6
20	347	338	340	341,6
24	333	330	334	332,3

The results of measured hardness are shown in Fig. 5 (after the first treatment – lasting 30 minutes).

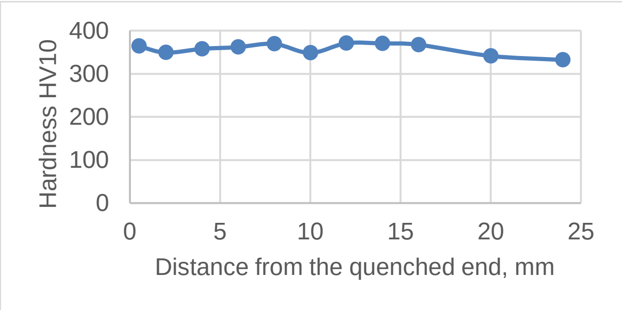


Fig. 5: Jominy hardness after tempering at 610 °C/30 minutes.

Figures 6 a), b) and c) show the microstructure in the quenched and tempered state (30 minutes) starting from the surface, through the transition zone to the core.

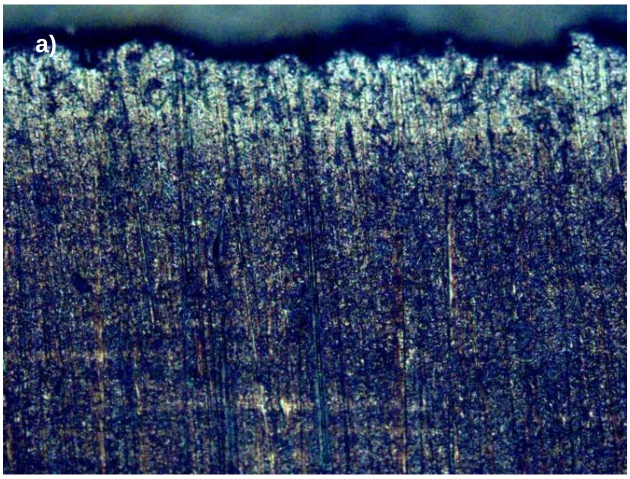
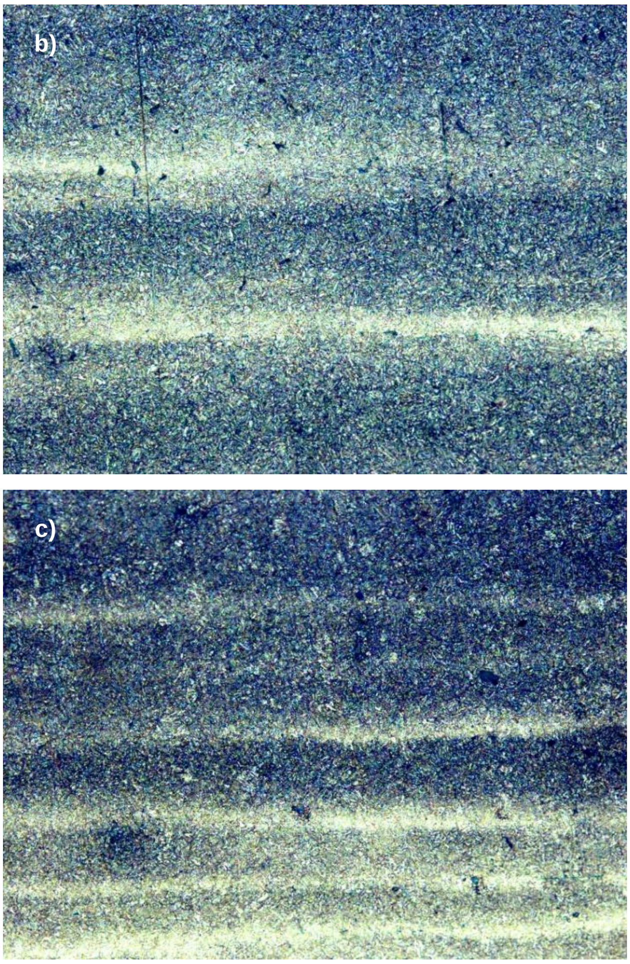


Fig. 6: Microstructure after quenching and tempering at 610 °C/30 minutes; a) surface; b) transition zone; c) core.



Continuation - Fig. 6: Microstructure after quenching and tempering at 610 °C/30 minutes; a) surface; b) transition zone; c) core.

The hardness data after the second treatment are shown in Tab. 5. and Fig. 7 (after the second treatment – lasting 60 minutes).

Figures 8 a), b) and c) show the microstructure of steel in the quenched and tempered state (tempering time 60 minutes) starting from the surface, through the transition zone to the core.

Tab. 5: Hardness after tempering at 610 °C/60 minutes (HV10).

Distance from the quenched end, mm	1. measur.	2. measur.	3. measur.	Average
0,5	331	329	330	330
2	322	323	320	321,6
4	320	322	322	321,3
6	319	323	322	321,3
8	335	330	331	332
10	324	330	330	328
12	326	325	322	324,3
14	316	309	307	310,6
16	307	309	309	308,3
20	296	294	290	293,3
24	296	303	311	303,3

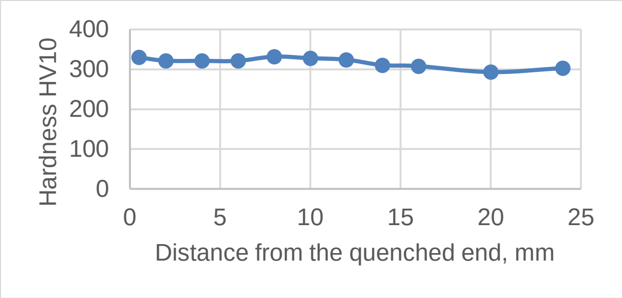


Fig. 7: Jominy hardness after tempering at 610 °C/60 minutes.

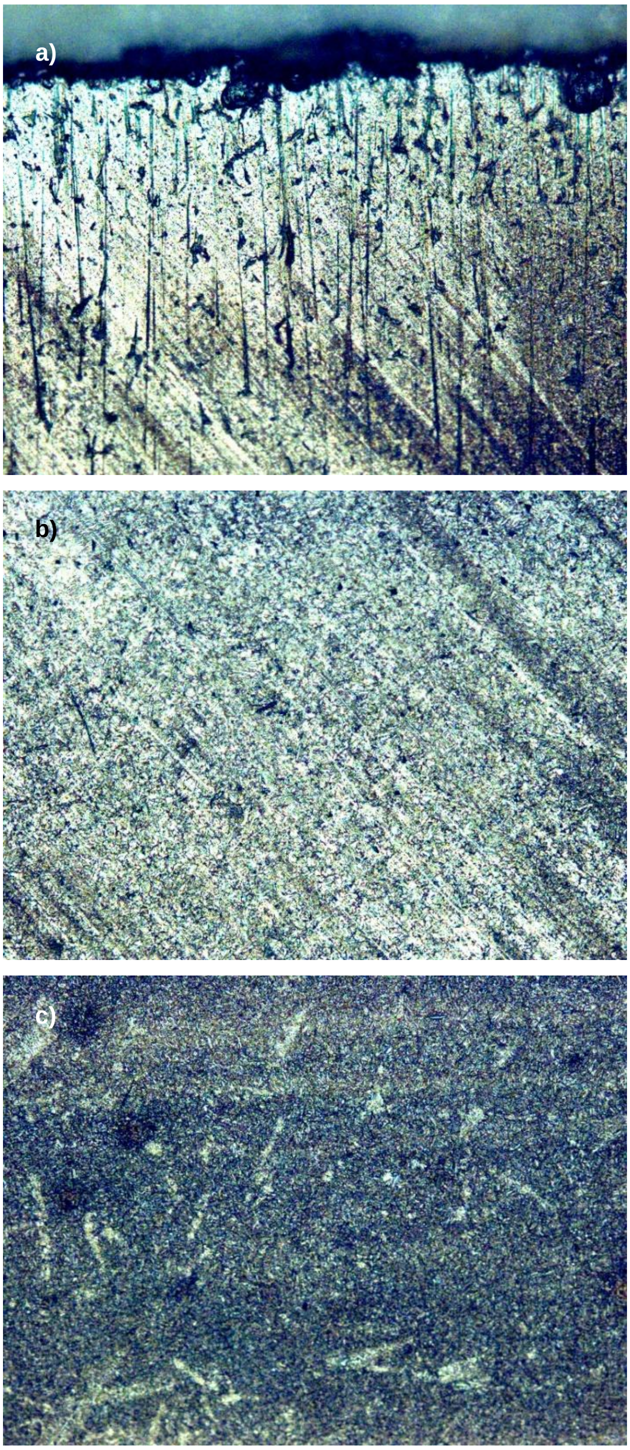


Fig. 8: Microstructure after quenching and tempering at 610 °C/60 minutes; a) surface; b) transition zone; c) core.

In Figures 4 a), 6 a) and 8 a) a white surface layer is visible, which indicates decarburization on the surface. Decarburization occurred due to quenching and tempering without a protective atmosphere. Based on the Steel Navigator web page [https://steelnavigator.ovako.com], the hardness according to the Jominy curve between 1,5 and 3 mm should be in the range of 699 and 671 HV, while in the present investigation it is significantly lower (Tab. 3, Fig. 3), which also indicates decarburization of the surface layer of the steel. In Figures 4 a), b) and c) the martensitic microstructure of the steel is visible, and in Figures 6 a), b) and c) and 8 a), b) and c) the tempered martensite is visible.

4 CONCLUSION

In the experimental part, it was determined that with a longer duration of tempering, the hardness further decreases, and therefore the steel must be tempered long enough to obtain the desired hardness, but not more than that, so that the hardness does not decrease. Before quenching and tempering, the hardness of the material was measured and it was 288,6 HV10 (the average value of five repeated measurements, Tab. 2). The hardness of the surface after quenching was 657,3 HV10, and in the core was 487,6 HV10 (Tab. 3, Fig. 3). After quenching, two tempering procedures were performed. The first tempering was carried out at 610 °C for 30 minutes, and the second tempering at 610 °C for 60 minutes.

Regarding the microstructure, a uniform microstructure was obtained across the cross section. Tempering at 610 °C for 30 minutes resulted in surface hardness of 364,3 HV10 and core hardness of 332,3 HV10 (Tab. 4, Fig. 4). Tempering at 610 °C for 60 minutes resulted in surface hardness of 330 HV10 and core hardness in the amount of 303,3 HV10 (Tab. 5, Fig. 5). According to the Steel Navigator and Steel Number web pages [https://steelnavigator.ovako.com/heat-treatment-guide/; https://www.steelnumber.com/], the hardness after quenching and tempering should range between 340 and 490 HV, which is the case in the present study. Steel Navigator [https://steelnavigator.ovako.com] states that tempering at 610 °C should give an approximate hardness of 305 HV. Longer tempering resulted in a greater drop in hardness, but it is still within the permissible hardness range.

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