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INFLUENCE OF TEMPERING TEMPERATURE ON MECHANICAL PROPERTIES OF G42CrMo4 CAST STEEL

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Abstract: *This paper explores the effects of tempering temperatures on the mechanical properties of G42CrMo4 cast steel, a versatile alloy commonly used in automotive and construction industries. Tempering, a critical step in the heat treatment process, aims to reduce residual stresses and enhance material reliability. The study investigates the influence of tempering temperatures (450°C and 600°C) on the steel's strength, ductility, and hardness through a series of experimental investigations, including heat treatment, machining, and tensile testing. Results indicate that while normalization treatment offers moderate strength and good ductility, quenching and tempering at 450°C significantly increase strength at the expense of ductility. Conversely, tempering at 600°C strikes a balance between strength and ductility.*

Keywords: *G42CrMo4, quenching, tempering, tensile test*

1. INTRODUCTION

Aim of this paper is to demonstrate, the effect of various tempering temperatures on mechanical properties of alloyed cast steel G42CrMo4. This particular cast steel, known for its high strength, impact toughness, and hardness, is frequently used in the automotive, construction, and various other industries. The chemical composition of G42CrMo4 cast steel in combination with suitable heat treatment, contributes to its mechanical properties such as high strength, impact toughness, and hardness, making it suitable for applications in automotive, construction and many other industries [1].

In some earlier researches it was also proved that tempering could be successfully used for lowering both amount of residual stress as well as deformation on hard-faced parts [2, 3].

J. Wang et. al in 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" investigated the influence of rapid tempering on various properties of ultrafine bainitic steels, providing a good support for developing tempering process for this steel type. [4]

K. Gupta et al. in the paper "*CO2 corrosion resistance of low-alloy steel tempered at different temperatures*" investigates the influence of tempering temperatures on the corrosion resistance of materials, therefore giving good foundation when choosing tempering temperatures for materials exposed to CO2. [5]

S. Henschel in his research [6], investigates the influence of non-metallic inclusions on fracture toughness of material at various temperatures, thus giving information on material behaviour in such conditions.

D. Kreweth et al. [7] presented a research related to fracture behaviour of G42CrMo4 steel under high-cycle fatigue regime. Fractural behaviour was monitored using thermal camera, thus time needed for crack to form and to grow up to part failure is determined. The mentioned studies did not directly investigate the tensile properties of castings in different conditions, but they helped compare

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the results in the improved (heat-treated) state. Apart from steel standards, we have not found similar research in the literature.

2. MATERIALS AND METHODS

G42CrMo4 cast steel belongs to the group of alloyed cast steels. Its chemical composition is shown in Table 1.

This cast steel often undergoes different heat treatments to adjust mechanical properties for a certain purpose. Typical heat treatment for this cast steel consists of quenching and tempering (Q+T). Therefore, this cast steel was chosen for experimental investigations. Mechanical properties of cast steel in both normalized and quenched heat-treated states found in literature are shown in Table 2.

Table 1. Chemical composition of G42CrMo4 cast steel [8]

Chemical element	C	Si	Mn	Cr	Mo	P	S
Amount, %	0.38-0.45	max 0.4	0.6-0.9	0.9-1.2	0.15-0.30	0.025	0.035

Table 2. Mechanical properties of G42CrMo4 cast steel [8]

State	R_m, MPa	$R_{p0.2}$, MPa	A, %	Z, %	Impact energy, J
Normalized	670	435	25.2	60	87
Q+T	1100-1300	900	10	40	30

G42CrMo4 cast steel due to its favourable properties is widely used in industry. Despite the long presence of G42CrMo4 cast steel in industry application, research of this material is still ongoing.

Primary goal of tempering is to reduce residual stresses in the material caused by previous thermal processes, such as quenching or welding. This helps to improve the overall stability and reliability of the material. Temperatures for tempering typically range from 300°C to 600°C [9]. The specific temperature chosen depends on the desired outcome and the material being treated.

Experimental investigation involved preparing initial pieces, their heat-treating, machining specimens on a CNC lathe, and conducting tensile tests. The heat treatment process included quenching the material followed by tempering at different temperatures. By examining the mechanical properties such as yield strength, tensile strength, and elongation of G42CrMo4 cast steel in its normalized state and after quenching and tempering at moderate (450°C) and high (600°C) temperatures, aim is to provide a comprehensive understanding of how tempering temperature affects the performance of this alloyed cast steel.

The selection of the most favourable thermal treatment regime for the examined steel was performed based on the TTT diagram (Fig. 1) for the considered steel, and the aim of the heat treatment was to achieve the most favourable values of strength and ductility [1].

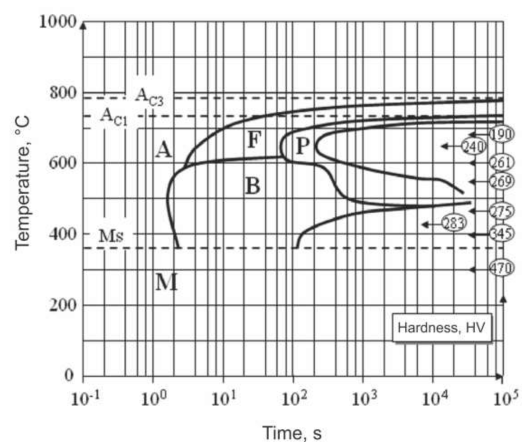

Figure 1. TTT diagram for 42CrMo4 steel [1]

In both cases, tempering was conducted after the quenching. For quenching, the material was heated in an electric furnace up to 860°C, held at that temperature for 1 hour, and cooled down to room temperature in an oil bath. After cooling down in oil, the material was once again heated. In the case of moderate tempering, the material was heated up to 450°C, held for 45 minutes, and then cooled down in free air. In the case of high tempering, the material was reheated up to 600°C after quenching, held at that temperature for 45 minutes, and afterward cooled down in free air, as in the case of moderate tempering. Thermal cycles for both heat treatments are given in Figures 2 and 3 [1].

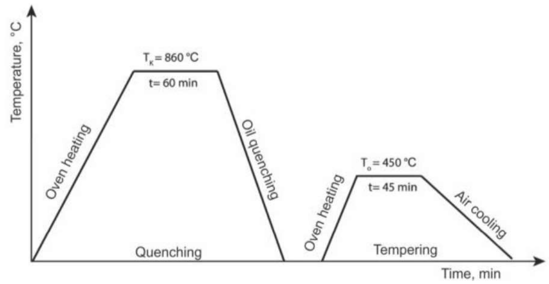

Figure 2. Heat-treatment regime for mid-tempered specimens [1]

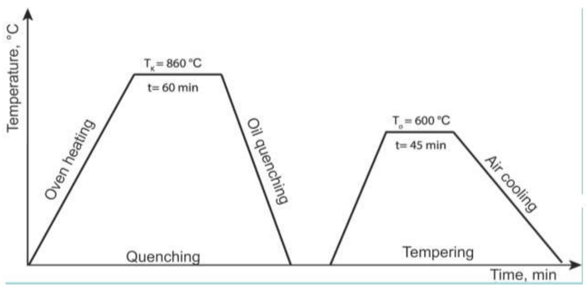

Figure 3 Heat-treatment regime for high-tempered specimens [1]

After the heat treatment was successfully conducted, specimens for tensile tests were machined from heat-treated material on a CNC lathe. For tensile testing, specimens with an initial diameter (d_0) of 9 mm and a gauge length of 90 mm were used. The appearance of the prepared specimens after machining is given in Fig. 4.

Figure 4. Geometry of specimens prepared for tensile tests [1]

After machining of specimens, tests were conducted. Tensile tests of specimens were conducted on a universal testing machine ZWICK/ROELL Z100. The tensile test was conducted with a loading rate of 10 mm/min at room temperature.

3. RESULTS AND DISCUSSION

After the conducted test on prepared specimens (normalized, mid-tempered, and high-tempered), the following results were obtained and displayed in Table 3. Stress-strain curves are displayed in Figures 5-7.

Table 3. Results obtained by tensile testing [1, 8]

Heat-treatment	Specimen number	$Rp_{0.2}$, MPa	R_m, MPa	A, %
Normalized	1	360	760	18
	2	360	746	15.33
	3	346	755	16.67
Q+T (at 450°C)	1	1531	1616	2.01
	2	1649	1673	5.2
	3	1628	1628	2.51
Q+T (at 600°C)	1	801	966	6.66
	2	809	963	6.01
	3	831	973	6.33

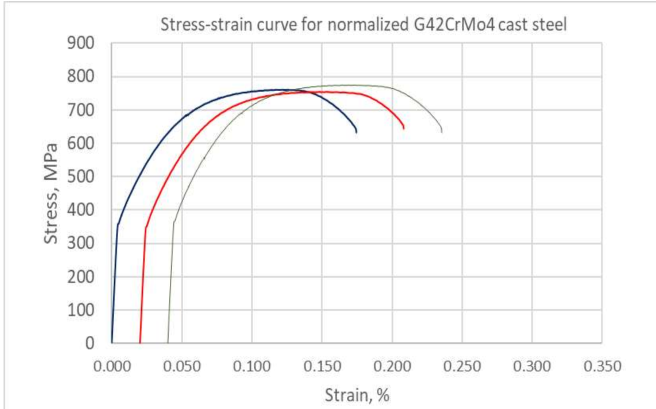

Figure 5. Stress-strain curves for normalized samples of G42CrMo4 cast steel [3]

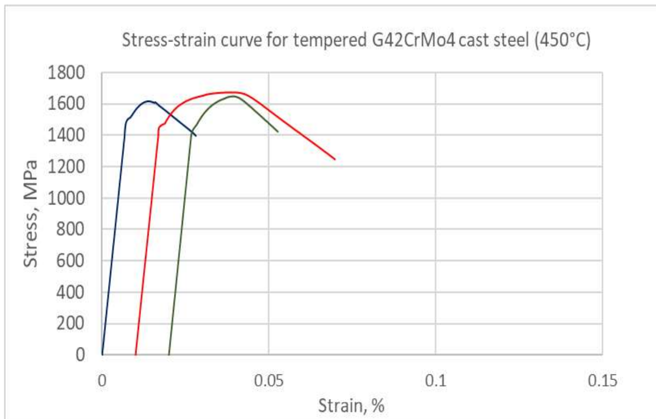

Figure 6. Stress-strain curves for the quenched and mid-tempered samples of G42CrMo4 cast steel [1]

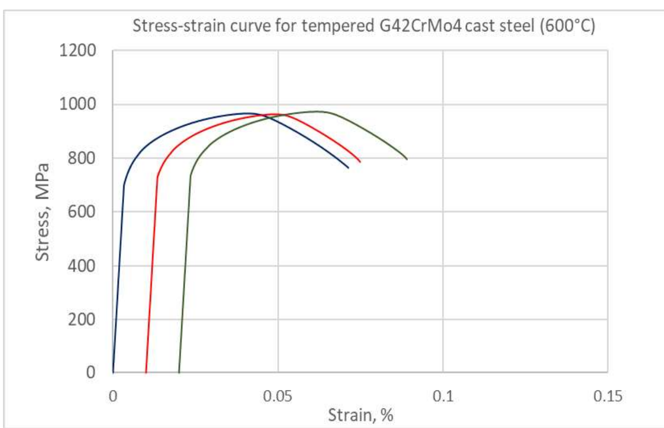

Figure 7. Stress-strain curves for quenched and high-tempered samples of G42CrMo4 cast steel [1]

Tempering temperatures closer to 300°C generally result in higher hardness and strength, while higher temperatures lead to increased ductility and toughness. This is achieved through the redistribution of carbon atoms in the material, which affects its microstructure and mechanical properties. One can conclude that tempering is a critical step in the heat treatment process, allowing for the adjustment of mechanical properties to meet specific performance requirements while ensuring the stability and integrity of the material [2].

By analysis of the results given is section 4, one can conclude that specimens which were subjected to the normalization treatment achieve moderate yield stress values (346-360 MPa), with slight variation among the test specimens. Moderate tensile strength ranging from 746 to 760 MPa is measured. Elongation values range from 15.33% to 18%, showing acceptable ductility for this treatment. Overall, this heat treatment allows for G42CrMo4 cast steel to achieve a good compromise between strength and ductility.

Specimens that were quenched and tempered at 450°C showed greater values of yield stress and tensile strength. Yield stress value for this material state ranges between 1531 and 1649 MPa, which is far greater than values for normalized specimens. Tensile strength ranges from 1616 to 1673 MPa, exceeding double the value of tensile strength for normalized specimens. That results were expected since the lower tempering temperature provides greater mechanical properties [10].

Values of elongation for this state of material are significantly lower than values in the normalized state. For this state, elongation ranges from 2.01% to 5.20% compared to the range from 15.33% to 18% of normalized specimens. This indicates reduced ductility which is caused by applied heat-treatment.

Specimens tempered at 600°C achieve mechanical properties which are intermediate compared to the previous two states. Yield stress values range from 801 to 831 MPa and tensile strength values from 966 to 973 MPa. Values for both properties are higher than values for the normalized state but lower when compared to values achieved with specimens tempered at 450°C. Elongation values range from 6.01% to 6.66%, suggesting that ductility is still reduced when compared with normalized specimens. When comparing with values achieved for specimens tempered at 450°C, ductility is improved.

4. CONCLUSION

In this paper, on specimens prepared from alloyed cast steel G42CrMo4, effect of various tempering temperatures on mechanical properties was demonstrated. Three batches of tensile specimens were prepared. One batch was machined from normalized G42CrMo4, the second was quenched and tempered at 450°C, and the third was also quenched and tempered at 600°C.

Following conclusions could be drawn:

• Normalizing treatment provides moderate strength and good ductility,

• Quenching and tempering at 450°C result in high strength but reduced ductility and

• Quenching and tempering at 600°C offer a balance between strength and ductility.

In conclusion, the results of the mechanical testing highlight the versatility of G42CrMo4 cast steel and emphasize the importance of thoughtful material selection and heat treatment optimization in engineering design and manufacturing processes.

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