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Heat Treatment of Steel 100CrMn6: Influence of Temperature and Austenitization Time

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This study deals with influence of temperature and time of austenitization on final mechanical properties, especially Rockwell hardness (HRC), obtained after heat treatment of steel 100CrMn6 (1.3520). Following process parameters of heat treatment were varied: time of austenitization and type of cooling medium, which has a significant effect on final strucutre, thus mechanical properties. These parameters were varied according to reccomended range given in material sheet. As can be seen from results, different temperature and time of austenitization influenced final hardness after hardening and tempering. Lower temperature and shorter time of austenitization led to insufficient homogenization of austenite and incomplete transformation to martensite and bainite, which resulted in lower hardness. On the other hand, higher temperature and longer time of austenitization can lead to coarser austenite grain, which can also result in lower hardness.

Keywords: Heat treatment, Hardening, Tempering, Austenitization, Hardness

1 Introduction

Goal of hardening is the increase of hardness of steel. This goal can be easily reached by other means of heat and mechanical treatment, although, the most common method is hardening. Principle of hardening rests in transformation of perlitic or perlite-ferritic structure to martensitic or bainitic structure. This means that steels suitable for hardening must have at least 0.3 % of carbon. Steels with lower percentage of carbon can be transformed to steels with low amounts of martensite, which alters its hardness insufficiently.

Hardening is used to increase the hardness of a material. It is a type of heat treatment, during which the material gets heated to austenitization temperature. Hypo-eutectoid steels have to be heated above Ac3, while hyper-eutectoid steels must be heated above Ac1. This is commonly followed by holding the temperature and then cooling by critical speed. Fast cooling suppresses creation of ferrite and perlite. Preserved unstable austenite subsequently transforms at around 500 °C to bainite or martensite. Hardness of martensite increases with increasing content of carbon, simultaneously with its fragility. For this reason, quenched steels often get tempered. Only steels with low carbon content possess good toughness, which is why tempering is obsolete for them. [1, 2]

The most important phase of heat treatment is the rate of cooling, which depends on chosen coolant. Nevertheless, all types of hardening coolants must take the heat away from the parts or the entire cross-section of parts with higher speed than critical cooling speed of given material. Hardening medium must also fulfill these conditions:

- resistance to heat decomposition and oxidation,
- simple removability from surfaces of quenched materials,
- proper cooling kinetic in entire temperature range,
- non-reacting with surfaces of quenched parts. [1, 2]

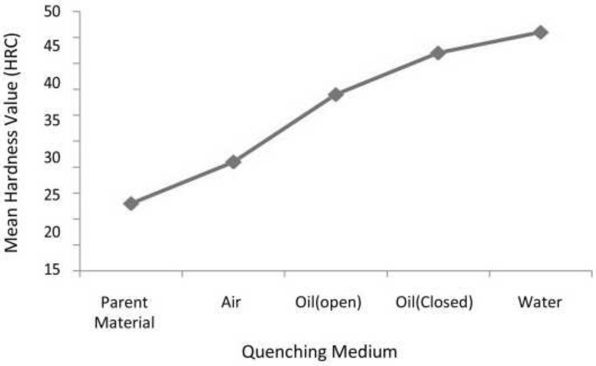


Fig. 1 *Influence of cooling medium on gained hardness [4]*

Cooling of steel after the heat treatment must be sufficiently quick, in order for the austenite to transform to martensite. On the other hand, faster cooling also leads to significant difference in temperatures on the surface and within the material, which results in thermal dilation and creation of external tensions. External tensions can breach cohesion of material, especially during application of external load. Due to this, it is most important to choose the correct cooling rate. Figure 1 displays the influence of cooling medium on hardness of treated part. [3, 4]

The problematic of steel heat treatment has been investigated by numerous publications which describe the influence of process parameters of heat treatment on final properties, such as chemical composition, hardness, yield strength and ductility (elongation). Authors of aforementioned publications were mostly using following heat treatment methods: annealing, normalization, water and oil hardening and tempering. Tests conducted in this publication were done in order to determine properties of used steel, so future parts can be made with tailored properties. [5-10]

Goal of heat treatment is the adjustment of grain size, structure and release of tension in material. Objective of this publication is the evaluation of heat treatment influence and process parameters (austenitization temperature, time of austenitization and cooling medium) on selected steel. This part of work describes preparation of test samples and conducted hardness tests. Acquired knowledge about heat treatment processes can significantly contribute to the clarification of questions arising from their manufacturing.

2 Experimental part

Process parameters of heat treatment (austenitization temperature, time of permanence and cooling medium) were varied for selected steels, for which hardness was then measured. Measurement of properties was done 10 times on each sample by Rockwell method. The results were evaluated and graphically presented.

2.1 Tested material

Steel 1.3520 (100CrMn6) manufactured by Saarstahl was chosen as tested material. The steel designation is done according to ČSN EN 10 213 standard, and its chemical composition can be seen in Table 1. It is a Cr-Mn steel which is suitable for rolling-element bearings. This steel is characterized by its high resistance to wear and tear. Tested samples were cut from steel in cylinder shape with 20 mm diameter and 20 mm length.

Tab. 1 *Chemical composition of steel 1.3520*

Chemical composition:	C	Mn	Si	Cr
Wt %	1.00	1.10	0.60	1.50

2.2 Heat treatment

Samples were quenched with three varying temperatures and two austenitization durations which were chosen according to technological data of selected steel. Furthermore, two types of cooling mediums were tested. Following the hardening, the samples were tempered according to parameters given in data sheet. Process parameters were varied according to recommendations from data sheet. These parameters can be seen in Table 2.

Heat treatment was done in hardening station SKM manufactured by LAC. Hardening was done in furnace LH, while tempering was done in furnace PP 20/65 also made by LAC. Oil and water were used as hardening medium.

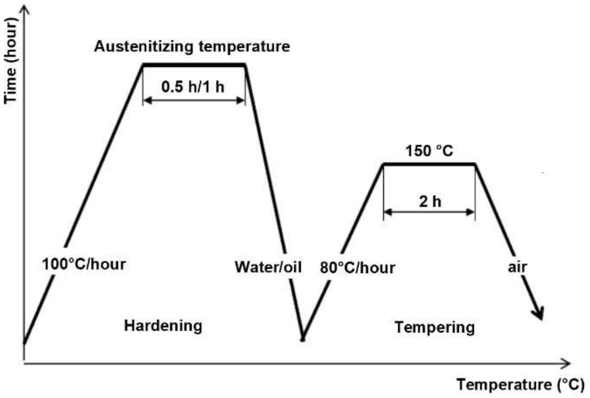


Fig. 2 *Hardening and tempering diagram of steel 100CrMn6*

Tab. 2 *Variation of heat treatment conditions*

Hardening of steels		
Austenitizing time	hour	0.5, 1
Cooling medium	-	water
Austenitizing temperature	°C	780, 795, 810
Cooling medium	-	oil
Austenitizing temperature	°C	810, 820, 830
Tempering of steels		
Tempering time	hour	2
Tempering medium	-	air
Tempering temperature	°C	150

***Fig. 3** Heat treatment – hardening furnace, samples*

2.3 Hardness measurement (Rockwell)

Hardness of samples was first measured on non-altered material, and then on the same sample after hardening and tempering with three different temperature regimes. Hardness was measured by Rockwell method on Rockwell hardness tester HR-150A. Diamond cone with tip angle 120° was used as indentor. The sample was put under initial load (98.07 N), which was manually set by rotating spindle. Scale of hardness tester was zeroed in loaded phase. Afterwards, sample was fully loaded (1373 N), so the final load (1471 N) can be reached in 3 to 6 seconds, as prescribed by appropriate testing standard. Hardness HRC was recorded after de-loading directly from the scale. Value of hardness in Rockwell test is defined by depth of indentation left in material after withdrawal of any additional loads.

3 Results

Experimental part was mainly concerned with hardness testing of steel 100CrMn6 (1.3520) prior to and after heat treatment (hardening and tempering). Hardness testing was done by Rockwell method. Values measured for samples prepared with varying temperature and duration of austenitization were compared between each other. Water and oil were used as cooling medium during hardening. Steel was cooled on air during tempering. Measured data of non-treated steel and heat-treated steel (water as cooling medium) can be seen in Table 3.

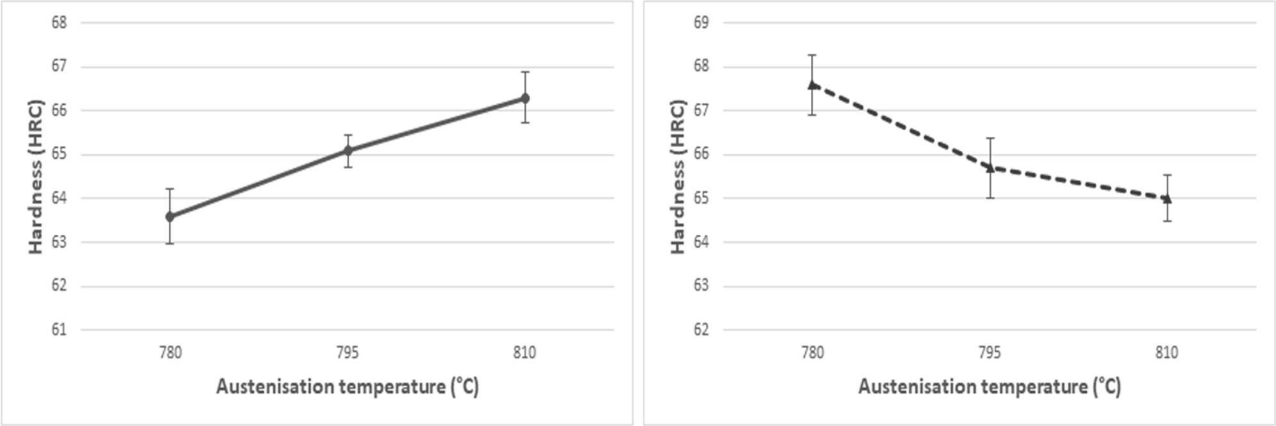
***Tab. 3** Hardness HRC – tempering medium water*

Hardening of steels							
Cooling medium	Original material	**water**					
Austenitizing time		**0.5 h**			**1 h**		
Austenitizing temperature		780 °C	795 °C	810 °C	780 °C	795 °C	810 °C
Measurement	HRC	HRC	HRC	HRC	HRC	HRC	HRC
Mean	9	64	65	66	68	66	65
Standard deviation	1.0	1.3	0.7	1.2	1.3	1.3	1.1
Tempering of steels							
Tempering time	Original material	**2 h**					
Tempering medium		**air**					
Tempering temperature		**150 °C**					
Measurement	HRC	HRC	HRC	HRC	HRC	HRC	HRC
Mean	9	62	63	64	64	63	61
Standard deviation	1.0	1.2	0.7	1.1	1.3	1.3	1.0

Averages of measured results of hardness after hardening were compared for samples prepared with austenitization duration 30 and 60 minutes and temperatures 780 °C, 795 °C and 810 °C. Quenched steel was cooled in water medium.

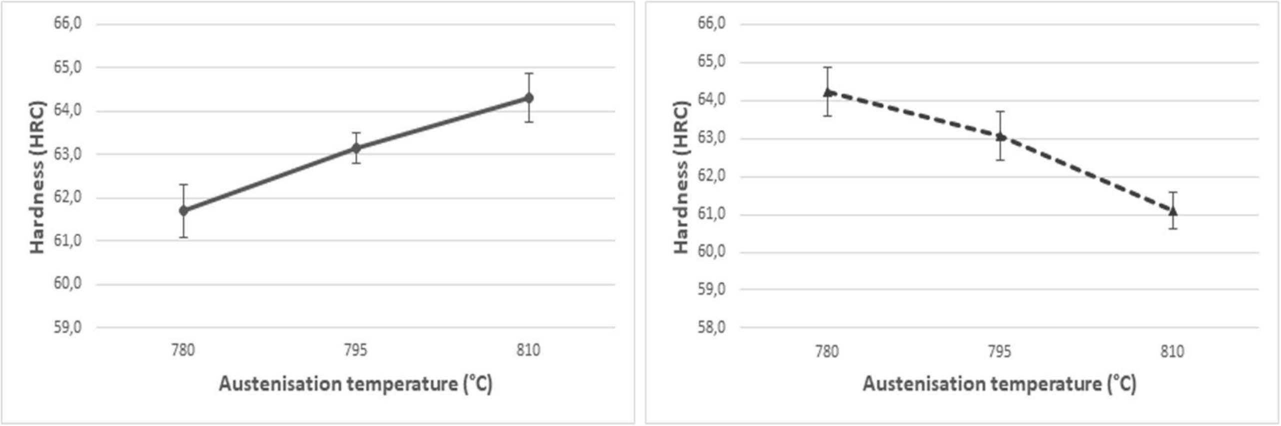
Measured results (Figure 4) show that non-treated steel had hardness of 9 HRC (185 HB). An increasing trend in hardness in dependence on increasing temperature was observed for samples austenitized for 0.5 h. Hardness measured in samples austenitized at 780 °C was 64 HRC, while hardness for samples prepared at 810 °C was 66 HRC, which was a difference of 5 %. On the other hand, opposite trend was observed for 1 hour austenitization duration. Samples prepared at 780 °C demonstrated 68 HRC, while samples austenitized at 810 °C showed hardness of 65 HRC. This decrease was 4 %. It was found that hardness of samples quenched at 780 °C was 6 % higher when austenitized for 1 h than for 0.5 h. Values of hardness for steels quenched at 795 °C were approximately the same for both austenitization durations, about 65 HRC, while hardness of steel (65 HRC) quenched at 810 °C was higher when austenitized for 0.5 h. Highest average hardness (68 HRC) was reached with hardening temperature 780 °C and austenitization duration 1 hour. These changes at varying times and temperatures of austenitization were caused by homogenization of austenite and creation of differing lamellas of martensite with residue of austenite.

Quenched steel samples were subsequently tempered (150 °C, 2h). As can be seen in Figure 5, observed trends were similar as with quenched steel with one particular difference, which was the decrease of hardness values for all temperatures and times by approximately 4 %.



(a) **(b)**

Fig. 4 *Hardening: water as cooling medium: (a) austenitization duration 0.5 hour, (b) austenitization duration 1 hour*



(a) **(b)**

Fig. 5 *Hardening: water as cooling medium + tempering: (a) austenitization duration 0.5 hour, (b) austenitization duration 1 hour*

Measured values of steel with and without heat treatment (oil as cooling medium) can be seen in Table 4.

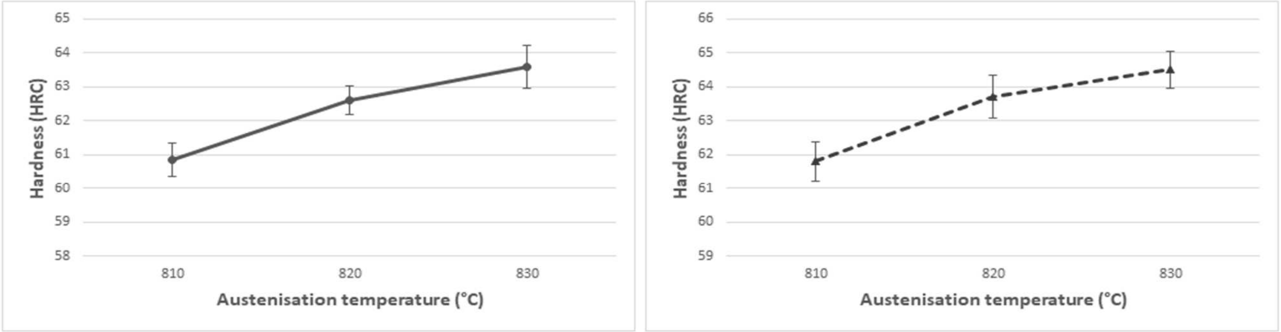
***Tab. 4** HRC Hardness – oil as cooling medium*

Hardening of steels						
Cooling medium	Original material	**oil**				
Austenitizing time		**0.5 h**			**1 h**	
Austenitizing temperature		810 °C	820 °C	830 °C	810 °C	820 °C	830 °C
Measurement	HRC	HRC	HRC	HRC	HRC	HRC	HRC
Mean	9	61	63	64	62	64	65
Standard deviation	1.0	1.0	0.9	1.3	1.1	1.3	1.1
Tempering of steels							
Tempering time	Original material	**2 h**					
Tempering medium		**air**					
Tempering temperature		**150°C**					
Measurement	HRC	HRC	HRC	HRC	HRC	HRC	HRC
Mean	9	58	59	60	58	61	61
Standard deviation	1.0	1.0	1.6	1.7	1.1	1.2	1.0

Displayed results of average hardness after hardening were compared for austenitization times 30 and 60 minutes at temperatures 810, 820 and 830 °C. Quenched steel was cooled in oil.

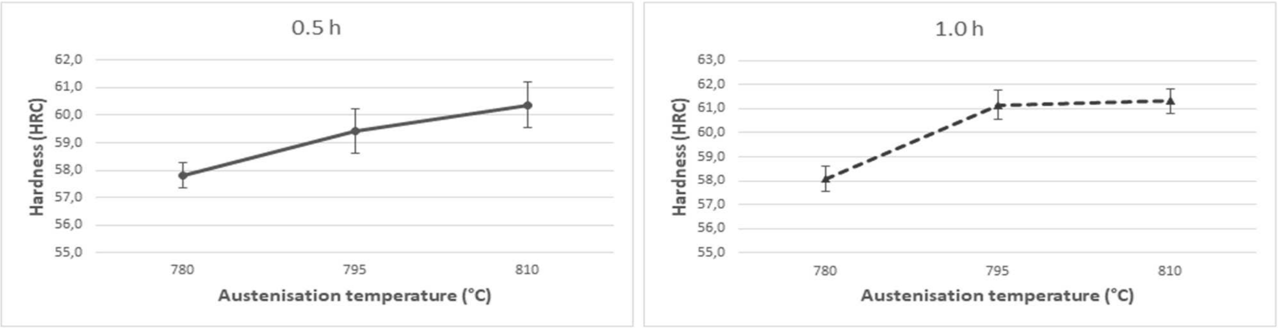
Untreated steel displayed hardness of 9 HRC (185 HB). Figure 6 shows average hardness in dependence on time of austenitization, specifically 30 and 60 minutes. Measured results show that higher austenitization temperature led to increasing hardness. Samples austenitized for 30 minutes at 810 °C displayed 61 HRC. For higher temperatures (830 °C), the hardness rose to 64 HRC, which was a difference of 5 %. Similar trend was observed in samples austenitized for 60 minutes at 810 °C, which displayed 62 HRC, and for samples quenched at 830 °C which showed 65 HRC. Difference in between these two was 4 %. Comparison of austenitization duration shows that higher times lead to increase of hardness, which was 2 % in this case. These changes could be caused by creation of martensite structure, which is more equally distributed when hardening in oil for all applied temperatures.

Subsequent low temperature tempering (Figure 7) manifested in decrease of hardness by 4 up to 8 %. This is important for removal of austenite residue and decrease of tension.



(a) **(b)**

***Fig. 6** Hardening: oil as cooling medium: (a) austenitization duration 0.5 hour, (b) austenitization duration 1 hour*



(a) **(b)**

***Fig. 7** Hardening + tempering: oil as cooling medium: (a) austenitization duration 0.5 hour, (b) austenitization duration 1 hour*

As the authors show in their publications [11-17], the temperature and austenitization time affect the change of mechanical properties. These results correspond and confirm the findings of the present work.

4 Conclusions

This study deals with the influence of temperature and time of austenitization on final hardness during heat treatment. Steel 100CrMn6 (1.3520) was selected as experimental material, which was quenched and tempered. As is evident from the results, different time of austenitization and temperature had an effect on final hardness after hardening or tempering. Lower temperature and shorter duration of austenitization led to insufficient homogenization of austenite, which resulted in incomplete transformation to martensite or bainite. Due to this effect, lower hardness was measured. On the other hand, high temperature and longer duration of austenitization can lead to coarser austenitic grain, which once again results in decrease of hardness. Besides the aforementioned parameters, the final hardness was also affected by cooling medium. It can be noticed that first two thermal regimes and longer duration of austenitization (60 minutes) led to higher hardness. On the other hand, samples exposed to third thermal regime had higher hardness when austenitized only for 30 minutes. This was true for materials cooled by water. On the opposite, when the samples cooled in oil, the hardness was always higher for longer durations of austenitization for all thermal regimes.

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