EFFECT OF HEAT TREATMENT ON QUALITY OF STEEL 42CrMo4

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ABSTRACT
Steel 42CrMo4 is the chromium, molybdenum and manganese low alloy steels usually used in hardened and tempered state. In this state this steel has good toughness, good torsional and fatigue strength. Its application is for statically and dynamically stressed components for engines and machines. In this article, the results of influence of different form of heat treatment on quality (microstructure and hardness) of steel are presented. Heat treatments like annealing (normalizing and soft annealing), hardening and tempering are carried out in atmospheric condition. From the results could be seen that in opposite of annealing the hardening treatment improves hardness of the material. Tempering process decreases hardness but it still higher than in the case of annealing. Microstructural analysis shows that temperature of heat treatment and a cooling rate had very important influence on microstructure and hardness of steel.

Key words:quality, heat treatment, microstructure, hardness

1. INTRODUCTION

Steel 42CrMo4 belongs to the group of steels that are heat treated before final use by a combination of quenching and tempering process in order to achieve the most favorable ratio of strength and ductility.These structural parts are exposed to dynamic stresses during work.The heat treatment gives structural strength, i.e. a high value of yield stress, tensile strength and toughness at room, high and cryogenic temperature [1-3].These steels usually contain from 0,25 to 0,6% carbon which allows to obtain the maximum martensite content after quenching and achieve the required hardness.In opposite, the hardenability of steel depends on the type and content of alloying elements, but also on the dimensions of the product and the quenching media.As an alloying element, chromium is dominant, but it is found in combination with molybdenum and nickel.These elements lower the temperature and the rate of $\gamma \rightarrow \alpha$ transformation and thus increase the hardenability.Tempering after quenching gives the greatest contribution to toughness.From the aspect of microstructure and its influence on toughness, martensite, bainite(upper bainite) are favorable, while lower bainiteand pearlite (coarse or fine) and especially ferrite are unfavorable because they reduce toughness due to the uneven distribution of relatively coarse carbides.The general rule when choosing these steels is to choose steels according to the best hardenability, i.e., the more alloyed steels for the larger the cross-sectional dimensions and the higher the stresses [2].Steel 42CrMo4 is the chromium and molybdenum low alloy steel that has good hardenability.These steels can also be used for higher temperatures (up to 550 °C), the cross-sectional dimensions up to Ø 250 mm and for the most stressed structures.The influence of heat treatment on microstructure and hardness of steel 42CrMo4are presentedin this work. The change in microstructure and hardness after the heat treatment process depends of the temperature of heat treatment and cooling rate.

2. EXPERIMENTAL PART

Material tested in this work was the steel 42CrMo4, Wn.1.7225.The chemical composition has given in Table 1 according to standard EN 10083-3-2006.

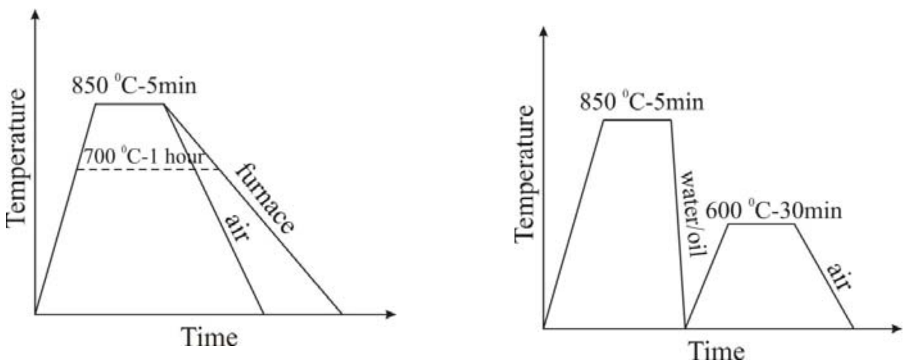
Table 1. Chemical composition of steel 42CrMo4 [4,5]

Steel	Chemical composition, wt.%						
	C	Si	Mn	P	S	Cr	Mo
42CrMo4	0,38-0,45	max.0,4	0,6-0,9	max.0,025	max.0,035	0,9-1,2	0,15-0,3

The analysis of a microstructure and hardness were done for a initial state and the seven heat treated samples. All the heat treated samples are heated in an electric furnace without a protection atmosphere and together with furnace from the room temperature. The heat treatment was done at Faculty for Metallurgy and Technology in Zenica. Processes of the heat treatments (normalizing, soft annealing, hardening and tempering) are described in Table 2 and Figure 1.

Table 2. Heat treatment of the steel 42CrMo4

Sample	Heat treatment
Sample 1	no heat treating, initial state
Sample 2	continuous heating at 850 ^{0}C/holding 5 minutes/cooling in air
Sample 3	continuous heating at 850 ^{0}C/ holding 5 minutes/cooling in furnace
Sample 4	continuous heating at 850 ^{0}C/ holding 5 minutes/cooling in air/ continuous heating at 700 ^{0}C/ holding 1 hour/cooling in furnace
Sample 5	continuous heating at 850 ^{0}C/ holding 5 minutes/cooling (quenching) in water
Sample 6	continuous heating at 850 ^{0}C/ holding 5 minutes/cooling (quenching) in oil
Sample 7	continuous heating at 850 ^{0}C/ holding 5 minutes/cooling (quenching) in water/ continuous heating at 600 ^{0}C/ holding 30 minutes/cooling in air
Sample 8	continuous heating at 850 ^{0}C/ holding 5 minutes/cooling (quenching) in oil/ continuous heating at 600 ^{0}C/ holding 30 minutes/cooling in air



a) *b)*

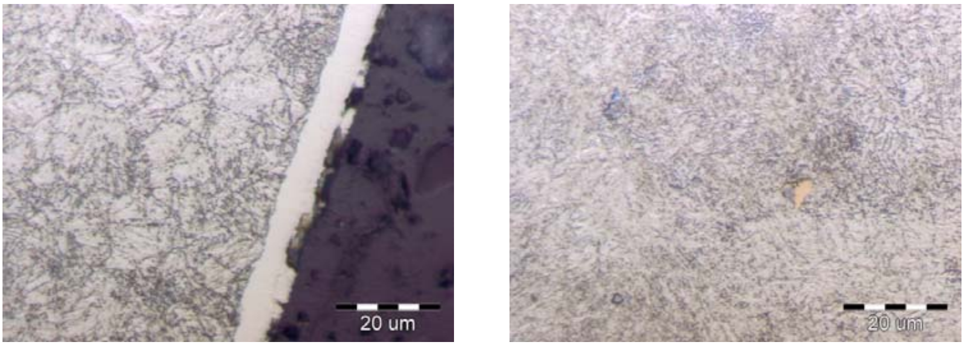
Figure 1. Technology of the heat treatment: a) for Sample 2,3 and 4, b) for Sample 5, 6, 7 and 8.

Before analysis of microstructure the samples were prepared by grinding, polishing and etching by Nital. The microstructural analysis was carried out by theOlympus optical microscope with maximum magnification of x1000. Hardness test, according to standard BAS EN ISO 6507-1:2018 [6], were performed on specimens prepared for microstructure analysis.

3. RESULTS AND DISCUSSION

3.1. Analysis of microstructure

The microstructure of the initial state and heat treated samples are shown in Figures 2-8.



a) *b)*

Figure 2. The microstructure of Sample 1 (the initial state: a) surface and b) center of sample, 1000x

Analysis the initial state showed that the steel 42CrMo4 was delivered in the heat treated state. A soft annealed microstructure was found, with the pearlite being formed in a globular form i.e. in the form of spherical carbide particles in the ferrite matrix, Figure 2.On the surface, it could be seen the white layer what point out on the surface treatment of the steel. In the sample could be seen presence of nonmetallic inclusions (Figure 2.b).The same microstructure was obtained in the case of the soft annealing at700^{0}C, Figure 3.

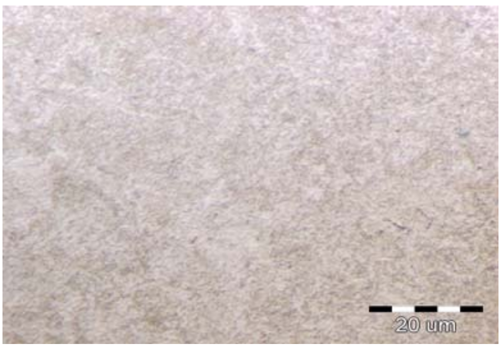
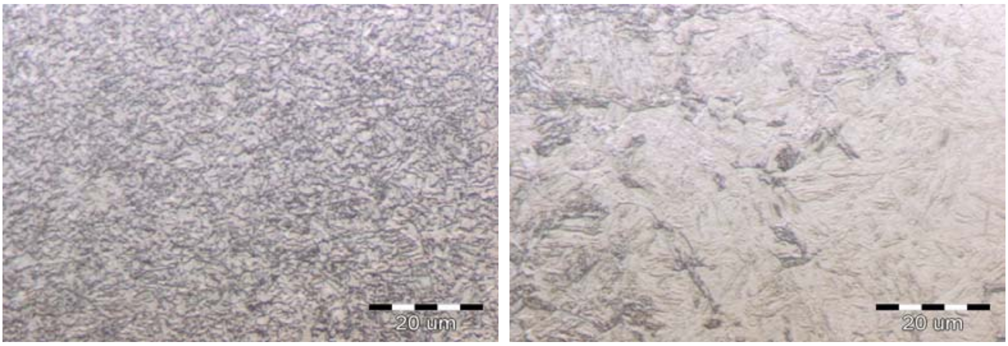


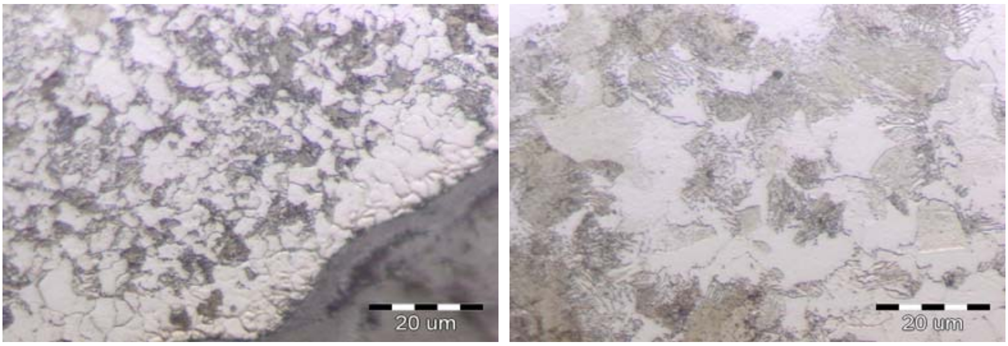
Figure 3. The microstructure of Sample 4, 1000x

The cooling rate after the normalizing at 850 ^{0}C had very important influence on the microstructure of steel. After cooling in the air the microstructure was a bainite (Figure 4), while product of cooling in furnace was ferrite-pearlite microstructure (Figure 5). On the surface of sample, the grain size is smaller than in the center of sample because of the intensity of cooling.The analysis of heat treated samples showed oxidation and decarburization on the surface, Figure 5.a. Reason for this was not use a protection atmosphere in the furnace during the heat treatment.



a) b)

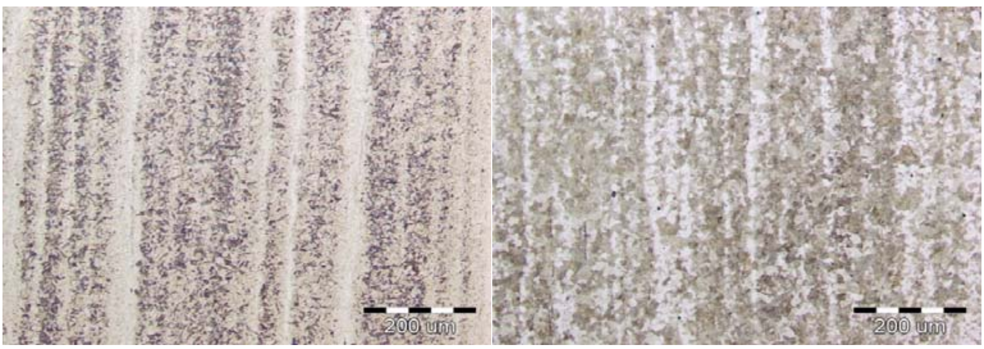
Figure 4. The microstructure of Sample 2: a) surface and b) center of sample, 1000x



a) b)

Figure 5. The microstructure of Sample 3: a) surface and b) center of sample, 1000x

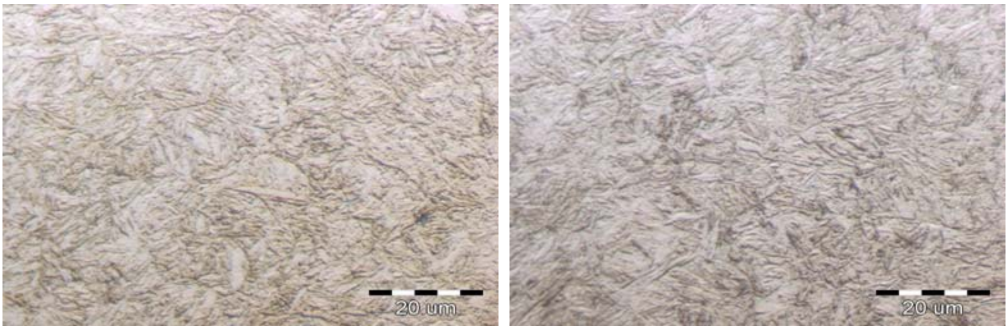
Analysis of microstructure on the longitudinal sample showed banded microstructure, Figure 6.



a) b)

Figure 6. The microstructure of a) Sample 2 (center) and b) Sample 3 (center), 1000x

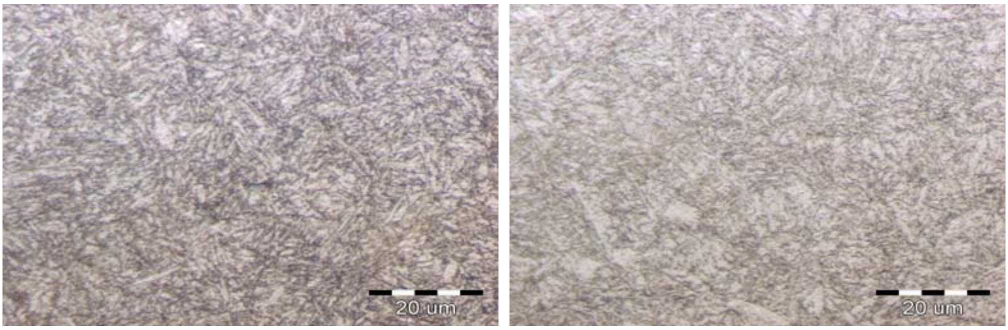
After cooling in water (Figure 7.a), the microstructure was martensite with bainite because the cooling rate was faster while after quenching in oil the microstructure was bainite (Figure 7.b) .



a) b)

Figure 7. The microstructure of a) Sample 5 and b) Sample 6, 1000x

During tempering the resulting microstructure contains bainite or carbides in the matrix of ferrite, Figure 8.



a) b)

Figure 8. The microstructure of: a) Sample 7 and b) Sample 8, 1000x

3.2. Analysis of hardness

The results of the hardness analysis are presented in Table 3.

Table 3. Analysis of hardness

Sample	**Heat treatment state**	**Hardness (HV10)**					
		Single values					Average
Sample 1	no heat treating, initial state	283	279	283	283	279	281
Sample 2	850 ^{0}C/5'/ air	599	599	599	572	599	594
Sample 3	850 ^{0}C/5'/ furnace	209	209	206	206	209	208
Sample 4	850 ^{0}C/5'/ air/700 ^{0}C/1h/ furnace	266	266	266	262	262	264
Sample 5	850 ^{0}C/5'/ water	707	707	707	724	724	714
Sample 6	850 ^{0}C/5'/ oil	690	690	673	690	690	687
Sample 7	850 ^{0}C/5'/ water/600 ^{0}C/30'/ air	322	333	322	322	322	324
Sample 8	850 ^{0}C/5'/ oil/600 ^{0}C/30'/ air	333	333	322	333	333	331
		Hardness (HV0,2)					
Sample	**Heat treatment state**	Single values					Average
Sample 1	surface - white layer	426	441	426	441	441	435

The analysis of the hardness results showed that the hardness of the initial and soft annealed state is similar, which is confirmed by the microstructure analysis. Microhardness of the white layer on surface of initial sample is 435 HV0,2 what implied that some kind of surface treatment was done probably with aim to improve wear resistant.Quenching in water or oil may increase the hardness by about 2,5 times with respect to the initial state. The tempering, whether it be quenching in water or oil, gives a hardness of 324 i.e. 331 HV. Unexpected results were obtained with the air-cooled normalization process. In this case a very high hardness value (594 HV) was obtained. It is almost three times higher than in the case cooling in the furnace (208 HV). The reasons for such a high cooling rate are in the dimensions of the samples (approx. 2x10 mm) as well as the chemical composition.

4. CONCLUSIONS

From the results it could be concluded follows:

- The initial state (who was unknown) is the soft annealed state (hardness of 281 HV10) where are spherical carbide particles are placed in the ferrite matrix with white layer hardness of 436 HV0,2. It means that some kind of surface heat treatment is done to improve wear resistance. The white layer analysis will be done in future research.
- By quenching it is possible to increase hardness about three times thanks to martensite or bainite microstructure.
- After tempering the hardness is almost the same whether it quenching in water or oil.
- Cooling in the air after the normalization gave almost the same hardness as quenching in oil thanks to bainitemicrostructure.
- Heat treatment should be done in a protective atmosphere to protect of the steel fromoxidation and decarburization.

5. REFERENCES

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