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EFFECT OF HEAT TREATMENT ON MICROSTRUCTURE AND HARDNESS OF STEEL 67SiCr5

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ABSTRACT
Steel 67SiCr5 is a alloyed carbon steel usually used for production of springs. It is used for load bearing springs, ring-shape springs, spiral springs, anti vibration springs etc. Springs steels are usually distribute in annealed or hardened and tempered state. Heat treating could be performed before or after springs forming. In this article, the results of influence of different form of heat treatment on microstructure and hardness 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. Also, a presence of a decarburization was noticed.

1. INTRODUCTION
Springs are important structural parts using for many purposes as to absorb the shocks or vibration, to measure the forces, to store the energy, control the motion, to return a component to its original position after displacement, to permit some freedom of movement between aligned components without disengaging them etc. The main requirements for springs materials are high elasticity limit, high ultimate strain, good creep rupture strength, ductility, good deformability in hot and cold state, quality surface, cleanliness of steel and low surface decarburization during heat treatment. Steel alloys are the most commonly used spring materials. The most popular alloys include high-carbon, alloy steels and stainless steels. High carbon spring steels are the most commonly used material because it is less expensive, it can be easily worked and it is readily available. These steels are not suitable for springs operating at high or low temperatures or for shock or impact loading [1]. Alloy steels are alloyed with silicone, manganese, chromium, vanadium, molybdenum and nickel. Steel 67SiCr5 is the springs steel alloyed with silicon and chromium. Chrome-silicon steel is an excellent spring material for highly stressed springs requiring long life and/or shock loading resistance and can be used from temperatures up to 300 ^{0}C.Silicon increases hardenability, wear resistance, elastic limit and yield strength and scale resistance in heat resistant steels but decreases resistance to decarburization. Addition of

chromium in steels enhances hardenability, corrosion and oxidation resistance. Mechanical and metallurgical properties of the steels as well as the springs steels could be changed by cold work or heat treatment. Usually applied heat treatment processes for the springs are soft annealing, normalizing, hardening and tempering. Soft annealing is usually used in the case of difficult shaping operation which involves cold working (cold coiling, cutting, stamping...). Normalizing may be necessary if the spring is exposed to high stresses and in such cases where day cause difficulties when shaped [2]. The quenched and tempered condition gives to spring steels optimum strength, toughness and vibration damping. If there is requirement for impact resistance, the springs should have better hardenability i.e. a content of martensite in center should be about 80 to 90%.For this reason, the standards prescribe the maximum dimension for individual types of steel [3].

In this work, the influence of heat treatment on microstructure and hardness of springs steel 67SiCr5 are presented. 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 springs steel 67SiCr5 with a chemical composition and mechanical properties have given in Table 1 and 2.

Table 1. Chemical composition of EN 67SiCr5 [4]

Steel	**Chemical composition, wt.%**					
	C	Si	Mn	P	S	Cr
67SiCr5	0.62-0.72	1.20-1.40	0.40-0.60	0.035	0.035	0.20-0.40

Table 2.Mechanical properties of EN 67SiCr5 [4]

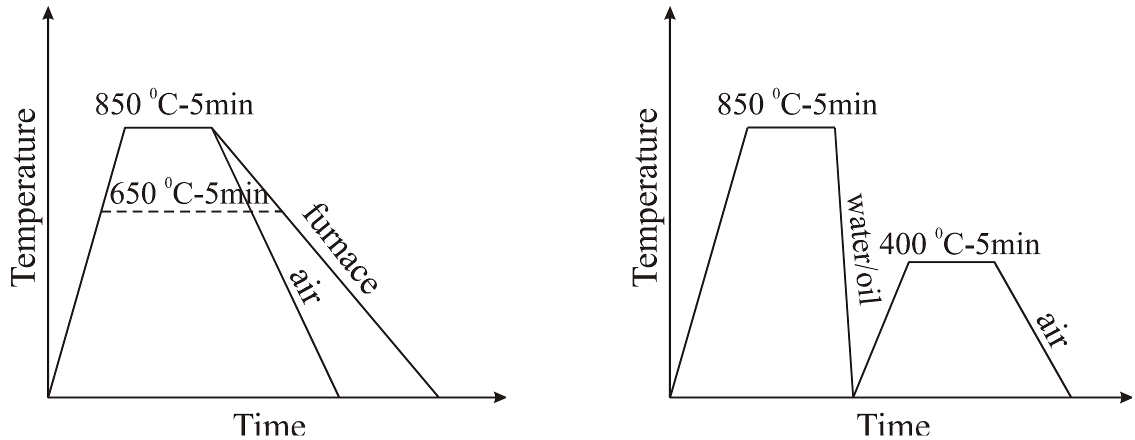
Steel	**Mechanical properties**					
	$R_{p0.2}$, MPa	R_{m},MPa	KV/KU, J	A, %	Z, %	HBW
67SiCr5	192 (≥)	797 (≥)	13	13	33	322

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. Processes of the heat treatments(normalizing, soft annealing, hardening and tempering) are described in Table 3 and Figure 1.

Table 3. Heat treatment of the springs steel 67SiCr5

Sample	**Heat treatment**
Sample 1	No heat treating, initial state
Sample 2	continuous heating at 850 ^{0}C/soaking 5 minutes/cooling in air
Sample 3	continuous heating at 850 ^{0}C/soaking 5 minutes/cooling in furnace
Sample 4	continuous heating at 650 ^{0}C/soaking 5 minutes/cooling in furnace
Sample 5	continuous heating at 850 ^{0}C/soaking 5 minutes/cooling (quenching) in water
Sample 6	continuous heating at 850 ^{0}C/soaking 5 minutes/cooling (quenching) in oil
Sample 7	continuous heating at 850 ^{0}C/soaking 5 minutes/cooling (quenching) in water/

	continuous heating at 400 ^{0}C/ soaking 5 minutes/cooling in air
Sample 8	continuous heating at 850 ^{0}C/soaking 5 minutes/cooling (quenching) in oil/ continuous heating at 400 ^{0}C/ soaking 5 minutes/cooling in air



a) b)

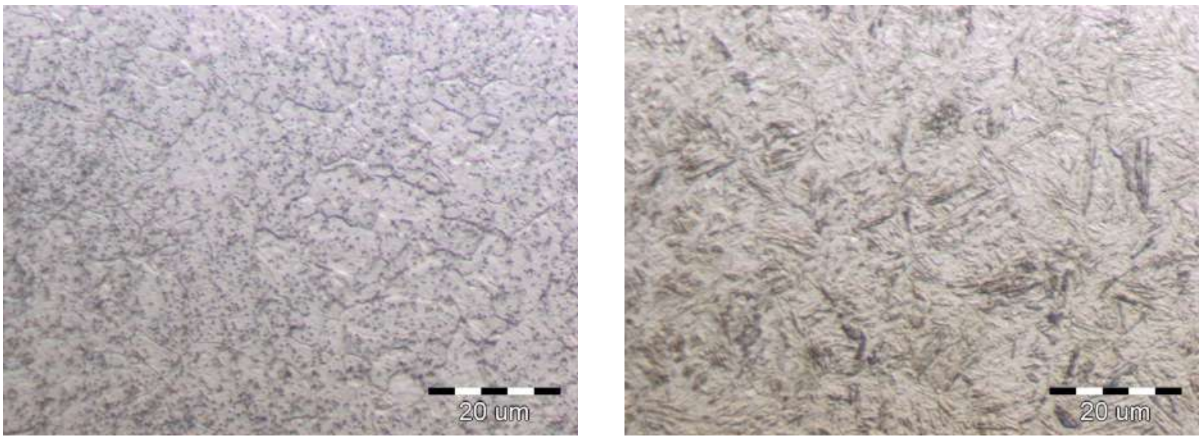
Figure 1. Technology of the heat treatment: a) for Sample 2,3 and 4, b) for Sample 5, 6, 7 and 8.

Before analysis of microstructure the samples were prepared by grinding, polishing and etching by Nital (HNO_3 + ethanol). 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, were performed on specimens prepared for microstructure analysis. Estimating of the depth of decarburization was done according to standard ASTM E 1077-01 (R 2005) and BAS EN ISO 6507-1:2018.

3. RESULTS AND DISCUSSION

Analysis of microstructure

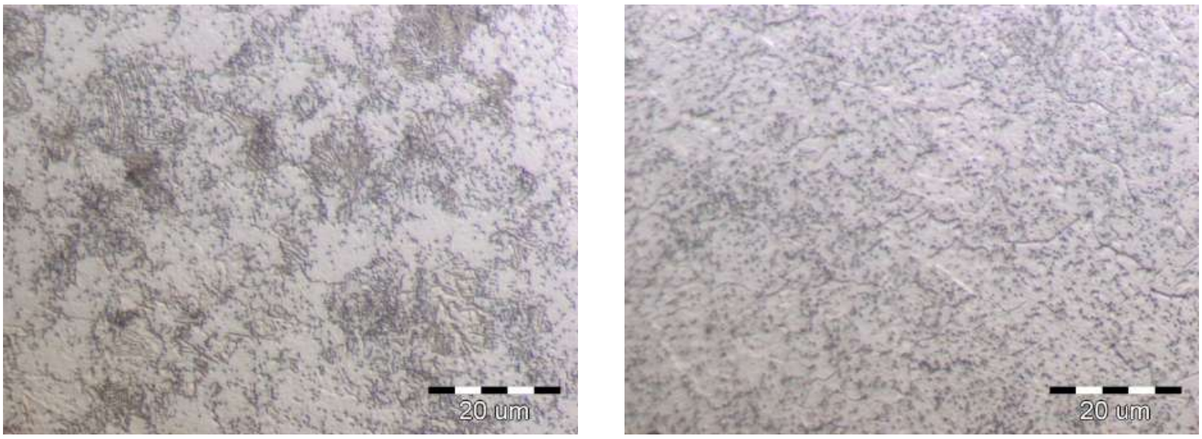
The microstructure of the heat treated samples and the initial state are shown in Figures 2-5. All samples showed fine grained microstructure.



a) b)

Figure 2. The microstructure of: a) Sample 1 (the initial state) and b) Sample 2 (heating at 850 ^{0}C/soaking 5 minutes/cooling in air), x1000

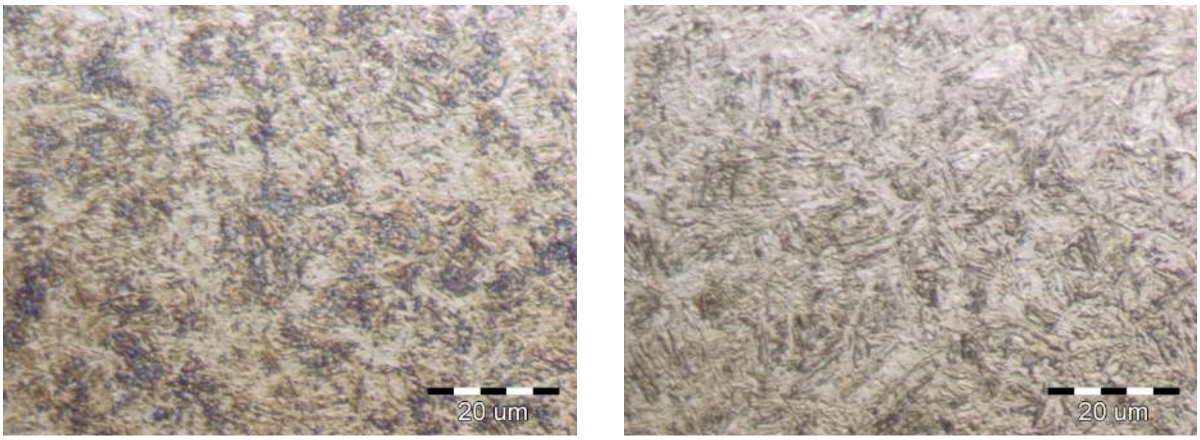
Analysis the initial state showed that the spring steel 67SiCr5 was delivered in the heat treated state. A soft annealed microstructure was found, with the perlite being formed in a globular form i.e. in the form of spherical carbide particles in the ferrite matrix, Figure 2.a. The same microstructure was obtained in the case of the soft annealing at 650 ^{0}C too, Figure 3.b. 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 2.b.), while product of cooling in furnace was ferrite-pearlite microstructure (Figure 3.a.). The ferrite-pearlite microstructurepresents the mixture of the carbide particles in the globular form and lamelar form in the ferrite matrix.



a) b)

Figure 3. The microstructure of: a) Sample 3 (heating at 850 ^{0}C/soaking 5 minutes/cooling in furnace) andb) Sample 4 (heating at 650 ^{0}C/soaking 5 minutes/cooling in furnace), x1000

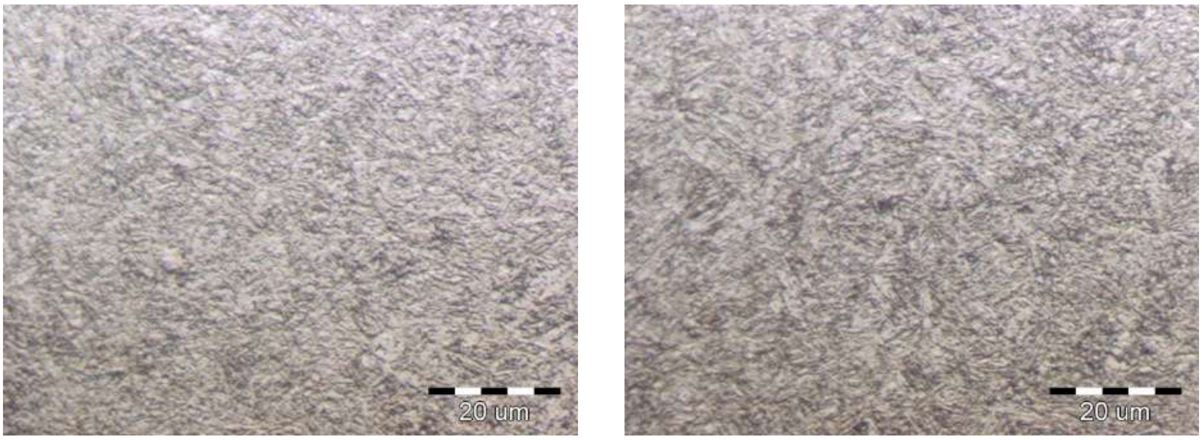
After quenching in oil the microstructure was bainite (Figure 4.b) while the microstructure after cooling in water (Figure 4.a) was martensite with bainite because the cooling rate was faster.



a) b)

Figure 4. The microstructure of: a) Sample 5 (heating at 850 ^{0}C/soaking 5 minutes/cooling (quenching) in water) and b) Sample 6 (heating at 850 ^{0}C/soaking 5 minutes/cooling (quenching) in oil, x1000

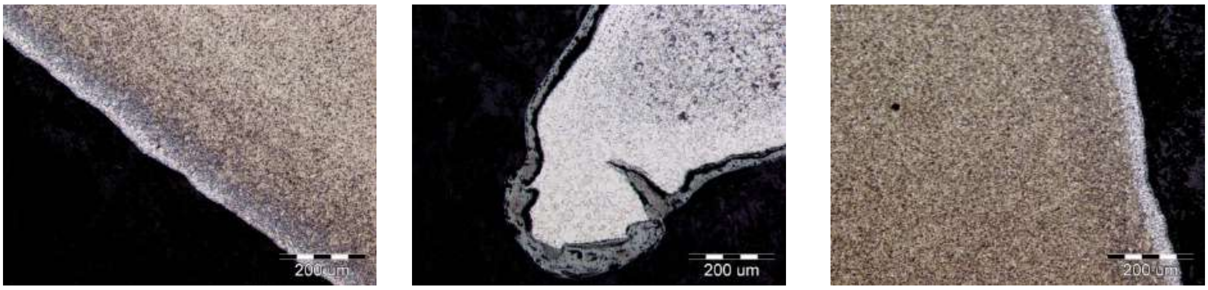
During tempering the resulting microstructure contains bainite or carbides in the matrix of ferrite, Figure 5.a and b.



a) b)

Figure 5. The microstructure of: a) Sample 7 (heating at 850 ^{0}C/soaking 5 minutes/cooling (quenching) in water/ continuous heating at 400 ^{0}C/ soaking 5 minutes/cooling in air) and b) Sample 8 (heating at 850 ^{0}C/soaking 5 minutes/cooling (quenching) in oil/ continuous heating at 400 ^{0}C/ soaking 5 minutes/cooling in air), x1000

The analysis of all heat treated samples (except of the soft annealed sample) showed decarburization on the surface, Figure 6. Reason for decarburization was not using a protection atmosphere in the furnace during the heat treatment. Also, the silicon as alloying elements contributes to decarburization. There is no general numerical limit on decarburization, and phrases such as "held to a minimum consistent with commercial quality" are very elastic [5] but it must be careful because it has been shown that decarburization can reduce the fatigue strength of high-strength steels (1655 MPa and up) by 70% to 80% and lower strength steels (965 to 1034MPa) by 45% to 55%.Surface treatments as a shot peening this problem could be dissolve or minimized [6, 7].



Sample 2 Sample 3 Sample 6

Figure 6. Example of decarburization on the sample surface, x100

Estimation of the depth of decarburization was done for three samples (Sample 2, 3 and 4) and results are presented in Table 4.

Table 4. The results of testing of the decarburization depth

Sample	**Depth of decarburization, µm**					
	Single values					
	1	2	3	4	5	Average
Sample 2	59.3	57.9	45.1	54.0	55.4	54.3
Sample 3	69.6	69.7	72.8	75.2	70.5	71.6
Sample 4	-	-	-	-	-	-

Analysis of results showed that there was not decarburization for the soft annealed sample and the depth of decarburization was higher for sample who was cooling in the furnace what was expected.

Analysis of hardness

The results of the hardness analysis are presented in Table 5.

Table 5. Analysis of hardness

Sample	**Hardness (HV 10)**					
	Single values					Average
Sample 1 (initial state)	176	170	185	186	179	**179**
Sample 2 850 ^{0}C/5'/ air	665	665	665	665	665	**665**
Sample 3 850 ^{0}C/5'/ furnace	187	186	186	187	187	**187**
Sample 4 650 ^{0}C/5'/ furnace	187	170	171	173	173	**175**
Sample 5 850 ^{0}C/5'/ water	824	824	824	824	824	**824**
Sample 6 850 ^{0}C/5'/ oil	698	698	681	681	681	**688**
Sample 7 850 ^{0}C/5'/ water 400 ^{0}C/5'/ air	473	498	503	514	514	**500**
Sample 8 850 ^{0}C/5'/ oil 400 ^{0}C/5'/ air	483	503	508	514	519	**505**

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. Quenching in water or oil may increase the hardness by about four times with respect to the initial state. The tempering, whether it be quenching in water or oil, gives a hardness of 500 i.e. 505 HV. Unexpected results were obtained with the air-cooled normalization process. In this case a very high hardness value (665 HV) was obtained, which almost corresponds to the hardness after oil quenching (688 HV). The reasons for such a high cooling rate are in the dimensions of the samples (approx. 2x70 mm) as well as the chemical composition. After normalization and cooling of the samples in the furnace, the hardness was 3.5x less than after air cooling.

4. CONCLUSIONS

From the results it could be concluded follows:

- The initial state (who was unknown) is the soft annealed state where are spherical carbide particles are placed in the ferrite matrix.
- By quenching it is possible to increase hardness about four 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 bainite microstructure.
- Heat treatment should be done in a protect atmosphere because the steel is sensitive to decarburization.

5. LITERATURE

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