



Effect of Austenization Temperature on the Microstructure in Cr-Mn-Si Steel

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Abstract: This work is a part of research on the microstructure and mechanical properties of Cr-Mn-Si steels after various thermal treatments. In order to increase the resistance of the materials against failure it is necessary to possess simultaneously high strength and plasticity at the same time. Normally, in conventional metals, this is impossible. The purpose of the present study is to trace the polymorphic transformation of the microstructure and the redistribution of the trace elements in the corresponding microstructural transformations of the steel at each stage of applied heat treatment - austenization, quenching, austempering, tempering. The chosen sequence of applied heat treatments is to obtain a bainite structure of up to 50% in order to achieve high strength and toughness of the material.

Keywords: bainite, retained austenite, steels, phase transformations,

I. INTRODUCTION

A number of devices in various fields of heavy industry and energy operate under extreme loads, at high temperatures and pressures, and not rarely in radioactive environments. In this regard, a number of studies have focused on finding steels with a suitable microstructure that have both high strength and good deformation and welding capability, which can work under severe operating conditions. In publications [1 - 6], it is shown that such are steels with microstructure consists of soft ferritic matrices and martensitic and/or bainitic particles. Other auteurs [8] reported that the mechanical properties of tempered martensite are more favorable than those of ferrite - bainite - martensite microstructure in 42CrMo4 steel. In the same publication is shown that the lower bainite which appears in acicular form provided a better combination of mechanical properties in AISI 4340 Steel. The microstructure of upper bainite - martensite in the same steel significantly lowers mechanical properties compared with the martensitic microstructures. In other publications [4, 7, 9 and others] is claimed that lower bainite- martensite microstructure provides good mechanical properties. Different structural morphologies have been investigated as a result of cooling from the austenitic temperature or after other heat treatments. Previous studies by the author [10, 11] have found that standard chromium-silicon steel acquires very good high strength and, at the same time, high ductility and crack resistance after corresponding isothermal hardening. The tensile strength of steel reached was 1120 - 1130 MPa, with a relative

elongation of 11.6 - 12.6% and fracture energy of 32 - 33 J [10]. Because the resulting bainite or martensitic structures are complex in nature and can change their morphology depending on various technological factors, as well as the amount of carbon and alloying elements in the steel [1], many questions and uncertainties remain regarding the transformations and resulting structures, which requires further research. The object of this work is to study and analyze the phase transformations and microstructure of the widely used chromium-silicon steel with a mean carbon content of 0.30%.

II. EXPERIMENTAL PROCEDURE

The chemical composition of the steel is given in Table 1.

Table – I: Chemical composition of CrMnSi

Element	C	Si	Mn	Cr	Cu	P	S
% wt.	0.33	1.29	1.1	1.06	0.09	0.017	0.018

The microstructures were examined by optical and scanning electron microscopes (Czech Focused ion beam equipped SEM Lyra, Tescan with Quantax EDS detector - Bruker) at different magnifications. Metallography specimens were cut from the impact test pieces. The specimens were etched with 3 % nitric acid, according to standards E3-95 Preparation of Metallographic Specimens, E407-93 Micro etching Metals and Alloys. The hardness of the specimens is measured in Rockwell test.

I. Heat treatment regimes

The present study investigates the structure of the test bodies after each stage of the selected heat treatment mode (Figure 1). The choice of austenisation temperature for alloy steels containing both carbide-forming elements and non-carbide-forming as silicon, albeit in a small amount, is made taking into account the influence of the heating temperature on structural changes, since the alloying elements have different effects on the growth of the austenitic grain.

The first stage of the treatment was continuous annealing at 930 °C in a carbon-containing medium and subsequent air cooling. The purpose of the treatment was to stabilize the structure in the core and to obtain a high surface hardness.

The second tap was isothermal hardening. It begins with austenization at 880 °C for 40 min. The austenization was carried out in an electric furnace from which the samples were quickly transferred to a salt bath at 275 °C for 5 minutes and immediately thereafter to another salt bath at 370 °C for 17 minutes. The baths consist of nitrates (KNO₃/NaNO₃, 1:1) for isothermal quenching followed by cooling in oil. Subsequent low temperature aversion at 250 °C for 180 minutes was applied.



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The mode selected is confirmed by what is described in the literature [2]. In steel CrMnSi at 370 °C, according to the dilatogram referred to in [2], by the 5th minute, the first phase of bainite conversion, proceeding by a carbide-free mechanism. Anticipated redistribution of carbon atoms but without carbide formation are shown. During the next 15 minutes of retention, a period of preparation of the carbide formation processes takes place. These carbides should be fine dispersed and this results in a decrease in the amount of carbon in the austenite. Further retention at this temperature results in coagulation of carbides, resulting in austenite depletion of carbon even more. There was a partial conversion of the austenite into the α phase and subsequently aversion of this phase. The hardness of the test body after this treatment is 42-43HRC.

The third treatment step was high temperature tempering at 640 °C for 12 hours and cooling at air. The preliminary purpose of the treatment was to stabilize the structure, to make the unconverted austenite impoverished by flying elements, the whole carbon to be in the form of cementite, not to remain unconverted cementite.

III. RESULTS AND DISCUSSION

Regime 1

Due to the long retention (regime 1), coagulation and recrystallization of the deformation structure of the parent metal occurs, separating coherent carbides (Fig. 2). Probably a process of the so-called grain refinement is clearing the crystals. To our surprise, the presence of isolated cerium oxides was detected (Fig.3).

The presence of cerium oxides could be explained by the desulfurization of the extracted steel, which is usually achieved by introducing cerium (0.2-0.3%) and silico calcium (0.2-0.3%) directly into the metal melt when poured into the bucket. On the other hand, it is known that the presence of rare earth metals in steel improves the welding ability and deformability in the hot state, which could also explain its presence in the steel. The more contaminants there are in the liquid steel, the more effective is the result of treatment with cerium.

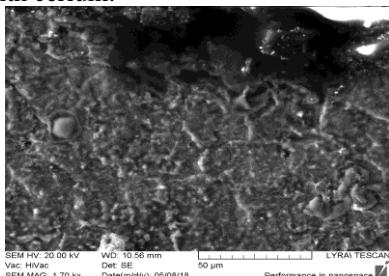


Fig.1. Microstructure after cementation

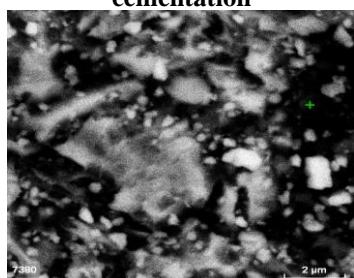


Fig.2. Cerium oxides and air cooling

The presence and amount of cerium in this steel was found to be 4.71 at. % (fig.4).

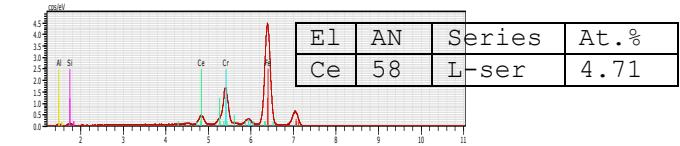
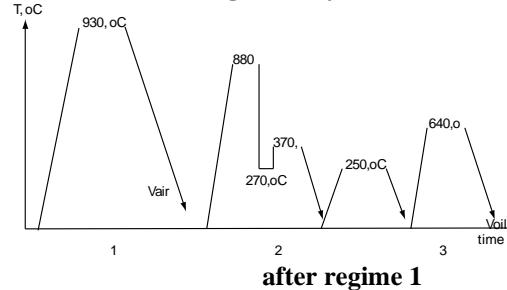


Fig.3. X-ray of the metal



Metallographic photographs (Fig. 5, a and b) show large decarbonized regions with recrystallized decomposed ferrite crystals and numerous dispersed coherently coupled carbides. Recrystallization and coagulation of the α -phase has occurred.

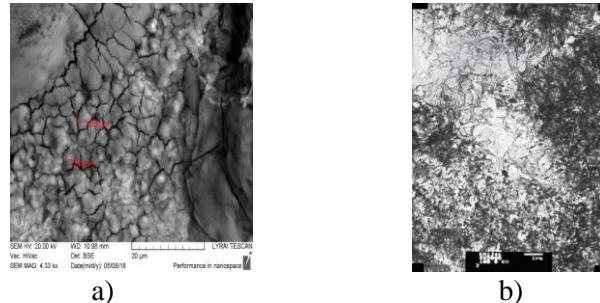


Fig.4. SEM (a) and TEM (b) image of decarbonized large areas with recrystallized decomposed ferrite crystals - matrix-martensite boundary

At the core, the structure is different from that of the surface of the sample body (Figure 6). Areas with different structure are observed, resulting from very long high temperature retention and subsequent slow cooling at the air. An extremely fine-grained ferrite matrix is observed. Martensite manifests itself as large isolated particles evenly distributed in the ferrite structure. Carbon is separated along the grain boundaries similar to that in the over eutectoid steels. The martensite is a batch type - the martensite needles start from the borders of the former austenitic grain (Fig. 6a) and are arranged at a different angle inside the grain. Layers of residual austenite that are thinner than the alpha bands are observed (Figure 6, c and d).

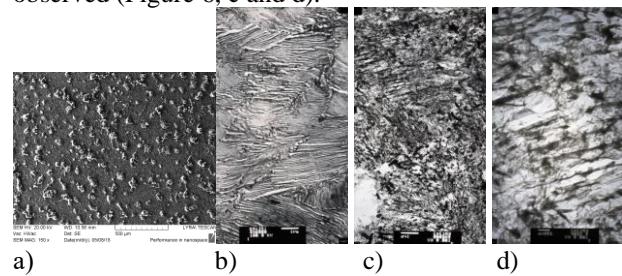


Fig.5. Microstructure at the core of the test body after regime 1:

a) SEM image in the dark field of view; b, c and d) TEM image

Extremely thin martensitic bands are visible whose edges are smooth (Fig. 6, c); among them are distributed austenitic islands (Fig. 6, d); large two types of carbides; expressed boundaries between the individual martensitic bands (Fig. 6, d). In the border region between the ferrite matrix and the martensitic needles, coagulated cementite are observed (Fig. 7). The resulting fine martensite, as a result of slow air cooling, tends to self-repel, leaving complex carbides on the alloying elements.

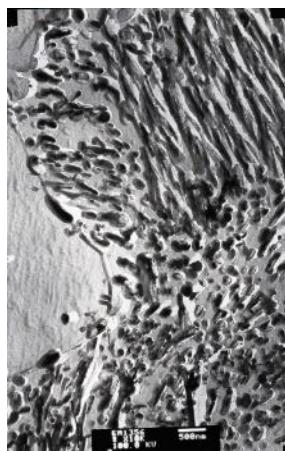


Fig 6. Boundary area between ferrite matrix and martensite with the presence of alloy carbides

Regime 2

The microstructure after isothermal retention for 15 min is characterized by the presence of regions of austenite, small bainite ferrite plates and small carbides of the alloying elements (Fig. 8).

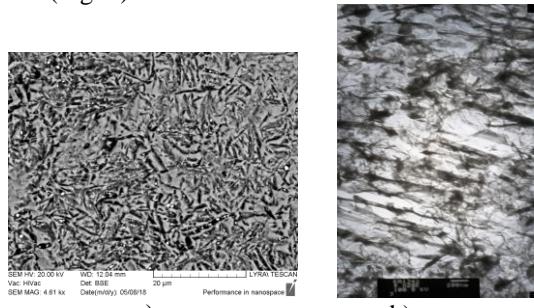
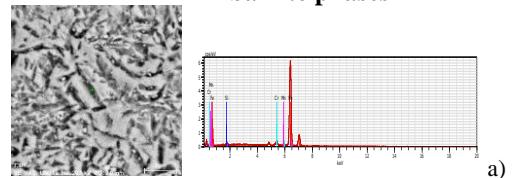


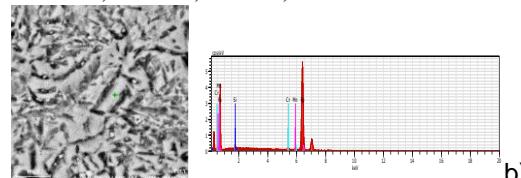
Fig.7. Microstructure after isothermal retention:
a) SEM and b) TEM image

It can be said that this is a structure of lower bainite, which consists of α -phase plates collected in packages and layers of residual austenite located between the α -phase plates (Fig. 8b). The thickness of the plates and the size of the packages are larger than in martensite. According to literature data [6], the concentration of carbon in the bainite α -phase does not exceed 0.02 - 0.04%. X-ray analysis revealed that the carbon content of residual austenite was 0.4% (Table 2, a). Probably, due to the presence of dispersed carbides along the boundaries of the alpha plates, its dimensions remain unchanged. Increasing the retention time at a given temperature leads to the formation of carbides between the residual layers of residual austenite (Fig. 9).

Table-II: Structure and composition of the austenitic and bainite phases



Fe=91.7, C=0.04, Cr=3.7, Si=3.2 %



Fe=95.2, C=0.04, Cr=2.25, Si=1.3 %

Regime 3

As a result of the successive heat treatments, the structure of the sample body is uniform throughout. Stabilization of the structure is observed after high temperature tempering.

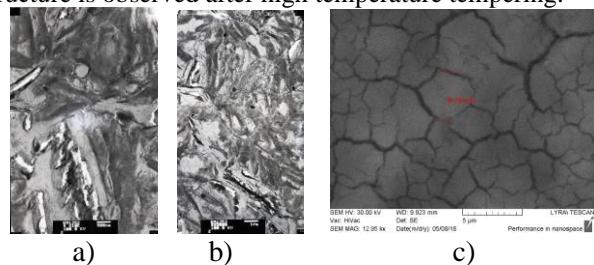
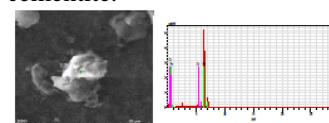


Fig.8. Structure after high temperature tempering: a) and b)
troostite and ferrite structure; (c) a carbide precipitations along
the boundaries of the former austenitic grain

Troostite + large ferrite regions (Figs. 9, 11) are observed with separate carbides of the alloying elements (Fig. 10). Fragmented carbide precipitations along the boundaries of the parents austenitic grains (Fig. 9c). Only ferrous and chromium is found in the ferrite regions (Fig. 10). Carbon is in the form of cementite.



Ele men t	at.%
Fe	35.23
C	63.19
Cr	0.54
Al	-
Si	0.43

Fig.9. Ferrite component

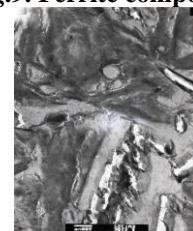
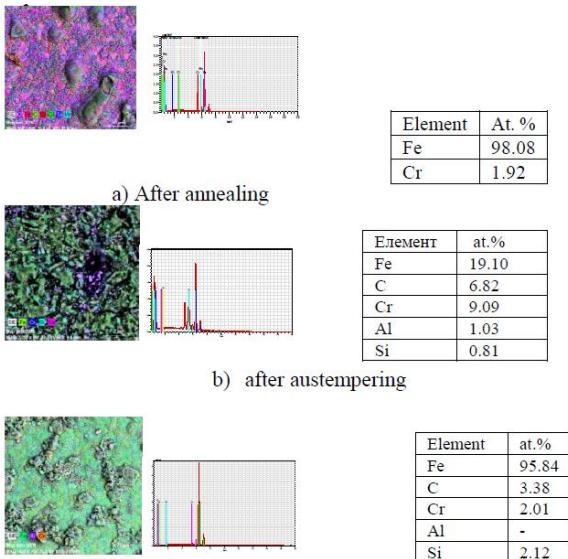


Fig.10. Troostite structure with the presence of many
very small types of carbide of the alloying elements

The analysis of the quantity of the elements reveals their redistribution after each treatment (Fig. 12). After initial annealing, the overall distribution indicates the presence of large amounts of carbon (Fig. 12a) in both martensite and cement. After high temperature aversion, this carbon decreases significantly (Fig. 12, c), indicating that it is concentrated in one phase - the cement. After isothermal quenching, carbon is present in both residual austenite and separated carbides.



C) AFTER high temperature tempering

Fig.11 Distribution of elements in the steel structure after isothermal quenching (a) and after high temperature tempering (b)

IV. CONCLUSION

- After the first cooling to martensite temperature, a rapid conversion of a portion of austenite to martensitic stretches was achieved.
- After the second cooling the austenite not converted up to this stage of conversion now is converted to bainite by isothermal retention. At this temperature already formed martensite is tempered.
- At tempering temperatures, the martensite present in the structure has become bainite. The resulting bainitis now turns to troostite.
- The amount of bainite obtained as a result of the last heat treatment is less than 50% of the total structure.

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