INDUCTION QUENCHING OF 100CrMnSi6-4 BEARING STEEL AFTER ACCELERATED CARBIDE SPHEROIDISATION AND LONG-DURATION ANNEALING

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Abstract

Soft annealing is an important and time demanding part of bearing steel treatment process. The experimental program of accelerated carbide spheroidisation deals with significant shortening of the time necessary for producing steel microstructure consisting of ferritic matrix and globular carbides. Globular carbide particles and the grain size of the matrix are significantly smaller after accelerated carbide spheroidisation process in comparison with conventional long-duration soft annealing. This fact ensures finer martensitic structure after hardening and this shows that the microstructure and properties of final hardened product are dependent on previous spheroidisation annealing. Finer carbides in structure enhance hardness and facilitate carbide dissolution during austenitisation. This effect enables quenching temperature lowering. It reduces the energy demand of the quenching process and mitigates the risk of residual stresses and distortion. The main objective of the present research was to identify the effect of the initial size of carbides and prior austenite grains upon the final microstructure and hardness of induction-quenched 100CrMnSi6-4 bearing steel. Microstructure evolution and hardness were monitored during austenitisation, quenching and subsequent tempering. Microstructure and properties after accelerated treatment were compared with those after conventional long-duration treatment.

Keywords: ASR, Accelerated Carbide Spheroidisation, Induction quenching, Bearing steel

1. INTRODUCTION

Typically, high-carbon bearing steels are supplied to bearing manufacturers in soft-annealed state [1]. Soft annealing ensures carbide spheroidisation, reduced hardness, good formability and a favorable microstructure for hardening. It involves long holding times at temperatures, which are usually slightly above the A1 temperature, and subsequent cooling in furnace. Diffusion-based processes [2] of this type are usually time-consuming and their times of up to tens of hours [3] make this type of annealing a very expensive heat-treatment process.

During the manufacture of bearings, bearing steels undergo hardening which consists of austenitisation, quenching and tempering. Sufficient amount of carbon should be dissolved into austenitic matrix during austenitisation for the desired material hardness after quenching to be achieved. On the other hand, undissolved carbides also have to be present in austenite to provide the pinning effect that prevents the austenite grain from coarsening. They also improve the wear resistance of the final structure. Quenching transforms the austenitic matrix to martensite. The finer the martensite, the better bearing performance is generally expected [4]. The final step, tempering, is necessary for internal stress relief, retained austenite decomposition and for dimensional stability during the bearing's lifetime.

The present paper describes a novel accelerated spheroidising process (ASR) and gives a comparison between the ASR and the conventional long-time soft annealing. Accelerated carbide spheroidisation can be induced by either heat treatment [5] or by thermomechanical processing [6]. Accelerated carbide spheroidisation leads to a significantly finer microstructure than long-duration soft annealing [7].It is a more favourable condition for subsequent quenching and tempering. The main objective of the present research was to identify the effect of the initial size of carbides and prior austenite grains upon the final microstructure and hardness of induction-hardened 100CrMnSi6-4 bearing steel. Microstructure evolution and hardness were monitored during austenitising, quenching and subsequent tempering. The austenitising time and temperature used after both accelerated and long-duration annealing were gradually optimised.

2. EXPERIMENTAL

2.1. Initial state

The experimental material was the 100CrMnSi6-4 bearing steel with a chemical composition given in **Table 1**. Fine and coarse initial states were obtained by ASR process (Accelerated Spheroidisation and Refinement) and conventional soft annealing. The accelerated carbide spheroidisation was performed by temperature cycling around A_1 temperature by induction heating. This treatment lasted 5 minutes. Long-duration soft annealing was conducted in atmosphere furnace. The schedule comprised heating to 790 C and slow cooling in the furnace. The soft annealing lasted 22 hours.

Globular carbide particles and the grain size of the matrix are significantly smaller after accelerated carbide spheroidisation process **(Fig. 1)** in comparison with conventional long-duration soft annealing **(Fig. 2)**.

Table 1 Chemical composition of the 100CrMnSi6-4 steel (wt. %)

C	Si	Mn	P	S	Cr	Ni	Al	Cu
0.94	0.65	1.16	0.014	0.012	1.54	0.03	0.026	0.02

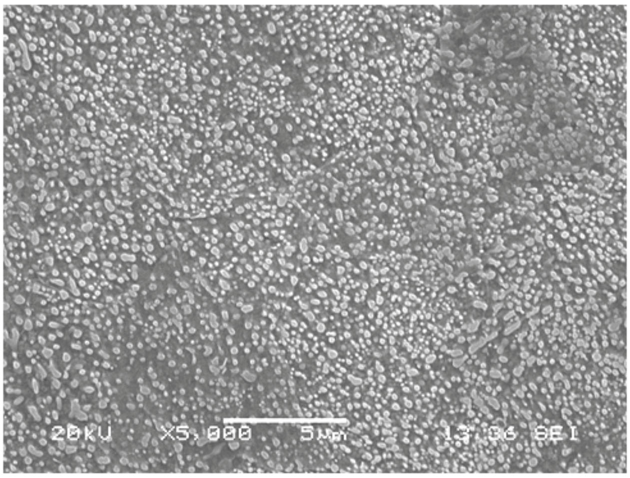

Fig. 1 Microstructure after ASR process, 264 HV10

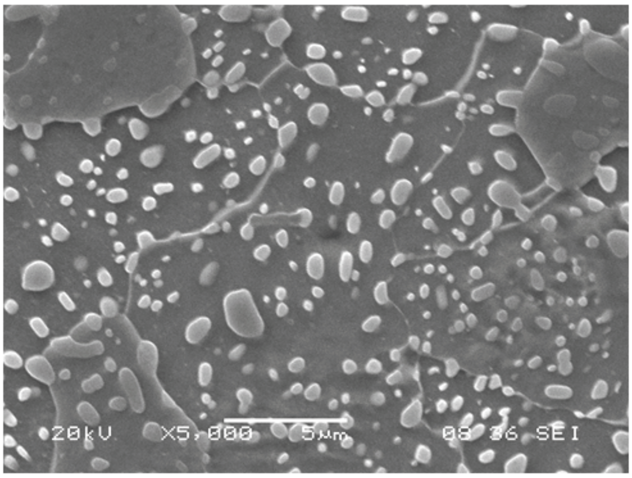

Fig. 2 Microstructure after long-duration annealing, 208 HV10

2.2. Hardening

The annealing (ASR or long-duration annealing) stage was followed by hardening, i.e. by quenching and tempering.

Austenitising was carried out using induction heating, as was the accelerated spheroidising process. The chosen heating rate was approximately 80 °C per second. Austenitising (quenching) temperature was between 850 °C and 1050 °C and the austenitising times were 5 and 20 seconds. Austenitising was followed by quenching in oil and tempering in an atmosphere furnace at the temperature of 240 °C for 4 hours. The carbides after ASR process were substantially smaller than after other treatments. These carbides were thus expected to dissolve more readily at a lower austenitising temperature. Quenching temperatures were therefore chosen in the range between 850 °C and 1000 °C. For specimens upon long-duration annealing, this range was 900-1050 °C. The main objective was to determine the process window, i.e. suitable quenching temperatures and times in relation to the initial condition of the material. The microstructure and hardness of individual specimens were studied after both quenching and tempering.

3. RESULTS AND DISCUSSION

3.1. Hardness and Microstructure

Hardness of the specimens was measured by Vickers method with the load of 3 kg. Hardness values were measured after quenching in oil and subsequent tempering. Quenching and tempering was preceded by either ASR or conventional long-time annealing. The line of indentations spaced at 0.5 mm was on the specimen cross-section along the entire diameter, starting 0.5 mm from the edge. The values across the cross-section were very similar. **Table 2** shows the resulting averages from three values measured at 1.5 mm, 2 mm and 2.5 mm below the specimen surface.

Table 2 Hardness after quenching and tempering of ASR-processed and long-duration annealed specimens

Austenitisation	ASR		Long-duration annealing	
	HV3 after quenching	HV3 after tempering	HV3 after quenching	HV3 after tempering
850 °C/5 sec.	782	716	-	-
850 °C/20 sec.	860	740	-	-
900 °C/5 sec.	816	747	827	680
900 °C/20 sec.	828	743	859	706
950 °C/5 sec.	735	693	831	708
950 °C/20 sec.	697	679	839	712
1000 °C/5 sec.	709	626	723	681
1000 °C/20 sec.	669	644	725	693
1050 °C/5 sec.	-	-	723	682
1050 °C/20 sec.	-	-	730	665

The hardness measurement revealed the same trend for both initial states - ASR, long-duration soft annealing. Samples quenched from the lowest quenching temperatures after 5 sec. austenitising time exhibited lower hardness due to low carbide dissolution. The hardness increased substantially with austenitising time increase to 20 seconds.

Higher quenching temperature led to higher carbide dissolution. Hardness, after quenching, showed decrease for both annealed stages with increasing quenching temperature in comparison with maximal hardness obtained at the lowest quenching temperature.

The hardness, after quenching and tempering, shows similar trends like just after quenching. However hardness differences among regimes are not so pronounced in case of the lowest and second lowest quenching temperature for both initial states.

Treatment after ASR process

Heating to the lowest quenching temperature 850 °C after ASR process retains most of the carbides in the structure. Carbide dissolution is most intensive on the boundaries of prior austenitic grains (**Fig. 3**). Austenitisation begins at grain boundaries and carbides were dissolved for the longest times in those regions. Hardness was dependent significantly on the austenitising time at the lowest quenching temperature.

Prolonged austenitising time caused hardness increase by almost 80 HV3, seemingly due to higher carbide dissolution. However, there was observed also the highest hardness decrease during tempering, 120 HV3. There was no significant amount of retained austenite detected in the structure.

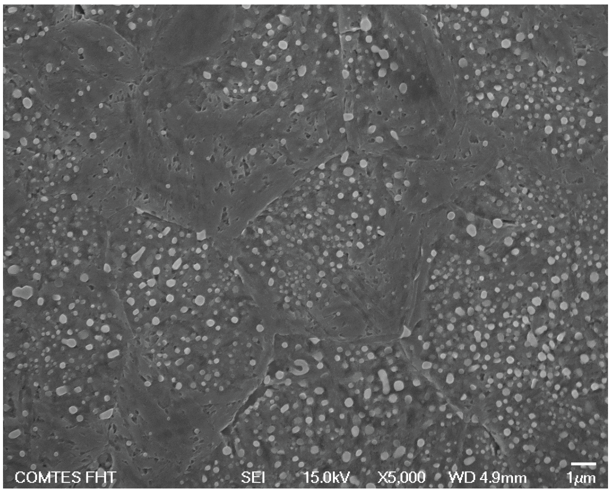

Fig. 3 ASR - 850 °C/20 sec.-oil, 860 HV3

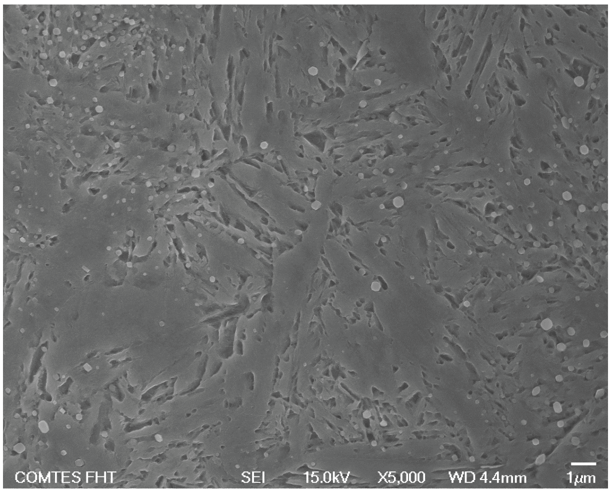

Fig. 4 ASR - 900 °C/20 sec.-oil, 828 HV3

Quenching temperature enhancement to 900 °C led to higher carbide dissolution. Martensite matrix was homogeneous in the sample (**Fig. 4**). Prior austenitic grain boundaries were not outlined by any microstructural feature.

Structures after quenching from temperatures 950 °C and 1000 °C were very similar. Carbides were almost completely dissolved regardless austenitising time and the microstructure consisted of coarse plate martensite with significant amount of retained austenite. Hardness was significantly decreased by retained austenite presence.

Treatment after long-duration soft annealing

Microstructure of samples with initial state after long-duration soft annealing was morphologically identical with those after ASR process, only coarser. Thus results obtained after quenching and tempering follows the same trends in terms of hardness and final microstructure. Only difference is temperature shift caused by coarser structure. Similar microstructures and maximal hardness were obtained by regimes with quenching temperature by 50 °C higher in comparison with ASR treated samples with finer structure.

Carbides remained mostly undissolved after quenching from the lowest quenching temperature 900 °C. There were present areas with more and less dissolved carbides, nevertheless the martensitic matrix exhibited the same morphology in whole sample (**Fig. 5**).

Quenching temperature 950 °C led to higher carbide dissolution accompanied with coarser martensite structure with small amount retained austenite in final structure.

Quenching temperatures 1000 °C and 1050 °C led to almost complete carbide dissolution. Carbide dissolution rate is slower for coarser structure. Hardness decrease with increasing quenching temperature was smaller than for ASR treated samples. This decrease was caused again by retained austenite occurrence in martensitic matrix (**Fig. 6**).

The highest hardness for both initial states after quenching was ca 860 HV10. It was achieved at temperatures 850 °C resp. 900 °C and 20 sec. hold for finer resp. coarser initial state. There was significant amount of undissolved carbides for both cases. Hardness after quenching drops with austenitising temperature increase significantly. However, hardness after quenching and tempering is stable in 50 °C temperature range for fine and coarse microstructure (**Table 2**). The hardness decreased less during tempering for fine-structured samples than for coarse-structured.

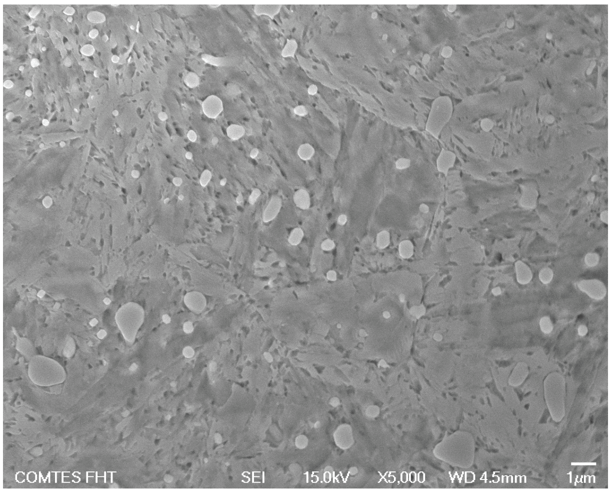

Fig. 5 Long-duration annealing - 900 °C/20 sec.-oil, 859 HV3

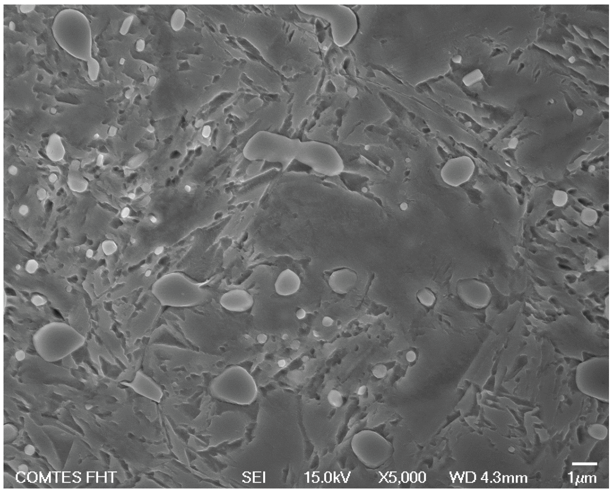

Fig. 6 Long-duration annealing - 950 °C/20 sec.-oil, 839 HV3

Martensite hardness is determined mainly by its carbon content and amount of retained austenite. If those parameters were the same for fine and coarse structure, resulting hardness after quenching was very similar. Tempering apparently reveals effect of structure fineness. The same hardness after tempering (ca. 740 HV3) was achieved for different microstructures after quenching for the fine initial state. Samples with coarser structure, having the comparable hardness after quenching with the fine-structured ones, reached after tempering lower hardness (ca. 710 HV3). Possible explanation is smaller martensite crystal size in finer microstructure accompanied with possibly denser carbide precipitation during tempering.

4. CONCLUSION

Induction hardening of 100CrMnSi6-4 bearing steel was performed for two initial states - fine structure obtained from ASR process (Accelerated Spheroidisation) and coarse structure obtained from long-duration soft annealing. Influence of the initial microstructure on the final hardness and microstructure was investigated. Finer structure spheroidised carbides in initial structure lead to finer martensite after quenching and higher hardness after tempering. Austenitisation kinetics was also affected, because fine carbides dissolved at higher rates. Sufficient carbide dissolution was achieved at austenitising temperature by 50 °C lower in comparison with coarse-structured material.

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