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PEARLITIC LAMELLAE SPHEROIDISATION DURING AUSTENITIZATION AND SUBSEQUENT TEMPERATURE HOLD

Typical processing routes for bearing steels include a soft annealing stage. The purpose of this procedure is to obtain a microstructure containing globular carbides in ferritic matrix. A newly developed process called ASR (Accelerated Spheroidisation and Refinement) cuts the carbide spheroidisation times several fold, producing considerably finer globular carbides than conventional soft annealing. Finer microstructure also leads to more homogeneous and finer structure after final hardening process. The present paper explores process of the accelerated spheroidisation (ASR) in steel 100CrMnSi6-4 with initial pearlitic structure. Cementite lamellae morphology was observed in different stages of austenitization. The heat treatment was performed using induction heating in quenching dilatometer. There was analysed influence of austenitization temperature and austenitization time on spheroidisation. Hardness and carbide morphology was observed. Deep etching was used to reveal evolution of cementitic lamellae fragmentation. It is favourable process especially in induction treatment of small parts.

Keywords: Accelerated Spheroidisation and Refinement (ASR), Annealing, Bearing Steel, Induction Heating

1. Introduction

Heat treatment of bearing steels typically includes soft annealing. It is due to manufacturing process requirements, most often those related to machining. The importance of decreasing the steel's hardness is matched by that of converting lamellar pearlite into globular cementite in ferritic matrix [1]. A conventional soft annealing schedule consists of long-term soaking at a temperature near A_1 and subsequent cooling in the furnace [2]. The entire process typically takes more than 20 hours [3]. Research of accelerated spheroidisation (ASR) showed that it is possible to spheroidise lamellar pearlite within several minutes.

If the steel is heated up between A_{c1} and A_{ccm} and the matrix contains sufficient amount of cementite particles, the cooling below A_{r1} temperature might result in divided eutectoid transformation. During this transformation the carbon previously dissolved in austenite contributes to growth of present cementite particles instead of lamellar pearlite formation [4].

2. Experimental

2. 1. Experimental material

The experimental material was the 100CrMnSi6-4 bearing steel grade with the chemical composition: 0.94% C, 0.65% Si, 1.16% Mn, 0.014% P, 0.012% S, 1.54% Cr, 0.03% Ni, 0.026% Al, 0.02% Cu. The material was supplied in the form of hot-rolled 21 mm-diameter bars. The as-received microstructure consisted of pearlite and small amount of secondary cementite (Fig. 1 [5]). The hardness was 383 HV.

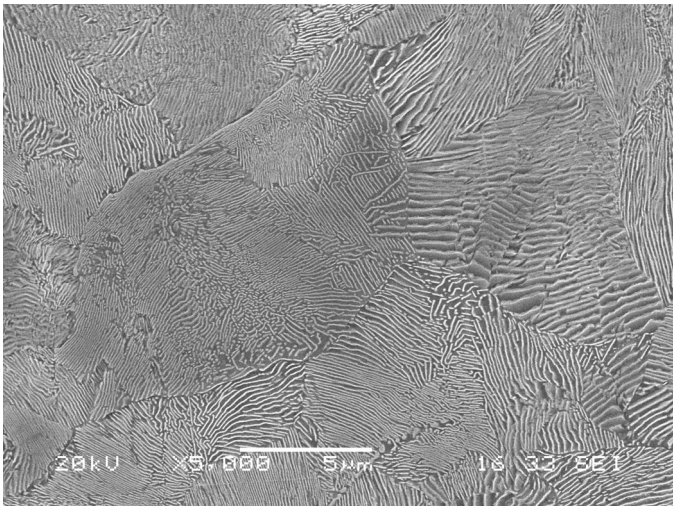

Fig. 1. Initial microstructure of 100CrMnSi6-4 steel. Lamellar pearlite [5]

2. 2. Heat treatment and analysis

The heat treatment experiment was conducted in the quenching dilatometer Linseis L78 RITA (Rapid Induction Thermal Analysis). The heat treated specimens were 4 mm in diameter

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and 10 mm in length. The specimens were heated by induction coil and cooled by flowing gas. The precise temperature controll and measurement were performed by type K thermocouple, welded to the sample centre. Length change was measured through glass push-rods by LVDT sensor. Phase transformations were evaluated from the length change by tangent method.

The heat treatment parameters were proposed in such way that carbide spheroidisation, material softening and time save could be evaluated in accordance to austenitization temperature and time. The heating rate was 35°C/s for all samples. The austenitization temperatures were 780, 800 and 820°C and austenitization times 15, 45, 120, 300 seconds. Two cooling rates were used – one for simulation of oil quenching of 15 mm round bar (labelled with letter q – e. g. Regime 780/15q), the other for air cooling of 15 mm round bar (labelled without letter q – e. g. Regime 780/15). The aim of this heat treatment simulation was to observe and evaluate the influence of austenitization temperature and time on carbide dissolution. The austenitization kinetics during heating over A_{c1} was evaluated from a sample heated to temperature 800°C and immediately cooled down with rate 100°C/s (Regime 800q).

Specimens for metallography were prepared by mechanical grinding and polishing. Microstructure was revealed by Nital etchant.

Deep etching was performed by Nital etchant. Samples were immersed in Nital for 40 minutes and rinsed carefully with pure methanol. Carbides were extracted by ultrasonicating of deep etched samples in methanol. Carbide particles formed during ultrasonicating homogeneous dispersion in methanol, which was evaporated on polished copper pad. Carbides spread on the copper pad were observed by scanning electron microscope JEOL 7400F.

Hardness was measured by automatic indentation machine Struers Durascan 50.

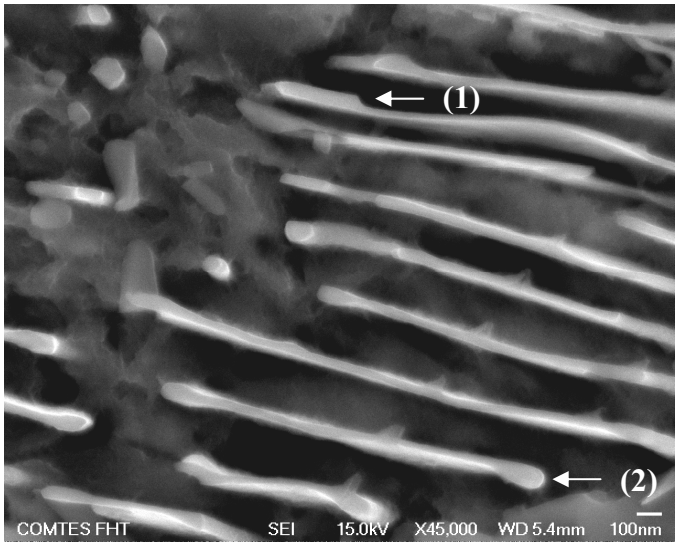

Fig. 2 Regime 800/15q. Dissolution of the cementitic lamellae in progress. Ridges thinning the lamella are formed (1) and thickened edges (2)

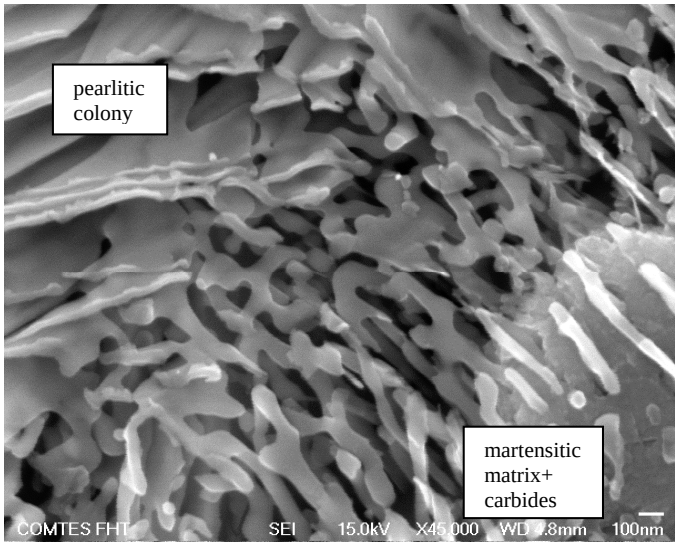

Fig. 3. Fragmentation at the α-γ interface. Regime 800q

3. Results and discussion

3. 1. Microstructure

Austenite formation is accompanied with cementite dissolution. Cementite is present in form of pearlitic lamellae in initial structure. Lamellae undergo dissolution from their sides, which determines form of their fragmentation. Ridges are formed in the lamellae. The ridges grow along the side of the lamellae and thin it. Also holes appear in the thinnest areas and thickened regions at the edges of the lamellae (Fig. 2).

Microstructure of the sample 800q with interrupted austenitization revealed that lamellae fragmentation take place in close vicinity of moving ferrite-austenite interface. Quenching stopped the austenitization process and freshly formed austenite was transformed into martensite. Deep etching removed ferritic matrix faster than martensite, as it is clearly visible in Figure 3. Lamellae fragmented into lace-like structures within 1 μm wide zone enclosing the α-γ interface.

Parallel rod formation was observed occasionally (Fig. 4). However, this morphology enables to observe interval between particular lamella fragments. Evolving rods are in the same distance not only in one lamella, but also in comparison with adjacent lamellae. It implies, that the spatial distribution of the fragments is not random, but is determined by conditions at the α-γ interface. This fragmentation characteristic cannot be easily observed in lace-like structures mostly evolved from the lamellae (Fig. 3).

Further cementite dissolution during austenitization hold does not change the morphology of fragmented lamellae as it was formed during pass of the α-γ interface. For all samples, the morphology seems to be the same. The only changing feature is amount of dissolved cementite. It grows with austenitization time prolongation and temperature rise. More cementite is divided into globules from rods and laces by continuing dissolution. Spatial density of cementite particles seems to be identical for all regimes with austenitization hold; more cementite dissolu-

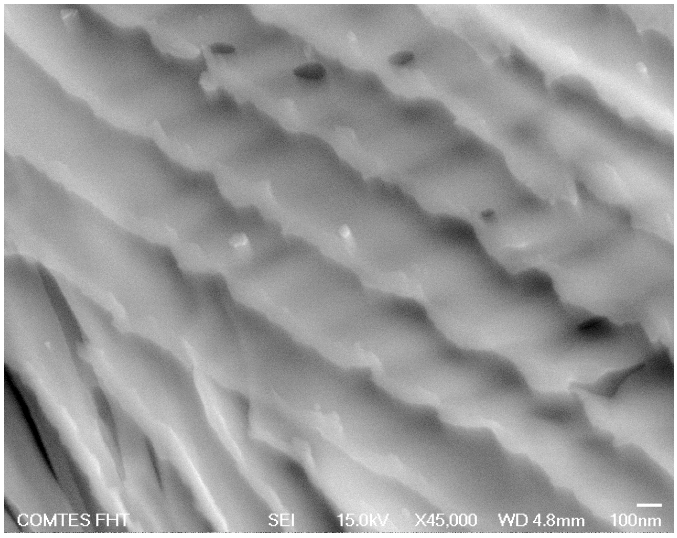

Fig. 4. Cementite lamellae fragmentation into rod-like particles. Regime 800q. Holes emerging between rods as beginning of separation process.

tion results only in overall particles shrinkage. It was observed in samples quenched after the austenitization. Austenitic matrix underwent martensitic transformation and cementite particles were preserved in state at the end of austenitization.

There were observed no regions with preferential dissolution in the structure. Undissolved cementite was homogeneously spread in martensitic matrix in form of globules and larger lamellae fragments.

Divorced pearlitic transformation took place during slow cooling simulating cooling in air. Final structure consisted of ferritic matrix and cementite. The cementite remained in morphology gained during austenitization. When too much carbon was dissolved, new pearlitic lamellae grew among undissolved cementite particles.

3. 2. Hardness

Hardness is listed in Table 1. From the values we can observe that in the slowly quenched specimens (divorced pearlitic transformation) the hardness increased with austenitization temperature. The hold time resulted in decrease of hardness first and then to hardness increase. The hold, where hardness decrease was observed, shrinked with temperature. This phenomenon should be a result of cementite dissolution and distribution kinetics.

TABLE 1

Hardness HV10

	15 sec.		45 sec.		120 sec.		300 sec.	
	Fast quenching	Slow quenching	Fast quenching	Slow quenching	Fast quenching	Slow quenching	Fast quenching	Slow quenching
780°C	864	332	867	306	849	301	843	310
800°C	892	321	884	305	884	307	859	317
820°C	884	341	890	314	908	325	855	332

The hardness increase is caused by formation of new pearlitic lamellae during cooling.

The hardness values in fast quenched specimens do not show any particular trend. This could be due to influence of both – hardening and increase of retained austenite content due to cementite dissolution.

3.3. Discussion

Cementitic lamellae fragmentation takes place during austenitization of pearlitic ferrite. Final spatial distribution of cementitic particles, if the spheroidisation completes, is probably determined by the very first fragmentation of pearlitic lamellae in vicinity of α-γ interface. Cementite dissolution follows afterwards, during the austenitizatization hold. Positions of cementitic globules are given; dissolution intensity only determines what fraction of the cementite is separated into individual globules and what fraction remains as rods or lace structures (Fig. 5).

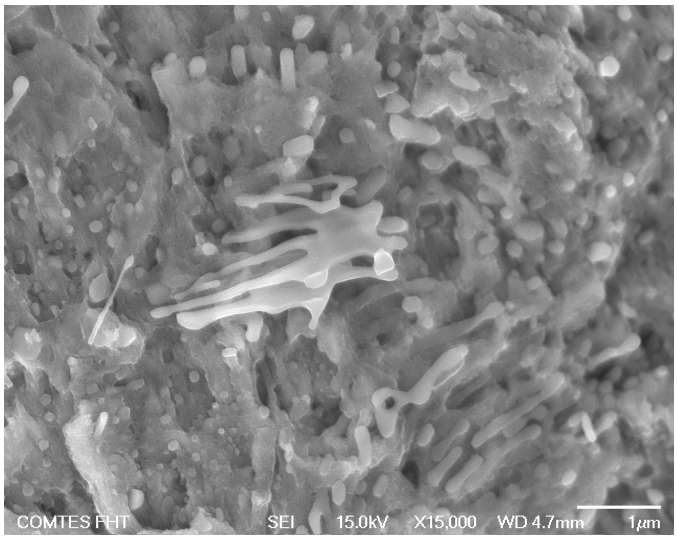

Fig. 5. Regime 820/120q. Cementite globules and lamellae fragments in the deeply etched martensitic matrix

Third phenomena taking place during ASR process is divorced pearlitic transformation during slow cooling (simulation of cooling in air). Carbon dissolved in austenite forms cementite on existing carbides, undissolved remnants of initial cementite lamellae. No new cementitic particles are formed during the transformation which is distinctive feature of the divorced pearlitic transformation.

Combination of three factors determines whether normal or divorced pearlitic transformation will take place during cooling: velocity of γ-α interface movement, carbon concentration in matrix and distance among cementitic particles already present in the matrix. For the divorced pearlitic transformation, all the carbon dissolved in austenite has to diffuse to the existing cementitic particles and form cementite on their surface. Velocity of γ-α interface movement is considered to be for all samples the same (the same cooling velocity) as well as distance between

cementitic particles. The only changing parameter is amount of dissolved carbon. In agreement with the theory, new cementitic lamellae were formed in samples with the longest austenitization time 300 seconds. Too much carbon was dissolved into austenite, so that it did not manage to diffuse completely to the cementite particles during cooling and normal pearlitic transformation took place alongside with the divorced transformation (Fig. 6).

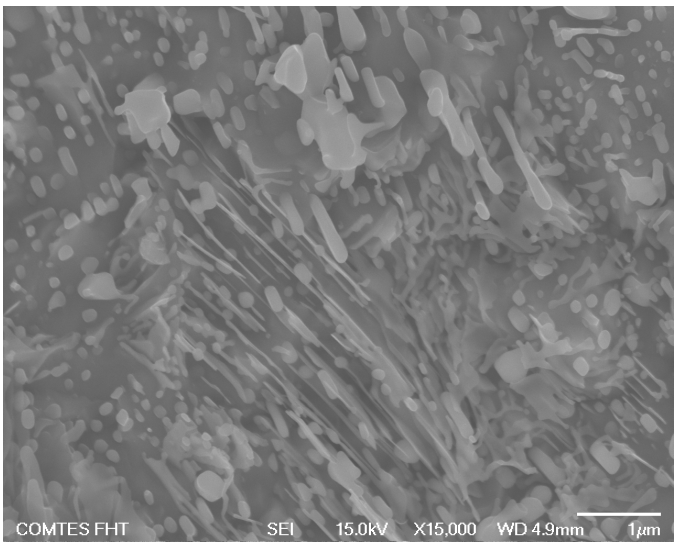

Fig. 6. Regime 820/300. Cementite globules hast the same spatial density like after short austenitization, however new pearlitic lamellae formed

Metallographic observation revealed that schedule with a single hold did not lead to complete conversion of original cementite lamellae. Original cementite lamellae were still discernible, although disintegrated into globular or bar-like fragments. Spheroidisation can be completed by repeating of the thermal cycle rather than intensifying the cementite dissolution, because in that case new pearlitic lamellae form during cooling. Upon three-stage repeated heating with 15 seconds holds (regime 780/3×15), cementite became almost fully spheroidised (Fig. 7 [6]).

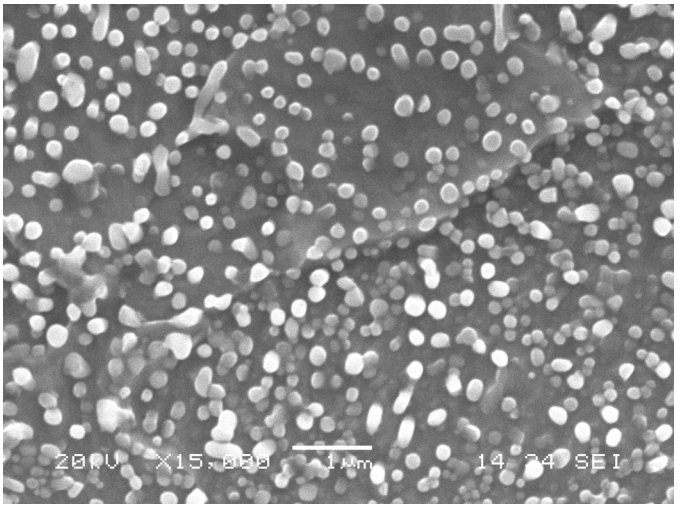

Fig. 7. Regime 800/3×15. Spheroidised structure after three temperature cycles

4. Conclusion

Detailed study of cementite morphology during austenitization showed, that ASR process has distinctive stages, each ensuring different quality of the resulting spheroidised structure.

Fragmentation of cementite lamellae takes place directly in close vicinity of α-γ interface during pearlitic cementite austenitization. It determines spatial distribution of cementitic globules, if formed afterwards.

Cementite dissolution during austenitization hold separates individual globules from lamellae fragments. The globules and fragments dissolves homogeneously in the volume of the material.

Divorced pearlitic transformation during cooling ensures, that no new cementite lamellae are formed.

Present article helped to determine suitable temperatures and times for ASR process of the steel 100CrMnSi6-4. Spheroidisation can be completed by repeating of the thermal cycle rather than intensifying the cementite dissolution, because in that case new pearlitic lamellae form during cooling.

Spatial density of globules in spheroidised structure can be probably controlled by the conditions of pearlitic ferrite austenitization, namely velocity of α-γ interface movement.

Acknowledgements

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