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ACCELERATED SPHEROIDIZATION AND REFINEMENT IN C45 STEEL

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Abstract: *The goal of research into rapid carbide spheroidisation is to significantly cut down the duration of elected heat treatment processes. Conventional methods of annealing steel stock to produce globular pearlite require long soaking times, up to several tens of hours, due to the diffusional nature of the process. The newly developed process based on rapid carbide spheroidisation consists in heating of a steel workpiece through thickness to a temperature no higher than A_{c1} and in subsequent plastic deformation. The combination of a suitable pre-heating temperature and an appropriate amount of strain leads to transformation of initial ferrite-pearlite microstructure with lamellar pearlite into desired ferrite matrix with spheroidised carbides.*

Keywords: *rapid spheroidisation, deformation, grain refinement*

1. INTRODUCTION

Current processes leading to carbide spheroidisation rely on diffusion of carbon in a steel heated to a temperature close to or lightly below A_{c1} (Ghosh S., 2010). Diffusion-based processes of this type are time-consuming. The holding times of up to tens of hours (Ata K. G. & Meisam S. A., 2010) make this type of annealing one of the most expensive heat treatment processes ever. During the annealing process, softening takes place in the microstructure together with recrystallization processes. Normally, the morphology of carbides changes as well (Nam W. J. & Bae C. M., 1999). The strength and hardness of the steel workpiece decline, while its ductility increases and its plastic deformation capability is recovered. The newly-designed and patented process of the company COMTES FHT brings several-fold reduction in the processing time and considerable cost savings. The present paper describes observation of the influence of plastic deformation on the carbide spheroidisation process in medium-carbon steel. Significant acceleration of the process is tied to annealing the material at a temperature close to A_{c1} while introducing plastic strain. (Zhang S. L. at al., 2006). The results are applicable to carbon steels, but general procedure can by easily adapted to low-alloyed steels.

2. EXPERIMENTAL PROGRAMME

The experiment was performed on structural steel C45. Its initial microstructure consisted of ferrite and lamellar pearlite with pronounced banding along the axusis of the bar (Fig. 1). The initial hardness was 180 HV. The processing was carried out in two stages. Conventional soft annealing was carried out first for the purpose of comparison. Then, thermomechanical treatment schedules were realized. The specimens were processed in an atmosphere furnace and plastically deformed between flat swages of a hydraulic press. Metallographic observation was performed on longitudinal sections of all specimens in order to examine and compare microstructures throughout the specimen cross-section. The sections were observed in light and scanning electron microscopes. Vickers HV30 hardness was measured on specimens.

2.1 Conventional Heat Treatment

For the purpose of comparison with the newly-designed thermomechanical process, conventional soft annealing was carried out. This heat treatment consisted in 12-hour hold at 710°C and slow furnace cooling (specimen R1).

2.2 Thermomechanical Treatment

The stock with the diameter of 50 mm and the length of 70 mm was heat treated in an atmosphere furnace and then formed to various reduction levels between flat swages of a hydraulic press with the ram speed of 25 mm per second. The schedules included heating to a temperature slightly below A_{c1}, holding and subsequent plastic deformation in a press. The schedules were designed to show the influence of the amount and direction of introduced strain. The strain was introduced either in a single direction perpendicular to the axis of the bar or in two perpendicular directions. The workpiece soaking temperature was constant for all schedules: 710°C.

In order to explore the impact of introduced strain on carbide spheroidisation, thermomechanical treatment with subsequent conventional furnace annealing was carried out. The soaking temperature was 710°C with the soaking time of 12 hours. Slow furnace cooling (specimen R2) was the same as in the conventionally treated specimen (R1).

At the first stage of thermomechanical treatment, plastic strain was introduced in a single direction with different magnitudes. Effective strain magnitudes in first three specimens 1; 2; 3, as shown by numerical simulation, were 1.0; 1.7 and 2.9 (Tab. 1).

At the second stage of thermomechanical treatment, plastic strain was introduced in two perpendicular directions with different magnitudes. The schedules were designed as paired ones where the magnitude of strain in the first deformation step was identical and the second one was different in each pair of schedules. In specimens 1a and 1b, the first effective strain level was 1.0, while the other one in perpendicular direction in specimen 1a was 2.3 and in specimen 1b it was 3.1. In specimens 2a and 2b the first strain magnitude was 1.7 and the second one 2.9 and 3.8, respectively. In specimens 3a and 3b the first strain magnitude was 2.9 and the second one 4.0 and 4.9, respectively (Tab. 1).

2.3 Numerical Simulation

Numerical simulations of all thermomechanical treatment schedules were performed in the software DEFORM. Effective strain magnitude and a temperature increase due to plastic deformation in the centre of the specimen were monitored (Tab. 1).

Effective strain was calculated by numerical simulation according to the equation (1).

$$\bar{\varepsilon} = \frac{\sqrt{2}}{3}\sqrt{\left(\varepsilon_1-\varepsilon_2\right)^2+\left(\varepsilon_2-\varepsilon_3\right)^2+\left(\varepsilon_3-\varepsilon_1\right)^2} \quad (1),$$

where ε_1, ε_2 and ε_3 are principal strains and $\bar{\varepsilon}$ is the effective strain.

	Soaking temp. [°C]	Values upon first deformation		Values upon second deformation		Hardness HV30
		$\bar{\varepsilon}$ []	T [°C]	$\bar{\varepsilon}$ []	T [°C]	
1	710	1.0	737	-	-	179
2	710	1.7	752	-	-	182
3	710	2.9	770	-	-	181
1a	710	1.0	737	2.3	759	175
1b	710	1.0	737	3.1	767	175
2a	710	1.7	752	2.9	757	170
2b	710	1.7	752	3.8	775	179
3a	710	2.9	770	4.0	741	176
3b	710	2.9	770	4.9	761	178

Tab. 1. Thermomechanical treatment schedules

3. RESULTS AND DISCUSSION

The conventionally treated specimen R1 underwent partial carbide spheroidisation throughout the volume upon 12-hour soaking at 710°C . Its hardness decreased to 148 HV.

Microstructure of thermomechanically treated specimen R2 which was then annealed for 12 hours at 710°C showed completely spheroidised carbides. Scarce traces of preserved cementite lamellae can be found only below the surface of the specimen where the strain level was lower.

Conventional annealing at a temperature slightly below A_{c1} was not sufficient for complete spheroidisation of carbides. Introduction of plastic strain has significantly boosted the carbide spheroidisation throughout the specimen.

Microstructures of specimens 1 through 3 from the first stage of thermomechanical treatment show dependence on the magnitude of introduced strain. With increasing strain magnitude (1<2<3) the proportion of spheroidised carbides. The ferrite grain was refined thanks to dynamic recrystallization. Average initial ferrite grain was 15 μm, while in thermomechanically treated specimens it was 3 μm. HV30 hardness values in these specimens were almost equal (180HV). This can be explained by the compensation of the hardness decline due to carbide spheroidisation by strengthening due to ferrite grain refinement.

The second stage of thermomechanical treatment (schedules with consecutive deformation steps in perpendicular directions) did not result in significant differences in hardness and carbide spheroidisation as compared to specimen no. 3. Almost complete carbide spheroidisation and ferrite recrystallization took place in the centre of the specimen where only scarce cementite lamellae were preserved (Fig. 2). The only detectable difference lies in different levels of banding of carbides depending on the strain magnitude.

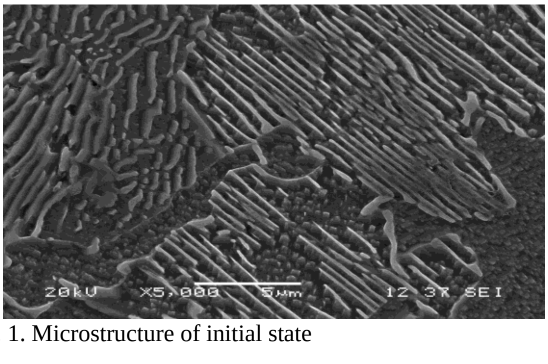

Fig. 1. Microstructure of initial state

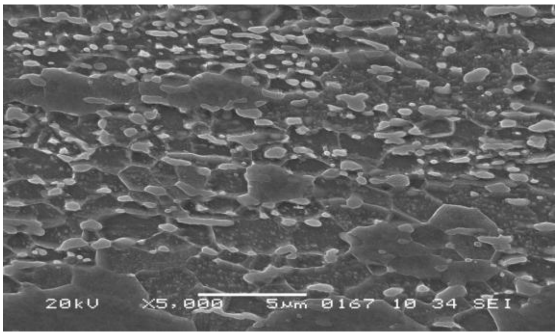

Fig. 2. Microstructure in the centre of the specimen no. 3a

4. CONCLUSION

Conventional annealing for 12 hours at a temperature slightly below A_{c1} and slow cooling in a furnace were not sufficient for complete spheroidisation of carbides. Complete spheroidisation of carbides throughout the volume of the specimen took place in relation to the thermomechanical treatment which induced the rapid spheroidisation process.

Specimens with a single deformation step show a clearly recognizable trend. With increasing strain, carbide spheroidisation and ferrite grain recrystallization get closer to completion. Hardness in all three specimens remains virtually constant. This can be explained in terms of the compensation of the hardness decline due to carbide spheroidisation by strengthening due to ferrite grain refinement. Specimens which underwent deformation in two perpendicular directions do not show significant differences in hardness and carbide spheroidisation levels. Almost complete carbide spheroidisation and ferrite recrystallization took place in all these specimens and only scarce cementite lamellae were preserved. The only detectable difference lies in different amounts of elongation of pearlite-ferrite grains in bands depending on the strain magnitude.

The results clearly indicate that from certain limit amount, further increase in plastic strain does not contribute to grain refinement and pearlite spheroidisation. Further grain refinement can be attempted through intensive localized deformation, such as by ECAP technique.

5. ACKNOWLEDGEMENTS

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