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D. HAUSEROVA*[#], J. DLOUHY*, J. KOTOUS*

# STRUCTURE REFINEMENT OF SPRING STEEL 51CrV4 AFTER ACCELERATED SPHEROIDISATION

Material research of the spring steels tries to meet requirements of the industry, which are mainly higher yield and tensile strength. Steel 51CrV4 is widely used for spring production. Optimization of its properties lies in tensile and yield strength enhancement without decrease in ductility in quenched and tempered state. This can be accomplished by structural refinement. One possible way to refine final quenched and tempered structure is refinement of the soft annealed structure before quenching. The article is devoted to accelerated carbide spheroidisation and refinement (ASR) and subsequent hardening of the 51CrV4 spring steel. Samples with different carbide size were prepared by conventional soft annealing in atmosphere furnace and ASR process by induction heating. Influence of the structural refinement on the properties of quenched and tempered state was studied.

*Keywords:* Spring Steel, Accelerated Spheroidisation, Refinement, Hardening

## 1. Introduction

Trends in design lead to saves in mass of components and improving their performance. This inevitably requires materials with better mechanical properties. Development in field of spring steels in focused mainly on enhancement of yield strength together with sufficient ductility [1]. Spring steels have to withstand relaxation and cyclic loading.

The structural relaxation mechanism is intensified upon growth in the carbon content, decrease in the tempering temperature, and increase in the relaxation temperature [2]. Large number of spring steel grades is based on silicon and manganese alloying. Desired mechanical properties are achieved by quenching and tempering. Optimization of its properties lies in tensile and yield strength enhancement without decrease in ductility in quenched and tempered state. This can be accomplished by structural refinement. One possible way to refine final martensitic structure is refinement of the soft annealed structure before quenching. A conventional soft annealing schedule consists of long-term soaking at a temperature near $A_{c1}$ and subsequent cooling in the furnace [3,4]. Spheroidisation process can be accelerated by rapid austenitization followed by divorced pearlitic transformation. Cementite must not be dissolved completely during the austenitization to provide cementite nuclei for divorced pearlitic transformation. During this transformation the carbon previously dissolved in austenite contributes to growth of present cementite particles instead of lamellar pearlite formation [5]. Research of the Accelerated Spheroidisation and Refinement (ASR) process showed that it is possible to spheroidise lamellar pearlite within several minutes by thermal [6,7] or thermomechanical treatment [8]. This treatment was used to obtain fine globular carbides homogeneously dispersed in ferritic matrix [9]. ASR process forms two or three times smaller carbide particles than conventional soft annealing. Such a fine structure possesses higher hardness and slightly worse machinability compared with conventional one, but also superior quality for hardening operation on the other hand [10].

## 2. Experimental

### 2.1. Experimental material

The experimental material was the 51CrV4 bearing steel grade with the chemical composition: 0.51% C, 0.27% Si, 0.96% Mn, 0.015% P, 0.017% S, 1.07% Cr, 0.003% Al, 0.01% W, 0.138% V, 0.0009% Ti, 0.002% Nb. The material was supplied in the form of hot-rolled 21 mm-diameter bars. The as-received microstructure consisted of bainite and pearlite (Fig. 1). The hardness was 345 HV10.

### 2.2. Heat treatment

Thermal treatment was divided into three stages:

- Accelerated Carbide Spheroidisation (ASR) – induction treatment
- Carbide Spheroidisation (conventional long-duration soft annealing – SA) – atmospheric furnace

* COMTES FHT A.S., PRUMYSLOVA 995, 334 41, DOBRANY, CZECH REPUBLIC

[#] Corresponding author: daniela.hauserova@comtesfht.cz

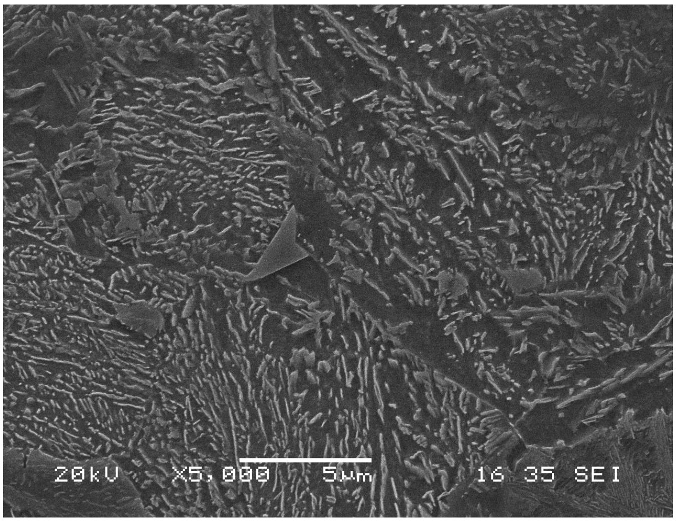


Fig. 1. Initial state microstructure, 345 HV10

- Hardening after ASR and conventional soft annealing – atmospheric furnace

**Spheroidisation**

The accelerated carbide spheroidisation (ASR) was performed using induction heating (Fig. 2). A medium-frequency converter ($f_{max}$ = 12 kHz) with the maximum power of 24 kW was employed. The solenoid-shaped inductor was designed with the purpose of providing as homogeneous magnetic field as possible along the length of the specimen, thus making the heating process uniform. The specimens were 16 mm in diameter and 400 mm in length. The inductor was PLC-controlled. The specimen temperature was measured by means of a thermocouple welded onto the specimen surface.

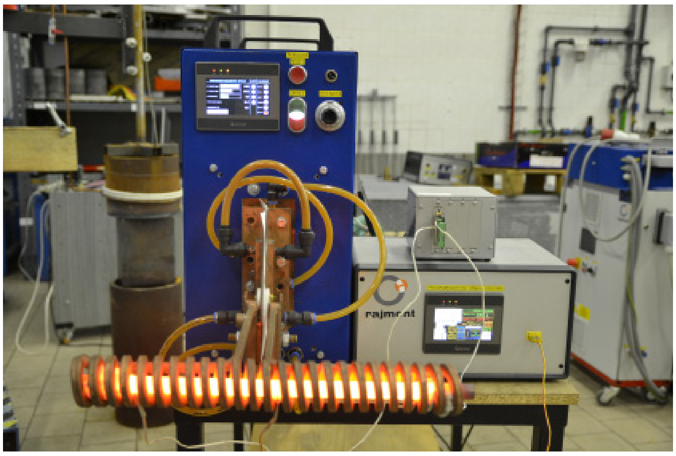

Fig. 2. Induction heat treatment – ASR

The schedule consisted of induction heating to the temperature of 760°C, 15-second holding, cooling in air to 600°C, reheating to 760°C, 15-second holding, cooling in air to 600°C, reheating to the temperature of 760°C, 15-second holding and cooling in air to the ambient temperature. The heating rate was approximately 10°C/second.

Long-duration soft annealing was conducted in atmosphere furnace. The schedule comprised heating to 720°C by heating rate 10°C/min, heating to 750°C by heating rate 15°C/hour, 4-hour hold at the temperature and controlled slow cooling in the furnace (15°C/hour to 720°C, 25°C/hour to 400°C).

**Hardening**

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

Austenitization was carried out in atmospheric furnace. The optimised austenitization (quenching) temperatures were 800, 820, 840, 860°C and the austenitization time was 30 minutes. Austenitization was followed by quenching in oil and tempering in an atmosphere furnace at the temperature of 450°C for 2 hours. The specimens were 16 mm in diameter and 16 mm in length. The main objective was to determine the process window, i.e. suitable quenching temperatures 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. Spheroidisation

The micrographs after ASR (Accelerated Spheroidisation) and conventional soft annealing show well-spheroidised cementite particles in a ferritic matrix. The carbide size after ASR ranged from 100 to 300 nm (Fig. 3). The carbide size after long-time conventional annealing was from 500 to 1000 nm (Fig. 4). The hardness after ASR process was 232 HV10, the hardness after conventional annealing was 179 HV10. It was controlled by the amount of carbides. Finer carbides were spread more densely in the matrix and caused higher dispersion strengthening of the material.

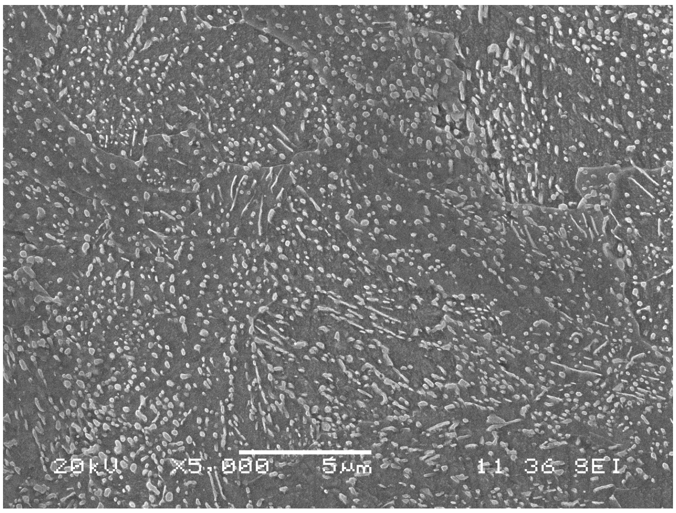


Fig. 3. Microstructure after ASR, 232 HV10

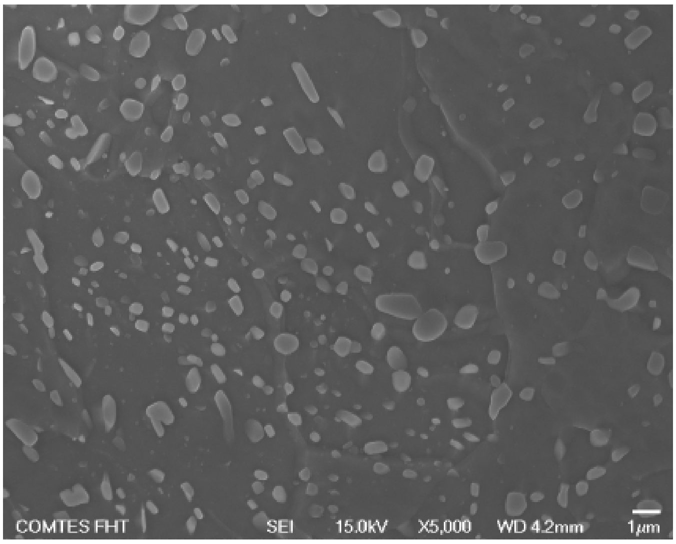


Fig. 4. Microstructure after soft annealing (SA), 179 HV10

### 3.2. Hardening

**Microstructure**

Several effects of the austenitizing temperature on the resulting microstructure and hardness were observed. The final microstructures in all hardened specimens consisted of tempered martensite and globular carbides. The specimens after accelerated spheroidisation schedules contained also substantially finer carbides in martensitic matrix than the conventionally-annealed specimens (SA).

Quenching from temperature 800°C resulted in martensitic microstructure with high number of undissolved spherical carbides (Figs. 5,6). SEM observation showed the carbides were spread homogeneously in the martensitic matrix for both SA (soft annealed) and ASR sample. Boundaries of prior austenite grains are observable in the SEM micrographs and were probably not pinned by undissolved carbides. The carbides are observed mainly inside the prior austenite grains than at their boundaries.

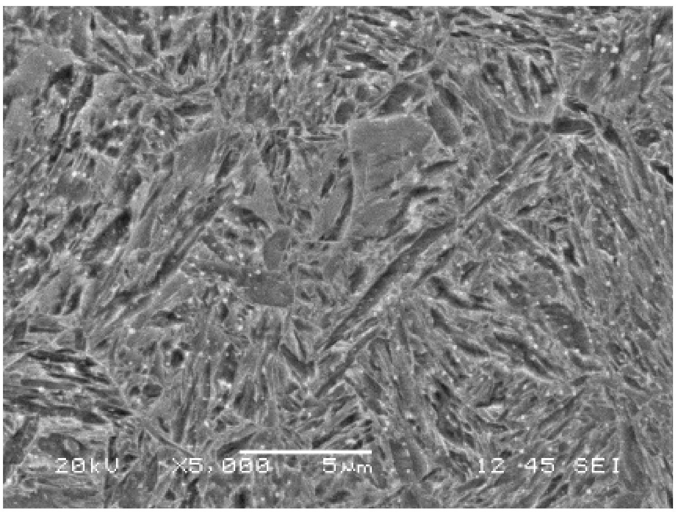


Fig. 5. Microstructure of the sample ASR 800 Q (ASR / quenching from 800°C), 677 HV10

They were probably not present in sufficient density and size to effectively limit austenite grains growth. Prior austenite grain size did not differ significantly between SA and ASR samples. Martensite is slightly finer in ASR sample (Fig. 5).

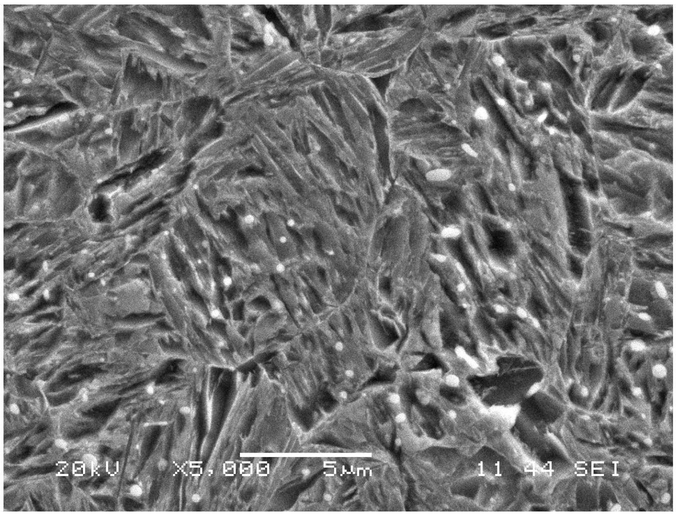


Fig. 6. Microstructure of the sample SA 800 Q (Soft annealing / quenching from 800°C), 624 HV10

Rise in quenching temperature caused larger portion of cementite to dissolve. There were practically no carbides present in the structure of the sample ASR 860 Q (ASR / quenching from 860°C) (Fig. 7). On the other hand, sample SA 860 Q (Soft annealing / quenching from 860°C) contained still undissolved carbides up to 0.5 µm diameter in martensitic matrix (Fig. 8).

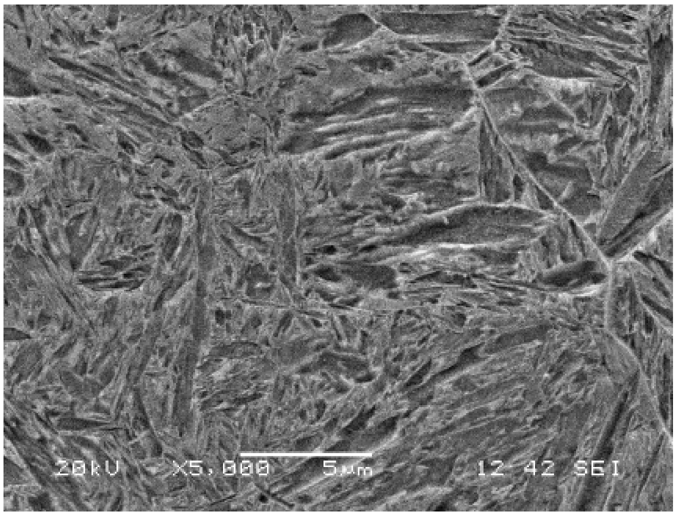


Fig. 7. Microstructure of the sample ASR 860 Q (ASR / quenching from 860°C), 706 HV10

All samples were tempered at 450°C for 2 hours. The tempering caused cementite precipitation in the martensitic matrix (Figs. 9,10). There is no apparent difference between precipitates shape, size and distribution among samples.

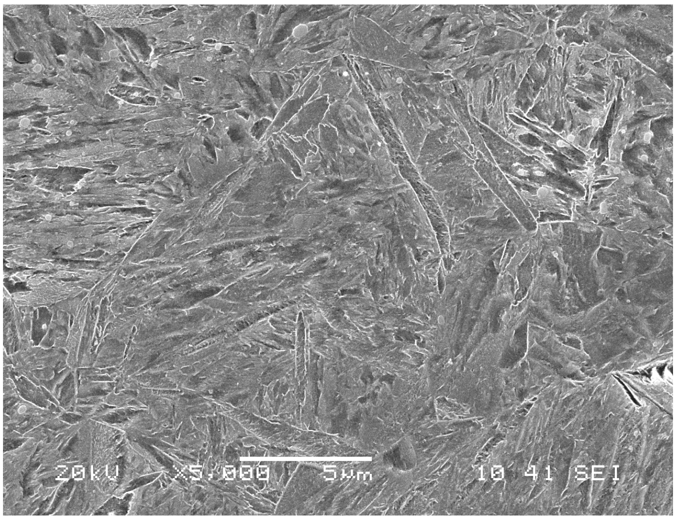


Fig. 8. Microstructure of the sample SA 860 Q (Soft annealing / quenching from 860°C), 679 HV10

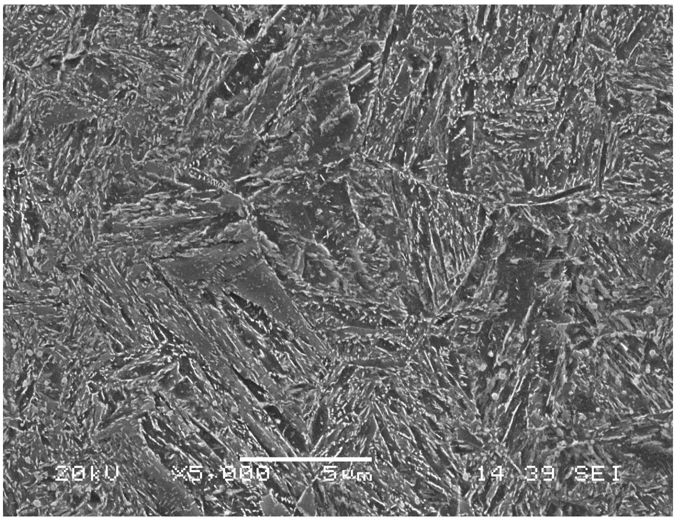


Fig. 9. Microstructure of the sample ASR 840 QT (ASR / quenching from 840°C / tempering), 446 HV10

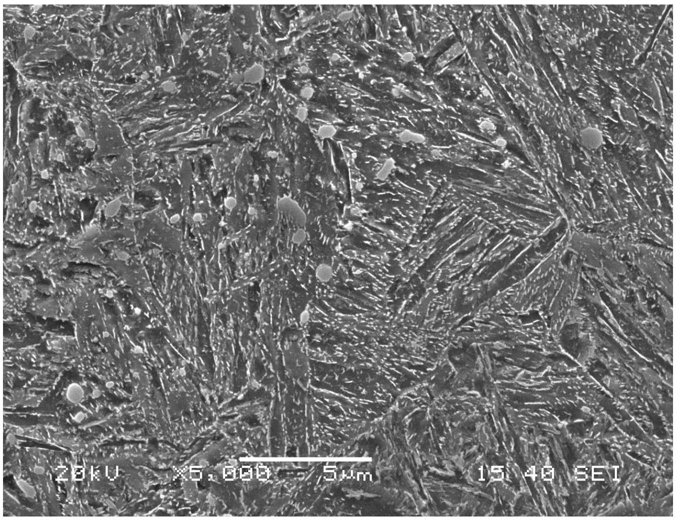


Fig. 10. Microstructure of the sample SA 840 QT (Soft annealing / quenching from 840°C / tempering), 424 HV10

ASR process lead to significantly finer carbides in comparison with soft annealing. This feature took effect in much faster carbide dissolution during austenitization at quenching temperature. Finer carbides after ASR induced finer martensitic structure only after quenching from the lowest temperature 800°C, where certain amount of carbides remained undissolved. Almost complete dissolution of fine carbides at higher temperatures lead to martensitic structures similar to structures obtained from soft annealed samples. The martensite crystals and prior austenite grains had comparable size between SA and ASR samples after quenching from temperature 820°C and higher, although there were still undissolved carbides in SA samples and practically no observable carbides in ASR treated samples. Austenite coarsening could be limited by temperature-stable vanadium carbides, which were not observable by SEM microscopy on etches sections.

### Hardness

There are hardness values listed in Table 1. Samples hardened after conventional soft annealing (SA) showed lower hardness both after quenching and tempering. Increasing quenching temperature brought higher hardness for soft annealed samples. This trend was not observed for samples after ASR treatment; hardness after quenching from temperatures 820, 840 and 860°C was almost identical. Hardness rise with increasing quenching temperature can be attributed to more advanced carbide dissolution, resulting in higher content of carbon in martensite. In case of ASR treated samples, probably the maximal hardness of the material after quenching was reached. Almost all carbides were dissolved at 820°C, while there were still some undissolved carbides in soft annealed sample even after quenching from 860°C. Samples after quenching and tempering shows the same trend. Soft annealed sample quenched from temperature 860°C and tempered reached the same hardness as sample after ASR treatment, quenched from 800°C and tempered.

TABLE 1

Hardness HV10 after quenching and tempering (SA – Conventional soft annealing; ASR – Accelerated Spheroidisation)

| Austenitization temperature [°C] | Hardness HV10 after treatment | | | |
|---|---|---|---|---|
| | SA, quenching | SA, quenching and tempering | ASR, quenching | ASR, quenching and tempering |
| 800 | 624 ±2 | 406 ±5 | 677 ±4 | 433 ±7 |
| 820 | 650 ±2 | 419 ±3 | 705 ±7 | 443 ±8 |
| 840 | 660 ±9 | 424 ±5 | 692 ±7 | 446 ±9 |
| 860 | 679 ±7 | 434 ±8 | 706 ±9 | 447 ±2 |

## 4. Conclusion

There were compared hardness and microstructure for hardened samples of 51CrV4 spring steel with different initial microstructures. Conventional long-duration soft annealing ensured spheroidised structure with carbide size up to 1000 nm. ASR (Accelerated Spheroidisation) treatment resulted in much finer structure composed of ferrite and mostly globular carbides with size max. 300 nm.

Quenching from temperatures in range 800°C to 860°C was performed with subsequent tempering. Samples after ASR treatment showed significantly faster carbide dissolution. There were almost none undissolved carbides in the structure after quenching from 820°C, while for soft annealed samples coarse carbides remained in structure even after quenching from 860°C. This resulted in higher hardness of ASR treated and hardened samples in comparison with soft annealed samples. Quenching temperature can be lowered from 860°C for soft annealed structure to 800°C for ASR treated samples with no loss of final hardness.

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