



Carbide spheroidisation in 100CrMnSi6-4 bearing steel by controlled rolling

J. Dlouhy*, D. Hauserova, Z. Novy

COMTES FHT a.s., Prumyslova 995, 334 41 Dobrany, Czech Republic

* Corresponding e-mail address: jaromir.dlouhy@comtesfht.cz

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ABSTRACT

Purpose: This article describes influence of thermomechanical treatment parameters on microstructure and mechanical properties of 100CrMnSi6-4 bearing steel.

Design/methodology/approach: Steel properties after accelerated carbide spheroidisation enables machining and cold forming as well as after conventional soft annealing. Apparently, structure after accelerated carbide spheroidisation is significantly finer than after long duration soft annealing – in terms of carbide particles and grain size. That enhances steel hardness and homogeneity of the structure in final state after hardening.

Findings: Presented experiment deals with accelerated carbide spheroidisation of 100CrMnSi6-4 bearing steel during final stage of hot rolling. Main purpose is to achieve microstructure consisting of globular carbides and ferritic matrix directly after hot forming.

Research limitations/implications: The combination of a suitable forming temperature, an appropriate amount of deformation and a possible reheating lead to globular carbide formation during austenite decomposition instead of cementite lamellae.

Originality/value: Experiment results are promising for quenching and tempering in comparison with structure after conventional soft annealing with coarser. Finer ASR structure retains finer austenite grain at quenching temperature and higher dispersion strengthening.

Keywords: Carbide spheroidisation; Thermomechanical treatment; Bearing steel; Controlled rolling

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Usual beginning of bearing semiproducts consist of casting, hot rolling with resulting pearlitic microstructure and soft annealing. Soft annealing ensures machinability of the steel as well as cold formability, depending on bearing production process [1]. Soft annealing is usually carried out as several hours lasting dwell slightly above temperature

A_1 with subsequent cooling in air. Resulting structure is composed of ferritic matrix with globular carbides with dimension range typically from 0.3 to 1.5 μm . Whole annealing lasts mostly from 20 to 30 hours [2].

Presented article deals with Accelerated carbide Spheroidisation and Refinement (ASR) achieved by thermomechanical processing of the steel 100CrMnSi6-4. Thermomechanical treatment was realized as controlled rolling with critical last deformation added in various

structural state of the steel during cooling or short reheating after the conventional hot rolling operation.

ASR process means literally fast cementite spheroidisation from original pearlitic lamellar form in tens of seconds or minutes. Characteristic feature of rapid spheroidisation is formation of considerably finer cementite globules and thus more homogeneous structure than after conventional soft annealing. ASR process used in described experiment used phenomena of cementitic lamellae fragmentation during rapid austenitization [3], plastic deformation and also mechanism of divorced pearlitic transformation [4,5].

2. Experimental

2.1. Material

The steel 100CrMnSi6-4 was supplied in form of continuously casted slabs, 150 x 150 mm in section, in as-casted state. Chemical composition is shown in Table 1. Initial microstructure was pearlitic with small amount of secondary cementite along primary austenite grain boundaries (Fig. 1). The hardness was 351 HV10. Samples for rolling were cut in form of 75 mm wide, 47 mm thick and 330 mm long balk.

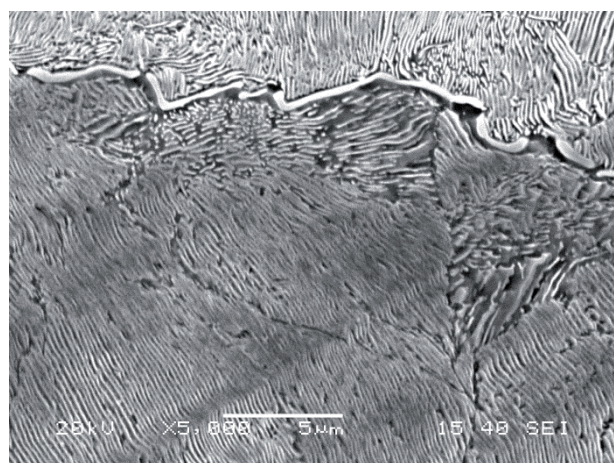


Fig. 1. Microstructure of the initial state, 330 HV10

Table 1.
Chemical composition of the 100CrMnSi6-4 steel

Element	C	Si	Mn	P	S	Cr	Ni	Al	Cu	Fe
wt.%	0.96	0.64	1.14	0.014	0.002	1.57	0.03	0.006	0.03	Bal.

2.2. Experimental rolling

The samples were rolled by experimental rolling mill. The rolling mill was used in duo configuration for hot rolling. Rolls diameter was 550 mm, maximal width of sheet was 400 mm and range of sheet thickness was from 5 to 100 mm. Maximal rolling speed was 1.5 m/s. The rolling mill is equipped by powered roller track on both sides (Fig. 2).



Fig. 2. Experimental rolling mill

Samples were heated in atmospheric chamber furnace. Sample temperature during controlled rolling was measured by pyrometers, placed on both sides of the rolling mill. When controlled cooling of the sample was required, sample was placed onto refractory pads and observed by thermocamera. When reheating of the sample during rolling schedule was required, sample was transferred into roller furnace (furnace temperature 1100°C) and send back after reheating.

ASR process consisted in thermomechanical processing of the sample with pearlitic structure after hot rolling. To achieve such structure, each sample was heated at the temperature 1000°C with 1 hour hold and subsequent hot rolling with rolling finishing temperature 800°C. This part of experimental regime simulated the conventional hot rolling. The sample was then let to cool down in air. After the pearlitic transformation, an thermomechanical processing was applied.

Sample 1 was processed as referential hot rolled sample. No thermomechanical processing was applied after hot rolling and the sample was let to cool down to room temperature in air. Samples 2 and 3 were deformed after pearlitic transformation at temperature 665°C (Fig. 3).

Sample 4 was reheated in roller furnace to temperature 830°C. The sample was in the furnace 150 seconds to reach this temperature. After that, the sample was let to cool down to room temperature in air. Samples 5, 6 and 7 were after reheating deformed by true strain 0.5 at temperatures between reheating temperature and pearlitic transformation temperature (Fig. 4).

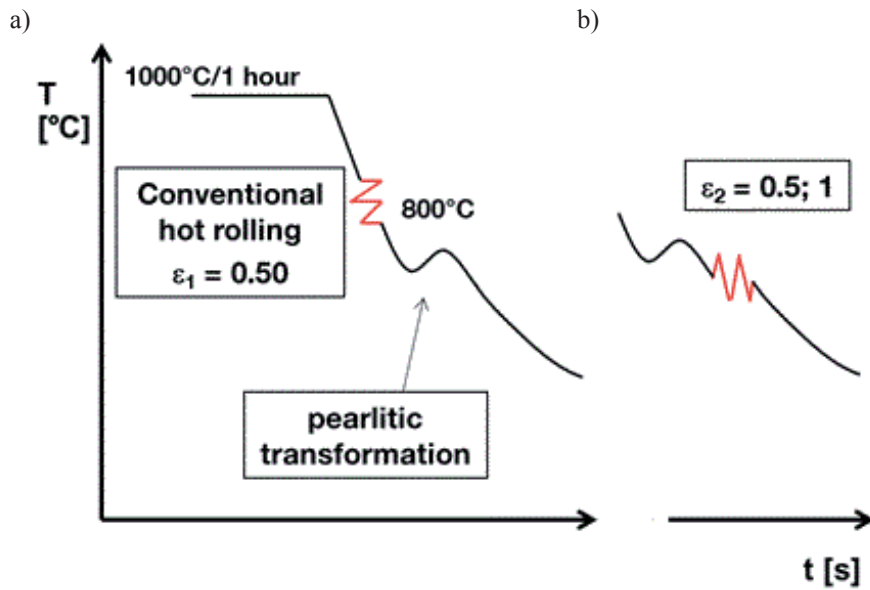


Fig. 3. Scheme of schedule for samples 1 (a), 2 (b; $\epsilon_2 = 0.5$) and 3 (b; $\epsilon_2 = 1$)

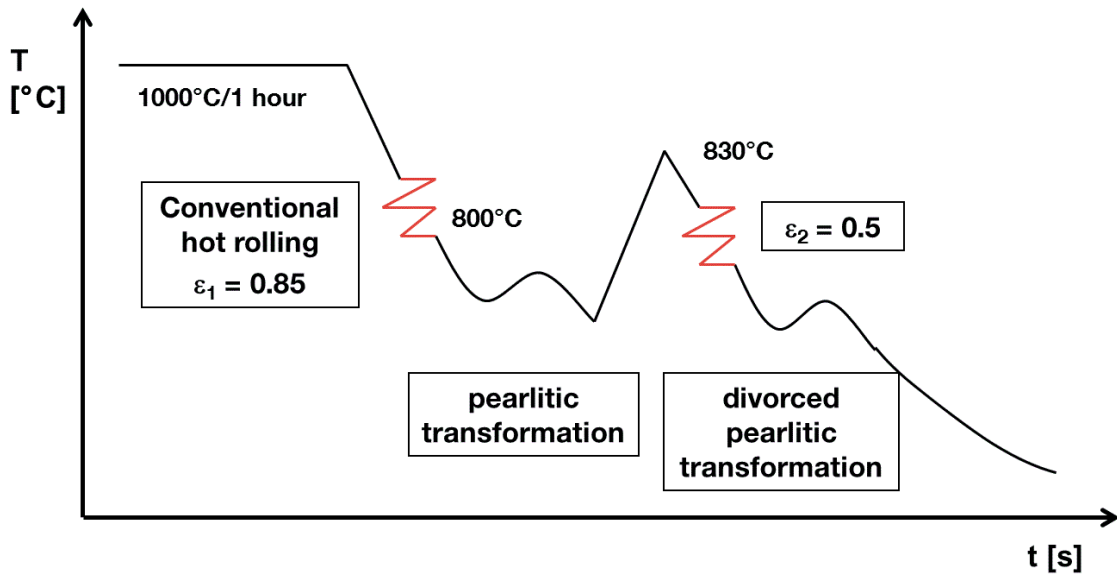


Fig. 4. Scheme of schedule for samples 4 ($\epsilon_2 = 0$), 5 (ϵ_2 at 810°C), 6 (ϵ_2 at 760°C) and 7 (ϵ_2 at 690°C)

2.3. Sample analyses

Rolled samples were analysed in their centre. There was prepared metallographic section in longitudinal direction. The section was observed by scanning electron microscope (SEM) and hardness HV10 was measured.

3. Results and discussion

3.1. Pearlite deformation

Sample 1 was treated by conventional hot rolling to gain referential pearlitic microstructure and properties in state after hot rolling. Fig. 3a) shows time-temperature curve observed after hot rolling. There was clearly visible sample heating due to latent heat of the pearlitic transformation. The heating began at temperature 675°C, the temperature raised to 685°C and then dropped again after the transformation. Sample had pearlitic microstructure with small amount of secondary cementite along prior austenite grains borders.

Samples 2 and 3 were deformed just after the pearlitic transformation finish at temperature 665°C. They were deformed in two reductions (sample 2) and 4 reductions (sample 3). Structure micrographs showed, that cementite lamellae were broken, fragmented and part of them was spheroidised. However, part of the pearlitic colonies remained intact in lamellar form (Figs. 5 and 6). The spheroidisation process was in homogeneous even in case of high deformation for sample 4 (true strain 1.0, i.e. reduction by factor 2.7).

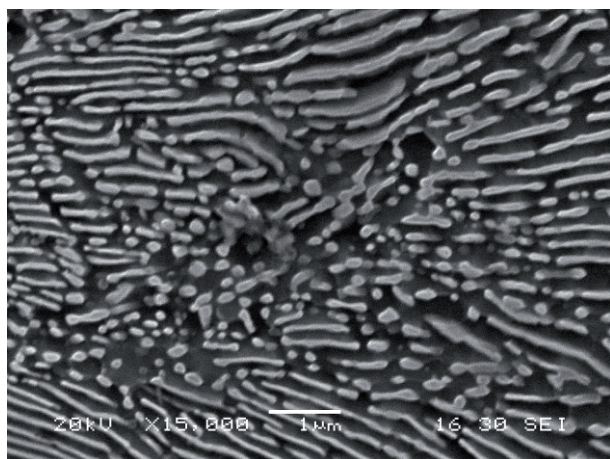


Fig. 5. Microstructure of sample 2, 342 HV10. Beginning of the cementite spheroidisation

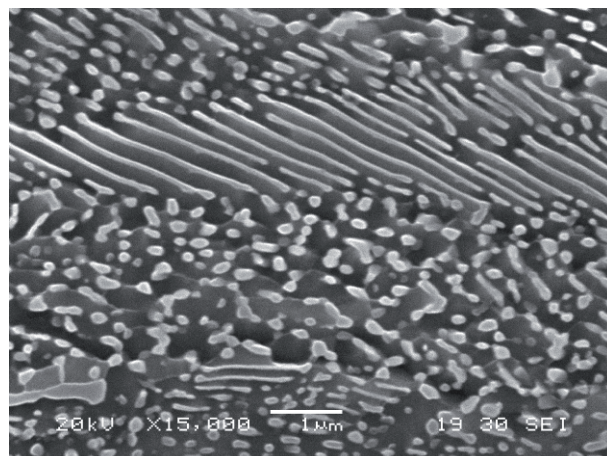


Fig. 6. Microstructure of sample 3, 343 HV10. Inhomogeneous spheroidisation

The homogeneous spheroidisation apparently requires even bigger reduction. Pearlite rolling also requires large rolling forces. The pearlite rolling is therefore not very suitable for industrial applications in rolling plant.

3.2. Austenite with cementite particles deformation

Another strategy was to deform steel with structure composed of austenite and non-dissolved pearlitic lamellae. Samples were reheated after hot rolling an pearlitic transformation in roller furnace. Reheating to from 665°C to 830°C was performed in 150 seconds. This reheating caused austenitization of the pearlitic ferrite, but only partial dissolution of cementite lamellae. Cementite lamellae form during dissolution lace-like and rod-like particles, which can be fragmented much easier by final deformation. Rolling forces are also considerably lower in comparison with pearlite deformation at temperature below A_1 .

Sample 4 was let to cool after reheating in air without deformation ϵ_2 . Resulting structure is composed of ferritic matrix and partially spheroidised pearlite. New pearlitic lamellae were not formed during cooling after reheating due to mechanism of divorced pearlitic transformation (Fig. 7).

Samples 5, 6 and 7 were deformed with deformation intensity 0.5 at temperatures between reheating temperature and beginning of divorced pearlitic transformation. Samples were deformed at different temperatures within this range (810°C, 760°C, 690°C). The microstructure of all three samples was very similar, consisting of ferritic matrix and globular carbides (Fig. 8).



Fig. 7. Microstructure of sample 4, 267 HV10. partially spheroidised and fragmented pearlitic lamellae

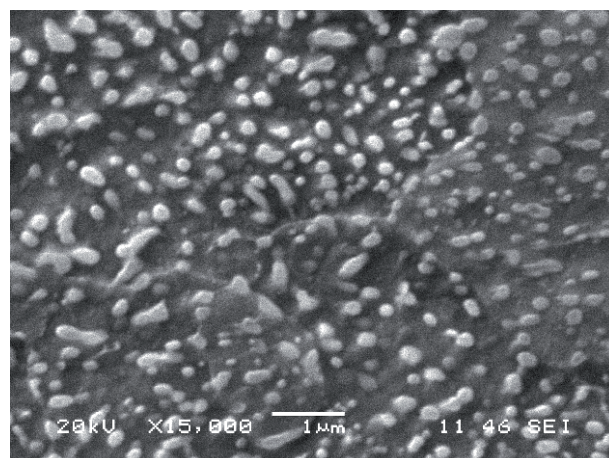


Fig. 8. Microstructure of sample 7, 278 HV10. Fully spheroidised structure with fine carbides

Table 2.

Schedules overview with resulting structures and hardness. FRT – final rolling temperature in, FDI – final deformation intensity (logarithmic), NR – number of reductions during final deformation step. Final microstructure: LP – lamellar pearlite, FP – fragmented pearlite, SP – spheroidised pearlite, IS – initial state

No.	Description	FRT, °C	FDI, -	NR	Final micro-structure	HV10
IS	Continuously casted material	-	-	-	LP	351
1	Hot rolling	800	0.85	2	LP	326
2	Pearlite deformation	665	0.50	2	FP	342
3		665	1.00	4	FP	343
4	Hot rolling + reheating to 830°C	-	-	-	FP	267
5	Deformation of austenite with cementite particles after reheating at 830°C	810	0.50	2	SP	270
6		760	0.50	2	SP	273
7		690	0.50	2	SP	278

Schedules overview with resulting structures and hardness is shown in Table 2. The hardness measurement showed hardness 326 HV10 for hot rolled material. Deformation of pearlite caused pearlitic lamellae fragmentation, but the deformed structure did not fully recover from plastic deformation because of hardness increase (samples 2 and 3). Reheating caused fragmentation of lamellae resulted in material softening to 267 HV10. Deformation after the reheating did not contribute to further hardness decrease; it caused structural change by spheroidisation completion.

4. Conclusions

The thermomechanical processing by controlled rolling was successfully carried out in order to induce accelerated

carbide spheroidisation and refinement in 100CrMnSi6-4 steel. Pearlite deformation at temperature slightly under A_1 led to inhomogeneous fragmentation and spheroidisation of pearlite. Accelerated carbide spheroidisation was reached by deformation of austenitic structure containing undissolved fragments of cementite lamellae. Fully spheroidised structure was reached by deformation of such a structure by logarithmic deformation 0.5 within temperature range 810°C-690°C after pearlitic structure reheating to 830°C. This thermomechanical processing resulted in ferritic matrix with homogeneously dispersed fine carbides. Final structure is promising for quenching and tempering in comparison with structure after conventional soft annealing with coarser. Finer ASR structure retains finer austenite grain at quenching temperature and higher dispersion strengthening.

Acknowledgements

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