www.czasopisma.pan.pl PAN www.journals.pan.pl

A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S

Volume 59 2014 Issue 3

DOI: 10.2478/amm-2014-0208

D. HAUSEROVA*, J. DLOUHY*, Z. NOVY*

EFFECT OF HEATING RATE ON ACCELERATED CARBIDE SPHEROIDISATION (ASR) IN 100CrMnSi6-4 BEARING STEEL

WPŁYW SZYBKOŚCI GRZANIA NA PRZYSPIESZONĄ SFEROIDYZACJĘ WĘGLIKÓW (ASR) W STALI ŁOŻYSKOWEJ 100CrMnSi6-4

Typical processing routes for bearing steels include a soft annealing stage, the purpose of which is to obtain a microstructure containing globular carbides in ferritic matrix. A newly developed process called ASR cuts the carbide spheroidisation times several fold, producing considerably finer globular carbides than conventional soft annealing. The present paper explores the effect of the heating rate and temperature on the accelerated carbide spheroidisation process and on the resulting hardness. Accelerated spheroidisation was achieved by thermal cycling for several minutes around various temperatures close to the transformation temperature at various heating rates applied by induction heating.

Keywords: Carbide spheroidisation, bearing steel, annealing, induction heating

Proces obróbki stali łożyskowych obejmuje wyżarzanie zmiękczające, którego celem jest uzyskanie mikrostruktury zawierającej kuliste węgliki w osnowie ferrytycznej. Nowo opracowana obróbka zwana ASR polega na wielokrotnym przerywaniu procesu sferoidyzacji, co prowadzi do wytworzenia węglików kulistych o znacznie mniejszych rozmiarach w porównaniu do tych, jakie powstają w konwencjonalnym procesie wyżarzania zmiękczającego. Niniejsza praca analizuje wpływ szybkości grzania i temperatury na proces przyspieszonej sferoidyzacji węglików i na uzyskaną twardość. Przyspieszoną sferoidyzację węglików uzyskano dzięki zastosowaniu cyklicznych zmian temperatury trwających kilka minut wokół określonych temperatur bliskich temperaturze przemiany za pomocą grzania indukcyjnego z różnymi prędkościami.

1. Introduction

Heat treatment of high-carbon steels typically includes soft annealing. The importance of decreasing the steel's hardness, yield strength and ultimate strength is matched by that of converting lamellar pearlite into globular cementite [1, 2]. The globular morphology of carbides greatly improves the steel's machinability and reduces the wear rate of cutting tools.

A conventional soft annealing schedule consists in long-term soaking at a temperature near A_{c1} and subsequent cooling in the furnace [3]. The entire process typically takes more than 20 hours [4]. The research effort was aimed at achieving carbide spheroidisation and hardness reduction in tens of seconds or several minutes at the most [5, 6].

The process that leads to accelerated carbide spheroidisation involves temperature cycling in an interval above and below A_{c1}. The austenitizing should not be complete, i.e. carbides must not dissolve fully in austenite [7]. During cooling, the partially dissolved cementite lamellae act as nuclei for cementite precipitation, which is a part of the transformation to pearlite. Hence, no new lamellae form in the process. By repeating the cycle of partial dissolution of lamellar pearlite and decomposition of austenite into pearlite, the lamellae break up and eventually spheroidise over a very short period of time.

Unlike experimental facilities, industrial plant conditions do not always allow the required process parameters to be met. Changes in the heating rate are accompanied by changes in the transformation temperatures. As a result, the accelerated spheroidisation process takes place within a certain temperature interval. The present paper gives a description of the process window (temperature interval) and its dependence on the heating rate applied in the accelerated spheroidisation and refinement process (ASR). The total heat treating time is on the order of minutes.

2. Experimental

2.1. Experimental Material

The experimental material was the 100CrMnSi6-4 bearing steel grade with the chemical composition given in Table 1. The material was supplied in the form of hot-rolled 21 mm-diameter bars. The as-received microstructure consisted of pearlite with a small amount of secondary cementite

TABLE 1

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

C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu
0.98	0.54	1.14	0.011	0.011	1.50	0.006	0.02	0.018	0.017

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

precipitated along prior austenite boundaries (Fig. 1). The hardness of the as-received material was 383 HV10.

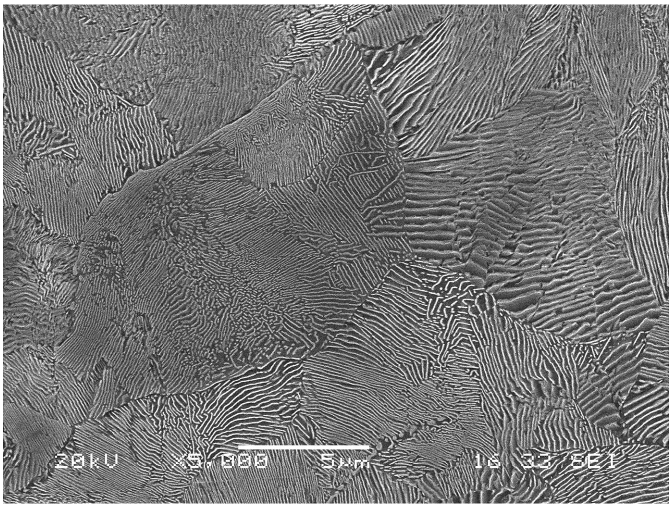


Fig. 1. Microstructure of initial state of 100CrMnSi6-4 steel – hardness 383 HV10

2.2. Heat Treatment

The heat treatment was performed using induction heating (Fig. 2). A medium-frequency 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 uniform. The inductor was PLC-controlled. The specimen temperature was measured by means of a thermocouple welded onto the specimen surface. The specimens for heat treating were 16 mm-diameter bars with the length of 100 mm. The heat treating schedules are shown in Table 2.

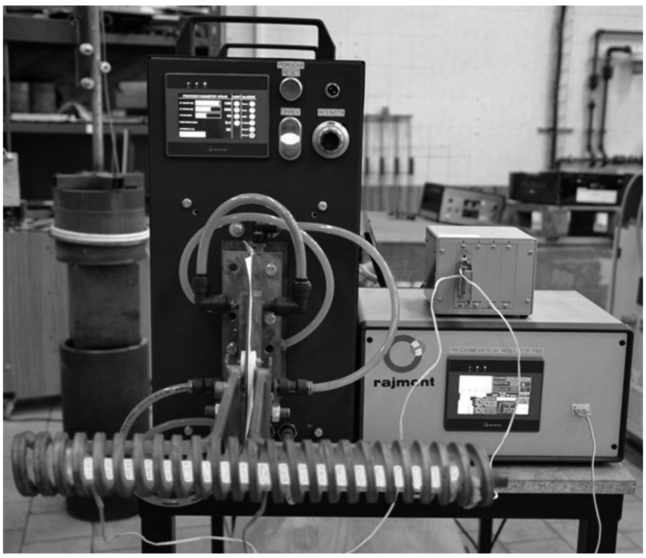


Fig. 2. Induction heat treatment

ASR process was successfully carried out during previous experiments by regime consisting of three temperature cycles with 15 seconds holds at temperature 780°C with heating rate of 15°C/s [8]. Regimes in this paper were chosen to determine intervals of suitable heating temperature and heating rates.

TABLE 2

Heat treating schedules

Heating rate	Holding temperatures					
20°C/s	740°C	760°C	780°C	800°C	820°C	840°C
60°C/s	740°C	760°C	780°C	800°C	820°C	840°C
180°C/s	740°C	760°C	780°C	800°C	820°C	840°C

The heat treating schedules consisted of heating at the rate of 20°C/s, 60°C/s or 180°C/s to a temperature between 740°C and 840°C, holding for 15 seconds, cooling in air to 630°C (below the pearlitic transformation temperature), reheating to the initial heating temperature, holding for 15 seconds, cooling to 630°C, reheating to the initial heating temperature, holding for 15 seconds and cooling in air to the ambient temperature. The heating rates of 20, 60 and 180°C/s apply to the temperature interval below the onset of the pearlitic transformation. Above the pearlitic transformation temperature, the actual heating rates decrease considerably due to the transformation. The initial heating temperature and the holding temperatures of 740, 760, 780, 800, 820 and 840°C were chosen in order to cover certain temperature intervals in dependence on the heating rate. The main purpose of this was to map the effect of heating rate and heating temperature on the carbide spheroidisation process and the relationship to the shift in the transformation temperature. This merlling is net in following text.

3. Results and Discussion

3.1. Microstructure Evolution

The micrographs below show microstructures on longitudinal metallographic sections through bar specimens. Transverse sections were observed to find how uniform the microstructure was across the bar cross section. The microstructure was uniform across the entire bar section in all specimens that were examined.

In the present experiment, the effect of heating rate, heating temperature and holding on the carbide spheroidisation process was explored.

Carbide Spheroidisation

Metallographic analysis revealed that the temperature of 740°C was too low for the purpose. Where the rates of 20 and 60°C/s were used, carbides only spheroidised in very few locations. Where the heating rate of 180°C/s was applied, the resulting microstructure was no different from the initial condition. The pearlite lamellae remained unchanged and no fragmentation or spheroidisation took place. It was impossible to identify the beginning of the pearlitic transformation in the temperature plots for any of these schedules. When the temperature of 760°C was used, some areas with spheroidised carbides began to appear (Fig. 3).

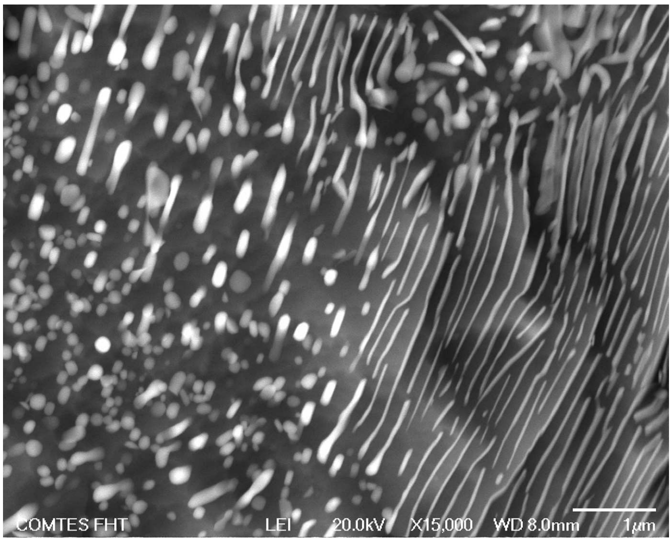


Fig. 3. Microstructure after schedule with heating rate 20°C/s and heating temperature 760°C – hardness 313 HV10

There was no substantial difference between the microstructures obtained with heating rates of 20 and 60°C/s. The heating rate of 180°C/s led to partial fragmentation of cementite lamellae (which changed into rod-like and worm-like particles). Using the heating and holding temperature of 780°C promoted the carbide spheroidisation. Schedules with the heating rate of 20°C/s result in an almost complete carbide spheroidisation. Incompletely spheroidised cementite lamellae are only scarcely found. Schedules with the heating rate of 60°C/s lead to greater numbers of partially fragmented cementite lamellae than the previous ones. The fragmentation of lamellae takes place. In specimens which were heated at the highest rate of 180°C/s, one half of cementite lamellae were partially fragmented and the rest of the carbides had globular form. The heating and holding temperature of 800°C combined with the heating rate of 20°C/s led to a completely spheroidised microstructure (Fig. 4). Incompletely spheroidised carbides were rare. Schedules with heating rates of 60 and 180°C/s led to microstructures with only small amounts of remaining undissolved cementite lamellae.

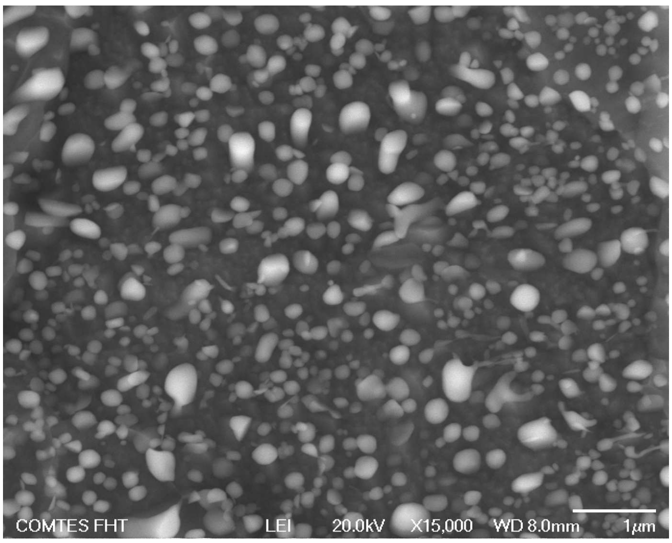


Fig. 4. Microstructure after schedule with heating rate 20°C/s and heating temperature 800°C – hardness 255 HV10

The heating and holding temperature of 820°C and the heating rate of 20°C produced small amounts of dispersed short cementite lamellae, which possibly formed during the last pearlitic transformation. The microstructures obtained with the heating rates of 60 and 180°C/s were spheroidised and contained no cementite lamellae. Schedules with the heating temperature of 840°C and the heating rate of 20°C/s produced microstructures with scarce new lamellae, which formed during the last pearlitic transformation. This was a result of excessive dissolution of cementite in austenite owing to the very high heating and holding temperatures. Specimens processed using the heating rate of 60°C/s contained areas with prior cementite and new cementite lamellae formed during pearlitic transformation. After the application of the heating rate of 180°C/s, greater amounts of prior cementite lamellae were found. The process was too rapid for the prior lamellae to spheroidise. However, the resulting microstructure also contained new cementite lamellae formed due to excessive dissolution of the prior ones caused by too high heating and holding temperatures (Fig. 5).

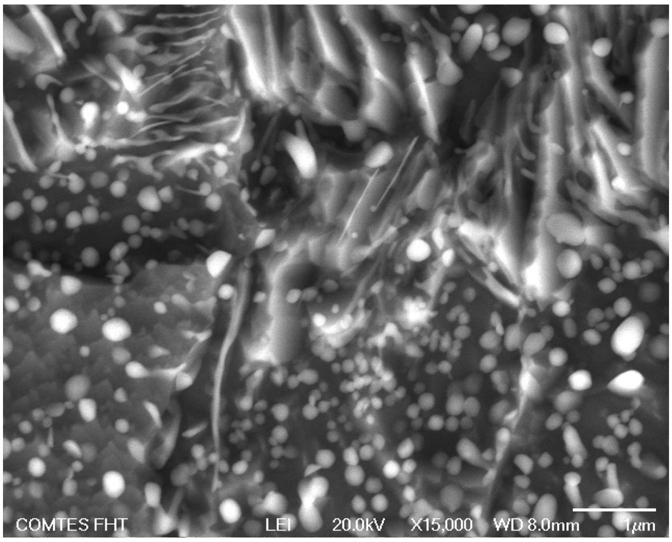


Fig. 5. Microstructure after schedule with heating rate 100°C/s and heating temperature 840°C – hardness 272 HV10

The change in the carbide morphology during ASR consists in the prior cementite lamellae becoming fragmented into rod-like or worm-like particles which further split into globular particles.

The presence of rod-like carbides in the final microstructure is probably governed by the speed of movement of the austenite-pearlite interface (Fig. 3). When the advancement of this interface slows down, the cementite lamellae disintegrate into globules just behind the interface (in the distance of several micrometres). At high interface advancement speeds, larger areas with rod-like and worm-like carbides remain in austenite. The highest heating rate led to formation of extensive areas with fragmented lamellae (Fig. 6). At lower heating rates, the resulting microstructure contained the prior lamellae or globules and an only a small amount of fragmented rod-like or worm-like cementite particles.

Fig. 6. Microstructure after schedule with heating rate 180°C/s and heating temperature 800°C – hardness 265 HV10. Large amount of fragmented pearlitic lamellae

Structure refinement

The heating temperature of 740°C resulted in the final microstructure being identical to the initial one, i.e. cementite lamellae in ferritic matrix, at all heating rates. At 760°C, islands of spheroidised cementite begin to form. Where the temperatures of 780°C through 840°C were used, the prior austenite grain became finer than in the feedstock, regardless of the heating rate (20, 60, 180°C/s).

Size of globular carbides formed during ASR process (Fig. 7) is significantly smaller than carbide size after conventional soft annealing (Fig. 8).

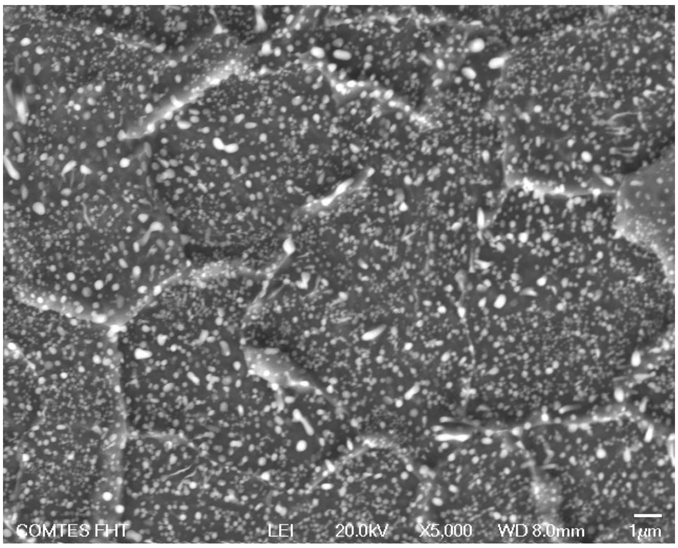


Fig. 7. Microstructure after schedule with heating rate 60°C/s and heating temperature 820°C – hardness 261 HV10

3.2. Hardness

The hardness of specimens is in agreement with their microstructures (Fig. 9).

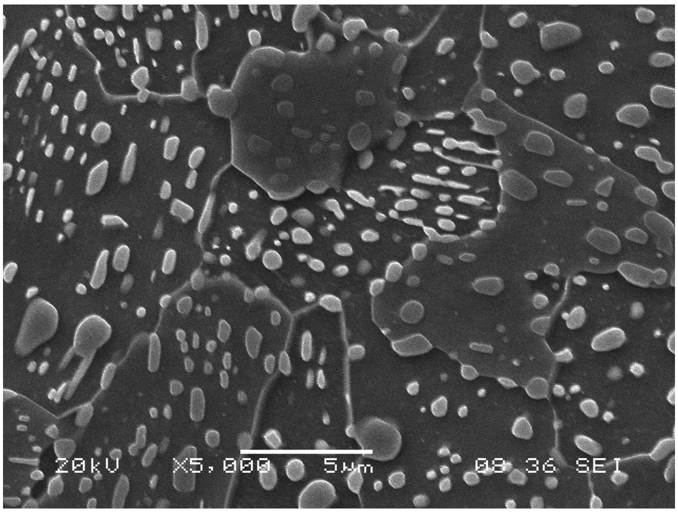
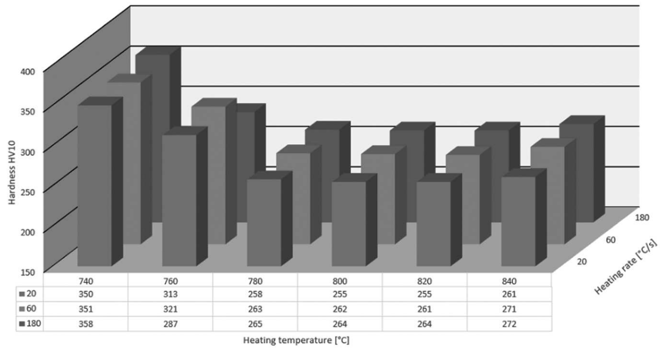


Fig. 8. Microstructure after conventional soft annealing (790°C/11hrs, furnace cooling) hardness 208 HV10



	740	760	780	800	820	840
20	350	313	258	255	255	261
60	351	321	263	262	261	271
180	358	287	265	264	264	272

Fig. 9. HV10 hardness achieved with individual schedules

Upon the heating temperature of 740°C hardness levels achieved with the heating rates of 20, 60 and 180°C/s are not substantially different from the hardness of the initial material of 383 HV10. The values are close to 350 HV10. With increasing temperature, the hardness of specimens decreases, as the fraction of spheroidised carbides increases. At the heating temperature of 840°C, hardness begins to increase again due to the presence of cementite lamellae. The schedule with the highest heating rate and highest temperature, 180°C/s and 840°C, led to the hardness of 272 HV10. The most favourable, i.e. the lowest hardness, and spheroidised microstructure were achieved with the schedule involving the rate of 20°C/s and heating and holding temperatures of 800 and 820°C.

4. Conclusion

Induction heat treatment was successfully used to facilitate accelerated spheroidisation of carbides in 100CrMnSi6-4 bearing steel. The resulting size of the carbides and prior austenite grain was much less than after conventional soft annealing processes. It was found that the accelerated carbide spheroidisation process and the resulting hardness are substantially influenced by the heating rate, heating temperature and the holding temperatures. Complete spheroidisation of carbides was achieved with the heating rate of 20°C/s and holding temperatures of 780°C and 800°C. The heating temperature of 820°C only led to formation of scarce and scattered short lamellae. With heating rates of 60 and 180°C/s complete spheroidisation of carbides was achieved in combination with heating and holding temperatures of 800 and 820°C. Optimum results were attained with the lowest heating rate. The resulting hardness of was 255 HV10.

Acknowledgements

The results presented in this paper arose under the project West-Bohemian Centre of Materials and Metallurgy CZ.1.05/2.1.00/03.0077 co-funded by European Regional Development Fund.

REFERENCES

[1] H.K.D.H. Bhadeshia, Progress in Materials Science **57**, 268-435 (2012).
[2] N.V. Luzginova, L. Zhao, J. Sietsma, Metallurgical and Materials Transactions A **513-521**, 39 (2008).
[3] W.J. Nam, & C.M. Bae, Scripta Materialia 313-318, 41 (1999).
[4] K.G. Ata, & S.A. Meisam, Journal of Iron and Steel Reasearch 45-52, 17 (2010).
[5] H. Jirková, D. Hauserová, L. Kučerová, B. Mašek, MATERIALI IN TEHNOLOGIJE/MATERIALS AND TECHNOLOGY 335-339, 47 (2013).
[6] B. Mašek, H. Jirková, L. Kučerová, Materials Science Forum 2770-2775, 706-709 (2012).
[7] D.V. Shtansky, K. Nakai, Y. Ohmori, Acta materialia, 2619-2632, 47 (1999).
[8] D. Hauserová, J. Dlouhý, Z. Nový, Materials Science Forum, 123-128, 782 (2014).

Received: 20 March 2014.