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Microstructural Modifications During Heating of Warm Rolled AISI 1015 Carbon Steel

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ABSTRACT

For industrial applications, warm working is very attractive due to certain advantages offered by this plastic deformation process. Heat treating of warm worked steels can lead to a significant improvement of their mechanical properties. The paper presents the influence of the heat-treating regime applied to warm rolled AISI 1015 carbon steel. The rolling was performed in the following conditions: temperature 670 ^oC – 550^oC, rolling speed 1.39 s^{-1} and deformation ratio 36.4 %. After rolling, the samples were reheated to 550^o, 600^o and 650^oC for a duration varying from a few minutes to 10 hours. The microstructural changes were assessed by light and electron microscopy and the possible heat treatments were considered.

Keywords*: ferrite-perleate steels, low carbon, steels, microstructure, warm rolling, heat treatments*

1. Introduction

The practice of rolling in the upper ferritic region instead of in the austenitic region has been termed as warm rolling [1]. Extensive research has been conduced to understand the physical metallurgy of warm rolling. The effect of warm rolling on the structure and properties of low carbon steel has been considered by Hawkins [2]. Modelling of warm rolling of low carbon steel have been effected by Serajzadeh [3]. In several works have been studied the microstructural development and mechanical behaviour during warm rolling [4], warm calibre rolling [5] and warm cross-wedge rolling of steels. For industrial applications, warm working is very attractive and offers certain advantages. Thus, compared to cold working, it requires lower deformation forces, can be applied to a broader range of steels, allows for higher deformation ratios, generates a more uniform deformation across the transversal section and leads to a less strained microstructure [6]. Compared to hot working, it leads to a finer microstructure with superior mechanical properties, better surface quality and better dimensional control, lower material losses due to decarburization and oxidation [7]. Attempts to apply thermochemical treatments to some carbon steels, previously subjected to warm working, have resulted in superior results as compared to those subjected to hot working [8].

Heat treating of warm worked steels can lead to a significant improvement of their mechanical properties. In order to fulfil this goal it is necessary to determine the optimum heat treating regime, taking into account the particularities and parameters of the plastic deformation (temperature, deformation ratio, deformation speed etc). The heating temperature must be limited, for hypoeutectoid carbon steels, to the ferrite-pearlite field, and the soaking time must be established such as to preserve the fine microstructure resulted after warm working. The present study has in view to determine the influence of the heating temperature and soaking time on the microstructure of AISI 1015 carbon steel previously subjected to warm rolling and to determine the possible heat treatment that can be applied after warm working.

2. Experimental details

Fully annealed AISI 1015 steel bars were first subjected to warm rolling under the following conditions: the temperature at the rolling start – 670°C, the temperature at the rolling end – 550°C, the rolling speed - 1.39 s^{-1} and the deformation ratio – 36.4 % [9]. A number of 36 samples were cut from these bars and heat treated in a laboratory furnace. The heating temperature and soaking time for each sample are given in table 1.

All the samples were then cooled in air. Microstructural changes that took place during the heat treatment were assessed by optical microscopy and scanning electron microscopy (SEM). This analysis was performed on the median longitudinal section of the samples (parallel to the rolling direction) after a proper surface preparation and etching with 4% Nital. The hardness of each sample was also measured on the same surface by Vickers method (HV20).

3. Results and Discussions

Figures 1 and 2 shows the structure of the warm-rolled AISI 1015 steel.

After warm rolling the microstructure of the steel consists of elongated, strained, ferrite of which grain boundaries can no longer be clearly distinguished and fine pearlite, distribute along the rolling direction (figure 1).

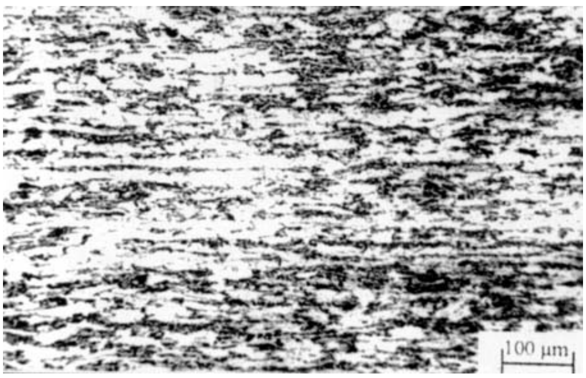

Figure 1. Microstructure of steel AISI 1015 after warm rolling.

Table 1. Parameters of the heat treatment applied to AISI 1015 steel after warm rolling.

Sample No.	Temperature [°C]	Time [min.]
1	550	1
2		3
3		5
4		10
5		15
6		20
7		30
8		60
9		120
10		180
11		300
12		600
13	600	1
14		3
15		5
16		10
17		15
18		20
19		30
20		60
21		120
22		180
23		300
24		480
25	650	1
26		3
27		5
28		10
29		15
30		20
31		30
32		60
33		120
34		180
35		300
36		480

Warm rolling leads to a marked finishing of the microstructure of AISI 1015 carbon steel. During deformation the ferrite grains are strained along the rolling direction and the pearlite is deformed, broken and globulised. The general aspect is that of lines of pearlite and very fine ferrite grains distributed alternatively with lengthened ferrite strips. Warm rolling leads to a very uniform straining in the cross-section

The pearlite grains are subjected to a spherulisation process (fig. 2 a). After warm rolling with a deformation ratio of 36.4 %, pearlite is almost totally with globular cementite intensity of globulisationis dependent on the applied deformation ratio , uniformly distributed in the ferrite matrix (fig. 2 b).

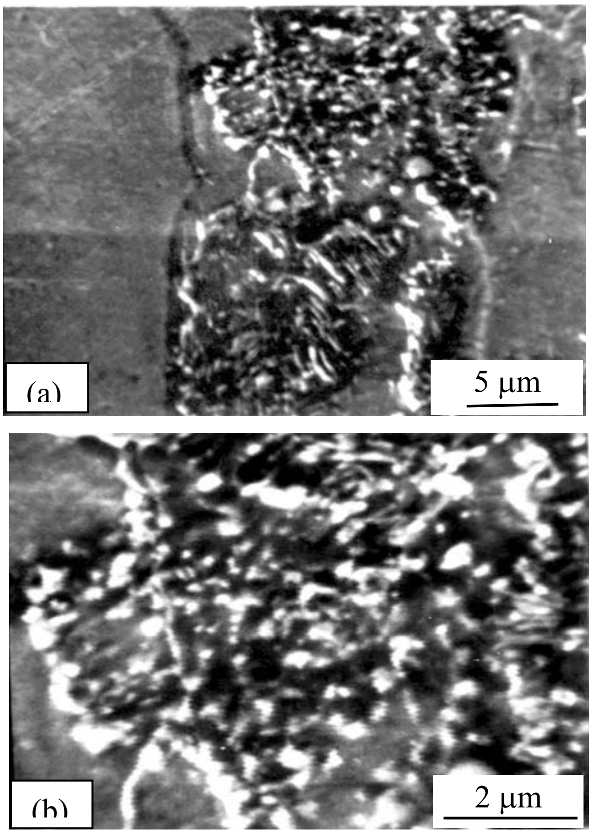

Figure 2. Microstructural modifications of the pearlite after warm rolling assessed by electron microscopy (SEM). Magnification (a) 5000:1, (b) 10000:1.

By heating the samples to 550°C, apparently, the microstructure preserves the same aspect as resulted after rolling: ferrite and pearlite distributed in lines (figure 3). After a soaking time of 10 minutes, the ferrite is completely recrystallised with clearly defined grain boundaries (figure 3a). Increasing the time from 10 minutes to 2 hours does not have any significant influence on the ferrite grain size. The microstructure remains fine, with less compact pearlite, distributed in lines as spheroidised aggregates (figure 3b). By increasing the duration further from 2 hours to 10 hours, the ferrite grains undergo a limited growth, pearlite becomes spheroidised but remains distributed in lines (figure 3c). The general aspect of the microstructure remains finely grained even after 10 hours.

The samples heated to 600°C are completely recrystallised after 10 minutes (figure 4a). The structure if finely grained with compact pearlite distributed in lines. After 15 … 30 minutes, the size of the ferritic grains increase significantly and pearlite becomes spheroidised with a distribution in lines (figure 4b). A mass globalisation takes place after a soaking time of 1 … 3 hours. After 3 hours the

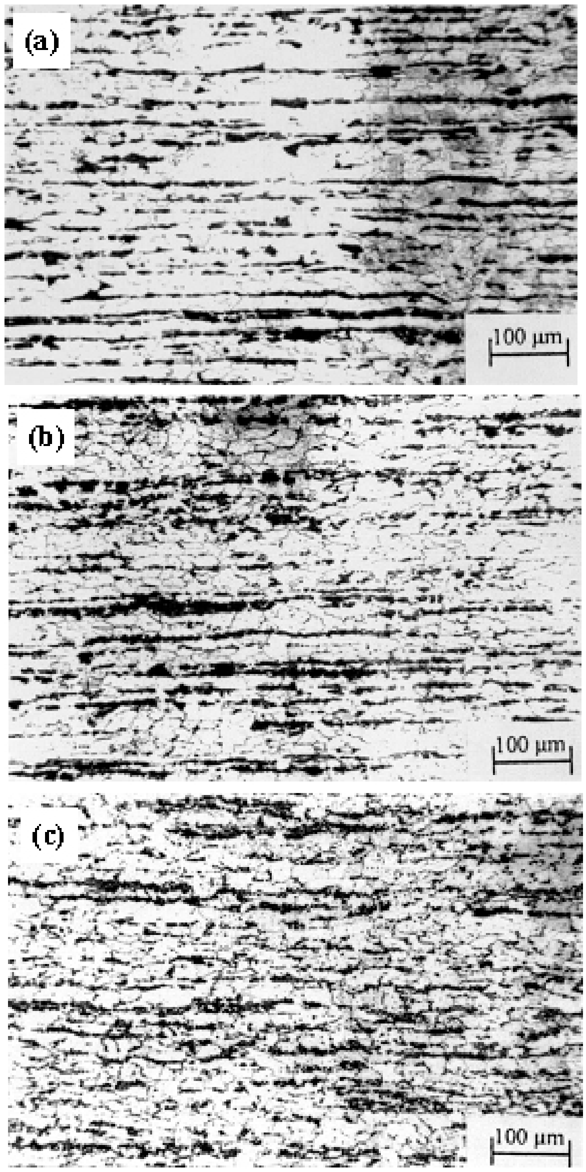

Figure 3. Microstructure of AISI 1015 steel after different soaking after different soaking times at 550 °C: a - 10 min.; b - 2 h; c – 10 h

microstructure consists of globular cementite uniformly distributed into the ferritic matrix (figure 4c). For longer soaking duration, 5 .. 8 hours, the globulisation effect disappears and the ferritic grains grow significantly (figure 4d).

The samples heated to 650°C have a similar structure to the samples heated to 600 °C, the higher temperature affecting only the speed of the structural modification processes. At 650°C, the samples are completely recrystallised after 5 min. (figure 5a). In the first 30 minutes, the ferritic grains grow significantly and pearlite, with an initial distribution in lines, becomes spheroidised (figure 5b). For a soaking time of 1 to 3 hours, a mass globulisation takes place (figure 5c). For longer soaking time (5 … 8 hours), the

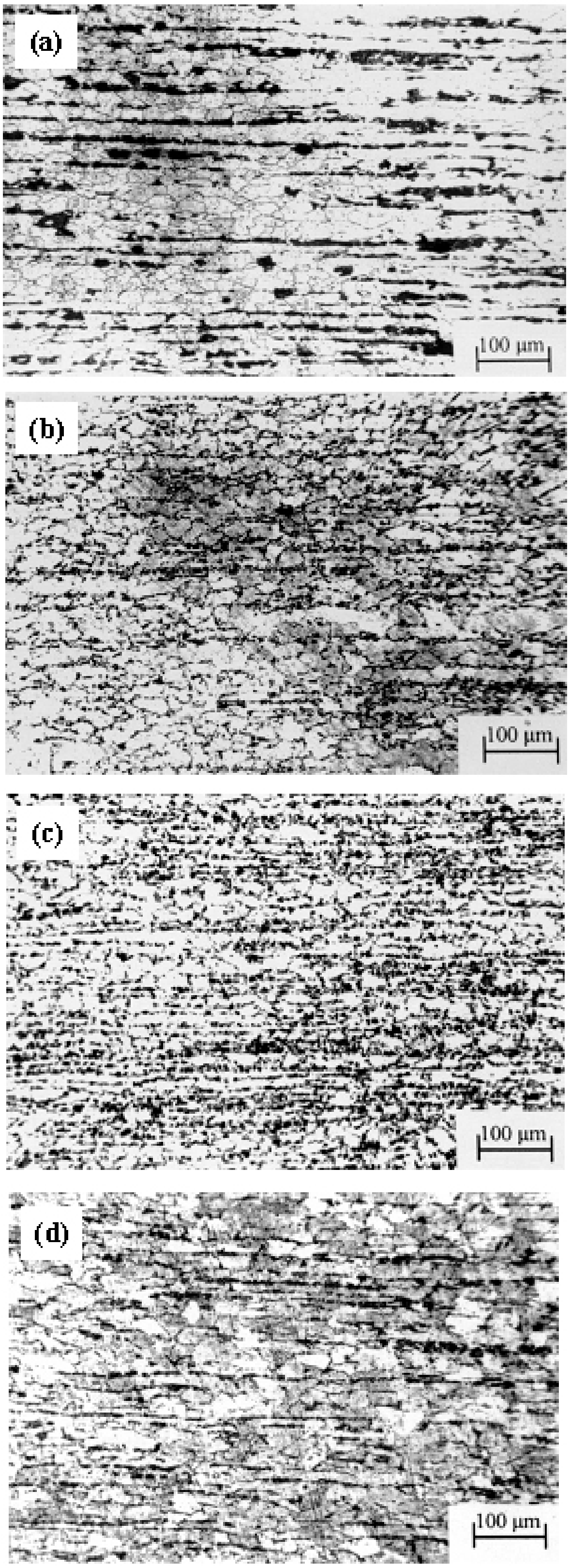

Figure 4. Microstructure of 0.15 % C steel after different soaking times at 600 º C: a - 10 min.; b – 30 min.; c – 3 h; d – 8 h.

For longer soaking time (5 … 8 hours), the globular aspect of the structure disappears and the ferritic grains grow very much (fig. 5d).

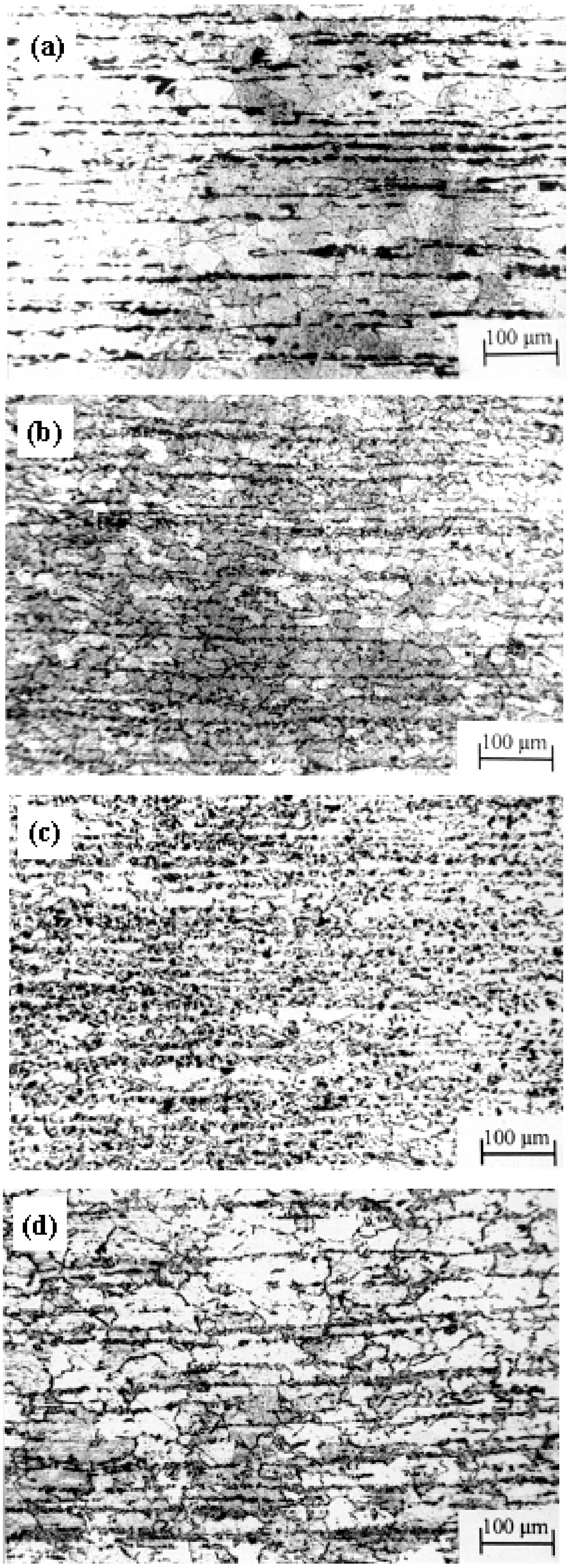

Figure 5. Microstructure of steel AISI 1015 after different soaking times at 650 º C: a - 5 min.; b – 30 min.; c – 3 h; d – 8 h. (optical microscopy)

This structure does not present a practical interest because the fine structure obtained by warm rolling is lost.

By SEM analysis it was found that after a soaking time of 30 minutes at 650^{o} C, the microstructure consists of recrystallised ferrite and pearlite grains containing globular cementite formations (figure 6a). Increasing the soaking time to 1 hour determines carbon diffusion at the ferrite grain boundaries and the precipitation of cementite (figure 6b). This process is completed after about 3 hours (figure 6c). The resulting structure can still be considered as finely grained and uniform.

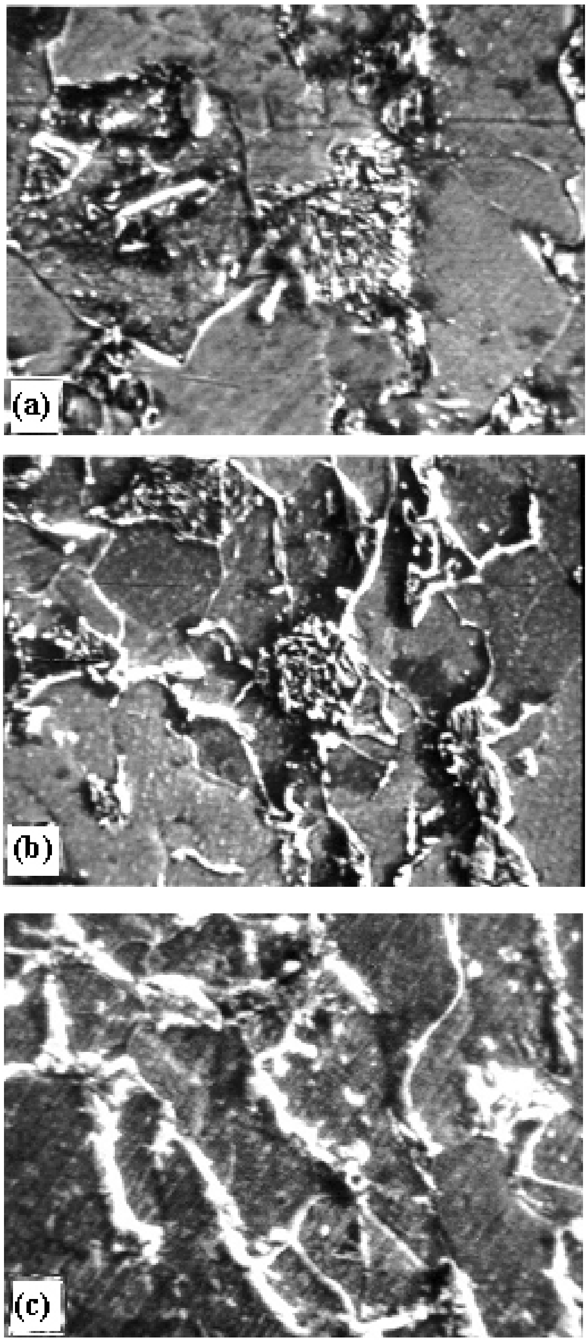

Figure 6. SEM micrographs of AISI 1015 steel after different soaking times at 650^{o}C: a - 30 min.; b – 1h; c – 2 h; d – 3 h (magnification 5000:1).

Figure 7 shows the variation of hardness with the heating temperature and soaking time. By heating the samples to 550^{o} C, the hardness decreases continuously with the soaking time. When samples are heated to 600^{o}C or 650^{o} C, in the first 30 minutes, the hardness decreases and then shows a small increase caused by the first stage of mass globulisation, which takes place for a soaking time of 1 to 2 hours. For longer soaking times, up to about 5 hours, the hardness decreases again and then the hardness is no longer affected in a sizable measure by the soaking time.

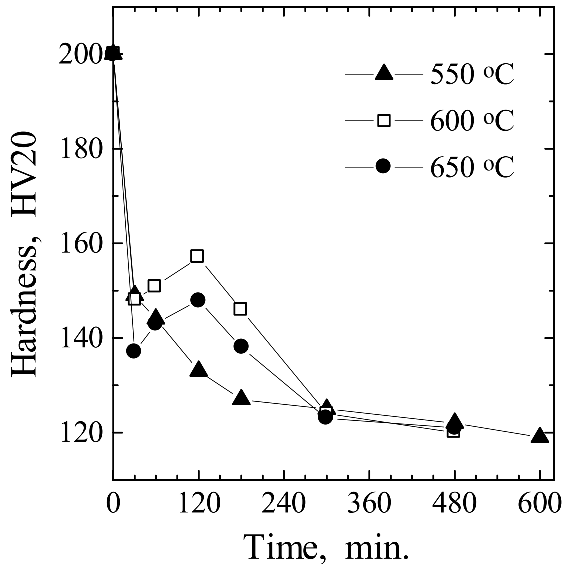

Figure 6. The influence of the temperature and the soaking time on the hardness of 0.15% C steel.

4. Conclusions

The experiments carried out on warm worked AISI 1015 carbon steel samples showed that if the samples are heated to 550^{o}C, the microstructure is completely recrystallised after a relatively short time (about 10 minutes). By increasing the soaking time, the size of the ferrite grains increases slowly, but even after 10 h the structure can be considered finely grained. Therefore, this steel, after warm rolling, can be subjected to a thermochemical treatment, such as nitriding, preserving the fine structure and improved mechanical properties of the core obtained by warm rolling.

By maintaining the samples at 600 ... 650^{o}C up to 30 minutes, the structure becomes fully recrystallised and the hardness decreases. At these temperatures, by a proper selection of the duration, it is possible to achieve an efficient stress relief of the warm worked steel without significant increase of the grain size.

A soaking time of 1 … 3 hours leads to the formation of a uniform, fine and globulised structure. The previously applied warm rolling shortens the time normally required for globulisation.

In conclusion, the warm rolling followed by a proper heat treatment can lead to new performances in processing of carbon steels.

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Modifications Microstructural pendant chauffer de Chaud a Roulé AISI 1015 Acier du Carbone

Résumé

Pour les applications industrielles, le fonctionnement chaud est très attirant dû à certains avantages offerts par ce processus de la difformité plastique. La chaleur qui traite d'aciers travaillés chauds peut mener à une amélioration considérable de leurs propriétés mécaniques.

Le papier présent l'influence du régime chaleur-traitant appliquée pour chauffer a roulé AISI 1015 aciers du carbone. Le rouler a été exécuté dans les conditions suivantes: température 670^0C. 550^0C, vitesse roulante 1.39 s^{-1} et difformité ratio 36.4 %. Après avoir roulé, les échantillons ont été réchauffés à 550^0, 600^0 et 650^0C pour une durée qui varie de quelques minutes à 10 heures. Les changements du microstructural ont été répartis par lumière et microscopie de l'électron et les traitements de la chaleur possibles a été considéré.