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The deformation analysis of 1008 steel at 0.01/s strain rate

N. Wolańska*, A.K. Lis
Institute of materials Engineering, Faculty of Materials Processing Technology and Applied Physics, Częstochowa University of Technology, Al. Armi Krajowej 19, 42-200 Częstochowa, Poland
* Corresponding author: E-mail address:npiwek@mim.pcz.czest.pl

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Properties

ABSTRACT

Purpose: The hot ductility investigations under strain rate 0.01/s were shown in this work.. The investigations were carried out on the low carbon-manganese steel 1008 with addition of boron.
Design/methodology/approach: The ductility of the steel was measured by reduction of area of fraction after the extension test in the temperature range from 700°C to 1200°C. The test was carried out with strain rates 0.01/s, which is characteristic for the continuous casting process. Samples of examined steel were divided to two origin regions of COS slab: columnar grains and equiaxial grains. The microstructures analysis were carried out on samples sectioned with tensile direction at fracture. The straightness of 1008 steel was also observed.
Findings: The received 40% and 23% ductility minimums of investigated steel for columnar and equiaxial grains respectively were found in the temperature range 800-950°C. These temperatures are connected with band straightening in the continues casting process. The ferrite-bainite and ferrite-pearlite microstructures after air cooling were observed. The straightness of investigated steel decreases with rising temperature.
Research limitations/implications:
Practical implications: The temperature of hot ductility minimum of investigated low carbon steel with addition of boron corresponds with straightening temperature of the strand, which is taken place close to 900°C during continuous casting process.
Originality/value: Available literature concerns investigations of low carbon steels but without boron addition, which expect to have strong influence on the position of the hot ductility minimum.
Keywords: Ductility; Hot ductility curves; True flow curves

1. Introduction

The investigations which described the steel characteristic are strongly connected with the technology of the hot working process. The fundamental researches of material with determined chemical composition and structure are carried out to assure the appropriate conditions of later technological processes. The yield point, the tensile strength, the elongation and the reduction of area values belong to the most important properties for the plastic working. The properties of the final product strongly depend on the structural changes during the thermo-mechanical treatment [1].

In the heavy industry the practical conventional continuous casting of steel a specially the straighten the strand operation is carried out at the high temperature and that temperature corresponds with the hot ductility minimum (>900^{o}C). All precautions are taken to edge cracking occurrence. Dynamic recrystallization cannot occur during straightening process. That is because the enhancement in ductility is much smaller then indicated by the normal tensile hot ductility curve where strains are much greater [2-8]. The minimum in the %RA-T curves can be used to characterize the ductility trough, what gives the possibility to compare the hot ductility of different continuous cast steels slabs, and may be used to predict the steel susceptibility to transverse cracking during continuous casting in practice [7-11].

2. Experimental

The tensile tests of the 1008 steel were performed using a Gleeble 3500 machine, which system is suitable to carry out high temperature tests. The cylindrical tensile samples of 10 mm in diameter and 120 mm length were heated to 1300°C with 20°C/s heating rate and soaked in this austenitizing temperature for 1 minute. Cooling to the test temperature in the range 700-1200°C was performed at a cooling rate of 10°C/s. The effect of deformation was investigated at 0.01/s strain rate, which is used during a continuous casting process. Finally, the test specimens were cooled in air. The deformation microstructures were characterized by optical microscopy to describe the effect of temperature on the deformed structure.

The investigations were carried out on the samples which were machined with their longitudinal axes parallel to the casting direction from the slab 105x105. The chemical composition of 1008 steel is given in Table 1. The examined low carbon steel has boron addition in amount of 50 ppm.

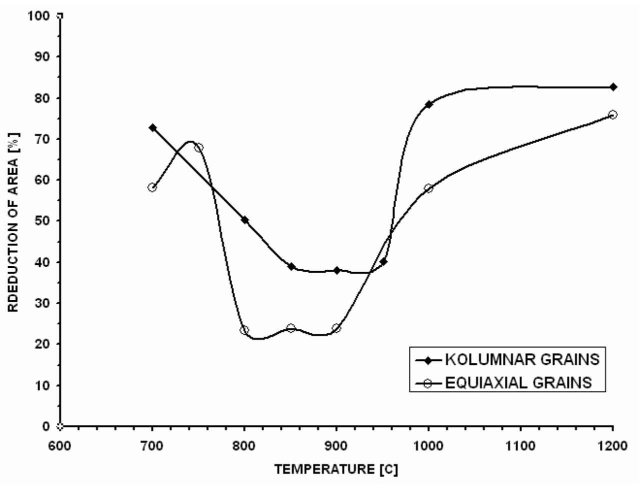

Fig. 1. The hot ductility curves

3. Results

3.1. Hot ductility curves

The effect of deformation was investigated at strain rates 0.01/s in two different kinds of samples. Samples of examined steel were divided to two origin regions of continuously cast slab: columnar grains and equiaxial grains The experimental data were plotted as the reduction of area at fracture in function of the temperature (Fig.1.). The %RA for the investigated steel tested at temperatures below 750°C is about 60-70% for both kinds of samples. As the temperature increases there is a rapid decrease in ductility to %RA values as low as 40% for samples with columnar grains and 20% for samples with equiaxial grains. Tensile testing at temperature greater than about 1000°C for both kinds of structure samples deformed with 0.01/s strain rate caused recovery of the ductility back to the high value about 70-80%. The loss of ductility at temperatures between 800 and 1000°C causes the %RA-T plots to exhibit a ductility trough.

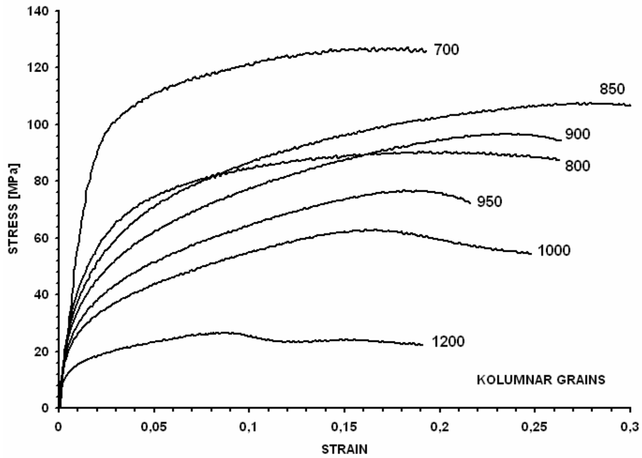

Fig. 2. True flow curves for columnar grained samples deformed with 0.01/s strain rate

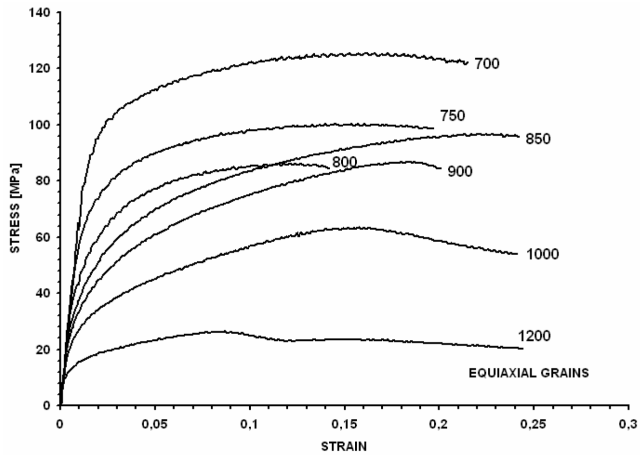

Fig. 3. True flow curves for equiaxial grained samples deformed with 0.01/s strain rate

3.2. True flow curves

On the base of the test described in experimental part, the true flow curves for each of samples of investigated steel with addition

Table 1.
The chemical composition of investigation steel [%]

C	Mn	Si	P	S	Al	N_2	B
0.08	0.46	0.1	0.013	0.016	0.003	0.009	0.005

of boron were plotted as the stress in function of the strain (Fig. 2, 3). As can be seen the value of the maximum stress is decreasing with rising temperature of experiment in both cases. Values of the maximum stresses for each samples from columnar and equiaxial grains deformed at individual temperature are similar. Moreover the shape of the flow curves for each temperature is similar too.

From the shape of true flow curves the kind of restoration process can be deduced. And for samples deformed at 700-800°C the recovery process can be seen. For samples deformed at 1000-1200°C the recrystalization process can be observed.

3.3. Microstructure

The deformation microstructures were characterized by optical microscopy and were taken from the neck of the sample close to the failure. Structures after deformation are shown in Figures 4-6.

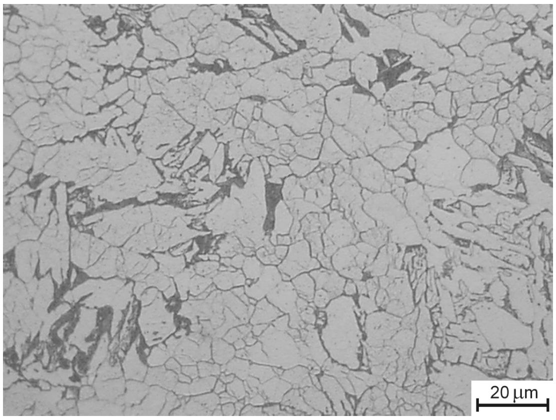

Fig. 4. Microstructure of a sample deformed at 800°C

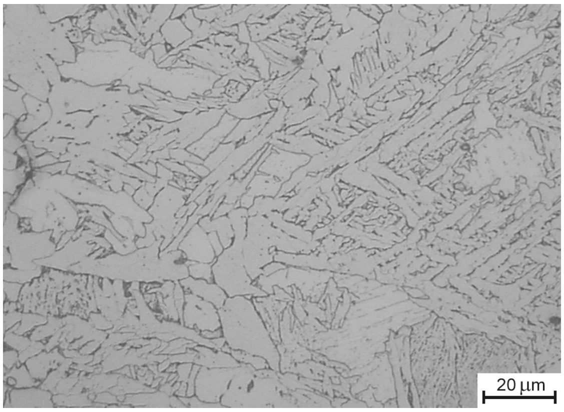

Fig. 5. Microstructure of a sample deformed at 900°C

The structure in the Figure 4 consist of pearlite- ferrite grains mainly on the deformed prior austenite grains boundaries. In the space between the ferrite-pearlite structure the bainite grains can be seen. In the Figure 5 the structure consists of Widmanstätten ferrite on the prior austenite grain boundaries and bainite with acicular ferrite inside. In the Figure 6 the structure consists of Widmanstätten ferrite and acicular ferrite. The needles of ferrite are much longer and slimmer because they were formed inside austenite grains which have grown after dynamic recrystallization. High hot ductility at temperature above 1000°C is due to decrease in boron segregation at austenite grain boundaries and easier commencement of dynamic recrystallization process and grain growth.

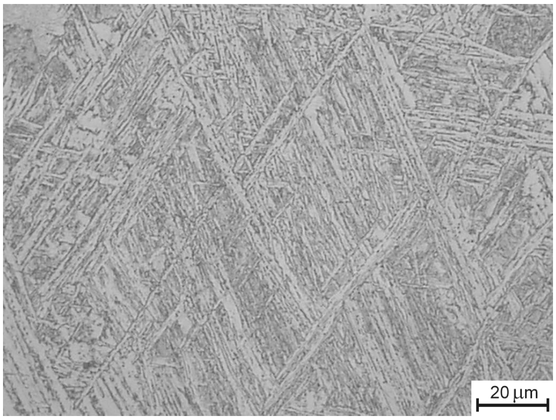

Fig. 6. Microstructure of a sample deformed at 1200°C

4. Discussion

The microstructure in the sample neck depends on the test temperature and the strain rate of deformation. During deformation with the low strain rate at temperatures >1000°C the ductility is very high, in accordance with the observation that dynamic recrystalization of the austenite has occurred. Dynamic recrystalization can be deduced from the flow curves (Fig. 2, 3), in which the onset of dynamic recrystallization can be detected at peak in stress. The ductility grows with temperature in this range and the microstructure is made of very long needle-shaped ferrite grains (Fig.6). That is because of austenite grain growth after dynamic recrystallization of austenite. When the dynamic recrystallization appears, the ductility of steel rises up, because each time the critical strain is reached, the grain boundaries on which cracking is taking place, are eliminated and new boundaries of different orientations are formed, so the stress concentration at the crack tip is eliminated. Due to boron carbide dissolution at high deformation temperature the segregation effect of boron is also diminished.

In the minimum of the hot ductility the segregation of boron to the austenite grain boundaries is enhanced what is observed at 950°C - 900°C. The ductility is however very poor. The fracture mode is intergranular, with the cracks propagating along the austenite grain boundaries. In the hot ductility minimum the microstructure is changed to the Widmanstätten ferrite on the prior austenite grain boundaries and bainite with acicular ferrite inside (Fig. 5) [2-5, 12-15]. H. Treppschuh et al [16] also discovered the tendency of boron to become concentrated at austenite grain boundaries. In our case for columnar dendritic grains due to the segregation effect of boron, the formation of an iron-boron- carbon eutectics may be one of the reasons ductility through at temperature 850 – 950°C. For equiaxial grains only solute drag effect by boron on the grain boundaries of primary austenite and boron–carbide precipitation are responsible for minimum hot ductility at 800- 900°C. That temperature range is suitable for advanced precipitation of boron carbides furtherer decreasing hot ductility. This requires transmission electron microscopy investigation which is going to be done in the nearest future. The confirmation of that assumption is based on the high flow stress at strains up to 0.1 strain at temperature 800-850°C which may arise from dislocations interaction with carbides– Fig.2 and Fig.3. Further increase of flow stress at 750°C and 700°C is due to existence of non recrystallised austenite and dynamically recovered ferrite in the structure while reduction of the area is increased once again to around 60-70% for both grain morphologies.

At deformation temperature above 1000°C dissolution of boron-carbides occurs, so higher deformation temperature 1200°C results in a coarsening of the primary austenite grains and therefore microstructure as shown on Figure 6 was observed.

At lower temperature only dynamic recovery is taking place (700°C and 800°C) and there is ferrite phase present in the structure during deformation. The ductility rises up with volume fraction of ferrite.

From all flow curves it could be concluded that the strain and stress decreased as the temperature is raised and properties like ultimate tensile strength and yield strength decreased with temperature.

Fracture in hot working steels, as a result of the tensile stress, are caused by the nucleation of intergranular cracks by grain boundaries sliding and their coalescence. At low stresses cracks initiate at grain boundary ledges but at high stresses or strain rates they occur at triple junction. For ferrite the ductility increases with the temperature because of the dependence of recovery what interfered with the crack nucleation process [2-6].

5. Conclusions

It was found that the hot ductility minimum of low carbon steel containing boron for strain rates 0.01/s is dependent on primary austenite morphology.

It was established that hot ductility through is in the temperature range 850-950°C for columnar grains and 800-900°C for samples from equiaxial grains.

That range of ductility minimum correspond to the solute drag effect of boron to austenite grain boundaries and probable boron carbide precipitation processes.

At temperature range of coexistence of two phases ferrite and austenite hot ductility is improved.

The carried out investigations can be used to proper designing of plastic working processes in the range of deformation temperature selection.

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