POLISH ACADEMY OF SCIENCES - COMMITTEE OF MATERIALS SCIENCE
SILESIAN UNIVERSITY OF TECHNOLOGY OF GLIWICE
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS
ASSOCIATION OF ALUMNI OF SILESIAN UNIVERSITY OF TECHNOLOGY

Conference Proceedings

12th INTERNATIONAL SCIENTIFIC CONFERENCE
ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

Quality analysis of the continuously cast billet structure and the mechanical properties of the wire rod C20D steel

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The research presented in the article has been aimed at determining the effect of boron addition on the mechanical properties and the structure of the low-carbon steel, C20D grade, during the manufacturing process. The correlation between the tensile properties and the steel hardness as the criterion of its final quality acceptance has been proposed. The effect of dispersed inclusions on the grain refinement has been observed and discussed.

1. INTRODUCTION

One of the steel used for the production of wire rods designated for further cold plastic working is C20D (1021) grade with the addition of boron in the amount of 30÷70 ppm. The advantage of adding boron to the chemical composition of steel is, that it strengthens the austenite solid solution during hot rolling less than other alloying elements, that effects on the increase of the hardenability such as Cr, Mn, Mo, Ni. Thus, it enables the comparatively easy hot and cold plastic working of the steel. The microadditions of boron can have similar influence on the improvement of the hardening capacity as other, more expensive alloying elements, which otherwise have to be added in larger amounts [1-3]. The maximum increase in hardness is already obtained with the boron content at ca.10 ppm as dissolved in ferrite solution. According to the other authors, the increase in the boron content to up to about 30 ppm significantly increases the steel hardenability. With further increase to 70 ppm of B, the hardenability value parameter increases only slightly more [4]. Boron has a very strong affinity to oxygen and nitrogen and forms boron oxides with oxygen, which are stable at low temperatures. Boron exists in all possible non-metallic oxide inclusions present in steels. These inclusions are usually placed in the interdendrite areas [5,6], what will also be presented in the paper.

2. INVESTIGATED MATERIAL

The chemical composition of killed low carbon steel C20D (1021B) was selected according to ASTM A510M and PN EN 10016-2. The samples were taken from the square 105 mm cast billets. After reheating they were controlled rolled into wire rods of 5.5 mm in diameter.

3. DISCUSSION ON THE QUALITY ASSESSMENT OF CONTINUOUSLY CAST INGOT STRUCTURE

Metalographic investigations were performed on specimens taken from the ingot which became damaged during the continuous casting process. Figure 1 presents the surface areas of the ingot structure with exterior cracks. The oxidized surface area containing scale layer and the ferrite-pearlite structure has been shown in figure 1a. In figure 1b the effect of graphite nodules on the microstructure changes i.e. the Widmanstätten formations and pearlite can be seen. The particle is a residual graphite nodule, which has not been dissolved completely in the steel matrix, probably in austenite before the occurrence of the transformation of austenite to ferrite. In the steel-making process the graphite powder was used in the insulating mixture which was applied on the top of molten steel. In between the coarse regions of Widmanstätten ferrite the effect of the ferrite-pearlite microstructure modification with very small, dispersed graphite powder and non-metallic inclusions can be seen in figure 2.

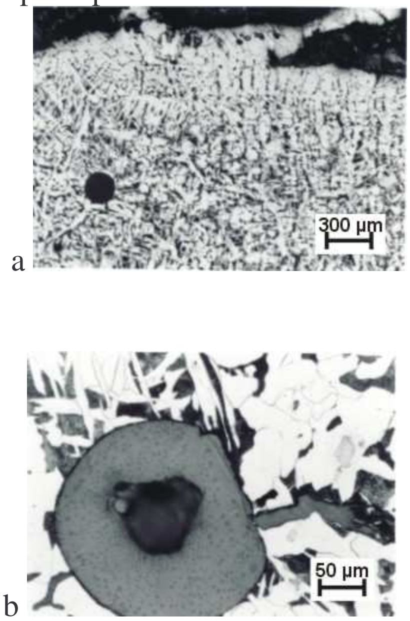

Figure 1. Microstructure of the continuously cast ingot surface layer

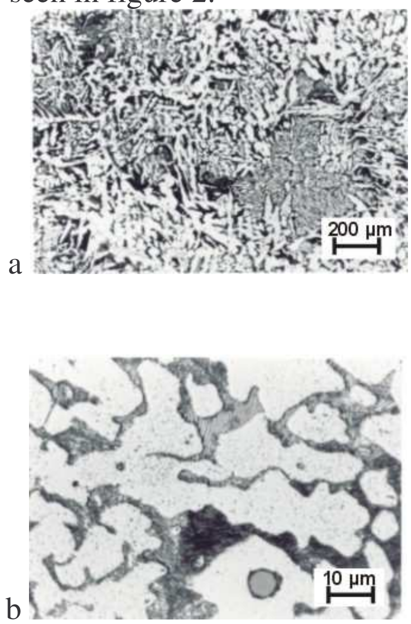

Figure 2. Interior microstructure of the continuously cast ingot

Recently, investigations of the desulfurization and dephosphorization processes of molten steel with refining slag containing CaO, MgO, SiO_2, Al_2O_3, Fe_2O_3 have been carried out. The introduction of graphite powder in the amount of 8÷12 % weight mass of the refining slag permitted of large dispersion of non-metallic inclusions occurrence in molten steel. Moreover, the addition of boron to steel in the amount of 70 ppm contributes to deep steel deoxidization. In addition, boron produces through oxides and boron nitrides with manganese sulfides an effect on the acceleration of austenite transformations into polygonal and acicular ferrite, formation inside the austenite grains.

In the opinion of Saito and DeArdo [7], the presence of particles of 0.2μm in diameter is the basis for a creation ferrite fine-grained microstructure of the grain size 7μm. While the heterogeneous nucleation of polygonal ferrite on prior austenite grain boundaries of the size

200μm and bigger and on the large inclusions greater than 2μm leads to the formation of ferrite grains of a diameter about 40μm following the $\gamma \rightarrow \alpha$ transformation during cooling at the rate of 0.08 K/s. This type of steel technology does not cause an intensive growth in the steel hardenability. On the contrary, it is aimed at obtaining more fine-grained microstructure of the C20D steel and the microalloyed steels, than the one obtained in the controlled rolling process. The scanning electron microscopy of the ingot structure has shown the occurrence of many oxide and sulfide inclusions. Also, the occurrence of boron oxide in the interdendrite area (figure 3) has been observed, identified together with SiC and (FeMn)S during the spectral linear quality analyses.

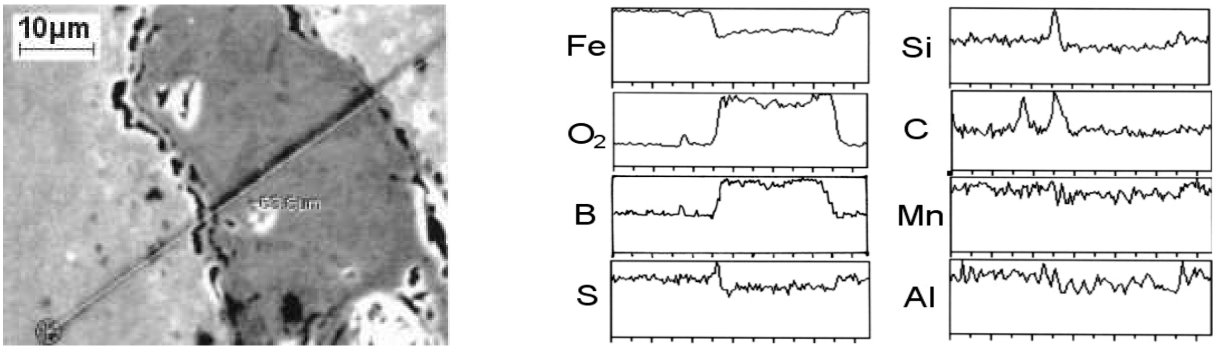

Figure 3. Spectral quality analyses of boron oxide, silicon carbides and manganese sulfides.

4.DISCUSSION ON THE RESULTS OF MICROSTRUCTURE INVESTIGATION AND THE WIRE ROD MECHANICAL PROPERTIES

The microscope analysis has evidenced the influence of the steel processing technology used on the creation in the wire rod a uniform ferrite-pearlite structure of the fine-grain size No. 9-10 according to the standard [9]. The bainite islands, the Widmanstätten ferrite and the bainite ferrite in the form of needles were also observed.

The results of the static tensile test and the hardness measurement helped to determine the average values of the YS, UTS, El and HV properties of C20D steel, which were respectively: 371.5 MPa, 523 MPa, 36.5 %, 173 HV5. The linear regression equations of the strength properties in the hardness function have been established in order to forecast the final product properties only on the basis of the hardness measurement conducted by means of the Vickers method. The linear relationships between the tensile properties and hardness have been presented in Table 1. The hardness distribution of C20D steel was measured on all Ø 5.5 mm rods of all investigated casts. In accordance with the factory standard [8], C20D steel should have the following strength properties: YS_{min}=350 MPa, UTS=490÷540 MPa, elongation El_{min}= 25%. The appropriate minimum and maximum hardness were calculated using the regression equations, and equal respectively: HV_{min}=151 for YS, HV=142÷189 for UTS and HV_{max}=242 for El. It has been stated that the distribution of the average hardness values is placed between the defined boundaries for individual properties. The received range of expected hardnesses is very wide and this is the reason why it cannot be considered to be a good determinant of the final product quality.

On the analysis of the results of the strength properties changes with the boron content in [ppm] a conclusion can be made, that the effectiveness of boron as an element which increases the strength of C20D steel by increasing its hardenability has been decided by the balance with nitrogen. The increase in the boron content from 40 to 70 ppm in the C20D steel cast has also been accompanied by the increase in the nitrogen content from 70 to 100 ppm and probably in oxygen, which resulted in the limitation of the boron influence on hardenability. Due to the affirmed occurrence of boron oxides and probably the baron nitrides the nucleation process of the δ–ferrite and austenite grains during the crystallization has been intensified. These second-phased dispersal particles, together with the graphite microparticles intensify the heterogeneous nucleation of ferrite during the $\gamma \rightarrow \alpha$ transformation. Thereby, the fine-grained ferrite-pearlite structure of continuously cast ingot is received after its solidification and cooling to ambient temperature.

Table 1
Correlation equations between the tensile properties of C20D (1021) steel and hardness HV5

Properties	Equation	Matching
YS – HV	YS = 201.805 + 0.981 HV	linear
UTS – HV	UTS = 331.596 + 1.107 HV	linear
El – HV	El = 65.011 – 0.165 HV	linear

5. ASCERTAINMENTS AND CONCLUSIONS

Generally, the linear correlation of tensile properties YS and UTS and El with change of the wire rod hardness has been ascertained for each of investigated rods.

Despite of the correlation between the mechanical properties and the hardness results found we consider that the measurement of the rod hardness cannot be a final acceptance criterion of the C20D (1021) wire rod quality.

A strong influence of the graphite powder and the dispersed non-metallic inclusions has been observed (including the manganese sulfides) on the modification of steel microstructure in the process of the continuously cast ingot crystallization towards the grain refinement.

The presence of non-metallic inclusions, mostly oxides, sulfides and the nodular graphite particles of high dispersion have been ascertained, which can also influence the grain refinement of the wire rod ferrite-pearlite structure.

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