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Properties of a Nb-V-Ti microalloyed steel influenced by cold rolling and annealing

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Properties

ABSTRACT

Purpose: was to investigate impact of cold forming and annealing on microstructural and mechanical properties of HSLA steel.
Design/methodology/approach: Testing of Nb-V-Ti microalloyed strip steel was based on a combination of cold rolling, recrystallization annealing, mechanical testing, metallography and TEM.
Findings: It was confirmed that by a suitable combination of size of previous cold reduction size and parameters of the following annealing it is possible to influence considerably a complex of mechanical properties of particular strips. Strength as well as plastic properties depended on the course of recrystallization and precipitates' coarsening during annealing.
Research limitations/implications: The experiment should be supplemented by the more detailed analyses of microstructure.
Practical implications: The results may be utilized for optimization of terms of heat treatment in a cold rolling mill, especially in accordance with specific requirements for a relation between plastic and strength properties of the investigated steel.
Originality/value: Research possibilities of VSB-TUO in the sphere of cold rolling of Nb-V-Ti HSLA steel were introduced in combination with the complex approach to processing of the obtained results.
Keywords: Mechanical properties; Cold rolling HSLA steel; Annealing- recrystallization; Microstructure- TEM

1. Introduction

Cold forming significantly influences structure and resulting material properties because in the given terms no recrystallization can occur. A gradual extension of grains in the direction of the principal deformation occurs and a deformation, structural as well as crystallographic texture arises, which causes a directional character of mechanical properties [1]. Heat treatment is included after cold rolling for removal of anisotropy of properties.

To factors influencing the resulting character of microstructure after annealing belong above all: the total reduction in cold rolling, temperature and time of annealing, cooling speed, but also the initial character of material structure before cold rolling [2-8]. Strength properties of material fall with increasing temperature of annealing, whereas plastic properties rise. Significant lowering of strength or hardness values occurs at temperatures which are close to 600 °C [9, 10]. The material properties reflect in principle the microstructure. From the viewpoint of service properties it is desirable optimum size of recrystallized grains after annealing, which will ensure favourable strength and plastic characteristics.

2. Experimental works

An intention of the performed experiment consisted both in studying influence of the annealing mode on mechanical properties of a Nb-V-Ti microalloyed strip steel and at the same time in describing mathematically stress-strain curves after cold rolling. Chemical composition of the tested steel in wt. % was as follows: 0.081 C – 1.36 Mn – 0.19 Si – 0.018 P – 0.008 S – 0.022 Al – 0.067 Nb – 0.033 V – 0.030 Ti – 0.0053 N.

Samples of pickled cuts of hot rolled strip of thickness 3.9 mm were used for cold processing. In the first stage of the experiment, the aim of which was to express effect of cold deformation or annealing mode on mechanical properties, the samples of strips with dimensions 3.9 x 25 x 500 mm underwent a total draught 5 % to 75 % during a multi-pass rolling. Annealing performed in a laboratory vacuum resistance furnace [11] by one of three of modes stated below followed (see Fig. 1). All annealing modes were realised in a protective atmosphere, consisting of a mixture of 90 % nitrogen and 10 % hydrogen.

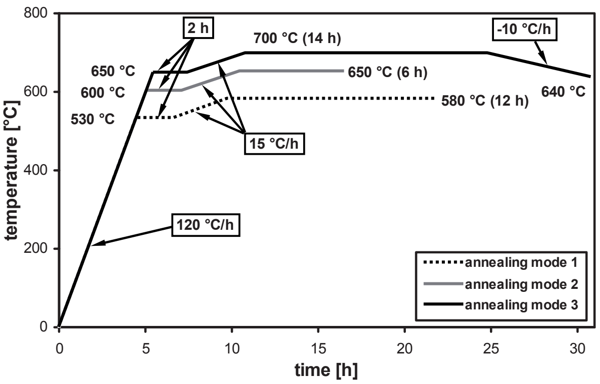

Fig. 1. Parameters of particular annealing modes

The aim of the second part of the experiment was to describe mathematically stress-strain curves. The initial state in this case was a state after hot rolling or a state after 50 % cold reduction and annealing by mode 2 mentioned above. In both cases the samples underwent a relative height reduction of 5 to 70 %. Particular partial reductions for both stages of the experiment were realised at the room temperature in the housingless hydraulically pre-stressed laboratory mill stand Q110 [11, 12].

The annealed samples (of the first part of the experiment) were subjected to tensile test at room temperature and hardness test according to Brinell (a ball with diameter of 2.5 mm was forced into the tested material with force of 1.84 kN) for determination of mechanical properties. The achieved results, i.e. hardness HB, yield stress YS [MPa], tensile strength TS [MPa] and the ratio of yield stress and tensile strength, expressed similarly as elongation A80 in %, were summarized by means of graphs in Figs. 2 – 4 in relation to the cold reduction size before annealing – ε [%]. The points plotted in an appropriate coordinate system were interpolated by curves „manually“, without any exact mathematical rules.

Mechanical properties were determined also for samples that were selected for finding out stress-strain curves. In this case the tensile test was quite sufficient to use. The values of yield stress YS [MPa] corresponding to various values of actual height reduction e_h, were interpolated by a power relationship (with regard to a physical character of the investigated process) in such a way that the obtained equation describing deformation hardening corresponded an analysis of the stress-strain curve by Hollomon [13].

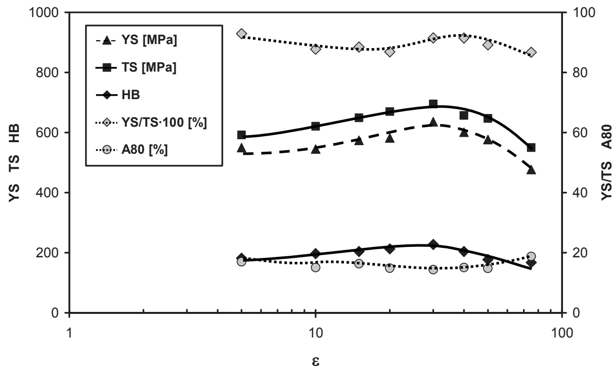

Fig. 2. Mechanical properties of samples annealed by mode 1

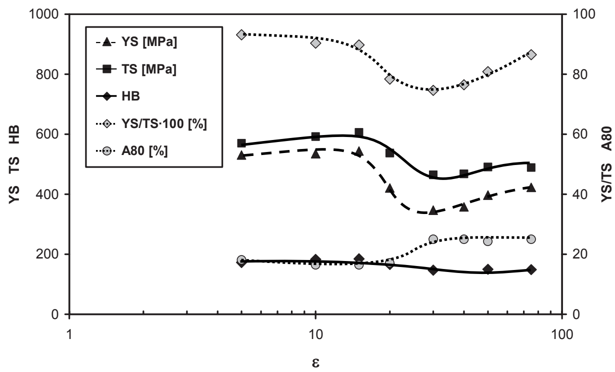

Fig. 3. Mechanical properties of samples annealed by mode 2

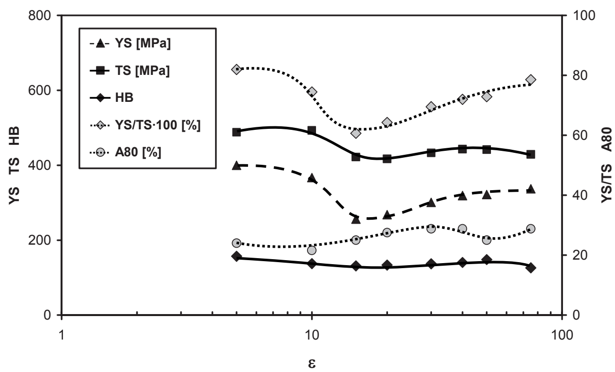

Fig. 4. Mechanical properties of samples annealed by mode 3

Samples for evaluation of structure by optical microscopy were taken from central parts of rolled out products (in a perpendicular section, parallel with the direction of rolling). The structure was evaluated with selected samples after annealing, but for comparison also with the initial – non-cold deformed sample

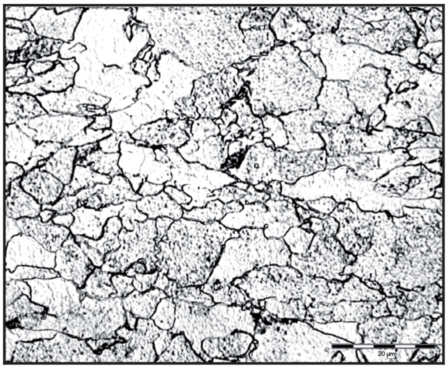

Fig. 5. Annealing mode 1, deformation 5 %

Fig. 6. Annealing mode 1, deformation 30 %

Fig. 7. Annealing mode 2, deformation 15 %

Fig. 8. Annealing mode 2, deformation 30 %

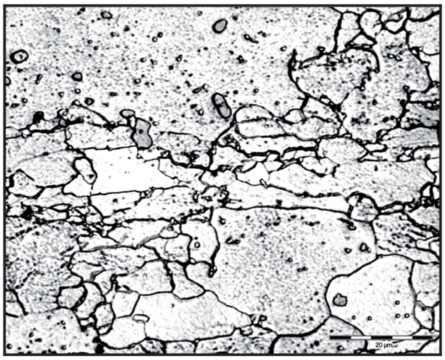

Fig. 9. Annealing mode 3, deformation 15 %

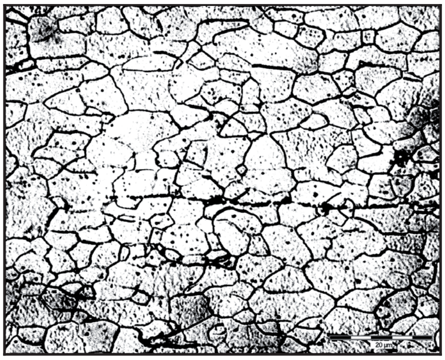

Fig. 10. Annealing mode 3, deformation 75 %

Microstructure of the chosen annealed samples can be seen in Figs. 5 – 10. All samples have essentially structure created by ferrite with low content of pearlite, a character of which (extent of spheroidizing) and region of occurrence depend on parameters of deformation and annealing.

3. Discussion of results

Annealing mode 1 (Fig. 2) is featured by a slow increase of strength properties with rising strain up to the value of $\varepsilon = 30$ %; after reaching this value a relative steep drop follows, which is caused by the course of recrystallization (Figs. 5, 6). Plastic properties (elongation and YS/TS ratio) were relatively less influenced by the previous deformation and they are worse than in case of other annealing modes.

Annealing mode 2 (Fig. 3) exhibits the most complicated course of mechanical properties because a slow rise of yield stress and tensile strength is followed by a steep drop of these properties after previous strains 20 % to 40 % (Figs. 7, 8). The reason is uneven coarsening of recrystallized grains. For strains above 40 % a rise of described properties occurs again. The trend of plastic properties is not so complicated.

In the case of annealing mode 3 (Fig. 4) a pronounced minimum of yield stress and ratio YS/TS is visible, together with maximum of elongation after deformation 15 %, which is due to abnormal coarsening of the recrystallized structure (Figs. 9, 10). Remarkable is a pronounced steeper drop and rise of yield stress in comparison to tensile strength, which is clear documented by the YS/TS ratio of these variables in the graph. Strength properties achieved by this mode of annealing are the lowest ones and, on the contrary, plastic properties (mainly after deformations around 15 %) the best ones, which is not surprising with regard to a high annealing temperature.

In case of annealing by the mode 2 first results were obtained from TEM analysis of chosen samples. By means of them it is possible to explain a significant fall of strength properties after the previous cold deformation with size of ca 30 %. Two types of precipitates exist in the steel. Relatively large particles (Ti,Nb)(C,N), formed already during solidification, did not exhibit any change in dependence on conditions of the following processing [14]. On the other side, very fine particles (V,Nb)(C,N) with size of the order of 10^1 nm, which were formed during hot rolling of strip and its cooling from the finishing temperature, changed their shape and size in annealing in dependence on size of the previous cold deformation. The increasing deformation meant the increase in constraining force for coarsening of these particles and at the same time for their change into the shape of short sticks. Coarsening of particles resulted in decrease of precipitation hardening, which resulted in fall of strength properties of the investigated steel [14, 15].

Trends of particular curves in all graphs reflect well the known relation between strength and plastic properties. Formability rises and vice versa strength properties fall with an increasing temperature of recrystallization annealing.

Equations describing deformation hardening of the investigated steel according to Hollomon were developed by means of a regression analysis. Two different characteristics of the initial state were assumed. The values of yield stress YS [MPa], gained by the tensile test, were related to previous logarithmic height strain e_h. The equation $YS = 877 \cdot e_h^{0.134}$ was derived for the state corresponding to hot rolling, whereas the equation $YS = 750 \cdot e_h^{0.190}$ was derived for the state after cold height reduction of 50 % and annealing by the mode 2. It is possible to state that intensity of deformation hardening makes no significant difference for both initial states and strains $e_h > 0.2$. Of course, the applied annealing mode after previous cold deformation of 50 % resulted in a pertinent decrease in strength properties.

4. Conclusions

Effect of the cold reduction size, together with various mode of heat treatment, on mechanical properties and the process of strain hardening, the character of which had been influenced by previous processing, of the investigated HSLA steel was studied. The experiment proved that by a suitable combination of reduction size and annealing mode it is possible to influence to a great extent the complex of mechanical properties of the studied steel.

Changes of strength and plastic properties were related to the course of recrystallization processes and to coarsening of precipitates during annealing after cold rolling.

Equations describing deformation hardening of the material were mathematically expressed, namely of yield stress in dependence on the height cold reduction in case of various initial states of the material.

Both phases of the experiment brought interesting pieces of information, the practical use of whose can be seen in optimization of conditions of rolling or heat treatment of the given steel in cold rolling mills, with the aim to obtain the desired complex of mechanical plastic and strength properties of the material.

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