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Influence of cold rolling and annealing on mechanical properties of steel QStE 420

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Properties

ABSTRACT

Purpose: was to investigate impact of cold reduction size and annealing on mechanical properties of HSLA steel.
Design/methodology/approach: Testing of strip steel QStE 420 was based on a combination of cold rolling, recrystallization annealing, mechanical testing and metallographic analyses.
Findings: It was confirmed that by a suitable combination of size of previous cold deformation and parameters of the following annealing it is possible to influence considerably a complex of mechanical properties of particular strips. Strength properties were more or less decreasing with the rising annealing temperature, whereas plastic properties were increasing.
Research limitations/implications: The experiment should be supplemented by additional modes of soft- and recrystallization annealing.
Practical implications: The results may be utilized for optimization of terms of heat treatment in a cold rolling mill, exactly in accordance with specific requirements for a relation between plastic and strength properties of the investigated material.
Originality/value: Research possibilities of VSB-TUO in the sphere of cold rolling were introduced for the first time.
Keywords: Mechanical properties; HSLA steel strip; Cold rolling; Recrystallization annealing

1. Introduction

Cold rolling 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 the arrangement of crystallographic lattice gains a directional character. Due to influence of deformation also a banding character of other structural phases has been developed, such as of inclusions, perlitic blocks, etc. A deformation, structural and crystallographic texture arises, which causes a directional character of mechanical properties [1]. As this phenomenon is mostly undesirable a 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, conditions of annealing (temperature, time), cooling speed, but also the initial character of material structure before cold rolling [2-6]. In this field of processing more and more new progressive types of material has currently been used, e.g. [7-11]. Generally – the more deformation of material before annealing, the lower initial temperature of recrystallization. At low temperatures the time needed for finishing of recrystallization is considerably higher and the required spheroidizing of carbides cannot be attained [12]. 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. Here the following is valid: The higher is the previous cold reduction, the more significant this fall is [12, 13]. 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.

The aim of this work was to investigate impact of various cold reduction size in combination with three modes of recrystallization annealing on mechanical properties of steel QStE 420.

2. Experiment

The initial material was in the form of pickled cuts of hot rolled strip with thickness 4.1 mm. Chemical composition of steel was as follows: 0.079 C – 0.85 Mn – 0.006 Si – 0.011 P – 0.006 S – 0.039 Al – 0.003 V – 0.002 Ti – 0.04 Nb – 0.003 N (wt. %). Samples in the form of stripes with dimensions 4.1 x 25 x 500 mm were rolled in several passes with total height reduction 5 to 75 %. Particular partial strains were realized at room temperature in the housingless, hydraulically prestressed laboratory mill Q110 (a four-high mill with work rolls of diameter 62 mm) [14, 15].

Annealing with one of three lower mentioned modes followed. It was carried out in a laboratory vacuum resistance furnace in the protective atmosphere consisting of 90 % of nitrogen and 10 % of hydrogen. Parameters of particular annealing modes are shown in Table 1. They may be described in a following system: speed of temperature increase up to an intermediate dwell // temperature of the intermediate dwell // time of intermediate dwell // speed of slow temperature increase // temperature of the dwell // time of dwell // speed of controlled cooling // temperature for finishing of controlled cooling.

Table 1.
Description of applied annealing modes

Mode 1	120 °C/h // 530 °C // 2 h // 15 °C/h // 580 °C // 12 h // – // –
Mode 2	120 °C/h // 600 °C // 2 h // 15 °C/h // 650 °C // 6 h // – // –
Mode 3	120 °C/h // 650 °C // 2 h // 15 °C/h // 700 °C // 14 h // -10 °C/h // 640 °C

The annealed samples underwent the tensile test at the room temperature and the Brinell hardness test (a ball of diameter 2.5 mm). The gained results – hardness HB, yield stress YS [MPa], tensile strength TS [MPa] and their ratio, as well as elongation A_{80} in %, were summarized in graphs in Figs. 1-3 in dependence on cold deformation (i.e. relative height reduction) before annealing – ε [%]. The found out points were plotted in a coordinate system and the corresponding curves were constructed „in a manual way“, without any exact mathematical rules.

3. Metallographic analysis

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. From Fig. 4 may be seen that structure after hot rolling was created almost exclusively by ferrite, with a minor occurrence of pearlite and very fine grains (a number of ferritic grain size G = 12-13). Nevertheless, not all ferritic grains were equiaxed.

Microstructure of the chosen annealed samples can be seen in Figs. 5-11. 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.

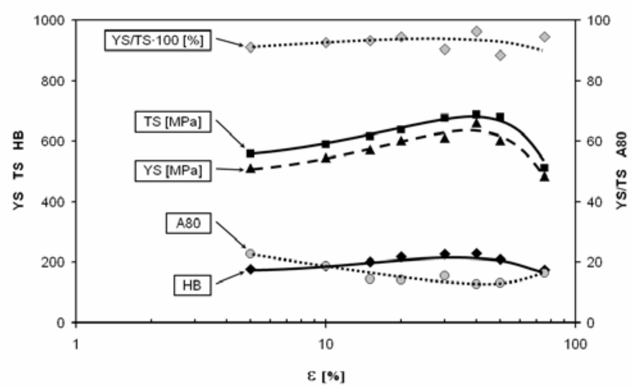

Fig. 1. Mechanical properties of samples annealed by mode 1

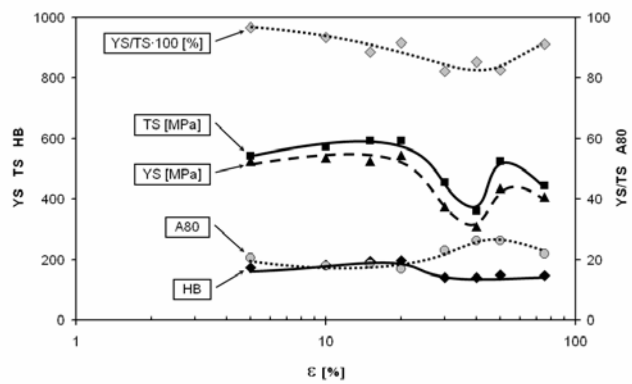

Fig. 2. Mechanical properties of samples annealed by mode 2

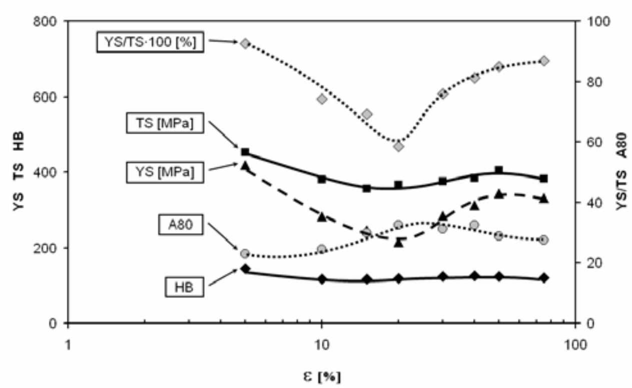

Fig. 3. Mechanical properties of samples annealed by mode 3

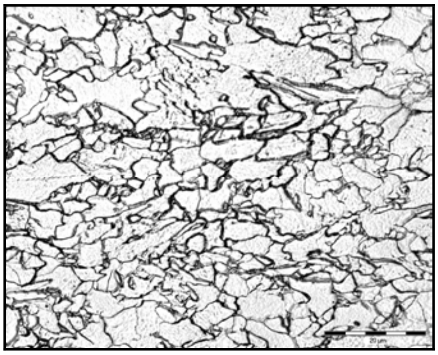

Fig. 4. Microstructure after hot rolling

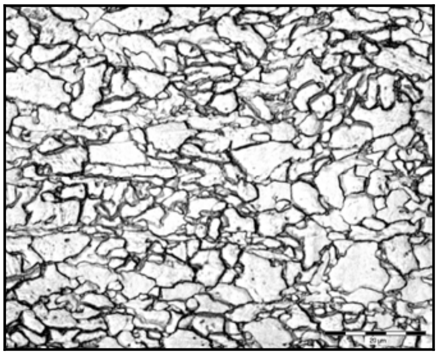

Fig. 5. Annealing mode 1, deformation 5 %

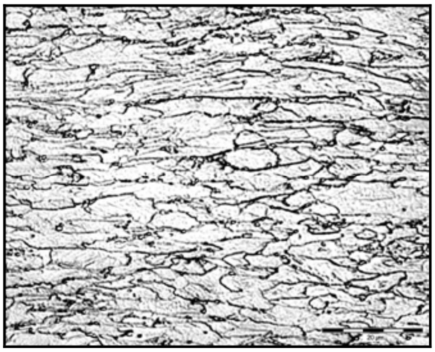

Fig. 6. Annealing mode 1, deformation 40 %

Fig. 7. Annealing mode 2, deformation 20 %

Fig. 8. Annealing mode 2, deformation 40 %

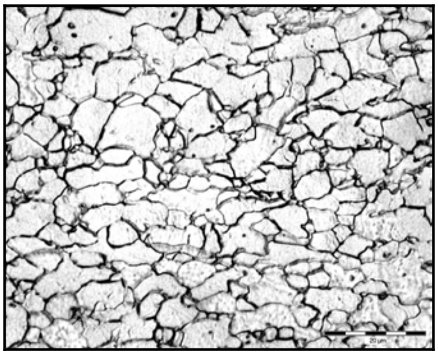

Fig. 9. Annealing mode 3, deformation 5 %

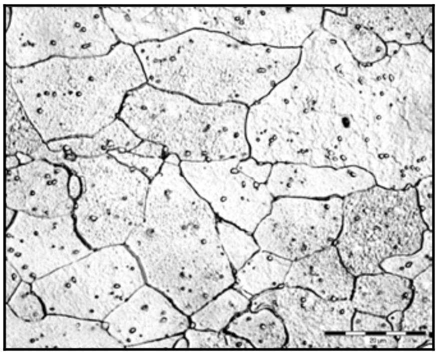

Fig. 10. Annealing mode 3, deformation 20 %

Fig. 11. Annealing mode 3, deformation 75 %

4. Discussion of results

Annealing mode 1 (Fig. 1) is featured by a slow increase of strength properties with rising strain up to the value of $\varepsilon = 40$ %; 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. 2) 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 a pronounced minimum of yield stress and ratio YS/TS is visible, together with maximum of elongation after deformation 20 %, which is due to abnormal coarsening of the recrystallized structure (Figs. 9-11). 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 20 %) the best ones, which is not surprising with regard to a high annealing temperature.

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.

5. Conclusions

By the described way it is possible to homogenize microstructure of strip and gain a major share of equiaxed grains of ferrite, but an average size of resulting grains is by no means significantly smaller than that one after hot rolling. It was confirmed that by a suitable combination of size of previous cold deformation and parameters of the following recrystallization annealing it is possible to influence (with a certain aim) a complex of mechanical properties of particular strips. Strength properties of material were more or less decreasing with the rising annealing temperature, whereas plastic properties were increasing.

With regard to the fact that demands of the client on resulting mechanical properties can vary a lot, it is of course not possible to establish a general-purpose annealing mode that would be the most suitable. Particular trends of strength and plastic properties correspond to each other and they may be utilized for optimization of terms of heat treatment of the investigated HLSA steel in a cold rolling mill, exactly in accordance with specific requirements for a relation between plastic and strength properties of the given material.

The new experimental equipment of the Institute of Modelling and Control of Forming Processes (VŠB-TUO) in the sphere of cold rolling (i.e. rolling mill Q110, plus vacuum annealing furnace CLASIC 1812 VAK [14]) was exploited for the first time.

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