MICROSTRUCTURAL CHANGES AND EVOLUTION OF MECHANICAL PROPERTIES OF COLD ROLLED AND ANNEALED HSLA STEEL STRIPS

Janošec M.[1], Palát J.[1], Schindler I.[1], Legerski M.[1], Růžička M.[2], Místecký E.[2]
[1]VŠB – Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, 17. listopadu 15, 708 33 Ostrava, Czech Republic, e-mail: marcel.janosec@vsb.cz
[2]NOVÁ HUŤ – Válcovna za studena, spol. s r.o., Štramberská ulice, 706 02 Ostrava, Czech Republic, e-mail: m.ruzicka@valcovna-nh.cz

MIKROSTRUKTURNÍ ZMĚNY A VÝVOJ MECHANICKÝCH VLASTNOSTÍ ZA STUDENA VÁLCOVANÝCH A ŽÍHANÝCH PÁRŮ Z HSLA OCELI

Janošec M.[1], Palát J.[1], Schindler I.[1], Legerski M.[1], Růžička M.[2], Místecký E.[2]
[1]VŠB – Technická univerzita Ostrava, Fakulta metalurgie a materiálového inženýrství, 17. listopadu 15, 708 33 Ostrava, Česká republika, e-mail: marcel.janosec@vsb.cz
[2]NOVÁ HUŤ – Válcovna za studena, spol. s r.o., Štramberská ulice, 706 02 Ostrava, Česká republika, e-mail: m.ruzicka@valcovna-nh.cz

Abstrakt

Byl proveden rozsáhlý program zkoušek HSLA oceli jakosti S 500 MC. Experiment byl založen na kombinaci válcování za studena, rekrystalizačního žíhání, mechanického testování a metalografického zkoušení. Vzorky v podobě pásků s rozměry 4 x 25 x 340 mm byly podrobeny více průchody celkové výškové deformaci v rozmezí 5 až 75 %. Jednotlivé deformace byly realizovány za pokojové teploty na bezstojanové, hydraulicky předepjaté laboratorní válcovací stolici Q 110. Poté byly vývalky žíhány ve vakuové peci s ochrannou atmosférou tvořenou $N_2 + H_2$. Vyžíhané vzorky byly dále podrobeny mechanickému zkoušení. Získané výsledky mez kluzu $Rp_{0.2}$ [MPa], pevnost Rm [MPa] a jejich poměr stejně jako tažnost A_{80} [%] byly sumarizovány v grafu v závislosti na relativní výškové deformaci před žíháním – ε [%]. Získané hodnoty jednotlivých mechanických vlastností byly v souřadnicovým systému prokládány křivkami „ručně“ bez jakýchkoliv exaktních matematických pravidel.

Bylo prokázáno, že kombinací vhodného stupně předchozí deformace za studena a parametrů navazujícího rekrystalizačního žíhání je možné do značné míry ovlivnit komplex mechanických vlastností jednotlivých pásů. Popisovanou cestou je možné homogenizovat mikrostrukturu pásu a získat tak většinový podíl rovnoosých feritických zrn, nicméně průměrná velikost výsledných zrn není významně menší než po válcování za tepla. Jednotlivé trendy pevnostních a plastických vlastností korespondují sobě navzájem. Tyto trendy jsou dány strukturotvornými procesy, které byly doloženy mikrostrukturními snímky. Získané výsledky mohou nalézt praktické využití ve válcovnách pásu za studena při optimalizaci podmínek tepelného zpracování zkoumané oceli.

Abstract

A large testing programme of an HSLA strip steel grade S 500 MC was conducted. The experiment was based on combination of cold rolling, recrystallization annealing, mechanical testing and metallographic examinations. Samples in the form of strips with dimensions 4 x 25 x 340 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. Afterwards the laboratory mill products were annealed in the vacuum furnace with the protective gas atmosphere consisting of N_2+H_2. The annealed samples underwent the mechanical testing. The gained results yield stress YS [MPa], ultimate tensile strength UTS [MPa] and their ratio, as well as elongation A_{80} [%], were summarized in graph in dependence on 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.

It was confirmed that by a suitable combination of previous total cold reduction and parameters of the following recrystallization annealing it is possible to influence a complex of mechanical properties of particular strips. 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. Particular trends of strength and plastic properties correspond to each other. These trends are caused by structure-forming processes which were documented by micrographs. Therefore achieved results can be used in practice mainly for optimization of conditions of heat treatment of the investigated steel in cold rolling mills.

Keywords: HSLA steel, cold rolling, annealing, mechanical testing, microstructure

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 strain 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, 3]. 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 [2]. 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 [2, 3]. 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 procedures

An intention of the performed experiment was mapping influence of total cold reduction in combination with annealing mode on mechanical properties of steel S 500 MC microalloyed by niobium, titanium and vanadium. Samples of pickled cuts of hot rolled strip of thickness 4 mm were used for simulation by rolling. Chemical composition of the studied HSLA steel is introduced in Table 1.

Table 1 Chemical analysis of the investigated steel in wt. %

C	Mn	Si	P	S	Al	V	Ti	Nb
0.06	1.38	0.24	0.013	0.005	0.022	0.03	0.02	0.07

Samples in the form of stripes with dimensions 4 x 25 x 340 mm were rolled in several passes with the total height reduction 5 to 75 %. Particular partial strains were realized at room temperature in the housingless, hydraulically prestressed laboratory mill stand Q110 – Fig. 1 (a four-high mill with work roll diameter 62 mm). Then annealing was followed. It was carried out in a laboratory vacuum resistance furnace in the protective atmosphere consisting of 90 % of nitrogen and 10 % of hydrogen (Fig. 2) [4]. Parameters of applied annealing mode are: heating rate up to an intermediate dwell – 120 °C/h; temperature of the intermediate dwell – 600 °C; time of intermediate dwell – 2 h; heating rate up to the dwell – 15 °C/h; temperature of the dwell – 650 °C; time of dwell – 6 h.

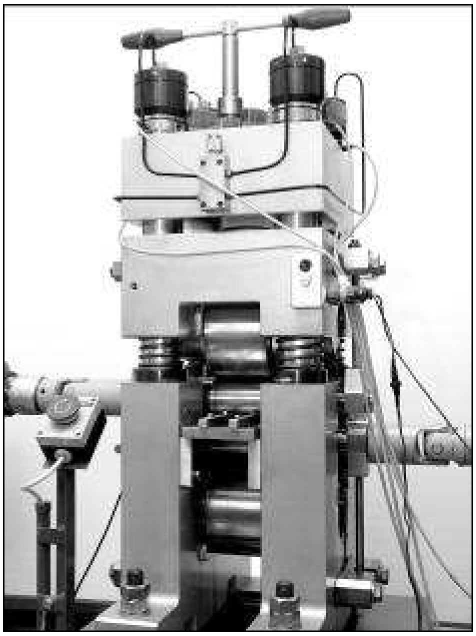

Fig.1 Rolling mill Q110

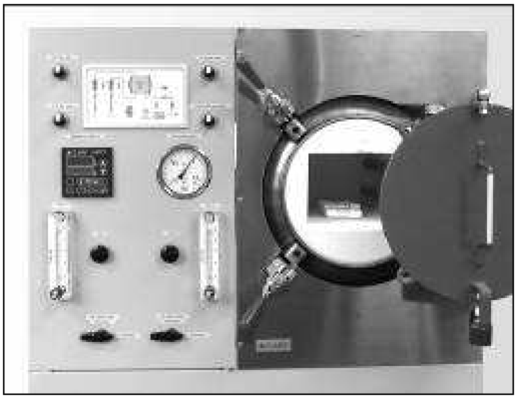

Fig.2 Electric laboratory vacuum furnace

The annealed samples underwent the tensile test at the room temperature. The gained results – yield stress YS [MPa], ultimate tensile strength UTS [MPa] and their ratio, as well as elongation A_{80} in %, were summarized in graph in Fig. 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.

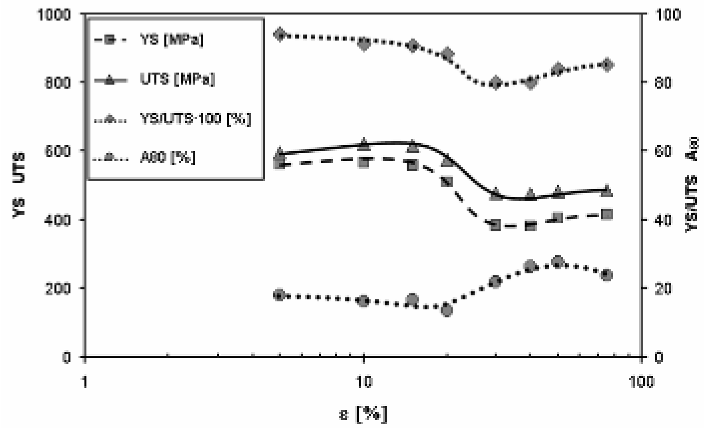

Fig.3 Mechanical properties of samples after cold rolling and annealing

3. Discussion of microstructural and mechanical properties

Samples for evaluation of structure by optical microscopy were taken from central parts of rolled out products (in the 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. It may be seen from Fig. 4 that structure after hot rolling was created by ferrite, with occurrence of pearlite.

Microstructures of cold deformed samples after annealing may be seen in Figs. 5 – 7. The selection of samples was based on the known fact that mechanical properties are essentially influenced by a character of microstructure. The structure after annealing is created by ferrite with a low fraction of pearlite, whose character and occurrence region (similarly like the ferritic grain) depends on total cold reduction and parameters of applied annealing mode [5].

For the reason that mechanical properties of the material reflect essentially its structural characteristics, their trend (Fig. 3) can be explained based on the microstructural analysis. The increasing intensity of cold deformation resulted in a gradual extension of grains, which create a basic matrix in the direction of principal strain. Marks of a strain-oriented structure can be observed in spite of the fact that, due to relatively high annealing temperature, the recrystallization occurs already after application of relatively low reductions. The described structural change can be seen in Fig. 5. It is possible to say that up to a value of height reduction ε = 10 or 15 % virtually no recrystallization occurs and the material undergoes work hardening. When higher values of the cold deformation are applied a share of recrystallized grains is gradually increasing (which is accompanied by a fall of strength properties). The completely, even though not fully uniform, recrystallized structure can be observed after height reduction of 30 % (Fig. 6). Use of draughts above 30 % resulted in the structure (ferritic grain size) that was progressively becoming uniform.

4. Summary

Thanks to microscopic analyses for selected height reductions, reasons for the described development of observed properties could be discussed. It was confirmed that cold rolling together with the applied annealing mode influence significantly character of the resulting ferritic grains. 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.

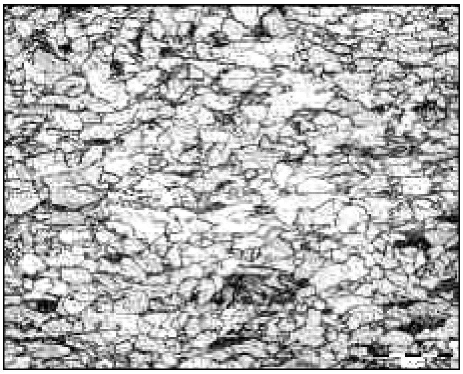

Fig.4 Microstructure of sample after hot rolling

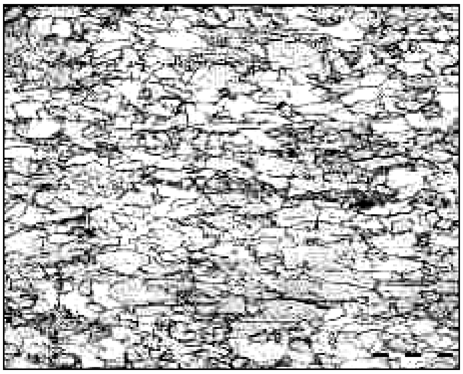

Fig.5 Microstructure of sample after cold rolling (ε = 15 %) and annealing

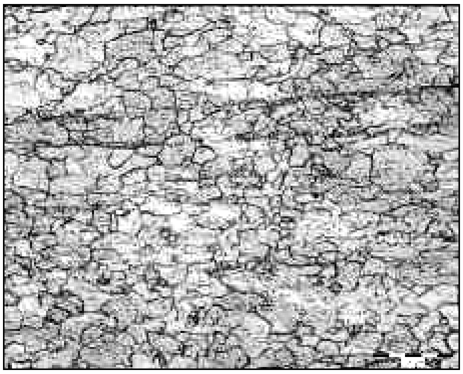

Fig.6 Microstructure of sample after cold rolling (ε = 30 %) and annealing

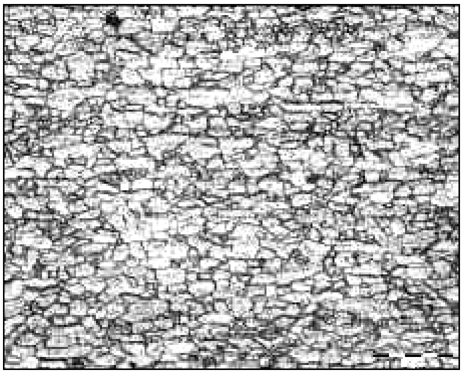

Fig.7 Microstructure of sample after cold rolling (ε = 75 %) and annealing

The experiment proved that a complex of mechanical properties (mainly strength) of one type of the material can be to a great extent influenced by a combination of cold deformation with recrystallization annealing. Trends of strength and plastic properties correspond very well not only with each other but also at the same time to characteristics gained from structural analyses.

Similar experiments were conducted already earlier in case of HSLA steel QStE 460 (0.08 C – 1.36 Mn – 0.18 Si – 0.03 V – 0.03 Ti – 0.07 Nb, all in wt %) [6]. Comparison of the reached results proved that mechanical properties of steels S 500 MC and QStE 460 after cold rolling and annealing performed with the described mode are quantitatively comparable. Also trends of strength and plastic properties in relation to the previous cold reduction are very similar, which is not a great surprise with regard to small differences in chemical composition of both steels.

Achieved results can be used in practice mainly for optimization of conditions of heat treatment of the investigated steel in cold rolling mills.

Acknowledgement

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