Archives of Materials Science and Engineering

Volume 36
Issue 1
March 2009
Pages 41-47

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Effect of cold rolling and annealing on mechanical properties of HSLA steel

I. Schindler [a,*], M. Janošec [a], E. Místecký [b], M. Růžička [b], L. Čížek [a], L.A. Dobrzański [c], S. Rusz [a], P. Suchánek [a]

[a] Institute of Modelling and Control of Forming Processes, VŠB – Technical University of Ostrava, Czech Republic

[b] NOVÁ HUT – Válcovna za studena, spol. s r.o., Czech Republic

[c] Division of Materials Processing Technologies, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland

* Corresponding author: E-mail address: ivo.schindler@vsb.cz

Received 12.02.2007; published in revised form 01.03.2009

ABSTRACT

Purpose: was to examine effect of the parameters of cold deformation and recrystallization annealing on mechanical properties of a Nb-microalloyed HSLA steel.

Design/methodology/approach: Research of strip steel QStE 420 was based on a combination of laboratory cold rolling, recrystallization annealing in vacuum furnace, mechanical (particularly tensile) tests and metallographic analyses.

Findings: It was validated that by a sophisticated combination of size of previous cold reduction size and parameters of the following annealing it is possible to impact markedly a set of final properties of particular strips. Formability of the studied HSLA steel rises and vice versa strength properties fall with an increasing temperature of annealing.

Research limitations/implications: The experiment should be supplemented by additional TEM analyses explaining the behaviour and role of precipitates.

Practical implications: The experimentally obtained particular trends of mechanical properties may be utilized for optimization of conditions of heat treatment of the investigated HLSA steel in a cold strip rolling mill, reflecting the specific requirements for a relation between strength and plastic properties.

Originality/value: Experimental potentialities of the Institute of Modelling and Control of Forming Processes in the sphere of cold rolling and heat treatment were introduced in their integrity for the first time.

Keywords: Mechanical properties, HSLA steel strip, Cold rolling, Recrystallization annealing

Reference to this paper should be given in the following way:

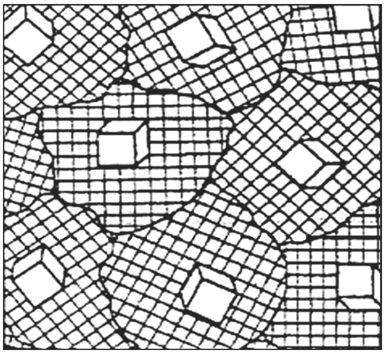
I. Schindler, M. Janošec, E. Místecký, M. Růžička, L. Čížek, L.A. Dobrzański, S. Rusz, P. Suchánek, Effect of cold rolling and annealing on mechanical properties of HSLA steel, Archives of Materials Science and Engineering 36/1 (2009) 41-47.

PROPERTIES

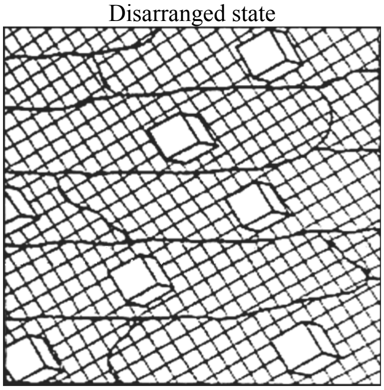
1. Introduction

Structure and resulting material properties are significantly influenced by cold rolling because in the given terms no recrystallization can occur. Extension of grains in the direction of rolling occurs and the arrangement of crystallographic lattice gets a directional character. Banding character of other structural phases, such as of inclusions, pearlitic blocks, etc. has been developed too. Three types of texture (i.e. deformation, structural and crystallographic texture) arise, which yields in a directional character of mechanical properties – see Fig. 1 [9]. Heat treatment is included after cold forming for removal of anisotropy of properties.

To factors influencing the final character of microstructure after annealing belong most importantly: the initial character of material structure before cold forming, the total cold reduction, annealing conditions (temperature and time) and also cooling speed [1,5,6,7,10,13,15,17, 18, 19]. More and more progressive types of material have been used in this field of processing – see e.g. [2,3,8,11,16]. As a whole, the more cold deformation of material before annealing, the lower initial temperature of recrystallization. At low temperatures the time necessary for finishing of recrystallization is much higher and the required spheroidizing of carbides cannot be completed [4].



Disarranged state



Structure oriented by deformation

Fig. 1. Illustration of origin of deformation textures of metal [9]

Strength or hardness properties of material generally decrease with increasing temperature of annealing, whereas plastic properties increase. Substantial lowering of strength values occurs at temperatures which are close to 600 °C – the higher is the previous cold deformation, the more important this fall is [4,12].

The main goal of this work was to study impact of various cold reduction sizes in combination with several modes of recrystallization annealing on mechanical properties of steel QStE 420.

2. Experiment

The input material was obtained in the form of pickled cuts of hot rolled strip with thickness 4.1 mm. Chemical composition of the studied HSLA steel is introduced in Table 1.

Table 1.
Chemical composition of steel (wt. %)

C	Mn	Si	P	S
0.079	0.85	0.006	0.011	0.006
Al	V	Ti	Nb	N
0.039	0.003	0.002	0.04	0.003

Flat samples with dimensions 4.1 x 25 x 500 mm were rolled in several passes with total (cumulative) height reduction 5 to 75 %. Particular draughts were realized at room temperature in the four-high housingless laboratory mill Q110 (Fig. 2) [14, 20]. Recrystallization annealing with one of three lower mentioned modes followed applying a laboratory vacuum resistance furnace (Fig. 3) and protective atmosphere consisting of 90 % of nitrogen and 10 % of hydrogen. Parameters of particular annealing modes are shown in Figs. 4-6.

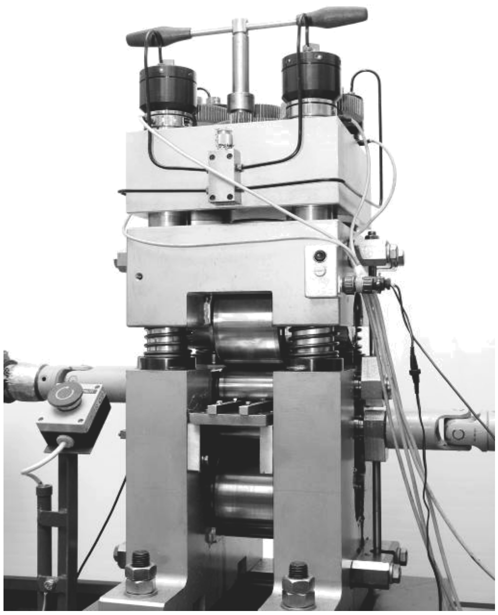


Fig. 2. Laboratory cold rolling mill Q110

2.1. Workplace character

The Institute of Modelling and Control of Forming Processes, where all experimental works were performed, had been established at the Faculty of Metallurgy and Materials Engineering (VŠB – Technical University of Ostrava) in 1996 within the frame of the program "Intensification of University Research" (Czech Ministry of Education). Thus a research workplace has been established with interdisciplinary team of mostly young workers and unique and continually developing experimental base.

The Institute deals with simulations of forming processes (mainly rolling) on devices largely similar to the industrial devices. It co-operates with plastometric laboratories (e.g. torsion plastometer at the Research and Development Institute of Vítkovice) and supplies data for mathematical modelling (FEM). In co-operation with other grant projects and based on purchase orders from metallurgical and machine plants the following questions are solved:

- structure-forming processes associated with forming and thermomechanical treatment of metal materials (influence on resulting properties, optimization of technologies);
- formability in conditions of longitudinal rolling;
- prediction of rolling forces (validation of mathematical models of deformation resistance).

Basic advantages of the selected type of physical modelling are as follows:

- high affinity to real conditions;
- high strain rates reached during rolling;
- resulting rolled products are due to their proportions and uniform deformation suitable for further investigation (metallography, tensile test etc.).

2.2. Characteristic of cold rolling mill

Rolling mill Q110 is a four-high housingless model mill, prestressed by 4 hydraulic nuts. It was designed for cold rolling of even very thin and high strength narrow strips. Rolls setting is manual with linear sensor measurement (accuracy 0.001 mm). Basic parameters:

- nominal diameter of work roll 62 mm;
- nominal diameter of back-up roll 150 mm;
- roll barrel 110 mm;
- separate drive of work rolls by AC motors with gears (installed power 1.6 kW);
- constant rolling speed approx. 0.1 m/s.

Computer program records torque on both driving spindles, roll-separating force under the pressure screw (shearing sensor 150 kN), roll gap and 8 additional parameters associated with prestressing of the rolling mill. In particular during cold rolling a compact set of digital measuring instruments is used (determination of the rolled product thickness).

2.3. Description of laboratory vacuum furnace

Electric laboratory vacuum furnace, type CLASIC 1812VAK is determined for heat treatment of laboratory rolled products by means of resistive heating. Temperature control is carried out by a controller CLARE 4.0.
Selected parameters:

- useful inner dimensions 450 x 200 x 200 mm;
- max. vacuum 500 Pa;
- max. overpressure 2000 Pa;
- 4 heating elements KANTHAL AI, installed power 5 kVA (400 V);
- thermocouple type S (Pt-PtRhlO) with length of 200 mm;
- speed of temperature changes (without charge): heating of the furnace to 1200 °C within 80 minutes, cooling from 1200 to 400 °C within ca 180 minutes;
- used gases: air, Ar, N_2, mixed gas $N_2 + H_2$.

Controller CLARE 4.0 – manual mode: dwell continuous or adjustable in the range 1 – 4999 minutes (i.e. more than 83 hours, or nearly 3.5 days); programmable mode: up to 10 programs, each of them can include up to 15 programmable blocks.

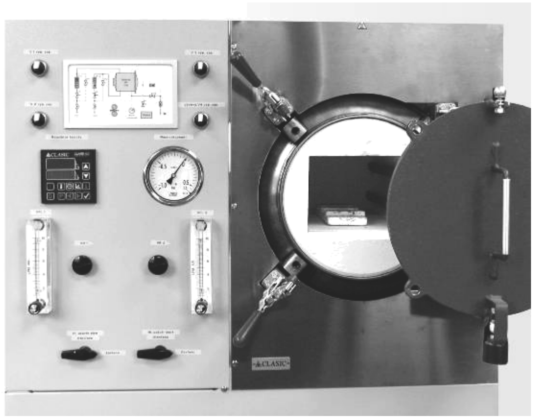


Fig. 3. Vacuum annealing furnace 1812VAK

2.4. Testing of mechanical properties

The rolled and annealed samples underwent the tensile test at the room temperature and the Brinell hardness test. The obtained results – yield stress YS [MPa], tensile strength TS [MPa] and their ratio, hardness HB, as well as elongation A_{80} in %, were plotted in graphs in Figs. 7-9 as a function of cold deformation before annealing (i.e. relative height reduction $-\varepsilon$ [%]). The corresponding curves were fitted „in a manual way“, without any exact mathematical rules.

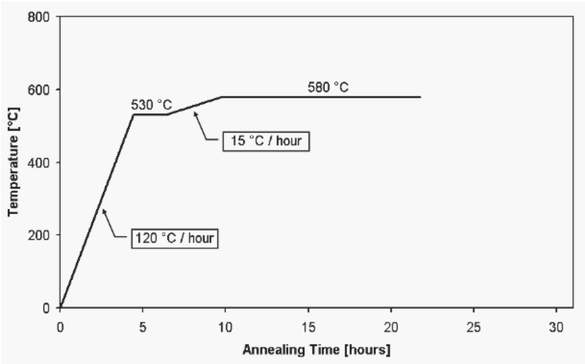


Fig. 4. Parameters of annealing mode 1

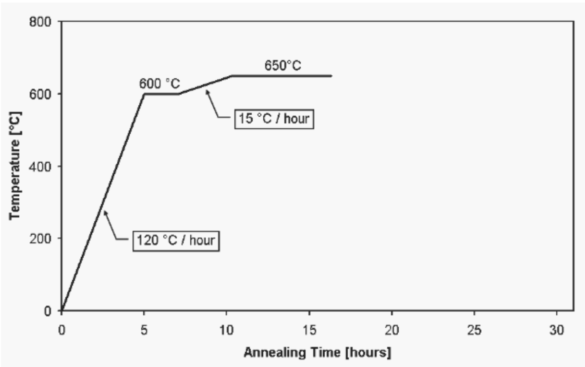


Fig. 5. Parameters of annealing mode 2

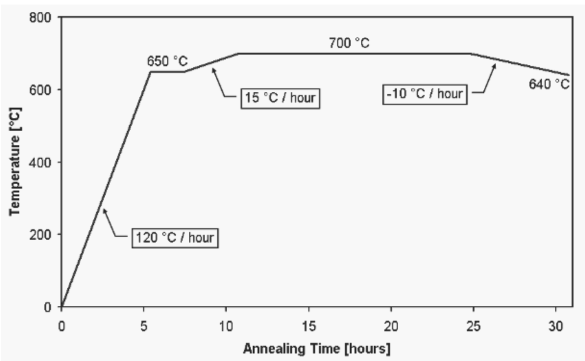


Fig. 6. Parameters of annealing mode 3

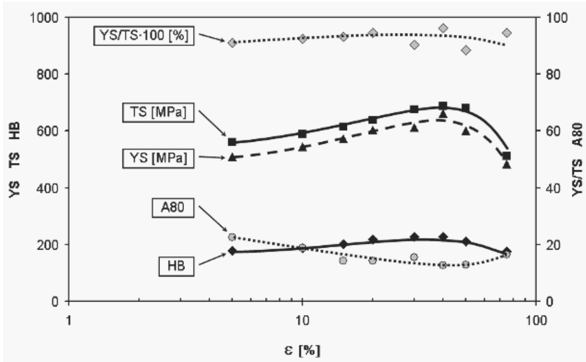


Fig. 7. Mechanical properties after annealing by mode 1

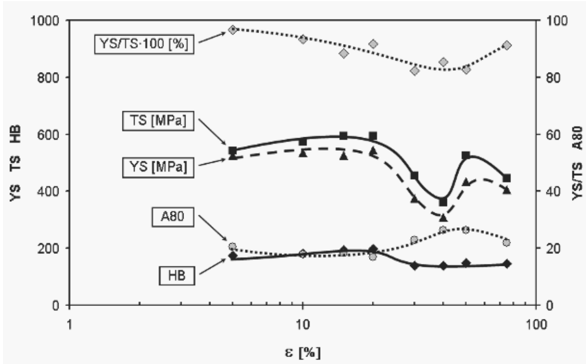


Fig. 8. Mechanical properties after annealing by mode 2

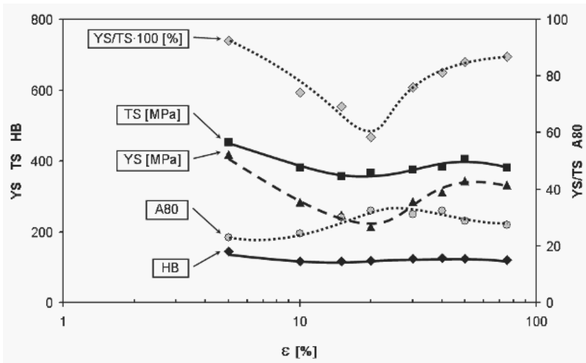


Fig. 9. Mechanical properties after annealing by mode 3

3. Metallographic analysis

Selected samples for metallography were taken from central parts of rolled out products (in a perpendicular section, parallel with the rolling direction). For comparison, microstructure was evaluated also with the initial, i.e. non-cold deformed sample.

Microstructure after hot rolling was created almost exclusively by ferrite, with a minor occurrence of pearlite (Fig. 10). Very fine grains occurred (a number of ferritic grain size G = 12-13).

However, not all ferritic grains were equiaxed. Microstructure of the chosen annealed samples can be seen in Figs. 11-22.

All annealed samples have microstructure created by ferrite with low content of pearlite, extent of spheroidizing of which and region of occurrence depend on parameters of deformation and thermal processing.

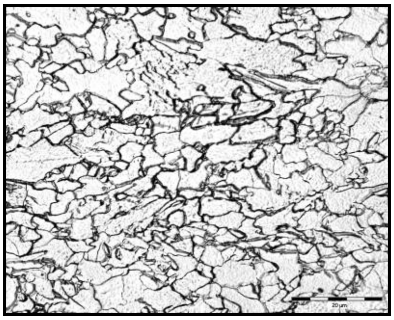


Fig. 10. Microstructure after hot rolling

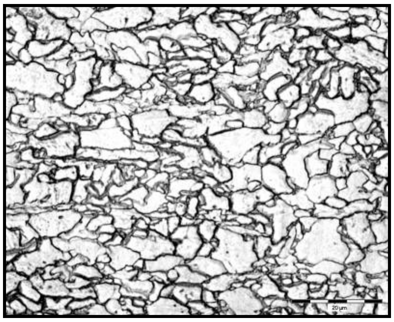


Fig. 11. Microstructure after ε= 5 % and annealing mode 1

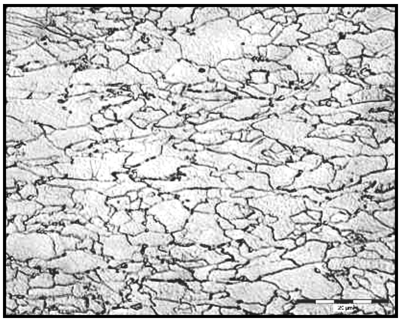


Fig. 12. Microstructure after ε = 15 % and annealing mode 1

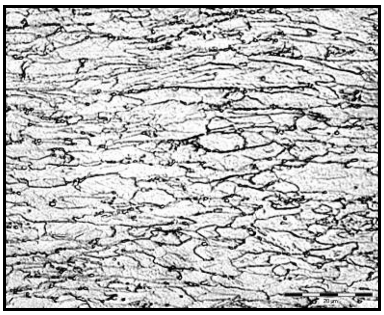


Fig. 13. Microstructure after ε = 40 % and annealing mode 1

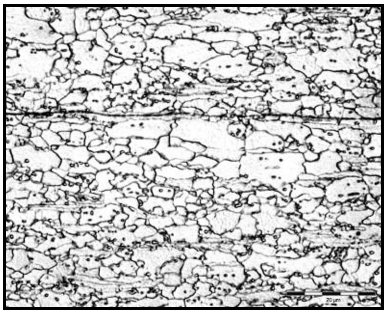


Fig. 14. Microstructure after ε = 75 % and annealing mode 1

Fig. 15. Microstructure after ε = 5 % and annealing mode 2

Fig. 16. Microstructure after ε = 20 % and annealing mode 2

Fig. 17. Microstructure after ε = 40 % and annealing mode 2

Fig. 18. Microstructure after ε = 75 % and annealing mode 2

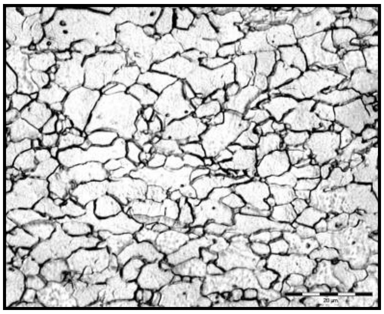


Fig. 19. Microstructure after ε = 5 % and annealing mode 3

Fig. 20. Microstructure after ε = 10 % and annealing mode 3

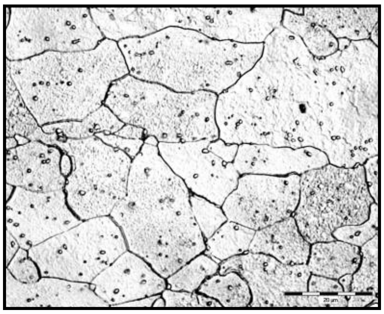


Fig. 21. Microstructure after ε = 20 % and annealing mode 3

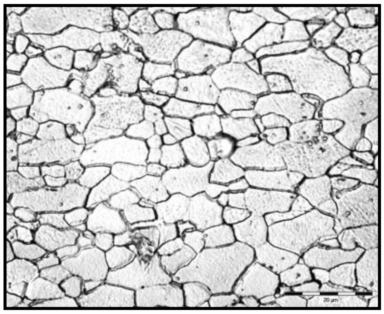


Fig. 22. Microstructure after ε = 75 % and annealing mode 3

4. Discussion of results

Annealing mode 1 (see Figs. 4 and 7) is characterized by a slow increase of strength properties with rising deformation up to 40 %, which is caused by partial recrystallization of the hardened material. Thereafter a relative sudden drop of strength properties follows, which can be explained by the course of recrystallization (see micrographs in Figs. 11-14). Elongation and YS/TS ratio are relatively slightly influenced by the previous cold deformation; they are weaker than in case of other annealing modes.
Application of the annealing mode 2 (see Figs. 5 and 8) resulted in the most complicated course of mechanical properties. A slow rise of strength properties is followed by a sudden drop of these properties after previous strains 20 – 40 % (compare microstructures in Figs. 15-17, 20). This is caused by heterogeneous coarsening of recrystallized grains. After cold reduction above 40 % a rise of yield stress and tensile strength occurs again. The observed trend of plastic properties is not so markedly complicated.

In the case of annealing mode 3, a noticeable minimum of yield stress and ratio YS/TS is visible together with maximum of elongation after cold reduction 20 %, which is due to abnormal coarsening of the recrystallized structure (see diagrams in Figs. 6 and 9 and micrographs in Figs. 19-22). A pronounced drop and rise of yield stress in comparison to tensile strength is evident, which is clearly documented by the YS/TS ratio in the diagram. Strength properties achieved by annealing mode 3 are the lowest ones in comparison with the other heat processing modes. On the contrary, plastic properties (particularly after cold reductions around 20 %) are the best ones in this case, which corresponds to a high annealing temperature.

5. Conclusions

The impact of various cold deformation size in combination with several modes of heat treatment on mechanical properties of the QStE 420 steel strips was ascertained. The new experimental equipment of the Institute of Modelling and Control of Forming Processes at VŠB – Technical University of Ostrava in the sphere of cold rolling was exploited, i.e. laboratory rolling mill Q110 as well as vacuum annealing furnace CLASIC 1812 VAK [20].

By the described combinations of cold deformation and recrystallization annealing it is possible to homogenize microstructure of the hot rolled strip and gain a major share of equiaxed ferritic grains, but an average size of resulting grains is not smaller in comparison with that one after hot rolling. It was confirmed that by a suitable set of size of previous cold reduction and parameters of the following heat treatment it is possible to influence a complex of mechanical properties of individual strips. Trends of the particular obtained curves in all graphs reflect the well-known relation between strength and plastic properties. Formability of the studied HSLA steel rises and vice versa strength properties fall with an increasing temperature of recrystallization annealing.

Demands of the client on resulting mechanical properties of the HSLA steel strip can vary a lot. With regard to this fact it is of course not possible to establish a general-purpose optimal annealing mode. The experimentally obtained particular trends of strength and plastic properties may be utilized for optimization of conditions of heat treatment of the investigated HLSA steel QStE 420 in a cold rolling mill, reflecting the specific requirements for a relation between strength and plastic properties of the given steel strips. The experiment should be supplemented by additional TEM analyses explaining the behaviour and role of precipitates during recrystallization annealing.

Acknowledgements

This work was done in the framework of solution of the project MSM6198910015, supported by the Ministry of Education, Youth and Sports of the Czech Republic.

References

[1] J. Adamczyk, A. Grajcar, Effect of heat treatment conditions on the structure and mechanical properties of DP-type steel, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 305-308.

[2] A. Asakura, K. Kosino, N. Iwasaki, Automotive application of high strength cold-rolled steel Transaction of the Iron and Steel Institute of Japan 21 (1981) 767-771.

[3] L. Čížek, M. Greger, R. Kocich, S. Rusz, I. Juřička, L.A. Dobrzański, T. Tański, Structure characteristics after rolling of magnesium alloys, Proceedings of the 13th Scientific International Conference "Achievements in Mechanical and Materials Engineering" AMME'2005, Gliwice − Wisła, 2005, 87-90.

[4] V. Dědek, Heat Treatment of the Cold Rolled Steel Strips, SNTL, Praha, 1964 (in Czech).

[5] J. Garcia-Vargas, D.A. Hardwick, W.M. Williams, Control of Mechanical Properties in Low Carbon Steel Using an Anneal – Strain – Anneal Method, Canadian Metallurgical Quarterly 19 (1980) 333-343.

[6] T. Gladman, The Physical Metallurgy of Microalloyed Steels, The Institute of Materials, London, 1997.

[7] M. Janošec, I. Schindler, J. Palát, L. Čížek V. Vodárek, E. Místecký, M. Růžička, L.A. Dobrzanski, S. Rusz, P. Suchánek, Properties of a Nb-V-Ti microalloyed steel influenced by cold rolling and annealing, Journal of Achievements in Materials and Manufacturing Engineering 20 (2006) 251-254.

[8] J.A. Juarez-Islas, R. Mendoza, J. Huante, M. Alanis, C. Gonzalez-Rivera, Processing of ultra low carbon steels with mechanical properties adequate for automotive applications in the as-annealed condition, Materials Science and Engineering A 276 (2000) 203-209.

[9] M. Kollerová, M. Žídek, B. Počta, V. Dědek, Rolling, ALFA, Bratislava, 1991 (in Slovak and Czech).

[10] P. Korczak, Influence of controlled rolling condition on microstructure and mechanical properties of low carbon micro-alloyed steels, Journal of Materials Processing Technology 157-58 (2004) 553-556.

[11] J. Lis, A.K. Lis, C. Kolan, Processing and properties of C-Mn steel with dual-phase microstructure, Proceedings of the 13th Scientific International Conference "Achievements in Mechanical and Materials Engineering" AMME'2005, Gliwice − Wisła, 2005, 395-398.

[12] N. Prasad, S. Kumar, P. Kumar, S.N. Ojha, Mechanical properties of cold-rolled annealed HSLA steel, Journal of Materials Science 26 (1991) 5158-5162.

[13] I. Schindler, M. Janošec, E. Místecký, M. Růžička, L. Čížek, L.A. Dobrzański, S. Rusz, P. Suchánek, Influence of cold rolling and annealing on mechanical properties of steel QStE 420, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 231-234.

[14] I. Schindler, P. Kozelský, V. Švinc, L. Černý, H. Kulveitová, L. Čížek, S. Rusz, M. Marek, T. Kubina, J. Sojka, Modelling of casting, hot-charge rolling and cold-strip production from high-carbon steel, Archives of Civil and Mechanical Engineering 4 (2004) 104-113.

[15] T. Tanaka, Controlled Rolling of Steel Plate and Strip, International Metallurgical Reviews 26 (1981) 185-212.

[16] K. Yoshida, Present and Future Status of High Strength Steel Sheets for Japanese Autobodies, Transaction of the Iron and Steel Institute of Japan 21 (1981) 761-766.

[17] J. Zrník, T. Kvačkaj, P. Horňak, V. Vrchovinský, Thermomechanical treatment of HSLA steel QStE 480MC, Proceedings of the 11th Scientific International Conference "Achievements in Mechanical and Materials Engineering" AMME'2002, Gliwice − Zakopane, 2002, 641-644.

[18] W. Ozgowicz, E. Kalinowska-Ozgowicz, A. Kurc: Influence of plastic deformation on structure and mechanical properties of stainless steel type X5CrNi18-10, Archives of Materials Science and Engineering 32/1 (2008) 37-40.

[19] Kurc, Z. Stoklos, Some mechanical and magnetic properties of cold rolled X5CrNi18-8 stainless steel, Archives of Materials Science and Engineering 34/2 (2008) 89-94.

[20] http://www.fmmi.vsb.cz/model/