Title: Some mechanical and magnetic properties of cold rolled X5CrNi 18-8 stainless steel

Author: A. Kurc, Zbigniew Stokłosa

Citation style: Kurc A., Stokłosa Zbigniew. (2008). Some mechanical and magnetic properties of cold rolled X5CrNi 18-8 stainless steel "Archives of Materials Science and Engineering" (Vol. 34, iss. 2 (2008), s. 89-94).

Archives of Materials Science and Engineering

Volume 34
Issue 2
December 2008
Pages 89-94

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

Some mechanical and magnetic properties of cold rolled X5CrNi18-8 stainless steel

A. Kurc [a,*], Z. Stokłosa [b]
[a] Division of Constructional and Special Materials, Institute of Engineering Materials
and Biomaterials, Silesian University of Technology,
ul. Konarskiego 18a, 44-100 Gliwice, Poland
[b] Institute of Materials Science, Silesian University,
ul. Bankowa 12, 40-007 Katowice, Poland
* Corresponding author: E-mail address: agnieszka.kurc @polsl.pl

Received 25.09.2008; published in revised form 01.12.2008

ABSTRACT

Purpose: The paper analyzes the influence of the degree of cold deformation on the structure forming and changes of mechanical and magnetic properties of cold-rolled sheet on austenitic X5CrNi18-8 stainless steel.

Design/methodology/approach: The investigations included observations of the structure on a light microscope, researches of mechanical properties in a static tensile test, microhardness measurements made by Vickers's method and magnetic behaviors determine by used normalized non-destructive testing methods (NDT). The analysis of the phase composition was carried out on the basis of X-ray researches. In the qualitative X-ray analysis the comparative method was applied. Whereas X-ray quantitative phase analysis was carried out by the Averbach Cohen method.

Research limitations/implications: The X-ray phase analysis in particular permitted to disclose and identify the main phases on the structure of the investigated steel after its deformation within the range 10%-70%. Moreover results of the X-ray quantitative analysis allowed to determine the proportional part of martensite phases α` in the structure of investigated steel in the examined range of cold plastic deformation.

Practical implications: The analysis of the obtained results permits to state that the degree of deformation has a significant influence on the structure, mechanical and magnetic properties of the investigated steel. Besides, it was found that the plastic deformation in cold rolling process of metastable austenitic steel type X5CrNi18-8 induces in its structure a phase transformation paramagnetic austenite into ferromagnetic martensite.

Originality/value: plastic deformation in cold rolling process in the austenitic X5CrNi18-8 stainless steel a good correlation was found between changes of the structure and the effects of investigations of the mechanical properties, connected with martensitic α’ phases forming. Existing this relation is of essential practical importance for the technology of sheet-metal rolling of austenitic steel.

Keywords: Metallic alloys; Austenitic stainless chromium-nickel steel; Plastic deformation; Structure and mechanical properties; Magnetic measurements; Cold rolling process

PROPERTIES

1. Introduction

Stainless steels are very important industrial materials because of their excellent corrosion resistance in various aggressive environments, attractive appearance, good weldability, ductility and mechanical properties. They are widely used in chemical, machinery, automobile and nuclear industry [1-5].The most common stainless alloys are austenitic steels, well-known as the 300 series. Austenitic stainless steels are essentially an iron-chromium-nickel alloys, contain between 18 and 30%wt. Cr, 0.03-0.1%wt. C and 8-20%wt. Ni [6-9]. They cannot be hardened by heat treatment, but can be hardened significantly by cold-working. Steels of this type have an austenitic structure (γ-phase, face-centered cubic) in annealed condition, but partially transform to martensite (α'-phase, body-centered cubic and ε-phase, hexagonal closed packed) during deformation. Austenite is formed through the generous use of austenitizing elements such as Ni, Mn, C and N [10-13].

2. Experimental procedure

The material used in the experiments is a low carbon metastable austenitic stainless steel, X5CrNi18-8, with the following nominal composition: C = 0.047%, Cr = 18.35%, Ni = 8.06%, Mn = 1.12%, Si = 0.42%, Cu = 0.36%, Mo = 0.28%, N = 0.06%, P = 0.028%, S = 0.006% and the balance Fe. The investigated material was supplied in the form of sheet-cutting steel about dimension like 40×700×2mm, as a result of industrial smelting from the UGINE&ALZ (Poland). The material was cold rolled within the range 10%-70% and samples for researches of the magnetic and mechanical properties, for microhardness measurements, metallographic observations and the X-ray phase analysis were cut.

The relative magnetic permeability μ were measured by Maxwell-Wien bridge at frequency about 1030Hz and magnetic field value of 0.5 A/m; open coil, demagnetization factor was numerically and experimentally determined. The coercive force H_c was measured by coercivemeter with permalloy probe [21]. The specimens used for magnetic measurements were cut into size of 12×100 mm in the rolling direction of different reduction in thickness. Both, the relative magnetic permeability μ and the coercive force H_c of investigated X5CrNi18-8 steel were carried out at room temperature.

Evaluation of the mechanical properties was made on the basis of taken measurements from statically tensile test on the universal testing machine ZWICK 100N5A. Dimensions of test samples were determinate on the basis of PN-EN 10002-1+AC1:2004 standard and cut from the steel sheet parallelly to rolling direction. Tensile tests were performed at room temperature.

Metallographic examinations of samples were performed on LEICA MEF4A optical microscope, equipped with Leica Qwin image analyzer. In order to distinguish martensite from austenite and to detect the nonmetallic inclusions the metallographic specimens were etched in the reagent Mi17Fe heated to a temperature of about 40°C, with a magnification of 100-1000x.

Measurements of microhardness of the investigated cold reduced sheets from steel X5CrNi18-8 were carried out by a microhardness tester PMT-3 produced by Hauser, according to the standard PN-EN ISO 6507-1:2007. Researches were made by Vickers's method on metallographic samples with a load of 50 g.

Phase analysis was carried out using the X'PERT PANalytica diffractometer equipped with cobalt anode. It was supplied by current intensity of 40 mA and the accelerating voltage of 45 kV. The length of radiation (λCoK_α) was 1.79021 Å. The data of diffraction lines were recorded by "step-scanning" method in 2Θ range from 40° to 115° and 0.1° step and a time of measurements amounting to 2 seconds in one measurement position. The obtained diffraction patterns were analyzed applying the program Diffract AT Search/Match.

X-ray quantitative phase analysis was carried out by the Averbach Cohen method [22]. In the calculation of the quantitative share of the phase α' the respective surfaces of the diffraction lines of the phases γ and α' were measured by means of a planimeter.

3. Result and discussion

The structure of the investigated austenite stainless steel type X5CrNi18-8 in delivery state (Fig. 1) shows equiaxial austenite grains about 20 μm average a diameter with many annealed twins and agglomerations of copper precipitations. In microstructure of steel X5CrNi18-8 displays also a small amount of spot non-metallic inclusions, mainly oxides, carbonitrides and sulfides.

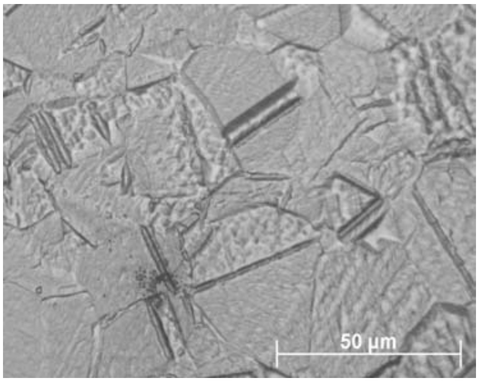

Fig. 1. Supersaturated austenite structure of X5CrNi18-8 steel in the delivered state; Etching - Mi17Fe; Mag. 500x

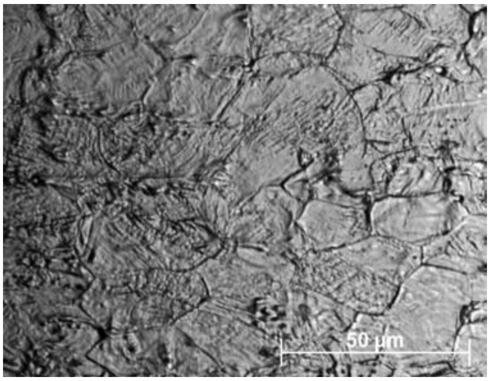

Fig. 2. Structure of investigated steel after deformation with draft 30%; Etching - Mi17Fe; Mag. 500x

In the investigated steel after cold deformation it was found a structure of elongated austenite grains with slip bands, and deformation twins (Fig. 2). Observations of the structure of steel type X5CrNi18-8 with degree of deformation, about 40% to 70% shows that in elongated γ grains there are areas of parallel plates characteristic for martensite α' (Figs. 3, 4 and 5).

During the cold rolling process with an increasing degree of deformation the α' phase is formed, which causes an essential size reduction of the steel structure and its strain hardening. The occurrence of martensite α' in X5CrNi18-8 steel confirm the results of mechanical investigations.

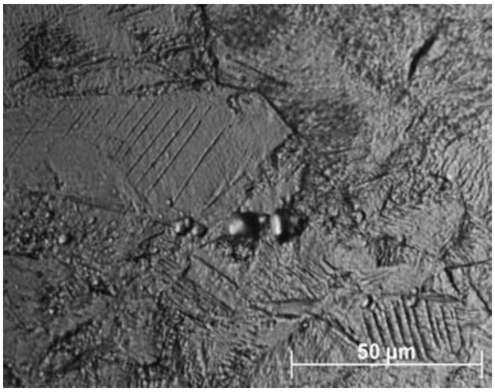

Fig. 3. Structure of investigated steel after deformation with draft 40%; Etching - Mi17Fe; Mag. 500x

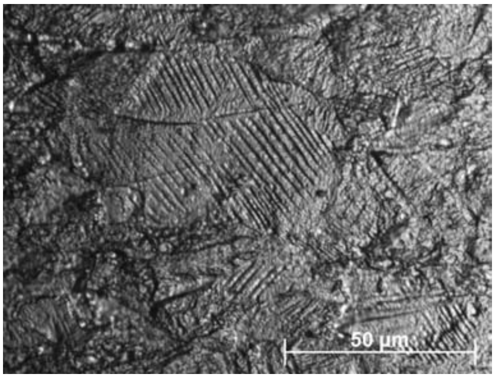

Fig. 4. Structure of investigated steel after deformation with draft 50%; Etching - Mi17Fe; Mag. 500x

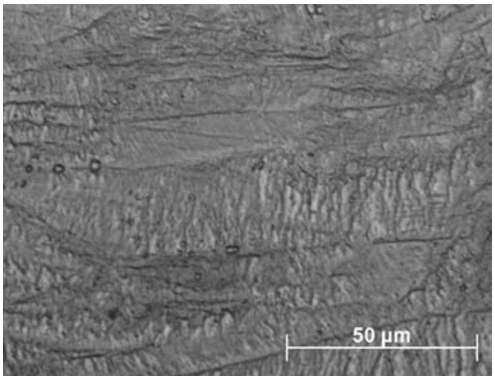

Fig. 5. Structure of investigated steel after deformation with draft 70%; Etching - Mi17Fe; Mag. 500x

The results of microhardness and mechanical investigations of investigated steel have been gathered in Table 1 and in Figs. 6 and 7. It has been found that the value of the yield point $R_{p0.2}$, tensile strength R_m and microhardness $HV_{0.05}$ increase with the degree of deformation, but the value of necking Z and elongation A decreases.

The yield point of investigated steel in the not deformed state is about 302 MPa, the tensile strength about 630 MPa, microhardness about 155$HV_{0.05}$, the elongation about 53% and the necking about 66%. With the increasing deformation within the range of 10%-70% the yield point of steel X5CrNi18-8 increases from about 535 MPa to about 1259 MPa, the tensile strength from about 763 MPa to about 1433 MPa, the hardness from about 234 $HV_{0.05}$ to 415 $HV_{0.05}$, while the elongation decreases from about 37% to about 1% and the necking from about 58% to about 23%.

Table 1.
Microhardness and mechanical properties of X5CrNi18-8 steel after cold deformation

Degree of plastic deformation [%]	Mechanical properties				
	$\overline{R}_{p0.2}$ MPa	$\overline{R}_m$ MPa	$\overline{A}$ %	$\overline{Z}$ %	$\overline{HV}_{0.05}$
0	302	630	53	66	155
10	535	763	37	58	234
20	758	909	21	45	287
30	941	1053	20	41	295
40	1041	1187	4	35	331
50	1198	1295	2	29	351
70	1259	1433	1	23	415

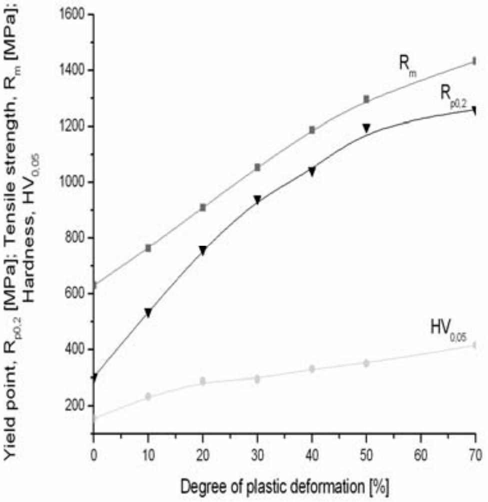

Fig. 6. Changes of the mechanical properties in investigated cold rolled steel depending on degree of deformation

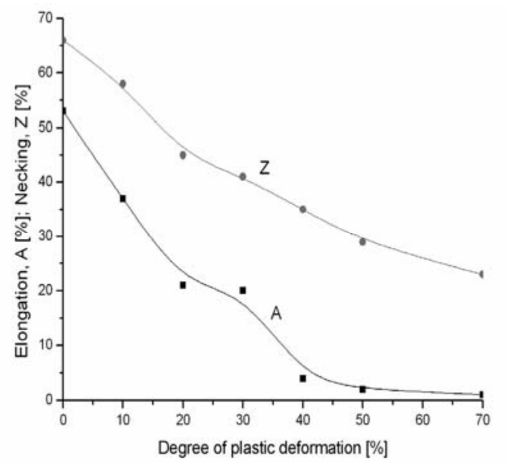

Fig. 7. Changes of the plasticity in investigated cold rolled steel depending on degree of deformation

X-ray investigations of X5CrNi18-8 steel deformed with draft from 10% to 70% confirmed the occurrence of α’ martensite in its structure. α’ phases were detected on diffraction patterns on the basis of the diffraction lines according to identifications from (110)α’ and (211)α’ reflection planes, which occurred with matrix lines Feγ from (111)γ, (200)γ, (220)γ and (311)γ reflection planes. It was also found that with the increase of deformation the share of the reflection lines (110)α’ in the dual line with the reflection lines (111)γ increases, too. It proves a distinct increase of α’ phase in the structure of the investigated steel. The results of the X-ray phase analysis have been gathered in Table 2 and Fig 8.

On the basis of X-ray quantitative phase analysis it was found that the amount of the analyzed α’ phase in the investigated steel structure increases with the deformation in the cold rolling process. In the undeformed state of steel the phase α’ does not occur, but after deformation with a maximum draft of about 70% the amount of martensitic phases is about 40% (Fig. 9).

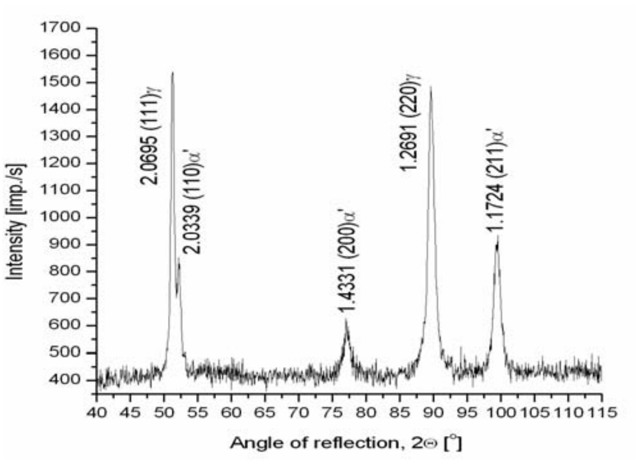

Fig. 8. X-ray diffraction patterns of steel X5CrNi18-8 with draft deformation 70%

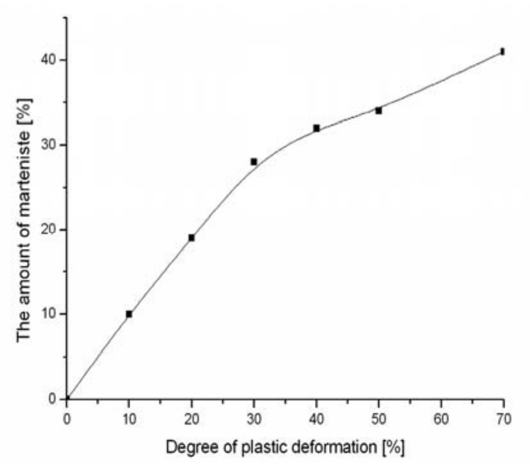

Fig. 9. Dependence of the volume fraction of α’- phase on degree of plastic deformation investigated steel

The investigations of magnetic properties allowed to determine the changes of the relative magnetic permeability (μ) and coercive force (H_c) of investigated steel type X5CrNi18-8. The results of the magnetic properties have been presented on Figs. 10 and 11.

On the basis of the realized investigations of magnetic properties it was found that with the deformation increasing of X5CrNi18-8 steel the relative magnetic permeability μ increases from about 1.05 to about 13.21 (Fig. 10), while the coercive force H_c decreases from about 5800 [A/m] to about 4100 [A/m] (Fig. 11).

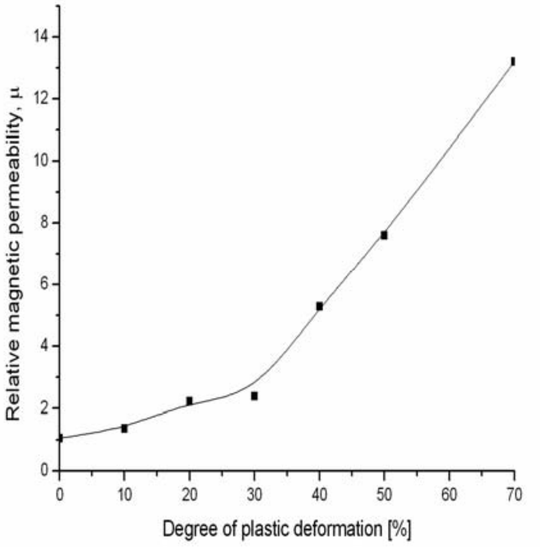

Fig. 10. Variation of relative magnetic permeability with the degree of plastic deformation investigated steel

Table 2.
Results of the X-ray phase analysis of the investigated steel with draft deformation 70%

	Evidence				Identified phase according to ICDD			
Line Number	Angle of reflection		Interplanar distance d_{ev} [Å]	Intensity I/I_{max} [%]	Interplanar distance d_{tab} [Å]	Intensity [%]	Plane (hkl)	Phase
	[°2Θ]	[°Θ]						
1	51.2161	25.6081	2.0695	100	2.075	100	111	γ
2	52.1815	26.0908	2.0339	55	2.0268	100	110	α’
3	77.2432	38.6216	1.4331	40	1.4332	45	200	α’
4	89.6302	44.8151	1.2691	96	1.2697	26	220	γ
5	99.4494	49.7247	1.1724	60	1.1702	30	211	α’

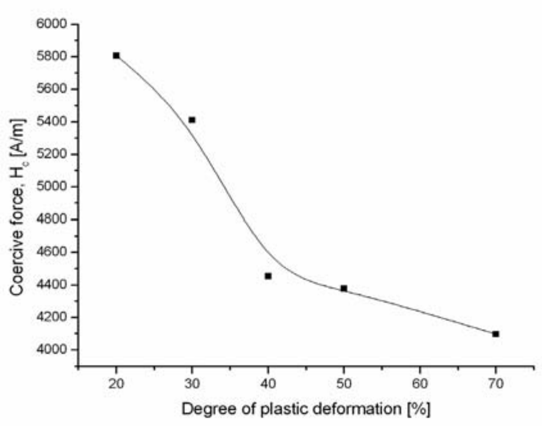

Fig. 11. Variation of coercive force in function of degree of plastic deformation for steel X5CrNi18-8

In the delivery state the X5CrNi18-8 steel characterized the magnetic permeability of about 1. After the plastic deformation within the range of 10%-70% relative magnetic permeability of investigated steel increases from about 1.36 to about 13.21, which proves about formed the α’ phase and induces in its structure a martensitic transformation γ → α’. Amount of formed phases increasing within the degree of deformation.

The obtained magnetic properties allow to classify the studied metastable austenitic steel in the delivery state as a paramagnetic material. After cold deformation in the range from 10% to 70% the ferromagnetic phase α’ was formed. The increase of the degree of deformation causes the increase of magnetic permeability as soon as the decrease of coercive force.

4. Conclusions

Based on the analysis of the obtained results of investigated stainless steel type X5CrNi18-8 in delivery state and after cold rolling process allowed to formulate the following statements:

- Plastic deformation in the cold rolling process of austenitic stainless steel type X5CrNi18-8 induces in its structure a martensitic transformation γ → α’. The occurrence of α' in studied steel confirm the results of magnetic and X-ray investigations.
- In the delivery state the X5CrNi18-8 steel has a single-phase austenite structure with grains about 20 μm average a diameter, twins and non-metallic inclusions, guarantee R_m about 630 MPa, $R_{p0,2}$ about 302 MPa, A about 53%, Z about 66% and hardness about 155 $HV_{0,05}$. After plastic deformation in the range 10%-70% in investigated steel structure the α′ phase occurrence, which influence on increase of the value of R_m from about 763 MPa to about 1433MPa, $R_{p0,2}$ from about 535MPa to about 1259MPa and $HV_{0,05}$ from about 234 $HV_{0,05}$ to about 415 $HV_{0,05}$ but decreasing A from about 37% to about 1% and Z from about 58% to about 23%.
- Amount of α’phase in X5CrNi18-8 steel depends from degree of plastic deformation. Deformation steel with draft 70% leads to about 40% part quantitative α’phase in structure of investigated steel.
- Diffraction lines (111)γ, (110)α’; (200)α’, (220)γ; (211)α’, (311)γ analysis phases of cold rolled the X5CrNi18-8 steel shows distinct texturing.
- Increase of degree deformation the X5CrNi18-8 steel within the range 10%-70% essentially influence on changes its magnetic properties causes increase magnetic permeability μ from 1.05 to about 13.21 and decrease magnetic field H_c from about 5800 [A/m] to about 4100 [A/m]. The martensite α’ phase is ferromagnetic phase.

References

[1] V. Tsakiris, D. Edmonds, Martensite and deformation twinning in austenitic steels, Materials Science and Engineering A 273-275 (1999) 430-436.
[2] H. Shin, T. Ha, Y. Chang, Kinetics of deformation induced martensitic transformation in a 304 stainless steel, Scripta Materialia 45 (2001) 823-829.
[3] A. Lebedev, V. Kosarchuk, Influence of phases transformations on the mechanical properties of austenitic stainless steels, International Journal of Plasticity 16/7 (2000) 749-767.
[4] V. Toshkov, R. Russev, T. Madjarov, E. Russeva, On low temperature ion nitriding of austenitic stainless steel AISI 316, Journal of Achievements in Materials and Manufacturing Engineering 25/1 (2007) 71-74.
[5] R. Reed, The spontaneous martensitic transformations in 18%Cr, 8%Ni steels, Acta Metallurgica 10 (1962) 865-877.
[6] S. Tavares, D. Gunderov, V. Stolyarov, Phase transformation induced by severe plastic deformation in the AISI 304L

stainless steel, Materials Science and Engineering 358A (2003) 32-36.

[7] A. De, D. Murdock, M. Mataya, Quantitative measurement of deformation-induced martensite in 304 stainless steel by X-ray diffraction, Scripta Materialia 50 (2004) 1445-1449.

[8] D. Jandova, J. Rehor, Z. Novy, Proceedings of the 10th Scientific International Conference "Achievements in Mechanical and Materials Engineering" AMME'2001, Gliwice–Kraków–Zakopane, 2001, 243-246.

[9] F. Ciura, A. Kruk, G. Michta, W. Osuch, Influence of temperature and deformation degree on structure and mechanical properties during the phase transformation in Fe-30%Ni alloy, Proceedings of the 9th Scientific International Conference "Achievements in Mechanical and Materials Engineering" AMME'2000, Gliwice–Sopot–Gdańsk, 2000, 67-71 (in Polish).

[10] P. Mangonon, G. Thomas, The martensite phases in 304 stainless steel, Metallurgical Transactions 1 (1970) 1577-1586.

[11] P. Hedström, U. Lienert, J. Almer, Stepwise transformation behavior of the strain-induced martensitic transformation in a metastable stainless steel, Scripta Materialia 56 (2007) 213-216.

[12] K. Pałka, A. Weroński, K. Zalewski, Mechanical properties and corrosion resistance of burnished X5CrNi18-9 stainless steel, Journal of Achievements in Materials and Manufacturing Engineering 16 (2006) 57-62.

[13] M. Ahlers, The Martensitic Transformation, Revista Materialia 9/3 (2004) 169-183.

[14] 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.

[15] J. Talonen, P. Nenonen, G. Pape, H. Hanninen, Effect of Strain Rate on the Strain-Induced $\gamma \rightarrow \alpha'$, Martensite Transformation and Mechanical Properties of Austenitic Stainless Steels, Metallurgical and Materials Transactions 36A (2005) 421-432.

[16] J. Echigoya, T. Ueda, X. Li, H. Hatafuku, S. Takashai, Martensitic transformation due to plastic deformation and magnetic properties in SUS 304 stainless steel, Journal of Materials Processing Technology 108 (2001) 213-216.

[17] S. Tavares, D. Fruchart, S. Miraglia, A magnetic study of the reversion of martensite α' in a 304 stainless steel, Journal of Alloys and Compounds 307 (2000) 311-317.

[18] K. Mumtaz, S. Takahasi, Magnetic measurements of martensitic transformation in austenitic stainless steel after room temperature rolling, Journal of Materials Science 39 (2004) 85-97.

[19] M. Milad, N. Zreiba, F. Elhalouanin, The effect of cold work on structure and properties of AISI 304 stainless steel, Journal of Materials Processing Technology 203 (2008) 80-85.

[20] S. Sagar, B. Kumar, G. Dobmann, D. Bhattachatya, Magnetic characterization of cold rolled and aged AISI 304 stainless steel, NDT & E International 38 (2005) 674-681.

[21] R. Nowosielski, R. Babilas, P. Ochin, Z. Stokłosa, Thermal and magnetic properties of selected Fe-based metallic glasses, Archives of Materials Science and Engineering 30/1 (2008) 13-16.

[22] B. Cullity, Elements of X-ray Diffraction, Addison-Wesley Series in Metallurgy and Materials, 1967.