



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

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## 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  $\alpha'$  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  $\alpha'$  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 ( $\gamma$ -phase, face-centered cubic) in annealed condition, but partially transform to martensite ( $\alpha'$ -phase, body-centered cubic and  $\epsilon$ -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  $\mu$  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 coercivimeter 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  $\mu$  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 ( $\lambda_{CoK\alpha}$ ) was 1.79021 Å. The data of diffraction lines were recorded by "step-scanning" method in  $2\theta$  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  $\alpha'$  the respective surfaces of the diffraction lines of the phases  $\gamma$  and  $\alpha'$  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  $\mu$ m 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.

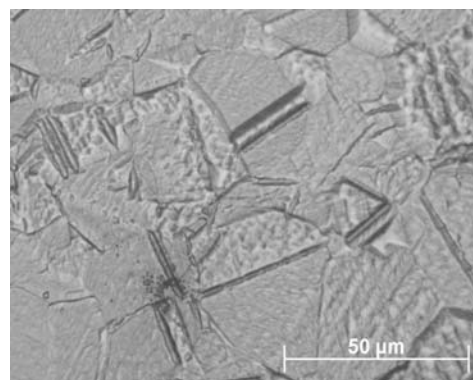


Fig. 1. Supersaturated austenite structure of X5CrNi18-8 steel in the delivered state; Etching - Mi17Fe; Mag. 500x

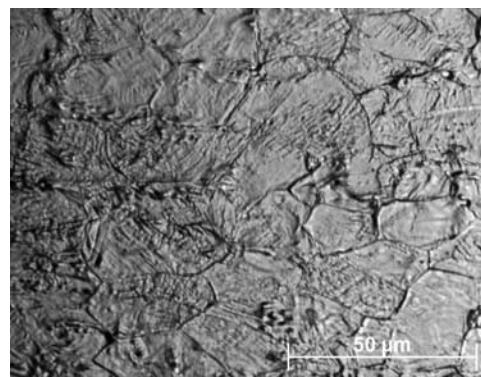


Fig. 2. Structure of investigated steel after deformation with draft 30%; Etching - Mi17Fe; Mag. 500x

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  $\gamma$  grains there are areas of parallel plates characteristic for martensite  $\alpha'$  (Figs. 3, 4 and 5).

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

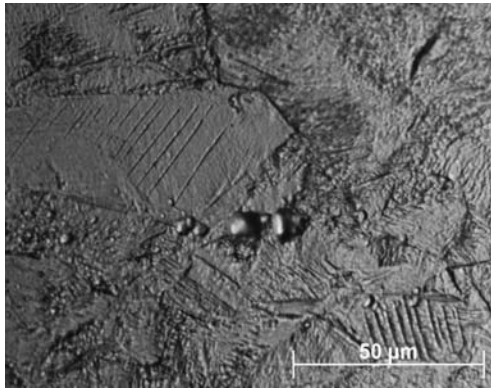


Fig. 3. Structure of investigated steel after deformation with draft 40%; Etching - Mi17Fe; Mag. 500x

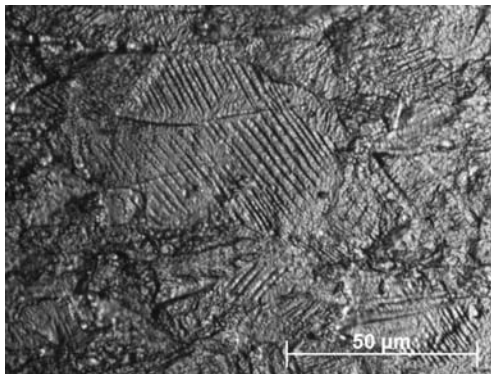


Fig. 4. Structure of investigated steel after deformation with draft 50%; Etching - Mi17Fe; Mag. 500x

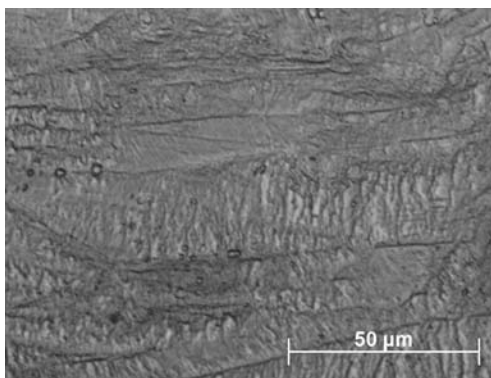


Fig. 5. Structure of investigated steel after deformation with draft 70%; Etching - Mi17Fe; Mag. 500x

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 155HV<sub>0.05</sub>, 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<sub>0.05</sub> to 415 HV<sub>0.05</sub>, 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				$\overline{HV}_{0.05}$
	$\overline{R}_{p0.2}$ [MPa]	$\overline{R}_m$ [MPa]	$\overline{A}$ [%]	$\overline{Z}$ [%]	
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

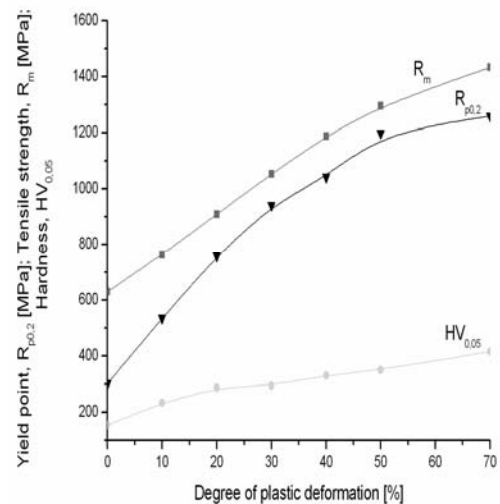


Fig. 6. Changes of the mechanical properties in investigated cold rolled steel depending on degree of deformation

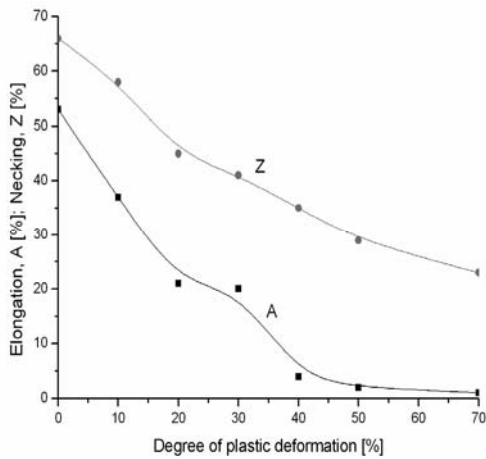


Fig. 7. Changes of the plasticity in investigated cold rolled steel depending on degree of deformation

X-ray investigations of X5CrNi18-8 steel deformed with draft from 10% to 70% confirmed the occurrence of  $\alpha'$  martensite in its structure.  $\alpha'$  phases were detected on diffraction patterns on the basis of the diffraction lines according to identifications from  $(110)\alpha'$  and  $(211)\alpha'$  reflection planes, which occurred with matrix lines  $Fe\gamma$  from  $(111)\gamma$ ,  $(200)\gamma$ ,  $(220)\gamma$  and  $(311)\gamma$  reflection planes. It was also found that with the increase of deformation the share of the reflection lines  $(110)\alpha'$  in the dual line with the reflection lines  $(111)\gamma$  increases, too. It proves a distinct increase of  $\alpha'$  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  $\alpha'$  phase in the investigated steel structure increases with the deformation in the cold rolling process. In the undeformed state of steel the phase  $\alpha'$  does not occur, but after deformation with a maximum draft of about 70% the amount of martensitic phases is about 40% (Fig. 9).

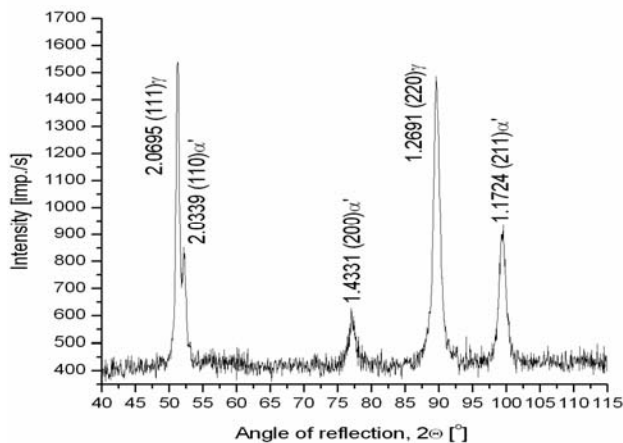


Fig. 8. X-ray diffraction patterns of steel X5CrNi18-8 with draft deformation 70%

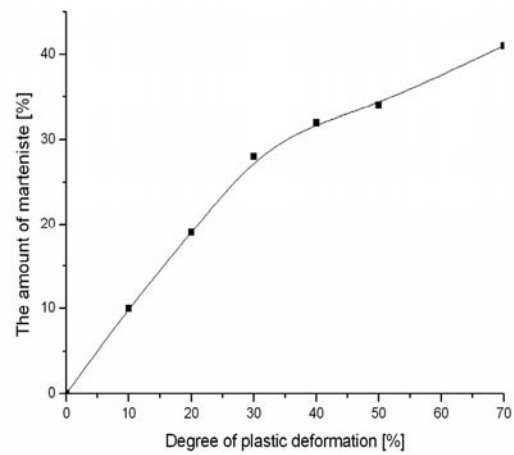


Fig. 9. Dependence of the volume fraction of  $\alpha'$  phase on degree of plastic deformation investigated steel

The investigations of magnetic properties allowed to determine the changes of the relative magnetic permeability ( $\mu$ ) 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  $\mu$  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).

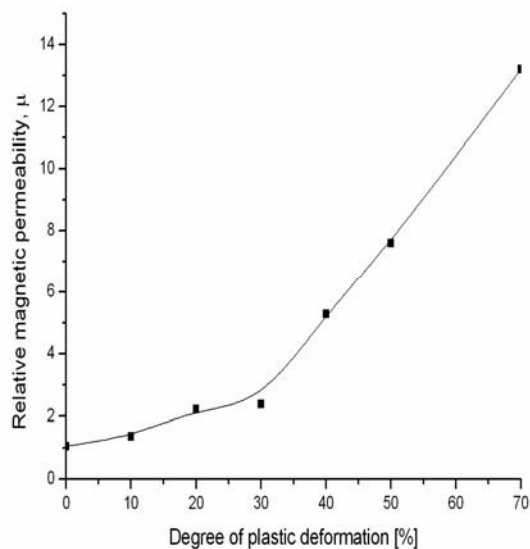


Fig. 10. Variation of relative magnetic permeability with the degree of plastic deformation investigated steel

Table 2.

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

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

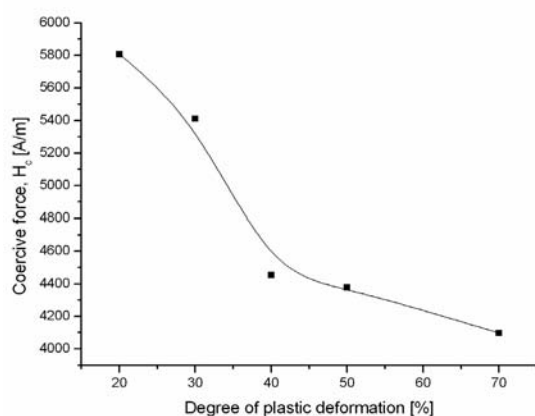


Fig. 11. Variation of coercive force in function of degree of plastic deformation for steel X5CrNi18-8

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  $\alpha'$  phase and induces in its structure a martensitic transformation  $\gamma \rightarrow \alpha'$ . 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  $\alpha'$  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  $\gamma \rightarrow \alpha'$ . The occurrence of  $\alpha'$  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  $\mu\text{m}$  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  $\alpha'$  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  $\alpha'$  phase in X5CrNi18-8 steel depends from degree of plastic deformation. Deformation steel with draft 70% leads to about 40% part quantitative  $\alpha'$  phase in structure of investigated steel.
- Diffraction lines (111) $\gamma$ , (110) $\alpha'$ ; (200) $\alpha'$ , (220) $\gamma$ ; (211) $\alpha'$ , (311) $\gamma$  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  $\mu$  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  $\alpha'$  phase is ferromagnetic phase.

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