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Influence of plastic deformation on structure and mechanical properties of stainless steel type X5CrNi18-10

W. Ozgowicz*, E. Kalinowska-Ozgowicz, A. Kurc
Division of Constructional and Special Materials, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: wojciech.ozgowicz@polsl.pl

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ABSTRACT

Purpose: The paper analyzes the influence of the degree of cold deformation on the structure and mechanical properties of austenitic stainless steel X5CrNi18-10.

Design/methodology/approach: The investigations included observations of the structure on a light microscope, researches of mechanical properties in a static tensile test and microhardness measurements. 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.

Findings: Plastic deformation in deep drawing process of container from investigated austenitic stainless steel induced in its structure martensitic transformation $\gamma \rightarrow \alpha'$.

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%÷50%.

Practical implications: The analysis of the obtained results permits to state that the degree of deformation has a significant influence on the structure and mechanical properties of the investigated steels. Besides, a good correlation was found between changes of the structure and the effects of investigations of the mechanical properties.

Originality/value: The analytic dependence of the yield point of the investigated steel on the draft degree in deep pressing process has been confirmed. Revealing this relation is of essential practical importance for the technology of sheetmetal forming of austenitic steel.

Keywords: Metallic alloys; Austenitic stainless chromium-nickel steel; Plastic deformation; Structure and mechanical properties; Deep drawing

PROPERTIES

1. Introduction

The existing demand for materials with high usable properties, a definite geometrical shape, a high resistance to the destructive effect of a aggressive environments, produced in compliances with a valid ecological standards, motivates the manufacturers to a continuous improvement in the engineering process, in particular of the steelmaking processes and plastic forming.

Metals and their alloys, mainly steels, belong to the most ecological and future constructional materials. The large demand for steel products is especially distinct in various industrial branches. The participation of these products in the total production remained on the same level for over 20 years, besides products from austenitic stainless steel constitute over 2/3 of this production [1-3].

Austenitic stainless steels are widely used materials because of their excellent corrosion resistance in various aggressive environments, combined with high mechanical and plastic properties. Steels of this type produced nowadays, can be divided structurally into: steels on a stable austenitic structure; steels with unstable austenite which can be transformed to the martensite as a result of plastic deformation; steels with an austenitic-ferritic structure [4-6].

Austenitic stainless steels contain most often about 16-25%wt. chromium, 0.1%wt. carbon and not less than 7.5%wt. nickel, which is indispensable to obtain of the single-phase structure γ. In the supersaturated state these steels are characterized by high plasticity and relatively low strength (R_m about 550 MPa; $R_{p0,2}$ about 200-250 MPa). Strain hardening of austenitic stainless steels is possible especially by cold working. Degree of strain hardening of these steels depends on the content of such elements as C, N, Mn, Ni and Cu [7-9].

Deep drawing is one of the generally applied methods of cold working of stainless steels. During this process in austenitic stainless steels at a higher draft degree the martensite transformation proceeds and the phase α' occurs in the structure. In austenitic stainless steels according to the chemical composition and the stacking fault energy, different transformations take place, such as: $\gamma \rightarrow \varepsilon \rightarrow \alpha'$ or $\gamma \rightarrow \alpha'$. The volume fraction of the particular phases influence the mechanical (strength, strain) and other properties for example corrosion resistance of these steels. The degree of martensite deformations depends on the volume of the applied draft, the chemical composition and plastic deformation temperature. Heating of austenitic stainless steels after cold rolling transformation $\gamma \rightarrow \alpha'$ can cause an inverse transformation of martensite to austenite after heating [10-15].

The aim of the tests was to define the influence of plastic deformation in deep drawing on the structure, mechanical properties and phases composition of the steel, particularly on the quantity of martensite α' in the structure of the investigated corrosion resistant stainless steels type X5CrNi18-10.

2. Experimental procedure

Investigations were carried out on austenitic stainless steel type X5CrNi18-10, resulting from industrial smelting from the JFE Steel Corporation (USA). The chemical composition of the investigated steel is to be seen in Table 1. The investigated material was supplied in the form of container with a diameter of 150 mm and heights 200 mm obtained in a deep drawing process from sheetmetal with a thickness of 0.3 mm. This sheet was sampled for research of the mechanical properties, for microhardness measurements, metallographic observations and the X-ray phase analysis (Fig. 1).

The mechanical properties were determined by means of a static tensile test at a traverse speed of 2 mm/min. Static tests were carried out on a testing machine Instron 4505. Samples for investigations of the mechanical properties were cut from the bottom and cylindrical parts of the container according to the scheme in Fig. 1a.

Metallographic investigations were made on longitudinal metallographic specimens ground and polished mechanically, according to the scheme in Fig. 1b. In order to detect the structure the metallographic specimens were etched in the reagent Mi17Fe heated to a temperature of about 40°C for 50-70 s. Metallographic observations of the investigated steel were made on an Axiovert 405 microscope with a magnification up to 500x. Microhardness measurements of the investigated steel X5CrNi18-10 were made by Vickers's method on metallographic samples with a load of 50 g, using the microhardness tester PMT-3.

X-ray examinations were run by means an X-ray diffractometer type DRON2, applying the filter radiation of an anode CoK_{α}. For the purpose of phase identification the range of angles 2Θ from 45^o to 115^o was analyzed. The step-scanning method was used at a step value of 0.1 in the scale 2Θ and a time of measurements amounting to 7 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 [16]. 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.

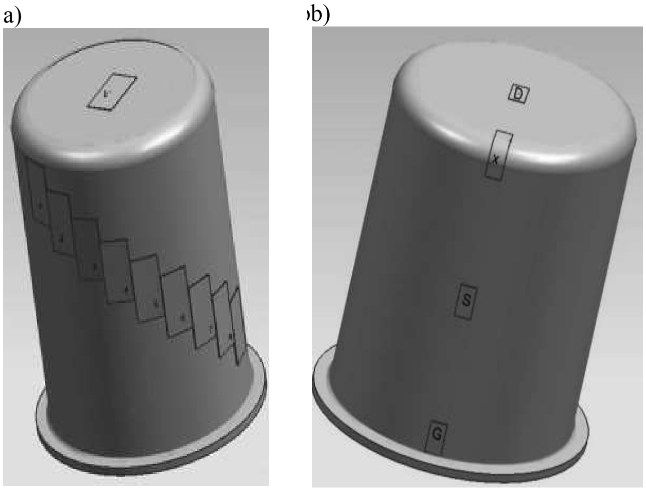

Fig. 1. Containers from stainless steel type X5CrNi18-10; the schema of taken samples for: a) mechanical properties and microhardness measurements, b) metallographic observations and X-ray analysis

Table 1.
Chemical composition of the investigated steel

Grade of steel	Kind of analysis	Chemical composition in mass %								
		C	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Cu**	**Ti**
X5CrNi18-10	ladle analysis	0.05	1.126	0.563	0.0411	0.0159	18.37	8.48	0.821	0.011
	by PN-EN 10088-1:1995	≤0.07	≤2.0	≤1.0	≤0.045	≤0.03	17.0÷19.0	8.0÷11.0	-	-

3. Results and discussion

In result of metallographic investigations the occurrence of a diversified structure of steel X5CrNi18-10 was found at the undeformed bottom and in the container shell which was deformed in draft from about 10% (area X) to about 50% (area G) - Fig. 1b. The steel structure at the container bottom shows equiaxial austenite grains about 22 μm average a diameter with many annealed twins, characteristic for the supersaturated state (Fig. 2). In the investigated steel there are agglomerations of copper precipitations and some non-metallic inclusions (Fig. 3). In the cylindrical parts of the container there was found a structure of elongated austenite grains. In elongated γ grains there are areas of parallel plates characteristic for martensite α' in the collar of the container (G) with a maximum degree of deformation, about 50% (Fig. 4). During the deep drawing of the container 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 results of the X-ray analysis and mechanical investigations confirm the occurrence of martensite α'. It was found that the value of the yield point $R_{p0,2}$ and hardness $HV_{0,05}$ increase with the degree of deformation, but the value of elongation A decreases (Fig. 5).

In the not deformed bottom of the container area the yield point of investigated steel is about 200 MPa, the hardness about $210HV_{0,05}$ and the elongation about 8.5%. With the increasing deformation within the range of 10-50% in the container shell of steel X5CrNi18-10 the yield strength increases from about 641 MPa to about 1088 MPa, the hardness from about 260 HV to 410 HV, while the elongation decreases from about 8% to about 4.5% .

X-ray investigations of steel X5CrNi18-10 deformed with draft from 30% to 50% confirmed the occurrence of α' martensite in the structure of the cylindrical parts of the container. α' phases were detected on diffraction patterns on the basis of the diffraction lines according to identifications from (110) and (211) reflection planes, which occurred with matrix lines Fe(γ) from (111), (002), (022) and (113) reflection planes and lines (620), (822), (844) of carbide $Cr_{23}C_6$ (Fig. 6). 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) Fe(γ) increases, too. It proves a distinct increase of α' phase in the structure of the investigated steel.

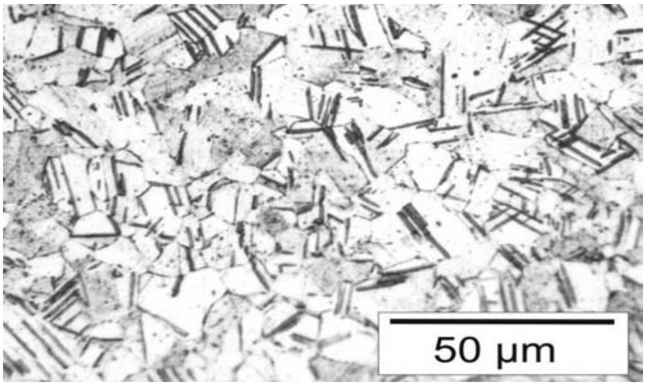

Fig. 2. Structure of investigated steel after supersaturation in water from temperature 1100°C. Etching - Mi17Fe

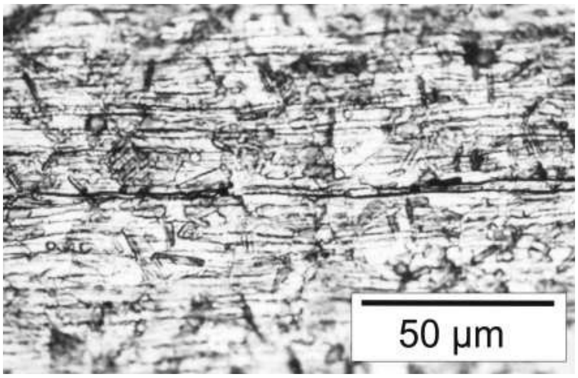

Fig. 3. Structure investigated steel after deformation with draft 30%. Etching- Mi17Fe

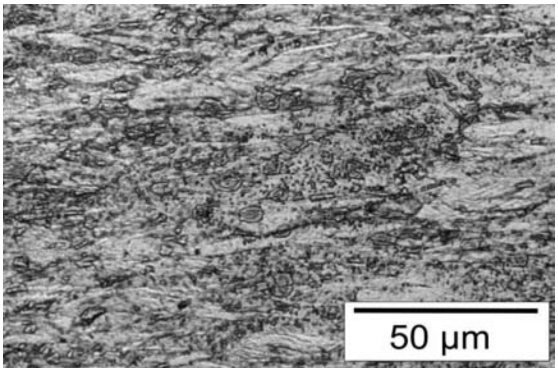

Fig. 4. Structure investigated steel after deformation with draft 50%. Etching- Mi17Fe

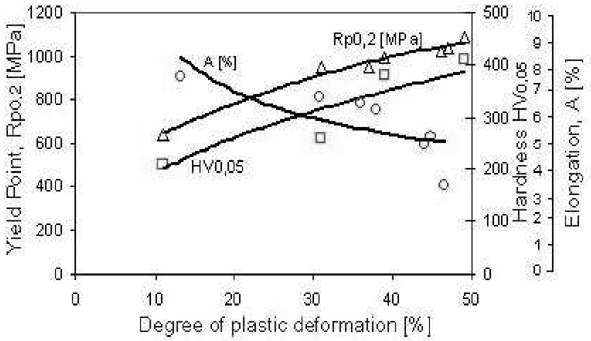

Fig. 5. The influence of plastic deformation on mechanical properties of investigated steel

The occurrence of the reflection lines (110) α' in diffraction patterns influences essentially the improvement of the procedure used in the phase analysis.

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 deep drawing process. At the undeformed container bottom the phase α'it does not occur, but in the deformed container shell the area with a draft of about 50% the amount of martensitic phases is about 20%.

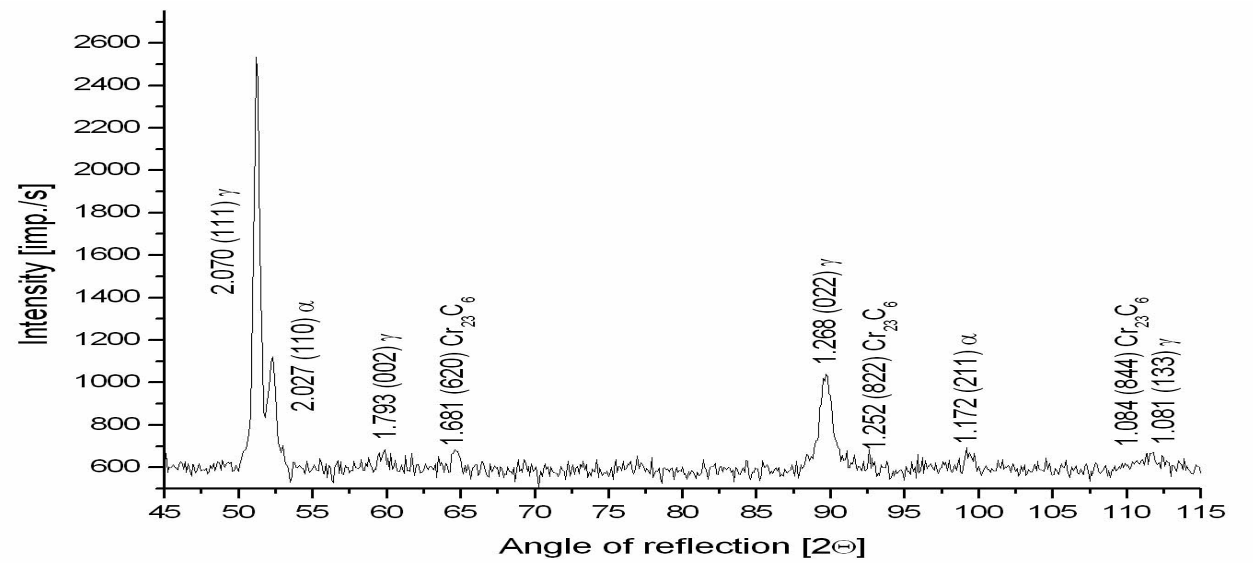

Fig. 6. X-ray diffraction patterns of steel X5CrNi18-10 with draft deformation 50%

4. Conclusions

1. Plastic deformation in the deep drawing process of a container of austenitic stainless steel type X5CrNi18-10 induces in its structure a martensitic transformation $\gamma \rightarrow \alpha'$.
2. In the undeformed state the steel X5CrNi18-10 has equiaxial grains γ with twins, characteristic for the supersaturated state, but after deformation with a draft of about 50% - in a structure with elongated austenite grains with martensite α' phase plates.
3. The increase of the deformation degree of steel X5CrNi18-10 in the range 10-50% causes an increase of the value of $R_{p0,2}$ from about 641 MPa to about 1088 MPa, $HV_{0,05}$ from about 260 HV to about 410 HV and elongation A decreasing from about 8% to about 4.5%.
4. X-ray quantitative phases analysis shows that the deformation of investigated steel with a draft of about 50% leads to a share of about 20% of martensitic α'phases in the steel structure.

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