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ANALYSIS OF THE INITIAL DEFORMABILITI OF AUSTENITIC STAINLESS STELLS WITH A BEND TEST

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Austenitic stainless steel solidify under non-equilibrium conditions, and form two-phase microstructure of austenite and δ-ferrite. Workability of steels in hot are better in the primary crystallization of δ-ferrite. The influence of chemical composition on solid-state formation of delta ferrite phase during hot deformation was investigated. The laboratory prepared austenitic stainless SS2343 steel with the Cr_{eq}/Ni_{eq} index – 1,62 were chosen for this research. The transformation of δ-ferrite during annealing in range 1 050 – 1 250 °C was analyzed. Hot bending test was selected for the evaluation of the initial plasticity of "as cast" SS2343 steel. Bending test of as cast steel plates with volume fraction 12,5 % of δ-ferrite have shown, that cracks do not form.

Key words: austenitic stainless steel, chemical composition, δ-ferrite, bending test, heat annealing

INTRODUCTION

The properties and performance of austenitic stainless steels are strongly related to their microstructures, especially the amount and distribution of delta ferrite. Microstructure according to this type of stainless steel, is defined by chromium and nickel equivalent (Cr_{eq}/Ni_{eq} index) [1,2]. The mechanism of solidification is principle in the following schemes:

$$L = L+\gamma = L+\gamma+\delta = \gamma+\delta \text{ (prim. austenitic)}$$

$$L = L+\delta = L+\delta+\gamma = \gamma+\delta \text{ (prim. ferrite)}$$

In function of the concentration of alloying elements, which are γ-or α-genes, the solidification can begins primarily through nucleation of austenite respectively in δ-ferrite [3,4]. During solicitation in austenitic-ferrite mode, δ-ferrite is formed between the dendritic interstice and are enriched with impurities elements. Ferrite nucleates in the Cr-rich and Ni-depleted regions as a non-equilibrium phase. Due to the high concentration of impurities in these places, cracks often occur, which are spreading during the forming. During solidification in ferrite-austenitic sequence, the crystalline grains of ferrite form within the dendritic branches of austenite. Here the concentration of impurities is lower than the average in the alloy, and therefore the possibility of cracking is smaller. The consequence of segregation at the boundaries of the dendrites is the mechanical instability of the steel during hot forming [5,6]. In the continuous casting of steels, where the cooling rate is very high, a part of metastable δ-ferrite is maintained at room temperature due to imperfect transformation of δ in γ. The parameters which affect the microcrostructure of materials under hot deformation can be divided in two groups of external (temperature, strain and strain rate) and internal (chemical composition) factors [7]. The aim of the study was to determine, if the presence and shape of the crystal grains of δ-ferrite does not worsen deformability during hot formability.

EXPERIMENTAL

The research focused on laboratory prepared SS2343 steel with the chemical composition given in Table 1. The Cr_{eq}/Ni_{eq} ratios was 1,62.

Table 1 **Chemical composition of austenitic steel SS2343 / wt./%**

C	Si	Mn	Cr	Ni
0,023	0,75	1,52	17,4	10,8
Ti	Mo	Al	P	S
0,05	2,62	0,009	0,052	0,017

For the laboratory austenitic steel SS2343, the thermodynamic calculations were performed with the Thermo-Calc program [8,9]. Volume fractions of polymorpus equlibrium phases were predicted in the temperature range 700 – 1 700 K. The phases considered in the thermodynamic calculation are liquid, f.c.c. (austenite), b.c.c. (α- and/or δ- ferrite), carbides $M_{23}C_6$, intermetalic σ sigma phases.

Hot bending test was selected for the evaluation of hot plasticity of "as cast microstructure" for selected steel. Samples for bend test were cast in a special mold, where dimensions of casted samples were 250 x 40 x 20

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mm. Test specimens were bended in a hot condition at temperature of 1 200 °C.

The maximum tensile deformation in bending area has reached 28 %. Specimen at maximum deflection section have virtually no spread. On Figure 1 we see the bend test specimen from the convex and lateral directions.

The content of δ-ferrite in sample steel SS2343 was between 10,7 % and 14,6 %. In laboratory steels, the proportion of δ-ferrite was slightly lower at the edge of the bending test piece, due to higher cooling rate of cooling.

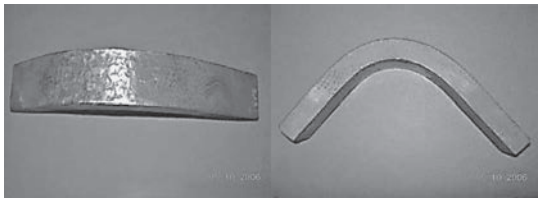

Figure 1. The macro image of the bend specimen

The content of δ-ferrite in the sample in the "as cast" state, depending on the temperature and time of annealing is shown in Table 2.

Table 2. **Contents of δ-ferrite in the bend test specimen according to the state-cast / annealed**

Temp. anneling (*T*/°C)	Proportion of δ-ferrite */wt./%*			
		1 050	1 150	1 250
cast -state	12,51			
annealing 5 min		8,64	5,07	6,17
annealing 40 min		8,29	2,64	5,52

The holding time at a certain temperature influences the ratio of ferrite content before and after annealing. The ferrite content decreases with a higher temperature and a longer annealing time, up to a temperature of 1 150 °C. Then the content of ferrite is approximately constant to the temperature of 1 200 °C. At annealing temperature higher than 1 250 °C, the ferrite content are increased again.

In the case of annealing, the δ-ferrite dissolves and changes shape. Solidification microstructure ("as cast") of the SS2343 steel and its microstructure after 5 minutes annealing at 1 050 °C is shown on Figure 2a and b, respectively. In "as cast" macrostructure are clearly seen structured ferrite network, after annealing at 1 050 °C are seen a single, partially enclosed residues ferritic cellular. In the case of annealing temperature of 1 150 °C, the ferritic network is no longer seen (Figure 3a); partially spheroidized ferrite has mainly form into roughly equiaxed grains. Therefore, the ratio between the energy of the surface and the volume energy of δ-ferrite is greatly reduced. After annealing at 1 250 °C the ferrite net transforms into the spherical islands (Figure 3b). With a longer annealing time (40 min), ferrite spheroidization is even more pronounced.

The chemical composition of δ-ferrite is independent of the temperature and annealing time, enriched with chromium and molybdenum, and depleted with nickel. The contents of chromium, nickel and molybdenum, and their distribution between δ-ferrite and austenite with respect to the temperature and time of annealing for steel SS2343 is shown in Figure 4. The Figure 4 shows that, for the same time of annealing, the

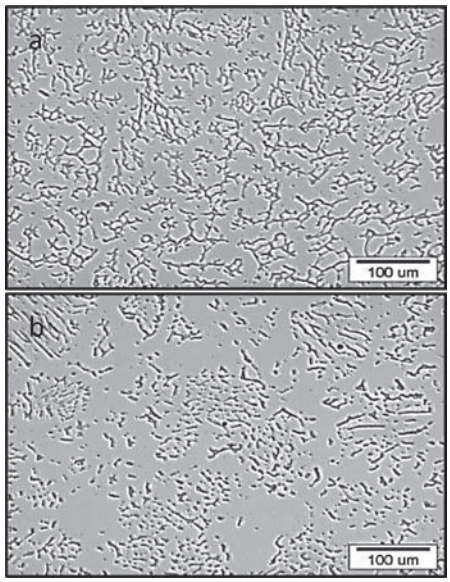

Figure 2. δ-ferrite in cast microstructure (a) and after 5 min annealing at 1 050 °C (b)

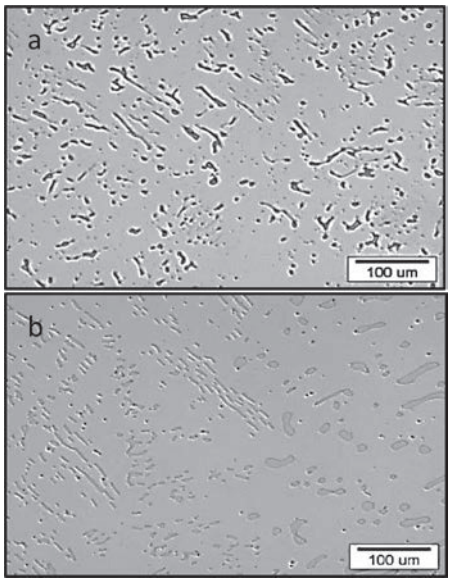

Figure 3. δ-ferrite in microstructure after annealing 5 min at 1 150 °C (a) and 5 min at 1 250 °C (b)

chromium content in δ-ferrite decreases slightly with a higher temperature.

The chromium content in δ-ferrite is slightly higher after the annealing time of 40 minutes. The same con-

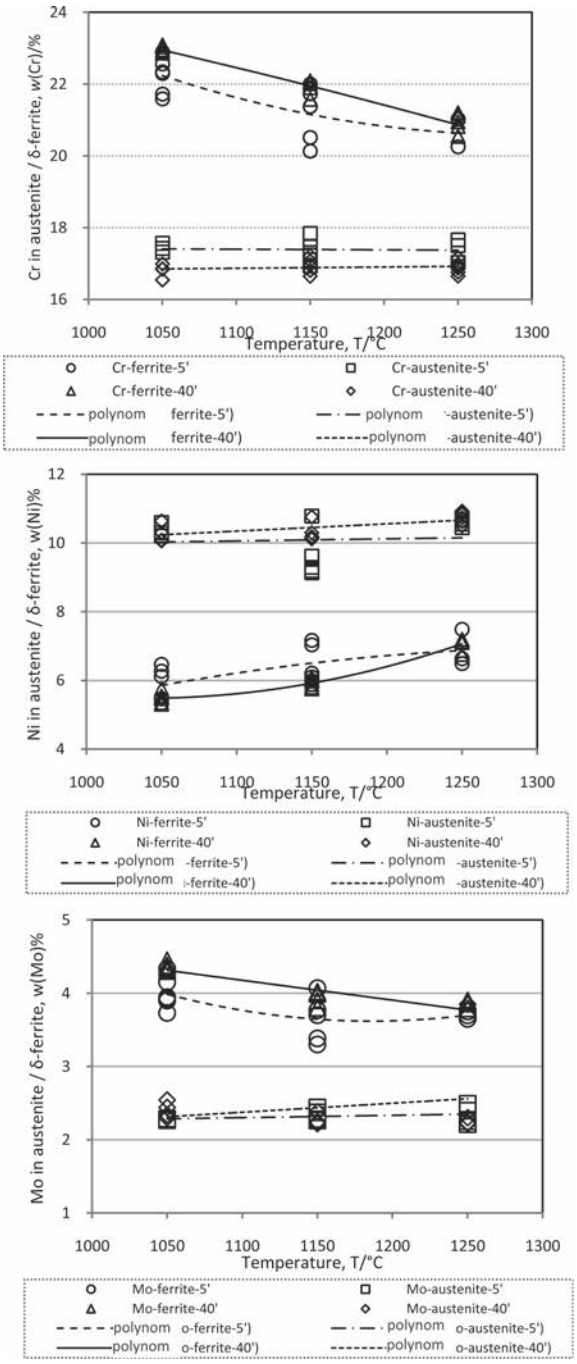

Figure 4. Distribution the content of Cr, Ni and Mo in the δ-ferite and austenite, on the temperature and time of annealing in SS2343 steel

tent of molybdenum slightly increases during a longer annealing.

Nickel content in the δ-ferrite increases with higher temperature and longer time of annealing.

Measurements of element content were made on the smallest grains of δ-ferrite, which were in the microstructure at individual annealing temperatures. The spread of the chromium, nickel and molybdenum content from the average content is much lower in the δ-ferrite than in austenite.

Linear analysis 23,3 μm length, through the »region« of γ - δ - γ, in SS2343 steel samples is showing the distribution of austenitic and ferrite - stabilizing elements in Figure 5.

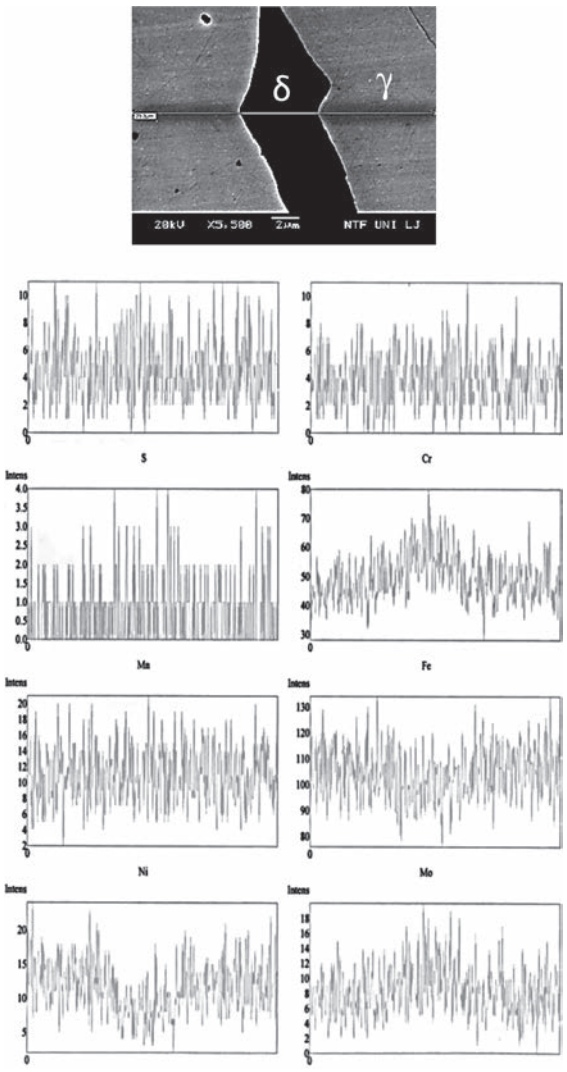

Figure 5. Linear distribution of elements through the "region" of γ - δ - γ in steel SS2343 after 5 min annealing at 1 150 ° C.

Thus, sulfur and phosphorus and manganese exhibit a high local concentration and are distributed in the austenite and δ- ferrite. The contents of chromium and molybdenum are greater in the δ-ferrite, while there is lower content of nickel in δ-ferrite.

CONCLUSIONS

The hot bending (bend test) was selected for the evaluation of the initial plasticity during forming of austenitic stainless steel SS2343. We assumed that the solidification microstructure of selected steel is not sensitive to the formation of the cracks during bending in the temperatures regions between 1 050 °C to 1 250 °C, regardless of the content and shape of the δ ferrite. At 28 % tensile deformation and the volume fraction of δ-ferrite up to 12,5 % did not reduce the deformability of steel namely at the surface and at the edges of the specimen, where they first appear in the rolling of industrial slabs. No visible cracks occurred on the tensile and pressure surfaces of the bending test piece. We did not find them on the edges of the rectangular test sample where the deformation was not only in tension.

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Note: Responsible person for English translation M. M. Travnik Vode, Višnja Gora, Slovenia