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The impact of deformation on structural changes of the duplex steel

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Materials

ABSTRACT

Purpose: Despite the many years' research on the plasticity of duplex steels, it was impossible to conclusively determine the mechanisms for structure recovery during the plastic deformation. The paper will attempt to provide explanations for the changes taking place in the steel structure during the superplastic flow.

Design/methodology/approach: After a solution heat treatment at 1250°C, the steel was subjected to cold deformation through rolling with the total 70% reduction. The specimens were tensioned in the "Instron" strength-testing machine at temperature 850°C at a rate of v_r=15×10^{-3} mm/s in a 0.005Pa vacuum. Structural examination was carried out using light and electron microscopy. The micro-diffraction technique was applied to provide diffraction images with Kikuchi lines.

Findings: A joint operation of structure reconstruction mechanisms during the deformation of the analyzed steel with the process of σ phase precipitation inhibiting further growth of the newly-formed grain has been determined.

Practical implications: The capacity for increased deformability through combined thermo - mechanical processes, requiring a precise selection of the deformation parameters, has been indicated

Originality/value: The results obtained are vital for designing an effective thermo - mechanical processing technology for the investigated steel.

Keywords: Superplastic materials; Plastic forming; Microstructure; Hot tensile test

1. Introduction

Recently, there has been a growing interest in (α+γ) duplex steels in many different industry branches, particularly on the chemical and petrochemical fronts [1-4]. Ferritic-austenitic steels are an alternative to single-phase steels characterized by an austenitic structure not only with regard to their properties but also because of the lower production costs connected with decreased amounts of nickel . These materials show very high resistance to corrosion coupled with high strength. The enhanced strength properties of two-phase steels when compared to single-phase steels, are connected with the presence of both ferrite and austenite in the steel structure, with the former affecting plasticity, and the latter possessing strengthening qualities. In many industry branches (α+γ), duplex steels of the have not been popularized well enough due to the problems they pose in shaping, resulting from the different properties of the two phases making up the material. Literature [5 - 8] provides information on plasticity tests carried out on ferritic-austenitic steels and oriented to provoke the effect of superplasticity by complex thermoplastic processes. Despite the many years' research on the plasticity of these steels, it was impossible to conclusively determine the mechanisms for structure recovery during the plastic deformation [9-12].

The influence of tension parameters on the technological plasticity and structural changes been shown in the papers [13, 14]. This paper will attempt to provide explanations for the changes taking place in the steel structure during the superplastic flow.

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2. Material and methodology

The research material was sheet metal with an initial thickness of h_0=3mm, made from the X2CrNiMoN22-5-3 steel and subjected to a solution heat treatment from T=1250°C (grade 1.4462 acc. to EN 10270) characterized by a ferritic-austenitic structure (Fig. 1) whose chemical composition is indicated in Table 1.

Table 1.
Chemical composition of the X2CrNiMoN22-5-3 steel (%-wt.)

C	Si	Mn	Ni	Cr	Mo	N	S	P
0.017	0.30	1.57	5.45	22.8	3.12	0.169	0.0009	0.019

The steel was subjected to cold deformation through rolling with the total relative draft of ε_h=0.7. Then samples were prepared for hot deformation by tension, with the initial length of the measurement base of 3mm. In order to stimulate the effect of superplastic flow, the tensioning was performed at T=850°C with the velocity of v_r=15×10^{-3}mm/s in vacuum of 0.005Pa

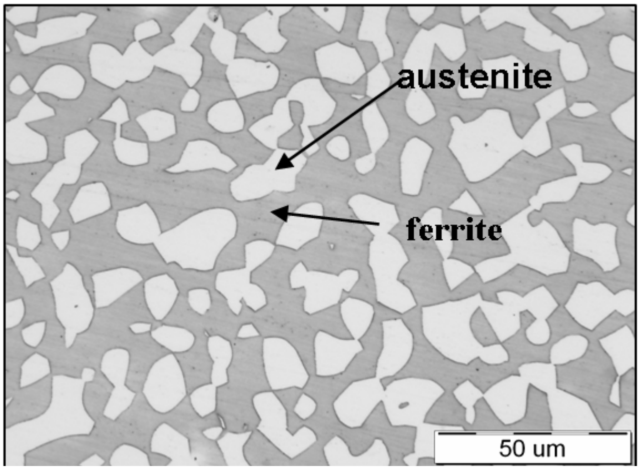

Fig.1. Structure of the X2CrNiMoN22-5-3 ferritic-austenitic steel after solution heat treatment from a temperature of T=1250°C with soaking time of 60 minutes and cooling in water. Austenite surface fraction is A_A=30±0.5%

The deformation was conducted to a predefined elongation until failure, after which samples were cooled down using compressed air. Elongation of the sample with an initial 3mm measurement base was marked as A_{3mm}. Material for investigations of the structure and substructure was sampled after tension. The structure was examined with a light microscope, while the substructure was examined with a transmission electron microscope, using the thin foil technique. To evaluate misorientation angles between adjacent subgrains, diffraction tests were carried out on a transmission electron microscope. The micro-diffraction technique was applied to provide diffraction images with Kikuchi lines. The misorientation angles were determined by using KILIN software.

3. Results

When tensioning the material at a temperature of T=850°C with the velocity of v_r=15×10^{-3}mm/s, elongation to failure was obtained at A_{3mm}=740%. The changes occurring in the structure of the X2CrNiMoN22-5-3 steel together with the distribution of misorientation angles in selected stages of tension are shown in Figures 2-6. After heating up to tension temperature, i.e. T=850°C, ferrite in the investigared steel undergoes transformation into austenite, in accordance with reaction and σ phase precipitates [10, 12]: $\alpha \rightarrow \gamma + \sigma$.

Following a solution heat treatment from T=1250°C and deformation of ε_h=0.7, and subsequent tension at T=850°C, the steel's structure consists of fine-grained austenite, σ phase precipitations and coarse-grained austenite formed in during the solution heat treatment. Extending both the heating time as well as elongation growth of A_{3mm} result in a reduction of the austenite fraction [14].

Some selected examples of the steel substructure after solution heat treatment beginning at 1250°C and elongation of A_{3mm}=60% corresponding to the maximum force value are presented in Figures 2, 3. We also observed austenite formed during the solution heat treatment and austenite created as a result of transformation from ferrite, as well as σ phase precipitates. Inside the coarse-grained austenite, there are some areas with major defects, free from the σ phase precipitates (Fig. 2). Remains of the cold deformation process as well as an outline of dislocation cells characterized by high dislocation density were also noted.

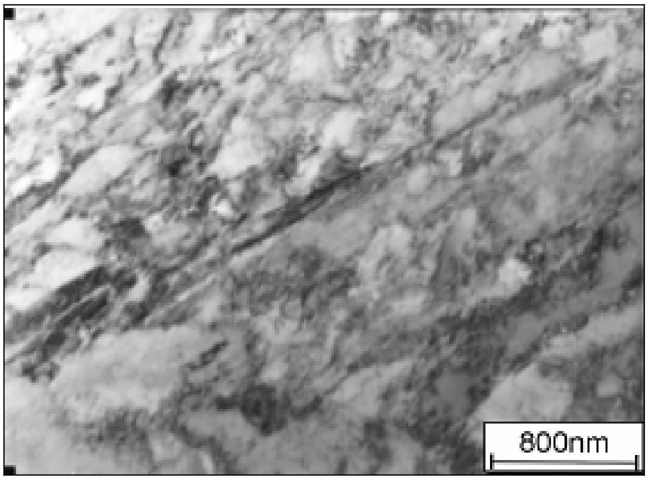

Fig. 2. The structure of steel subjected to tensioned at T=850°C with the velocity of v_r=15×10^{-3}mm/s, to the elongation of A_{3mm}=60%. Primary austenite region

In areas where the σ phase is present along with austenite formed as a result of transition from ferrite, the process of subgrain formation can be seen (Fig. 3), with the misorientation angles between individual subgrains not more than 5°. The phase precipitates mainly at austenite grain boundaries, but some precipitates are also visible inside the austenite matrix. Thus, the existing structural defects account for potential locations for the phase nucleation. In the course of deformation, new potential nucleation locations of the σ phase are being continuously created.

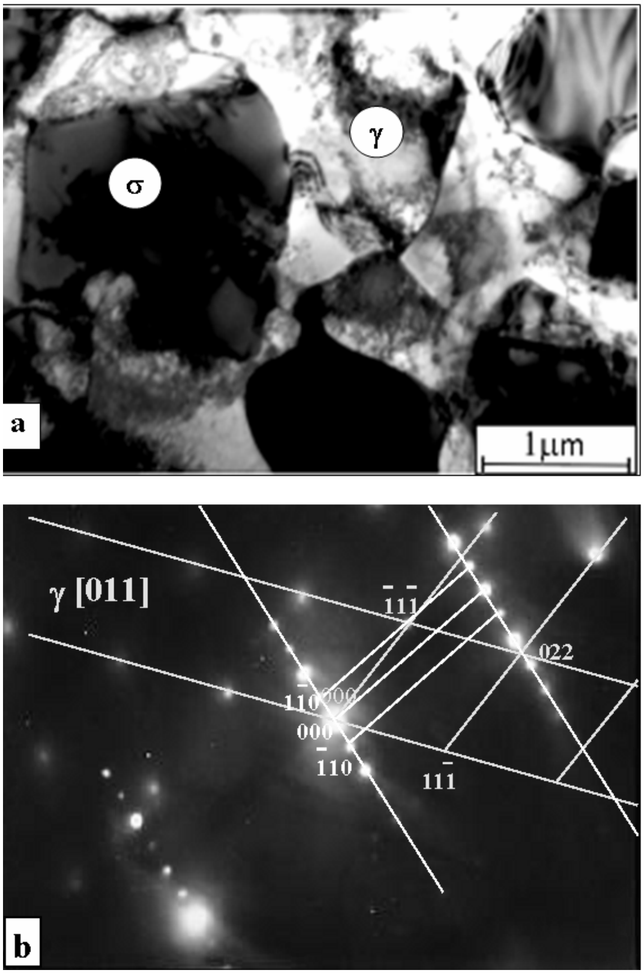

Fig. 3. The structure of steel subjected to tensioned at T=850°C with the velocity of $v_r=15\times10^{-3}$mm/s, to the elongation of A_{3mm}=60%, a - austenite region formed as a result of transition from ferrite and σ phase precipitates, b - diffraction from the centre figure 3 a

A statistical distribution of misorientation angles between grains following the deformation up to A_{3mm}=61%, implies the presence of austenite grains with misorientation angles between 10° and 38° (Fig. 4). Figure 5 shows the steel structure after elongation of A_{3mm}=200%. A subgrain structure is formed in the austenite, which later transforms into new grains. This fact is verified, inter alia, by the presence of extinction contours within the area of wide-anglegrains.

The nucleation of new grains can be observed, testifying to the dynamic recrystallization taking place mainly in regions of high dislocation density (Fig. 5a). Precipitation of the σ phase occurs at both grain boundaries and inside the austenite grain (Fig. 5b).

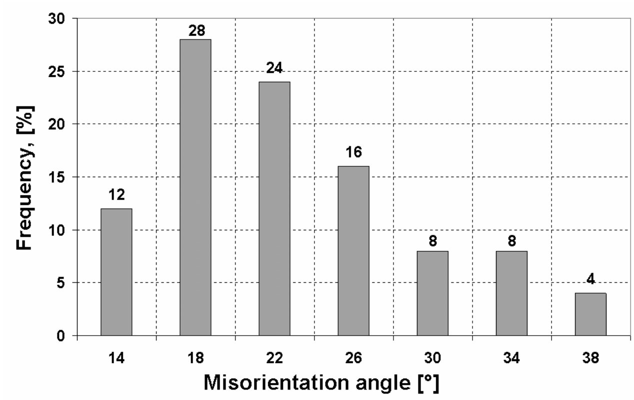

Fig. 4. Statistical distribution of the coarse-grained austenite's misorientation angle after elongation of A_{3mm}=60%

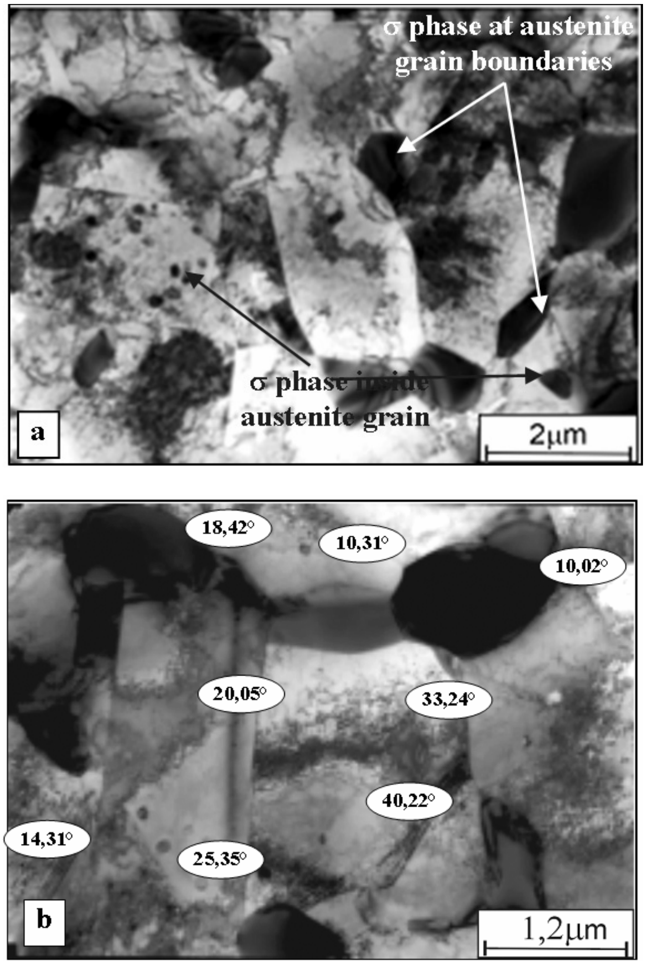

Fig. 5. The structure of steel subjected to tension up to the elongation of A_{3mm}=200%, a - Region of austenite and σ phase precipitation, b - Misorientation angles between austenite grains in the vicinity of σ phase precipitates

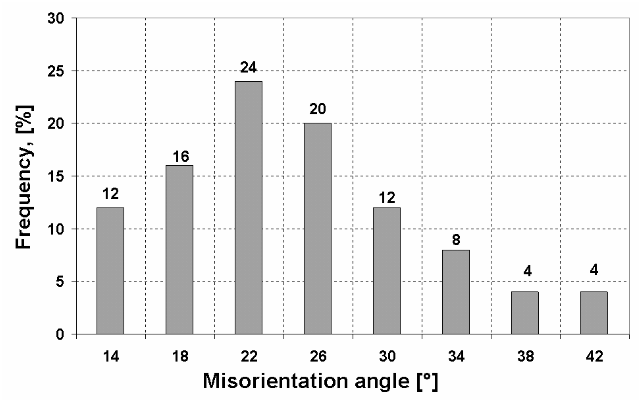

Fig. 6. Statistical distribution of the austenite grain's misorientation angle after elongation of A_{3mm}=200%

The statistical distribution of the grain misorientation angles following that elongation indicates an increased fraction of grains with higher angle values (Fig. 6). The misorientation angles' values range from 10° to 42°, with their most frequent range being 22-26°.

4. Conclusions

The conducted studies allowed an evaluation of changes in the structure of the analyzed X2CrNiMoN22-5-3 steel subjected to solution heat treatment from T=1250°C and cold deformation of ε_h=0.7 as well as determination of the course of the changes during tension in the conditions of superplastic flow. The obtained elongation of the steel until failure, A_{3mm}=740%, is distinctive of superplastic flow. This effect in ferritic-austenitic steel is linked to the $\alpha \rightarrow \gamma + \sigma$ transition occurring during deformation at the temperature of 850°C.

The structure consists of coarse-grained austenite formed during solution heat treatment, as well as fine-grained austenite and σ phase precipitates formed during deformation by tension. The increase in elongation from 60% to 200% results in a reduced fraction of coarse-grained austenite in the steel structure. The σ phase precipitates both inside grain and at austenite grain boundaries. The presence of fine σ phase precipitates, which inhibit the growth of new austenite grain and ensure a fine-grained structure during the process, have a profound impact on the superplastic flow effect.

A continuous reconstruction of the austenitic matrix takes place. The continuing recrystallization allows the formation of new, free from defects, equiaxial grain. The reconstruction of the structure is also reflected in the increased misorientation angle accompanying the increased elongation.

The paper illustrates a joint operation of structure reconstruction mechanisms during the deformation of the analyzed steel, i.e. the continuous dynamic recrystallization, consisting of an increase of the grain misorientation angle plus increased deformation accompanied by grain growth, and dynamic recrystallization, consisting of grain nucleation and growth of new grains with the process of σ phase precipitation inhibiting further growth of the newly-formed grain.

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