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The influence of thermo - mechanical processing on deformability and structural changes of duplex steel

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Materials

ABSTRACT

Purpose: In conventional hot deformation methods of duplex steels, low values of boundary strain are obtained, resulting from the disparate behaviour of ferrite and austenite. This paper analyses the capacity for enhancing deformability of two-phase ferritic-austenitic steels of the "duplex" type via thermo mechanical processing.
Design/methodology/approach: Steel specimens were subjected to cold deformation with a 70% rolling reduction. After a hot solution treatment beginning at 1350°C, the specimens were tensioned in the "Instron" strength-testing machine in temperatures ranging from 800 to 950°C at a rate of v_r=15×10-3÷3×10-1mm/s in a 0.005Pa vacuum. Structural examination was carried out using light and electron microscopy. A quantitative analysis of structural changes was performed using the „MetIlo" image analysis programme.
Findings: The process parameters at which the investigated steel shows the superplastic flow effect have 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

High-alloy steels of the duplex type (α+γ) of a ferritic-austenitic structure belong to the group of corrosion-resistant steels. They show higher corrosion resistance in comparison with steels of one-phase ferritic and austenitic structure, which, when coupled with their high strength and lower production costs resulting from a lower nickel content, makes them a material more and more widely used in a variety of industry branches [1÷3]. They are used for the production of desulfurisation, desalting and purifying machinery, as well as pipelines, tanks, pump components, or even bridge structural components [4, 5]. However, there are numerous branches of industry where the (α+γ) duplex steels have not yet been sufficiently popularised due to problems with their forming, resulting from different properties of the both phases which make up the material. The literature [6, 7] provides us with some information on plasticity tests conducted on ferritic-austenitic steels so as to induce the superplasticity effect as a result of complex thermo-plastic processes. Most frequently, superplasticity is determined by: heat treatment, cold plastic strain (normally below 50% of draft) and hot tension at a very low rate [6÷8]. The deformation process of (α+γ) duplex steels after cold plastic working is frequently carried out at a temperature of 700÷950°C, where precipitation of the σ phase takes place. The presence of the σ phase affects brittleness of the material at a temperature below 400°C, although it does not affect ductility at a temperature of 400÷950°C. In properly selected deformation conditions, the reduced in size precipitations of the σ phase make the steel attain superplastic properties [9, 10]. In spite of long-lasting research on plasticisation of these steels, the explicit determination of the structure reconstruction mechanisms during their deformation processes has proved to be unsuccessful [9 - 11].

This paper analyses the influence of temperature and tension rate on the superplastic flow of the (α+γ) duplex steel. The influence of tension parameters on the qualitative and quantitative image of structural changes has been determined. The paper is also an attempt at explaining the changes that take place in the steel structure during superplastic flow.

2. Material and methodology

The material for the research was a steel sheet of the initial thickness equal h_0=3mm, made from the X2CrNiMoN22-5-3 steel solutioned at T=1350°C (grade 1.4462 acc. to EN 10270), of a ferritic structure with an insignificant amount, i.e. 2.8% of austenite (Fig. 1) and a chemical composition presented 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 by rolling with the total rolling reduction ε_h =0.7. Next, specimens were made for hot deformation by tension, with the initial measuring basis length of 3mm. Tensile tests were performed by means of a hydraulic strength testing machine, Instron 8801. In order to induce the superplastic flow effect, tension was conducted in the temperature range of T=800÷950°C, at a rate of v_r=15×10^{-3}÷3×10^{-1}mm/s, in a 0.005Pa vacuum. The deformation process was conducted both until the predetermined elongation and until failure, with the specimens being cooled with compressed air. The elongation of a specimen with the initial measuring basis of 3 mm is designated as A_{3mm}. After tension, material for structural examination was taken from the specimens. Evaluation of the steel specimens' structures after failure was made at a 2mm distance from the failure point, whilst the structure of specimens deformed until the predefined elongation was evaluated in the place of the greatest localisation of the deformation. Observation of the structures was conducted on an "Olympus" light microscope and on a "Hitachi" S-4200 scanning microscope. The microstructure, including the σ phase, was detected by electrolytic etching in a 20% NaOH solution. A quantitative evaluation of the structure was conducted using the METILO programme [12, 13]. The following quantities were determined:

- surface fraction of individual phases A_A[%],
- mean grain plane section area (precipitations) $\bar{A}$ [μm^2],
- grain plane section variability ratio v($\bar{A}$) [%].

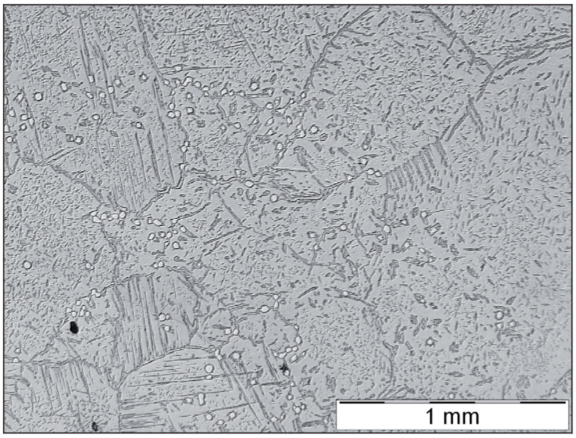

Fig. 1. Structure of the X2CrNiMoN22-5-3 steel after solution heat treatment from T=1350°C, with soaking time of 60 minutes and cooling in water. Surface fraction o Surface fraction of ferrite A_A=97.8%±0.5%

3. Results

Tensile curves presenting the influence of tension temperature at a rate v_r=15×10^{-2}mm/s of an earlier cold deformed steel, whose total relative rolling reduction was ε_h=0.7, on the course of changes of force (F) as a function of elongation A_{3mm} are shown in Fig. 2. After exceeding the value of F_{max} , tension takes place at a decreasing value of force until failure. The greatest elongation until failure, A_{3mm}=1250%, is achieved by the steel subjected to tension at a temperature T=950°C. An increase of tension temperature in the range of T=800÷950°C leads to obtaining greater and greater elongation until failure A_{3mm} .

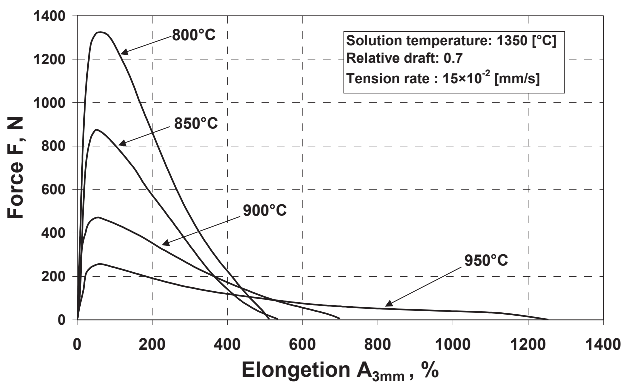

Fig. 2. Influence of tension temperature at a rate v_r=15×10^{-2}mm/s on the form of force/elongation curves

The results of the influence of tension rate at T=850°C of the cold deformed steel of a total relative rolling reduction ε_h=0.9 on the course of changes of force (F) as a function of elongation A_{3mm} is presented in Fig. 3

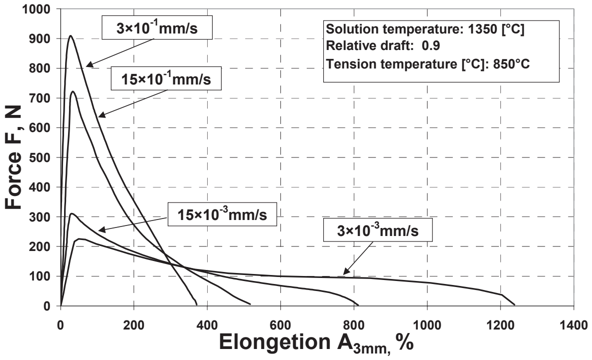

Fig. 3. Influence of tension temperature at a rate v_r=15×10^{-2}mm/s on the value of percentage elongation until failure A_{3mm}

The tensile curves obtained for the steel investigated show a similar shape. However, the rate at which the material "softens" during tension after exceeding the maximum force F_{max}, varies.

Ferrite in the ferritic-austenitic steel after its heating to the investigated range of tension temperature, i.e. T=800÷950°C, undergoes transition to austenite and precipitations of phase σ [8], according to reaction $\alpha \rightarrow \gamma + \sigma$.

The results of the influence of elongation A_{3mm} on the changes of structure during tensioning are shown in Fig. 4. In the structure of the steel after solution heat treatment from T=1350°C and deformation ε_h=0.7, followed by tensioning at T=850°C, an increase of the size of sigma phase is observed as the deformation increases paper.

The results of the quantitative analysis of structural changes depending on elongation are juxtaposed in Table 2. As elongation A_{3mm} increases, the surface fraction of σ phase grows and changes from 12.9%±0.5% at elongation A_{3mm}=24%, to a value equal 16.9%±0.5% at A_{3mm}=930%.

The increase of elongation A_{3mm} is accompanied by growth of the mean plane section area of precipitation, reaching the highest value, $\bar{A}$=1.19µm^2, at elongation after failure.

However, no explicit influence of elongation A_{3mm} on inhomogeneity of the σ phase precipitation size has been found.

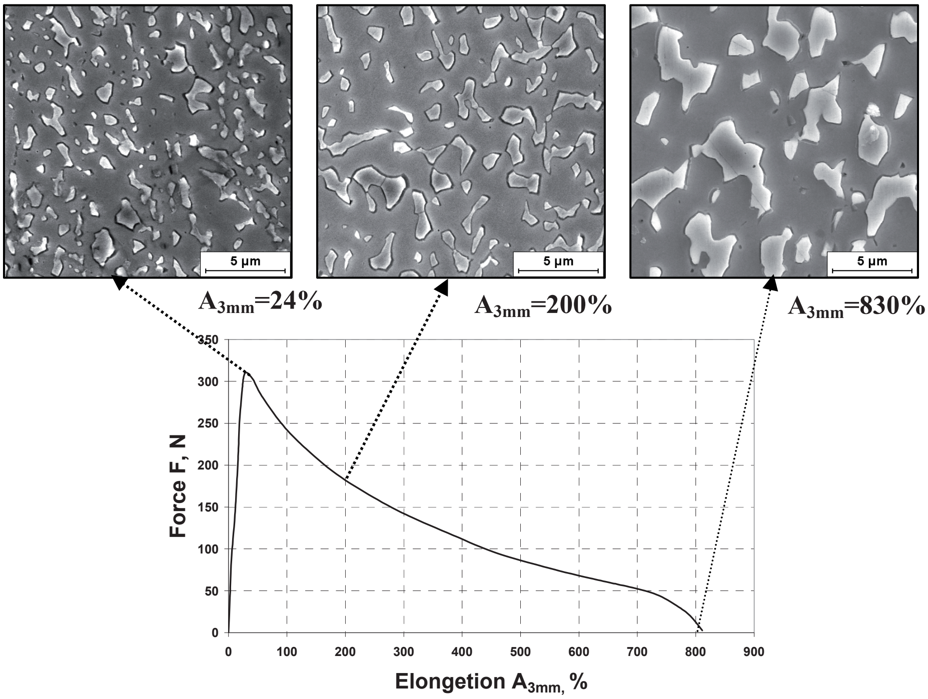

Fig. 4. Influence of elongation on the structure of steel tensioned at a temperature T=850°C and rate v_r=15×10^{-3}mm/s after cold deformation ε_h=0.7

Table 2.
Results of the influence of elongation A_{3mm} on the quantitative description of structural changes

	A_{3mm}=24%	A_{3mm}=200%	A_{3mm}=830%
Surface fraction of phase σ, [%]	12.9	13.1	16.9
Mean area of the σ phase precipitation, $\bar{A}$ [µm^2];	0.34	0.39	1.19
Inhomogeneity of the σ phase precipitation, v($\bar{A}$) [%],	85	57	148

4. Conclusions

The research carried out allow evaluating the influence of tension parameters on the obtained elongation until failure and changes in the structure of the X2CrNiMoN22-5-3 steel solutioned from T=1350°C and subjected to cold deformation, ε_h=0.7. It was shown in previous papers that solution heat treatment of the investigated steel from the temperature of 1350°C results in obtaining a ferritic structure. This, in turn, results in obtaining higher values of deformation until failure when compared to specimens deformed from a solutioned material from lower temperatures in the ferritic-austenitic scope [12]. The obtained elongation until failure amounting to A_{3mm}=370÷1250% testifies to the occurrence of the superplastic flow effect in the investigated range of tension parameters. The effect in the ferritic-austenitic steel in connected with the transition $\alpha \rightarrow \gamma + \sigma$ which takes place during the deformation process.

Increasing elongation during tensioning results in an increasing fraction and size of the σ phase in the material structure. The σ phase fraction in the steel structure after tensile tests at a tension rate of $v_r=15\times10^{-2}$mm/s depends on the temperature at which the process in conducted and it is in compliance with the CTW diagram [14, 15]. The precipitation process is the most intensive at temperature T=850°C. As the tension temperature increases in the range of T=800÷950°C, the percent elongation until failure, A_{3mm}, grows (Fig. 2, 3). The temperature increase is conducive to more intensive dynamic processes of structure reconstruction. The greatest elongation, A_{3mm}=1250%, was obtained at T=950°C, where the structure is still composed of austenite and σ phase precipitations. A continued increase of the process temperature in accordance with the equilibrium diagram [16] would cause precipitation of the ferritic (α+γ) phase, without a fraction of σ phase precipitation grains which hinder the growth. This, in turn, would lead to a grain growth and have an adverse effect on deformability of the X2CrNiMoN22-5-3 steel.

As the tension rate increases in the range of $v_r=15\times10^{-3}s^{-1}\div3\times10^{-1}$mm/s, decreasing elongation, A_{3mm}, is observed. A decreasing tension rate results in an increase of the fraction and size of the σ phase precipitations (Fig. 4.). This is connected with diffusion of the elements, nucleation and growth of the σ phase precipitations.

The results obtained are vital from the point of view of design of the thermoplastic processing technology for the investigated steel.

Acknowledgements

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