Letter to the Editor

The influence of plastic deformation on the reverse transformation $\alpha \rightarrow \gamma$ in Fe-30Ni alloy

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Abstract

The specimens of Fe-30Ni (wt.%) alloy were subjected to deformation-induced martensitic transformation. Thermo-mechanical treatment resulted in the formation of a composite-like microstructure in which the martensite is the strengthening phase. Rolling at temperature of austenite transformation start (A_S) leads to deformation-induced $\alpha \rightarrow \gamma$ reversed transformation. The achieved austenite exhibits a high density of defects, which influences strength and plasticity of Fe-30Ni alloy.

K e y w o r d s: iron alloys, deformation structure, reversed martensitic transformation, light microscopy (LM), transmission electron microscopy (TEM), rolling

1. Introduction

The investigations on improvement of mechanical properties of materials are focused mainly on modifications of chemical composition, heat treatment and thermo-mechanical treatment.

Changes in the morphology of phases can also lead to significant hardening, as was reported for brasses, pearlitic steels and Fe-Ni alloys [1].

The Fe-30Ni (wt.%) alloy exhibits austenitic structure at room temperature. Martensitic transformation can be achieved by quenching or plastic deformation. Under the appropriate rolling conditions (deformation mode, temperature, strain), composite-like materials with unique structure, texture and mechanical properties can be achieved [2]. The changes in morphology and volume fractions of phases result in meaningful increase of strength [3]. The improvement of plasticity can be achieved by thermo-mechanical treatment or conventional rolling and heat treatment leading to $\gamma \rightarrow \alpha$ and $\alpha \rightarrow \gamma$ transformations, and in consequence grain refinement [4, 5].

The previous work of the authors on the improvement of strength and plasticity of Fe-30Ni alloy [6] was focused on the achievement of composite-like microstructure by deformation-induced phase transformation followed by the cyclic thermo-mechanical treatment consisting of cooling in liquid nitrogen and annealing slightly above the temperature of austenitic transformation finish (A_F). After such treatment, the temperature of martensitic transformation start (M_S) decreased. The obtained grain refinement resulted in improvement of mechanical properties.

The aim of the present work was to improve the strength and ductility of Fe-30Ni alloy by deformation-induced reversed transformation.

2. Material and experimental procedure

The chemical composition of the investigated alloy is given in Table 1. The alloy was produced by vacuum melting, hot worked for 8 mm thick sheets and solution annealed at 1150 ℃ for 1 hour. The resulting as-received material exhibited austenitic structure. To achieve composite-like structure, the specimens were rolled with 30% strain in two paths, the first at room temperature and second in perpendicular direction at

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Table 1. Chemical composition of the alloy investigated (wt.%)

C	Mn	P	S	Cu	Cr	Ni	Fe
0.01	0.11	0.07	0.013	0.04	0.38	28.5	bal.

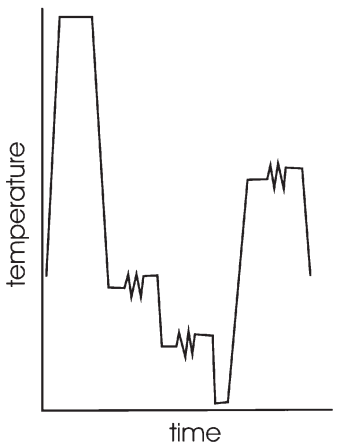

Fig. 1. Schematic diagram of the thermo-mechanical treatment.

a temperature of –80 °C. As was determined in the previous investigations of Fe-30Ni alloy [7], the temperature of deformation-induced martensitic transformation start M_D is approximately –30 °C, M_S temperature is approximately –90 °C and the temperature of reversed austenite transformation $A_S = 350$ °C. To finish martensitic transformation, the specimens were quenched in liquid nitrogen. After such treatment the volume fraction of martensite was 90 vol.%. More than 30 vol.% of martensite was oriented in one direction, which was the main factor influencing the strengthening [8]. At this temperature the third rolling with 30% strain was performed. A schematic diagram of the thermomechanical treatment is shown in Fig. 1.

Microstructural investigations were carried out by means of light microscopy (LM) and transmission electron microscopy (TEM) after each step of thermomechanical treatment. The martensite volume fraction was determined using magnetic and stereological methods. Quantitative metallography measurements of martensite volume fraction V_V^M were performed by the point-counting method using the formula:

$$V_V^M \cong P_P^M.$$

The mean number of points in the particular phase P_P^M was calculated as:

$$P_P^M = \frac{\sum_{i=1}^{k} P_i^M}{k \cdot z}, \tag{1}$$

where z is the number of measuring points, k is the number of measurement areas. In our case $z = 529$, $k = 15$.

The error of measurements δ was calculated using the equation:

$$\delta = u_\alpha \sqrt{\frac{P_P^M(1 - P_P^M)}{k \cdot z}}, \tag{2}$$

where k is the number of measurement areas, z is the number of measuring points, $u_\alpha = 1.96$, for reliability level = 0.95.

Mechanical properties: ultimate tensile strength R_m, yield strength $R_p0.2$, total elongation A_5 and uniform elongation A_r were determined by tensile tests. The results were compared with those obtained for different variants of thermomechanical treatments, namely:

1. rolling with 30% strain at room temperature + perpendicular rolling with 30% strain at −80 °C,
2. as in variant 1 + quenching in liquid nitrogen,
3. as in variant 2 + annealing at 500 °C for 5 minutes,
4. as in variant 2 + rolling with 30% strain at 350 °C.

3. Results and discussion

After perpendicular rolling and quenching in liquid nitrogen, the martensite plates are preferentially-oriented transcrystalline in one direction (Figs. 2 and 3). The estimated volume fraction of martensite is 90 vol.% [8]. The following deformation at temperature of 350 °C led to reversed $\alpha \rightarrow \gamma$ transformation. Microstructural analysis showed that the transformation was not completed, and only a part of the total volume fraction of martensite was transformed to austenite, as is illustrated in Fig. 4. The austenite and martensite volume fractions are determined to be: $V_V^A = 23 \pm 1$ vol.%, $V_V^M = 76 \pm 1$ vol.%, respectively.

Rolling at A_S temperature led to reversed transformation, after which the volume fraction of martensite decreased to 14 vol.%. Figure 5 shows the TEM image of the microstructure after reversed transformation. The austenite exhibits high density of dislocations, which are formed both in former martensite and during plastic deformation.

Results of tensile tests showed pronounced increase of mechanical properties in comparison with material

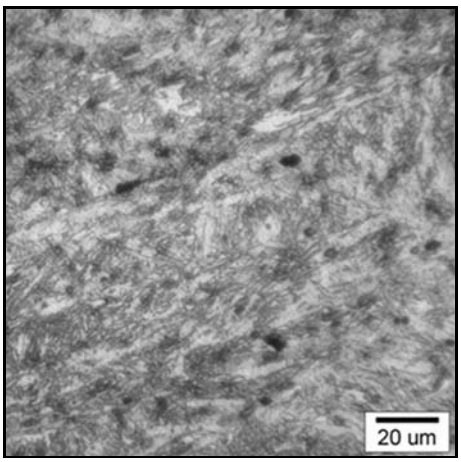

Fig. 2. Microstructure of the alloy after variant 2 of thermo-mechanical treatment.

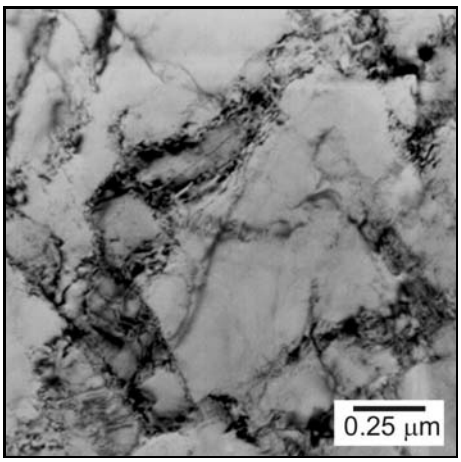

Fig. 5. TEM image of the microstructure of the alloy after deformation according to variant 4.

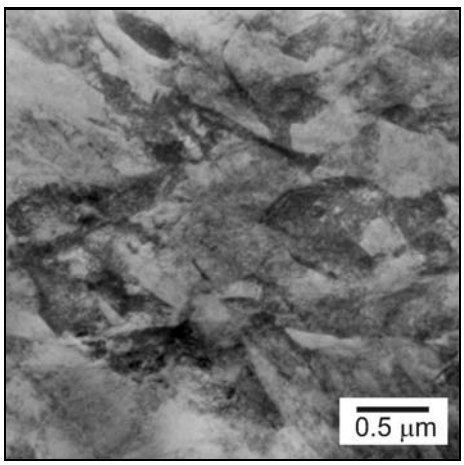

Fig. 3. TEM image of the microstructure of the alloy after deformation according to variant 2.

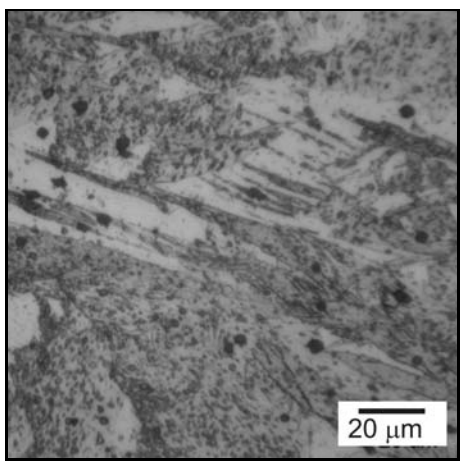

Fig. 4. Microstructure of the alloy after variant 4 of thermo-mechanical treatment.

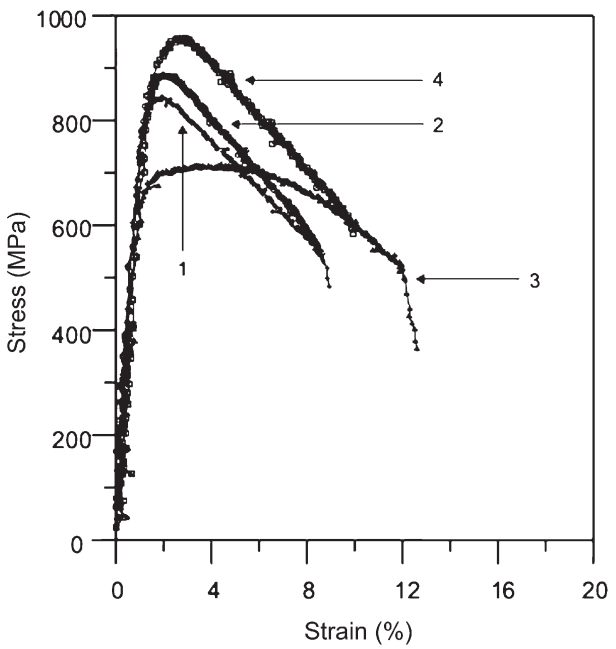

Fig. 6. Tensile curves of specimens deformed according to variants 1–4.

subjected to other variants of thermomechanical treatment. Figure 6 shows the comparison of tensile curves obtained according to different variants. The values of mechanical properties determined by tensile tests are listed in Table 2.

The results showed that reversed $\alpha \rightarrow \gamma$ transformation can be induced by plastic deformation, which leads to improvement of mechanical properties. A high density of defects in austenite influences good strength and plasticity.

Table 2. Results of tensile test of specimens after selected variants of thermo-mechanical treatment

Variant	R_m (MPa)	$R_p0.2$ (MPa)	A_5 (%)	A_r (%)
1	873	799	9.3	1.8
2	889	842	8.9	2.2
3	651	599	12.7	4.3
4	956	905	10	3

4. Conclusions

1. It was demonstrated that the reversed $\alpha \rightarrow \gamma$ transformation could be induced by deformation.

2. The reversed austenite inherits high dislocation density of former martensite and those formed during the plastic deformation.

3. Deformation leading to reversed $\alpha \rightarrow \gamma$ transformation strongly influences the improvement in mechanical properties of Fe-30Ni alloy.

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