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EFFECT OF PHASE TRANSFORMATION ON THE AUSTENITE AND MARTENSITE TEXTURES IN Fe-30Ni ALLOY

WPŁYW PRZEMIAN FAZOWYCH NA TEKSTURY AUSTENITU I MARTENZYTU W STOPIE Fe-30Ni

The effect of phase transformation on the texture development upon deformation, quenching and annealing was investigated in the Fe-30Ni alloy. Deformation induced $\gamma \rightarrow \alpha$ transformation took place during rolling of Fe-30Ni alloy and textured α-phase appeared in the samples structure. Quenching of previously deformed samples caused martensite texture strengthening as an effect of the thermally induced martensitic transformation. During subsequent annealing the reverse transformation proceed leading to the austenite and martensite textures very similar to those, which were caused by deformation. These result points out the reversible character of the texture changes caused by thermally induced phase transformation and stable character of transformation effects introduced by plastic deformation. On the base of the ODF calculations and texture simulations it was concluded that Kurdjumow-Sachs relationship gives the best description of the $\gamma \rightarrow \alpha \rightarrow \gamma$ transformations in Fe-30Ni alloy.

Keywords: Fe-30Ni alloy, texture, austenite, marteniste, phase transformations

Badano wpływ przemian fazowych na rozwój tekstury w czasie odkształcenia, chłodzenia i wyżarzania stopu Fe- 30Ni. W czasie walcowania w strukturze stopu Fe-30Ni pojawia się steksturowany martenzyt jako efekt indukowanej odkształceniem przemiany $\gamma \rightarrow \alpha$. Schłodzenie odkształconych próbek do temperatury ciekłego azotu powoduje wzmocnienie tekstury martenzytu co jest efektem przemiany fazowej indukowanej termicznie. W czasie nagrzewania wcześniej odkształconych i schłodzonych próbek zachodzi przemiana odwrotna prowadząc do uzyskania tekstury austenitu i martenzytu niemal identycznej z uzyskaną po odkształceniu. Wskazuje to na odwracalny charakter zmian tekstur spowodowanych indukowaną cieplnie przemianą austenitu w martenzyt i bardzo stabilny charakter efektów transformacji fazowej, która była spowodowana odkształceniem. Na podstawie analizy funkcji rozkładu orientacji i przeprowadzonych symulacji tekstur stwierdzono, że relacja Kur-

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d j u m o w a - S a c h s ' a najlepiej opisuje transformacje $\gamma \to \alpha \to \gamma$ zachodzące w stopie Fe-30Ni.

1. Introduction

The Fe-30Ni alloys are of special interest of many research groups due to their properties and application [1-6]. In these alloys $\gamma \to \alpha$ transformation takes place and (ferrite) martensite can reverse to austenite by non-diffusional mechanism in $\alpha \to \gamma$ transformation, manifested in a memory-shape effect. The influence of thermo- mechanical treatment on the structure of these alloys was investigated in previous works [5, 6]. It was found that special thermo-mechanical treatment enables to obtain the composite-like structures with exceptional mechanical properties. These specific structures can be obtained in martensite transformations, which can be induced thermally or by plastic deformation. Martensite morphology in Fe-30Ni alloys strongly depends on appropriate thermo-mechanical treatment conditions. The change of deformation conditions (deformation mode, temperature and degree of reduction) enables for a modelling of martensite morphology and its volume fraction. For better understanding of these processes in present work the texture development was investigated in the course of thermo-mechanical treatment of Fe-30Ni alloy.

Phase transformations occur usually when material is processed by hot or cold rolling or by heat treatment. The $\gamma \to \alpha$ martensite transformation may be induced by plastic deformation at temperature lower than M_d or thermally induced during cooling below the M_s temperature. The reverse $\alpha \to \gamma$ transformation usually proceeds by re-heating over austenite start temperature A_s. If the parent phase is textured, the phase transformation occurs in textured material. Therefore a product of the transformation also exhibits texture. This can be explained on the base of the knowledge that a characteristic crystallographic relation connects the product with the parent phase in diffusionless first order transformations. Usually B a i n, K u r d i u m o v - S a c h s (K-S), or N i s h i y a m a - W a s s e r m a n n (N-W) relationships are proposed to describe martensitic transformation [1-4].

In Fe-30Ni alloy the austenite γ–phase is stable at room temperature. For this reason Fe-30Ni alloy is more suitable to study $\gamma \to \alpha$ transformation in comparison to numerous commercial steels of where all described transformations occur at elevated temperatures. This makes difficult to study mentioned relationships because of the experimental problems for studying textures at high temperatures. In Fe-30Ni alloy it is also possible to study partially transformed structures at room temperature at which both the austenite and product martensite co-exist.

2. Material and experimental procedure

The chemical composition of the investigated Fe-30Ni alloy is given in table. To obtain starting material, ingot of the alloy was cast in vacuum, hot rolled to the thickness of 8mm and subsequently annealed at 1150°C for 1h. This treatment gave starting samples with the homogenous austenite structure and nearly random texture.

TABLE

Chemical composition of the investigated alloy in wt. %

C	Mn	P	S	Cu	Cr	Ni	Fe
0.01	0.11	0.07	0.013	0.04	0.38	28.3	balance

Starting material was first cold rolled at room temperature to 30% deformation. Then the deformed samples were divided into three groups and each group was treated according different thermo-mechanical schedule:

— quenched in liquid nitrogen (directly after cold rolling)

— cross rolled 30% at room temperature and subsequently quenched in liquid nitrogen

— cross rolled 30% at -30°C and subsequently quenched in liquid nitrogen.

After quenching all samples were annealed at 550°C for 10 minutes to induce reverse $\alpha \rightarrow \gamma$ transformation. On each stage of the thermo-mechanical treatment texture and structure investigations were performed.

Cross rolling in the present material was done in such a way that rolling plane (RD/TD) from the first stage became the longitudinal plane (TD/ND) at the next one. This mode of rolling schedule with the change of the rolling plane was introduced to obtain special composite-like martensite structure in deformed materials. Commercial advantage of such microstructures is its higher toughness of the material [5, 6]

3. Texture measurements

X-ray texture measurements were carried out on a computer controlled 4-circle goniometer in the back reflection mode by use of the Bruker AXS D8 Advance diffractometer. All texture measurements were done at room temperature, what was possible due to the fact that martensite start M_s temperature in Fe-30Ni alloy is lower than room temperature and austenite start A_s temperature in reverse $\alpha \rightarrow \gamma$ transformation is higher than the room temperature [7].

Textures were examined by measuring of incomplete pole figures {110}, {200} and {211} for the martensite and {111}, {200} and {220} for the austenite phase, using cobalt X-ray tube. Incomplete pole figures ($\alpha_{\max} = 70°$) were measured in $\alpha \times \beta = 5° \times 5°$ steps. The orientation distribution function (ODF) of the both phases were calculated by the series expansion method and are presented in the Euler space with φ_1, ϕ and φ_2 angels with in range from 0° to 90° — Fig 1 and 2. In the current work the ODF's are plotted as isointensity diagrams in Euler space. To present austenite texture φ_2 = const, whereas martensite φ_1 = const ODF's cross-sections are used.

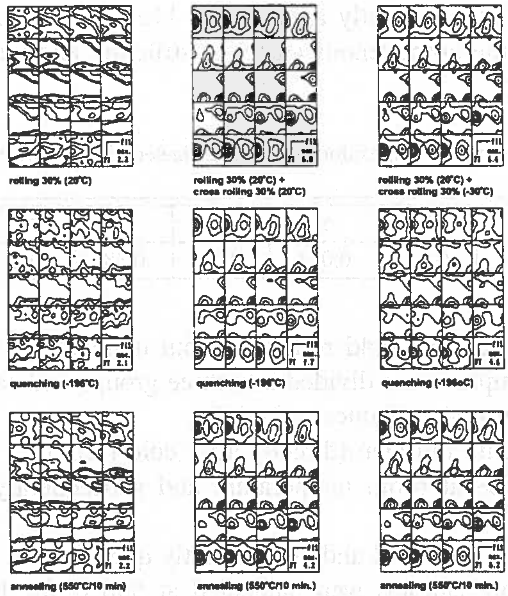

Fig. 1. ODF's φ_2 = const, cross sections presenting austenite textures of Fe-30Ni alloy after subsequent deformation and heat- treatment

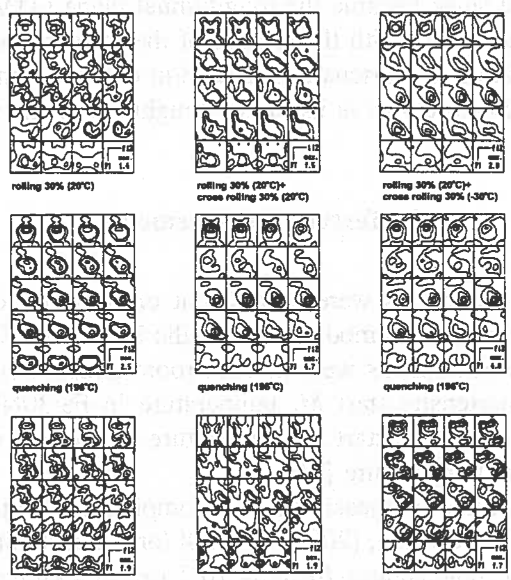

Fig. 2. ODF's φ_1 = const, cross sections presenting martensite textures of Fe-30Ni alloy after subsequent deformation and heat-treatment

4. Experimental results and discussion

Quantitative phase analyse revealed that only starting material had austenite single--phase structure with random texture, whereas materials on each stage of the processing exhibited two-phase structures. The phase composition of investigated material was varying from austenite in the starting material to dominating martensite structure after quenching and back dominating austenite after re-heating accompanied by some amount of α-phase.

The austenite and martensite textures for entire processing and the whole transformation cycle are presented in figures 1 and 2 respectively. Starting material exhibited not textured austenitic single-phase structure. Austenite texture development and deformation-induced phase transformation took place during cold rolling. Typical austenite texture was observed in 30% rolled samples and this texture became stronger after second rolling for both i.e. room and –30°C rolling temperature. This texture can be described by orientation α- fibre $<110>$||ND with the major {011}$<100>$, {011}<511> components and much weaker {011}<211> orientation. Within this texture also τ-fibre <110>||TD, S-type {123}<111> and {134}<111> orientations are present too. Cold rolling up to 30% of reduction caused the $\gamma \rightarrow \alpha$ phase transformation and the appearance of textured martensite within the structure of Fe-30Ni alloy. Martensite texture was weak and even second rolling at –30°C did not lead to the evident martensite texture strengthening. About 5% of martensite were detected in the samples after cold cooling at room temperature. After second rolling at –30°C about 7% of martensite was detected in deformed structure indicating that M_d temperature is higher than –30°C [7].

Well-pronounced texture changes occurred when cold rolled samples were quenched in liquid nitrogen. Austenite texture became weaker, however without change of the type. At the same time, due to the thermally induced phase transformation, martensite with the strong texture was obtained. This texture can be described mostly by the strong α-fibre $< 110 >$||RD. As a result of thermally induced phase transformation over 80% of martensite was present in samples structure after quenching [7]. Comparison of the textures after different thermo-mechanical schedule indicates that austenite with the stronger texture gave as a product more textured martensite.

At the next experimental step, reverse $\alpha \rightarrow \gamma$ transformation was induced by annealing of the previously deformed and quenched samples. After annealing and resulting phase transformation the austenite texture was almost the same as the texture of the material after cold rolling (before quenching). Small differences were also observed in martensite textures after annealing and those after cold rolling (prior to quenching). Since annealing did not lead to the starting single-phase austenite structure it means that only effects of thermally induced phase transformation are reversible. After whole transformation cycle both the material structure and texture is preserved that is the indication thet martesitic structure induced by strain is stable.

5. Transformation texture calculations

When the crystallographic orientation relationship between parent and product phase is known, transformation texture can be calculated and the relation between parents and product textures can be analysed. In the case of the $\gamma \rightarrow \alpha$ transformation such simulation can be performed in two ways: (i) martensite texture after $\gamma \rightarrow \alpha$ transformation can be simulated on the basis of measured austenite texture, (ii) parent austenite texture can be calculated on the base of experimentally measured martensite texture. By comparison of experimentally measured and calculated textures, the relation describing mutual orientation between parent and product phase, which is taken for evaluation, can be verified or proposed.

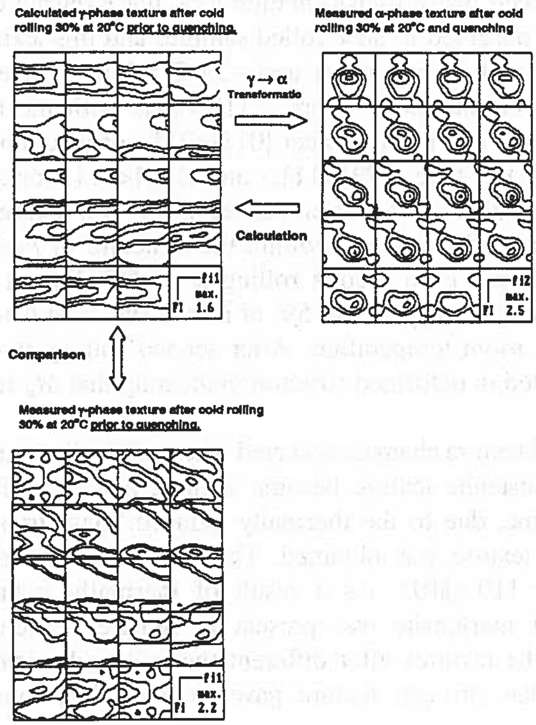

Fig. 3. γ-phase texture calculated on the base of measured α-phase and measured γ-phase texture

In the current experiment only the later procedure (ii) was applied. The example of the calculated texture and its comparison with the experimental texture are given in figure 3. All simulations were carried out assuming that each parent orientation is transformed according to Kurdjumov-Sachs into 24 product orientations without variant selection. These calculations were done with the assumption that there are not favourable relations and all 24 mutual orientation variants between martensite and austenite gave the same contribution to the texture transformation. Comparison of the calculated (with the above assumption) and measured austenite textures indicates that they are very similar for all employed thermo- mechanical schedules. This could be the prove that Kurdjumov-Sachs relation is that which describes transformation in Fe-30Ni alloys and that there are no preferable variants in- between 24 theoretical possible relations.

6. Conclusions

- Strain and thermally induced $\gamma \rightarrow \alpha$ phase transformations are reflected in the austenite and martensite texture changes in Fe-30Ni alloy.
- Typical austenite and martensite textures are developed during deformation of Fe-30Ni alloy.
- Martensite texture resulting from $\gamma \rightarrow \alpha$ strain induced transformation is stable upon annealing. On the contrary texture changes caused by thermally induced $\gamma \rightarrow \alpha$ phase transformations have reversible character.
- Kurdjumov-Sachs orientation relationship is that which describes texture changes in Fe-30Ni alloys during $\gamma \rightarrow \alpha$ and $\alpha \rightarrow \gamma$ phase transformation.

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