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DEVELOPMENT OF THE ORIENTATION RELATIONSHIP BETWEEN FERRITIC AND AUSTENITIC PHASES DURING LONG TIME ANNEALING OF DUPLEX STAINLESS STEEL

ZMIANY RELACJI ORIENTACJI MIĘDZY FAZAMI W STALI FERRYTYCZNO-AUSTENITYCZNEJ ODPORNEJ NA KOROZJĘ PODCZAS DŁUGOTRWAŁEGO WYŻARZANIA

The paper presents an analysis of the orientation relationship development between ferritic and austenitic phases during long time annealing. The investigated material was duplex stainless steel. After cold-rolling with 80% reduction in thickness the samples were annealed at temperature 1050°C for 1, 10, 100 and 1000 h. The microstructure and texture were examined by optical microscopy, SEM / EBSD technique as well as X-Ray diffraction.

It was found that the occurance of the special misorientation (Kurdyumow- Sachs relationship) between ferrite and austenite grains increased with annealing time. The development of texture components in the austenitic and the ferritic phases has been also analysed.

Keywords: duplex stainless steel, annealing, texture, microtexture.

W pracy przedstawiono analizę zależności pomiędzy orientacjami sąsiadujących faz w stali odpornej na korozję (ferrytyczno-austenitycznej), poddanej długotrwałemu wyżarzaniu. Po odkształceniu 80% nadanemu przez walcowanie w temperaturze pokojowej, próbki wyżarzano w temperaturze 1050°C przez 1, 10, 100 oraz 1000 h. Zmiany mikrostruktury i tekstury badano przy pomocy mikroskopii optycznej oraz elektronowej (mikroskop skaningowy, dyfrakcja elektronów rozproszonych wstecznie) jak również dyfrakcji rentgenowskiej. Stwierdzono, że występowanie specjalnej dezorientacji (relacji Kurdiumowa–Sachsa) pomiędzy ziarnami fazy ferrytycznej i austenitycznej powiększało się ze wzrostem czasu wyżarzania. Analizowano również rozwój składowych tekstur fazy ferrytycznej i austenitycznej.

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1. Material

The investigation was carried out on duplex stainless steel of the chemical composition Fe- 24.16Cr-5.48Ni-3.27Mo-1.20Mn-0.54Si-0.153N-0.022C-0.021P-0.001S wt. % [1].

Before annealing the steel was rolled at room temperature with 80% reduction in thickness. Annealing was conducted at 1050°C, for: 1 , 10, 100 and 1000 h. Before annealing the samples were sealed in evacuated quartz capsules.

The annealing temperature was the same as the anealing temperature of steel before cold-rolling with 80% reduction in thickness.

2. Results

Metallographic examinations were carried out on mechanically and eloctrolytically polished longitudinal sections, afterwards electrolytically etched in a solution of 40 g NaOH in 100 ml of H_2O at room temperature and at 2 V. The values of a mean intercept of austenite grains and the volume fraction of austenite are given in

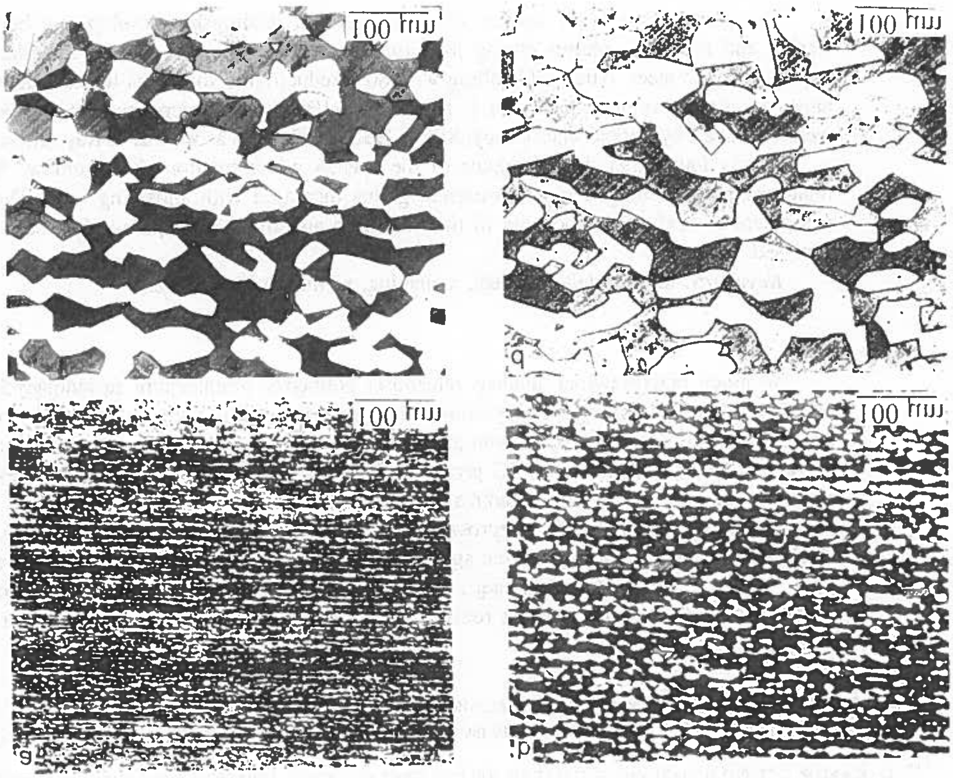


Fig. 1. Microstructures after annealing: a) 1 h, b) 10 h, c) 100 h, d) 1000 h

Table 1. The intercept of austenite grains was measured in the direction parallel to the normal direction. Microstructure development with the annealing time is ilustrated on micrographs from an optical microscope in Fig. 1.

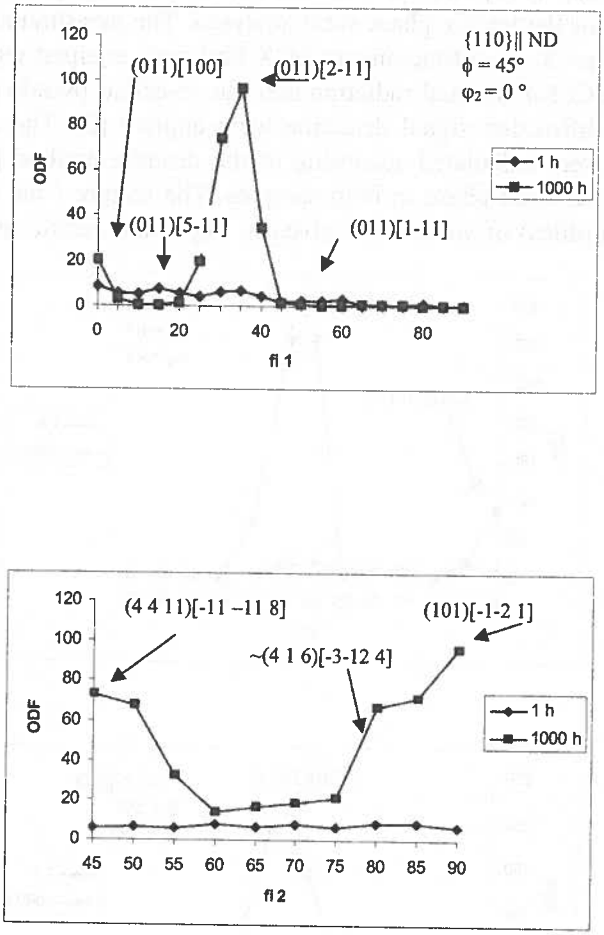
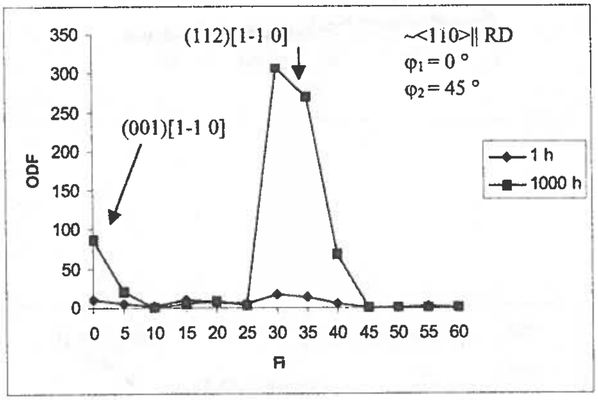


Fig. 2. Orientation distribution function profiles of austenitic phase

A little increase in the volume fraction of austenite was observed with annealing time. After 1 h of annealing the volume fraction of austenite was 36.7% , whereas after 1000 h it increased to 40.4%. The significant increase of the size of austenite grains took place with the progress of the annealing time. The mean intercept of austenite grains after 1 h annealing was 3.8 μm, and after 1000 h was raised to 29.6 μm (Table 1).

In a sample annealed for 1 h the austenite grains were significantly elongated along the rolling direction and formed a typical band-microstructure (Fig. 1a). With prolonged annealing time the austenite grains became more equiaxial and ceasing of the banded character of the microstructure took place (Fig. 1). However, the plane sections of the boundaries between austenite and ferrite were more numerous and the austenite grains became more polyhedral.

The texture was measured for samples annealled for 1 h and 1000 h. The incomplete pole figures of {100}, {110} and {211} planes for the austenite phase and {100}, {110} and {111} planes for the ferritic phase were analysed. The measurements were realized by means of Philips X-ray diffractometer of X'Pert type equiped with ATC-3 texture goniometer . The CoKα filtrated radiation and the so-called pseudo position-sensitive technique of the diffraction signal detection were applied [2]. The orientation distribution functions were calculated according to the discrete method [3] from the pole figures measured for each phase in both samples. The texture (the orientation distribution function profiles) of austenite is given in Fig. 2 and ferrite in Fig. 3.



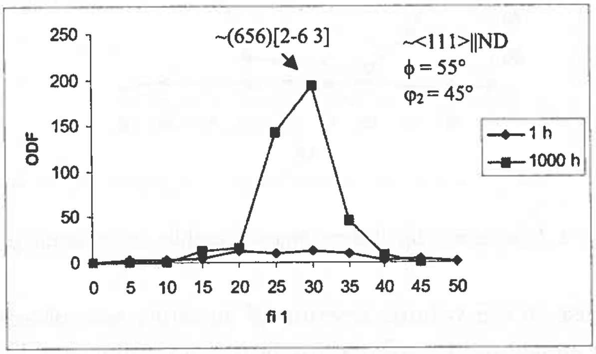


Fig. 3. Orientation distribution function profiles of ferritic phase

Microtexture analysis for 1, 10, 100 and 1000 h samples was performed from the sets of single orientations obtained by EBSD technique [4] (ESEM Philips electron microscope with HKL Technology equipment) measured on the planes perpendicular to the transverse direction (longitudinal section). An examplary orientation map for 1000 h annealing time is shown in Fig. 4.

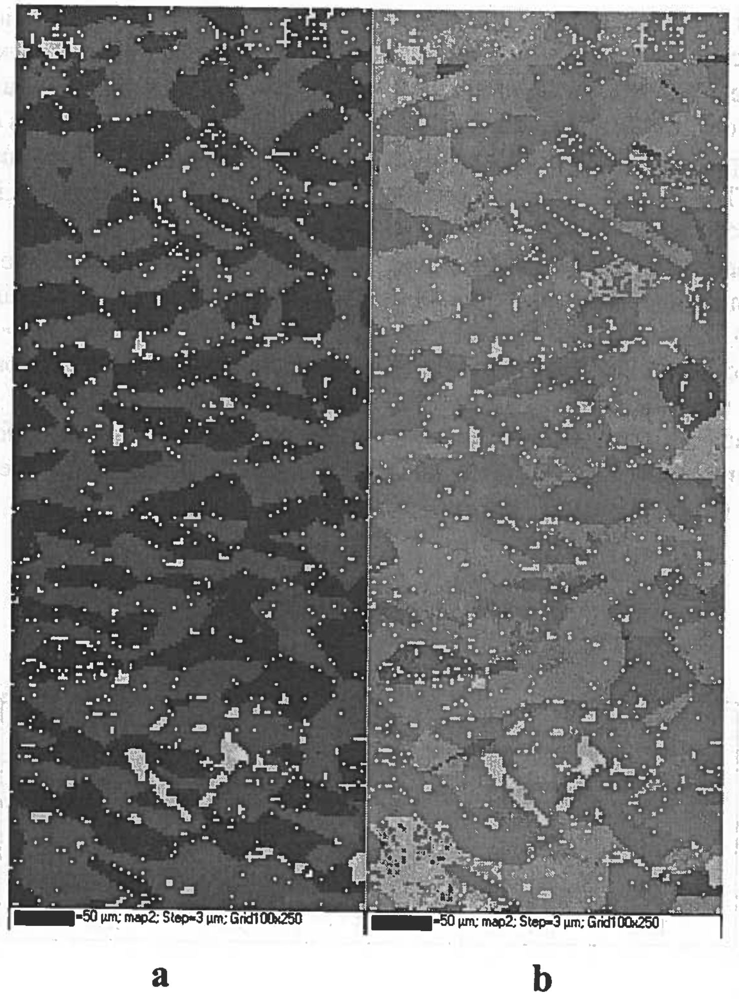


Fig. 4. Microtexture after 1000 h annealing time: a) distribution of phases austenitic (black), ferritic (grey), b) orientation map — the shades relate to various orientations, unresolved diffractions (white)

3. Discussion

The annealing behaviour and recrystallization textures of duplex stainless steels were analysed by J. Keichel et al [5, 6] , W. Ratuszek et al [7], N.L. de Lima et al [8]. The differences between orientation distributions in fcc and bcc phases of duplex stainless steel and the single phase materials were found and discussed.

The texture of austenitic phase (Fig. 2) in a sample annealed for 1 h could be characterized by concentration of orientations along the limited fibre {110}||ND: from Goss orientation {110}<001> through {110}<115> to {110}<112> and further to the orientation {110}<111>. A local maximum of the orientation density near the orientation{112}<111> is shifted towards the {4 4 11}<11 11 8> orientation. A local maximum occurs near the orientation {4 61}<112>. The sharpening of the texture (about 10-fold increase of the maximal value of ODF) took place in a sample annealed for 1000 h. The decomposition of the fibre {110}||ND occured. The orientations concentrate around the position {110}<112> with scattering towards {110}<115> and the Goss orientation. The successive local ODF maxima are in the positions {4 4 11}<11 11 8> and {4 6 1}<3 4 12>.

A characteristic feature of the texture of ferritic phase (Fig. 3) is the concentration of orientations around the fibre <110>||RD. In both samples (annealing times: 1 and 1000 h) the main maximum corresponds to the position {112}<110>. The other characteristic fibre {111}||ND is poorly developed, and the orientations concentrate in {665}<236> near the position {111}<112>. Similarly, as in the austenitic phase, in a sample annealed for thousand hours in comparing to the sample annealed for one hour, the sharpening of the texture (about 15-fold increase of the maximal value of ODF in the position {112}<110>) took place.

TABLE 1

Annealing time, h	Mean intercept of austenite grain		Mean volume fraction of austenite	
	μm	σ^*	%	σ
1	3.76	1.34	36.72	2.84
10	6.70	2.40	36.92	3.10
100	12.30	5.11	39.90	3.94
1000	29.63	11.75	40.38	1.61

In the case of the sample annealed for one hour, the limited fibre <110>||RD extends from {001}<110> through {114}<110> to {112}<110>. Local ODF maxima occur also in the positions {001}<140> and near the {113}<361> ones. The concentration of orientations arround the position {665}<236> is expanded towards the orientation {111}<112>. In the sample annealed for one thousand hours the orientations concentrate around {112}<110>, {665}<236> and {001}<110> positions.

The analysis of the orientation relationship between neighbouring measuring points of the ferritic and the austenitic phase was carried out. It was found that the Kurdyumov-Sachs relationship (Table 2 and 3) dominated in the misorientation distributions for all annealing times. The other misorientations were randomly distributed. For the shortest annealing time (one hour) a weak local maximum was found in the position {ω = 30, ~<110>}.

TABLE 2

Annealing time, h	FCC	BCC
1	(112)[-1 –1 1]	(112)[1 –1 0]
1000	~(4 4 11)[-11 –11 8]	(112)[1 –1 0]
1, 1000	(0 1 1)[2 –1 1]	~(111)[1 –2 1]
1000	(4 6 1)[3 –4 12]	~(6 5 6)[2 –6 3]

TABLE 3

Annealing time, h	K-S,%
1	7.5
10	11.8
100	16.0
1000	25.0

4. Conclusions

Analysis of the misorientation distributions has shown that with continuing annealing time the occurance of Kurdyumov-Sachs relationship between the ferritic and the austenitic phase increases (Table 3).

Textures of the ferritic and the austenitic phases in annealed duplex stainless steel differ from textures usually found for recrystallized ferritic and austenitic stainless steels.

— in the austenitic phase in addition to orientations belonging to the fibre {110}||ND the components {4 4 11}<11 11 8> and ~{461}<112> occur. The component {461}<112> evolves towards the {461}<3 4 12> orientation with increasing annealing time.

— in the ferritic phase the fibre {111}||ND is poorly developed; the orientations concentrate near the position {665}<236>. Orientations belonging to the fibre <110>||RD are the dominating ones.

Some of the main texture components of the ferritic and the austenitic phases remain in the Kurdyumov-Sachs relation (Table 2).

Acknowledgements

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