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CHANGES IN PLASTICITY OF Al – Fe 0.6% – Si 0.3% ALLOY DEFORMED BY ACCUMULATIVE ROLL BONDING METHOD

ZMIANY PLASTYCZNOŚCI STOPU Al – Fe 0.6% – Si 0.3% PODDANEGO PROCESOWI ARB

Severe plastic deformation enables obtaining materials characterized by ultrafine grained (UFG) structure (nanostructure). High grain refinement increases the strength of materials according to Hall – Petch relation and in case of UFG materials the high ductility of these materials is also reported. Accumulative Roll Bonding (ARB) method, by the process of consecutive reduction equal to 50% of two sheets – pack in each rolling pass, satisfies the condition of severe plastic deformation and enables obtaining the theoretically unlimited high plastic deformation.

In the paper the changes in the mechanical properties and microstructure of Al – Fe 0.6% – Si 0.3% alloy processed in 1 pass up to 10 passes according to ARB procedure are reported. The optimal processing conditions are proposed to obtain maximum of strength accompanied by maximum plasticity.

Keywords: accumulative roll bonding, ultrafine grain structure, Al – Fe 0.6% – Si 0.3% alloy, mechanical properties, microstructure, EBSD

Metody intensywnych odkształceń plastycznych umożliwiają uzyskiwanie struktury ultradrobnokrystalicznej. Silne rozdrobnienie mikrostruktury powoduje wzrost własności wytrzymałościowych zgodnie z zależnością Halla-Petcha oraz wysoką ciągliwość tych materiałów. Jedną z metod intensywnych odkształceń plastycznych jest walcowanie akumulacyjne, polegające na wielokrotnym walcowaniu pakietu dwóch blach zgniotem 50%.

W pracy przedstawiono wyniki badań zmian własności mechanicznych oraz mikrostruktury stopu aluminium Al – Fe 0.6% – Si 0.3% walcowanego metodą ARB od 1-krotnego do 10-krotnego pakietowania. Najlepszą kombinację własności mechanicznych, tj. wytrzymałości i ciągliwości, uzyskano po 7-krotnym pakietowaniu.

1. Introduction

There can be observed increased interest in the techniques of severe deformations which enable to obtain ultrafine grain structure. The methods of severe plastic deformations comprise, among others, the Equal Channel Angular Pressing (ECAP) [1-4], High Pressure Torsion (HPT) [1-5] and Accumulative Roll Bonding (ARB) [7-9].

The ARB method consists in rolling with 50% reduction of two metal sheets stacked in a pack. The obtained sheet is cut into halves and after preparing the adhering surfaces and folding in a pack, they are subjected to successive rolling cycles. The concept of the ARB process is shown in Fig. 1.

If we assume g_0 as the initial thickness of the sheet, then after successive cycles of ARB process the approximated thickness of the layer is $g_n = \frac{g_0}{2^n}$, while the total reduction after n-cycles is $z_n = 1 - \frac{g_n}{g_0} = 1 - \frac{1}{2^n}$. At the assumption that the material is deformed in a plane state

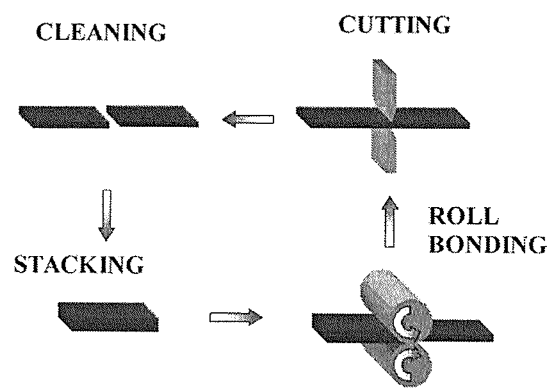

Fig. 1. Scheme of the Accumulative Roll Bonding process

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of strain and in accordance with Huber – von Mises – Hencky plasticity condition [6] the equivalent deformation is calculated according to the dependence $\varepsilon_n = \left[\frac{2}{\sqrt{3}}\ln(\frac{1}{2})\right] * n = 0.8 * n$.

2. Experimental procedure

The material used in the investigations was Al – Fe 0.6% – Si 0.3% alloy subjected to recrystallization at the temperature 450°C, with the initial grain size of about 20÷30 μm. The chemical composition of the alloy is given in Tab. 1.

TABLE 1

Chemical composition of Al – Fe 0.6% – Si 0.3% alloy (% wt.)

Materiale	Fe	Si	Sn	Cr	Cu	Zn	Ti	Mn	Mg	Al
Al-Fe-Si alloy	0.55	0.25	0.11	0.09	0.08	0.08	0.07	0.04	0.02	bal.

Two sheets of 1 mm thickness, 30 mm wide and 250 mm long, folded in a pack, were subjected to Accumulative Roll Bonding process. The surfaces of adhering sheets were wirebrushed and degreased. The packs were rolled at ambient temperature with 50% reduction and next cut into halves, and subjected to successive cycles. There were obtained materials after 1 to 10 cycles with equivalent deformation $\varepsilon_n = 0.8 \div 8.0$. The rolling process was realized using a laboratory rolling mill with the roll diameter 150 mm and the rate 4.3 m/min.

The obtained sheets were subjected to mechanical investigations carried out on plane, longitudinal samples using the tensile testing machine Instron 3382 and to microstructural investigations using TEM Philips CM20 microscope and FEI E-SEM XL30 – observations were carried out on the rolled surface.

3. Results and discussion

On the basis of the obtained results it has observed that the strength gradually increases up to 8 cycles, attaining the tensile strength about 2.5 times higher in comparison with the initial material. Increase in the number of cycles to above 8 causes the reduction of the strength properties. On the other hand, the percent elongation attains the maximal value of about 16% after the 7th cycle, and next it decreases. In Table 2 there are presented the mean values of the mechanical properties.

In Fig. 2 there has been presented the dependence of the mean mechanical properties on the number of ARB rolling cycles and equivalent strain.

TABLE 2

Mean values of the mechanical properties of samples after successive ARB rolling cycles and for the starting material after recrystalization (denoted R)

Number of cycles	ε_n	$R_{p0.2}$ [N/mm^2]	R_m [N/mm^2]	A [%]
1	0.8	107.70	153.89	9.70
2	1.6	132.98	164.84	9.88
3	2.4	113.40	166.73	10.50
4	3.2	143.93	168.81	11.04
5	4.0	117.95	177.25	14.20
6	4.8	115.43	178.11	15.01
7	5.6	125.53	177.51	15.70
8	6.4	122.70	182.06	12.91
9	7.2	146.30	179.64	10.43
10	8.0	133.40	179.51	8.37
R	–	49.30	70.97	37.30

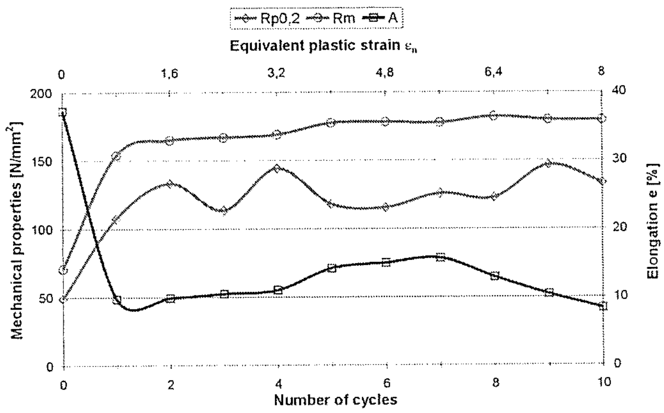

Fig. 2. Dependence of the mean mechanical properties on the number of ARB rolling cycles and the corresponding equivalent strain

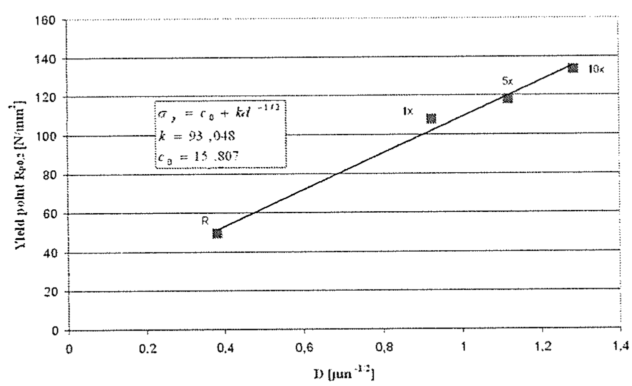

Fig. 3. Hall-Petch dependence of the yield point as a function of the grain size (The size of grain was marked on basis of TEM microstructures, executed for chosen of cycles)

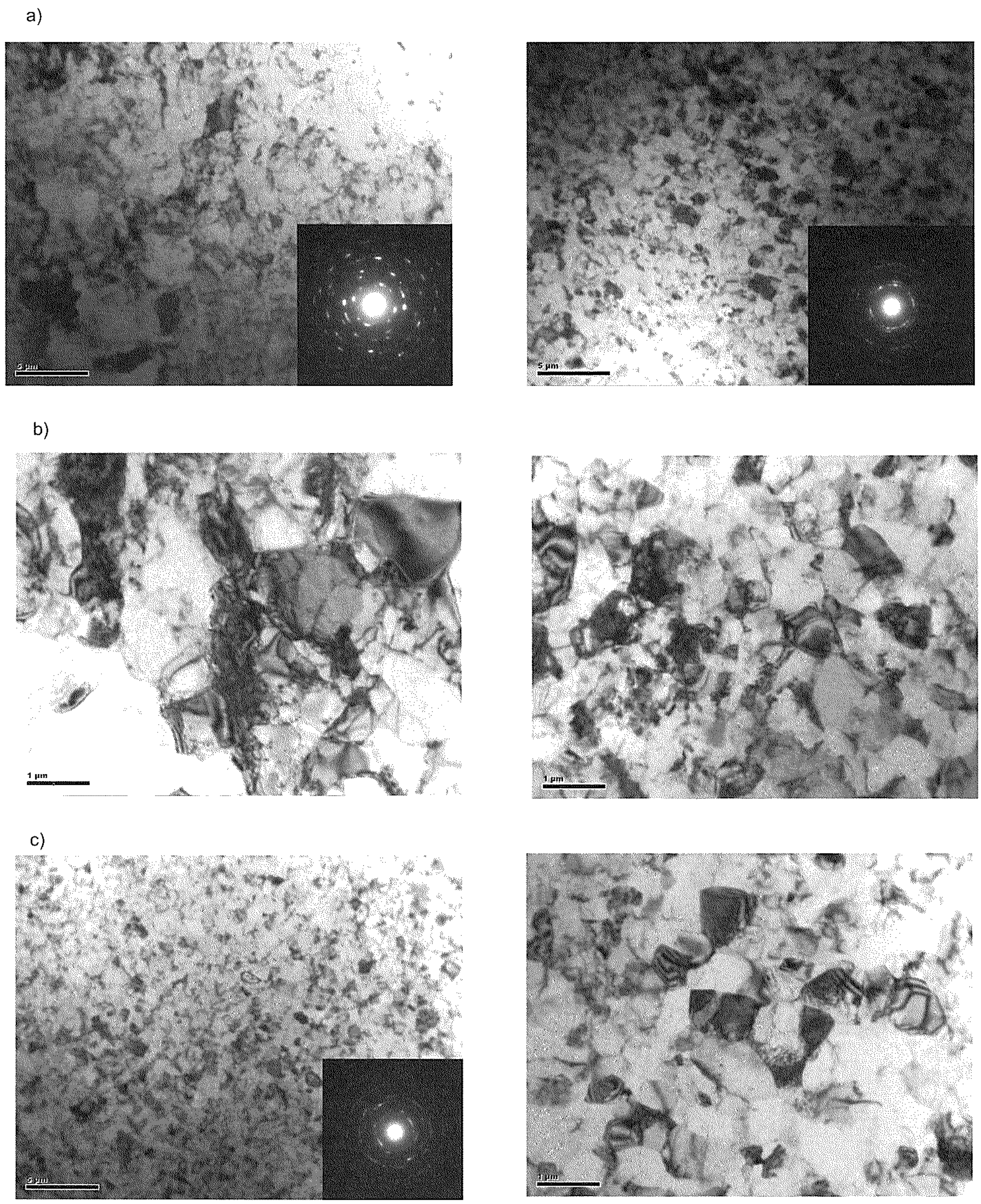

Fig. 4. Microstructure of Al-Fe-Si alloy rolled by ARB method: a) after 1, b) after 5 and c) after 10 cycles, observations on rolled surface

In Fig. 3 there has been presented the dependence of the yield point as a function of the grain size in the form of Hall-Petch equation. With increasing refinement of the microstructure there can be observed the increase in the value of the conventional yield point.

Observations using TEM allow to state that with the increase of the deformation there takes place the refinement of the microstructural. After 1 cycle of the ARB process (Fig. 4a) the grain size is about 1 m, after 5 ARB cycles (Fig. 4b) the structure is relatively homogeneous with the subgrain size of about 400÷500 nm, whereas after 10 cycles (Fig. 4c) a non-homogenous structure is observed. There occur grains with a size less than 400 nm, as well as subgrains with the diameter above 600 nm, which, as it is assumed, underwent recrystalization.

On the basis of investigations using SEM the analysis of EBSD was carried out in other to estimate the distribution of the grain size. Figure 5 shows the maps of scanning: a) in a sample after 5 cycles (ε_n = 4.0), and b) after 10 cycles (ε_n = 8.0). Since the analysis has not been completely solved, the obtained results do not allow to estimate the granularity unambiguously. The obtained distributions, shown in Fig. 7, indicate strong refinement of the microstructure. After 10 ARB cycles the sample is characterized by a mixed microstructure; there may be distinguished both very small grains as well as grains with a diameter above 1 m. Analysis of the misorientation angle of the grains boundary (Fig. 8) has revealed that in the microstructure after 5 ARB cycles there appear grains boundary of a small and a great angle, whereas in a sample after 10 cycles there appear boundaries of a small angle in majority of grains.

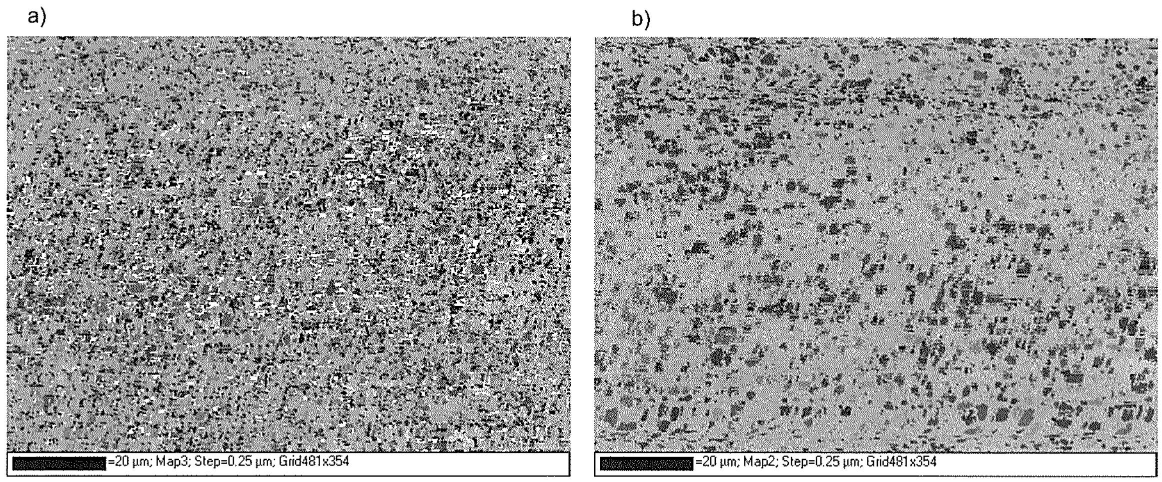

Fig. 5. EBSD scanning map for the evaluation of granularity in a sample after: a) 5 and b) 10 ARB cycles

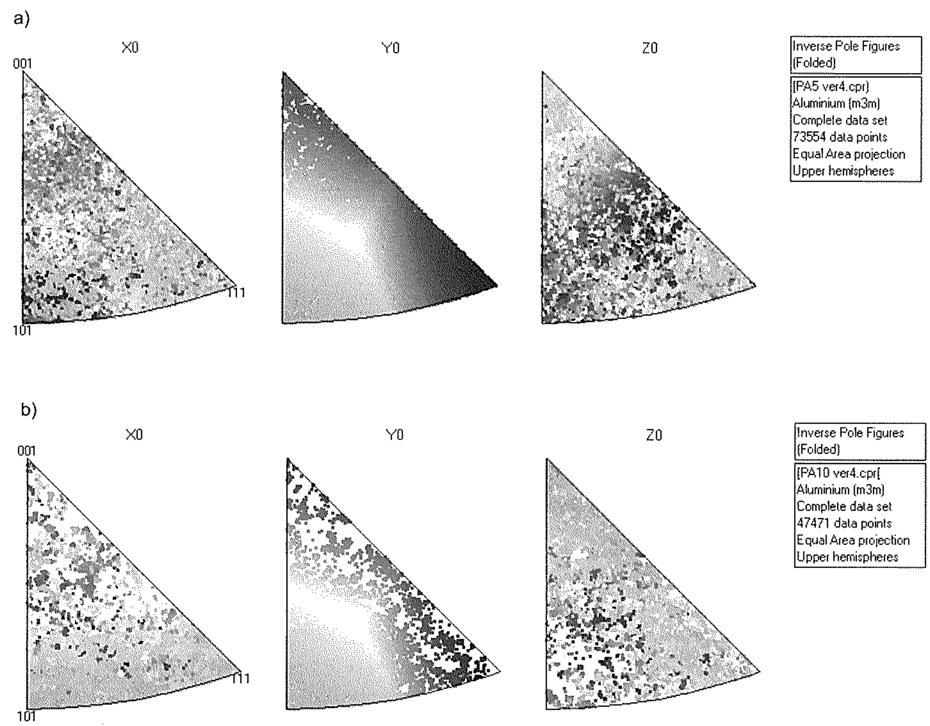

Fig. 6. Inverse pole figures in a sample: a) 5 and b) 10 ARB cycles, X0, Y0 and Z0 are parallel to rolling, transverse and normal directions respectively

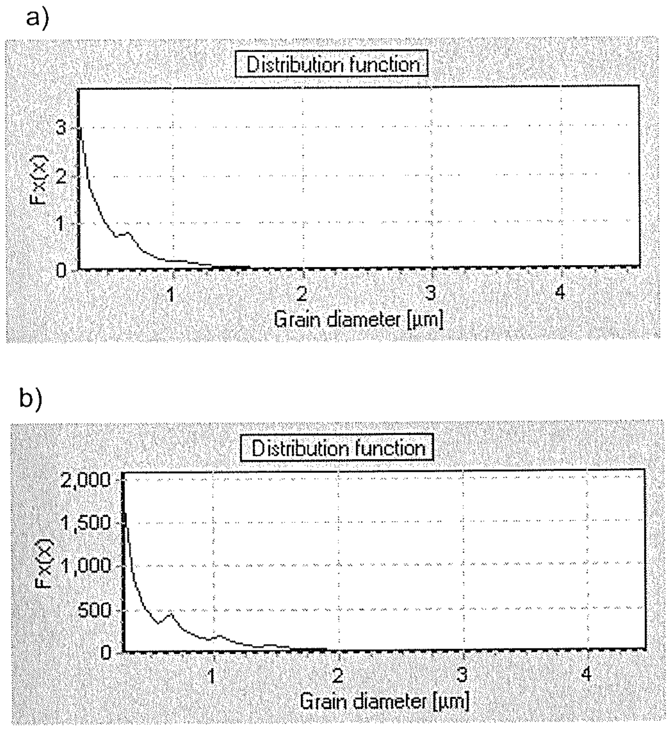

Fig. 7. Distribution of the grain size in a sample after: a) 5 and b) 10 ARB cycles

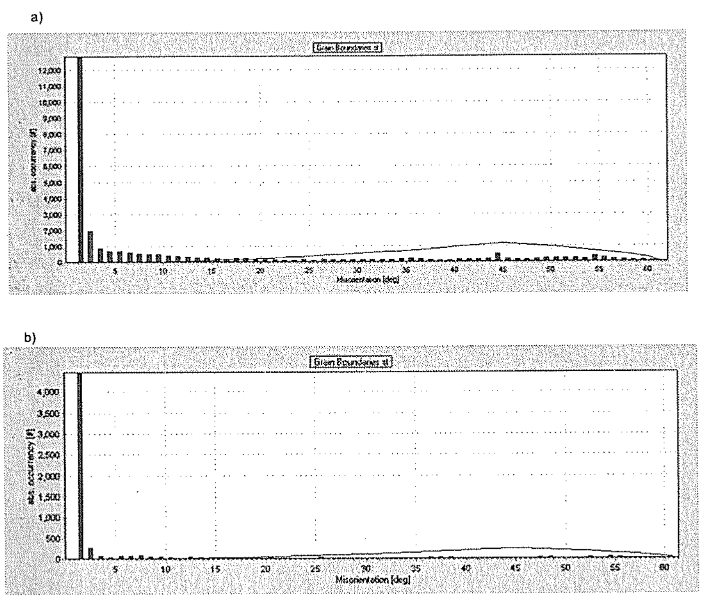

Fig. 8. Misorientation angle of grains in a sample: a) 5 and b) 10 ARB cycles

4. Summary

It has been observed that with the increase of the deformation degree there increase the strength properties. The highest value of tensile strength has been obtained for samples after 8 cycles, with the equivalent strain equal to $\varepsilon = 6.4$. In the next two passes there can be observed a slight decrease of strength. In the case of relative elongation the tendency to grow is maintained up to the 7^{th} cycle, attaining the value of about 16% and then it begins to drop.

With increasing number of cycles there can be observed systematic refinement of the microstructure. After 5 cycles the structure of the material is homogeneous and the mean grain size is about 400÷500 nm, whereas in a sample subjected 10 times to ARB rolling the structure shows inhomogeneity; there can be observed grains with a size above 600 nm. EBSD analysis has confirmed TEM observations, i.e. strong refinement of the microstructure after 5 cycles and inhomogeneity after 10 cycles. The observed increase of the grain size due to the beginning of the recrystallization processes, activated by high plastic deformation.

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