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TEXTURE AND RESIDUAL STRESSES IN THE CuSn6 ALLOY SUBJECTED TO INTENSE PLASTIC DEFORMATION

This paper presents the results of analysis of commercial CuSn6 alloy in form of strips at semi-hard state, plastically deformed in the process of repetitive corrugation. The influence of process parameters on the value of residual stresses and texture of examined material was investigated. As a result of residual stress analysis, the presence of compressive stresses for all analysed samples, regardless of the method of plastic working and direction of measurement, was confirmed. The distribution and the value of the stresses depend on the applied deformation process. Texture analysis shows that in the classically rolled strip, in addition to the Brass {110}<112> component, also the Goss {110}<001> and Copper {112}<111> components are present, and their contribution diminishes with the increase in the number of cycles of repetitive corrugation process. After intense plastic deformation the strip is characterised by two distinct texture components, {110}<112> and {110}<111>.

Keywords: CuSn6 alloy, repetitive corrugation, intense plastic deformation, texture, residual stresses

1. Introduction

Dynamic development of new technologies of plastic forming of metals, has caused increased interest in the subject of crystallographic texture formation [1-3]. The crystallographic texture of metal strips influences the deformation distribution and material flow during plastic deformation process. The anisotropy of properties due to the occurrence of the texture can adversely affect the forming process of the material and its characteristics [1,4-6]. Currently, new plastic forming processes are being developed which allow controlled formation of crystallographic texture. To the group of plastic deformation methods one can include: equal channel angular pressing (ECAP), accumulative roll bonding (ARB), high-pressure torsion (HPT), hydrostatic extrusion (HE) and repetitive corrugation and straightening (RCS) [7-12]. The methods are based on the conventional plastic processing technologies (rolling, forging, drawing), but they are applied with the use of modified standard equipment. The main purpose of using these methods is not to shape, as in the case of conventional plastic processing, but to obtain the required physical and mechanical properties of the processed material. In addition to the possibility of the formation of ultra-fine grain (UFG) structure, intense plastic deformation methods allow for avoiding or changing a preferred orientation of crystallites effects in plastically deformed metal. One of the most effective methods of intense plastic deformation is repetitive corrugation and straightening (RCS) [13,14]. This process involves cyclic corrugation and straightening of metal sheets or tapes, to induce accumulation of plastic deformation energy. This paper presents the results of the author's studies on the influence of the modified repetitive corrugation and straightening process, on the properties of CuSn6 alloy strips.

2. Experimental procedure

Texture analysis of the studied samples was conducted by means of diffraction method on the Panalytical X'Pert Pro diffractometer [15,16], using filtered radiation from the cobalt anode X-ray lamp ($\lambda_{K\alpha}$ = 1.79 Å). In order to determine the normal distribution of the selected planes and to determine the orientation distribution function (ODF) of the tested strips after 1, 15 and 35 cycles of repetitive corrugation, as well as classically rolled strips, pole figures were recorded for the four crystallographic planes giving the most intensive diffraction lines. The analysis of the obtained pole figures and of the orientation distribution function of the tested samples were made using LaboTex 3.0 software while applying Schulz defocusation correction formula.

The measurements of residual stresses were carried out by means of the $\sin^2\psi$ method. The angle ψ of the sample tilt relative to the primary beam was varied within the angle range of 0÷75°. The analyses were performed in the X'Pert Stress software using the available methods of describing diffraction lines by means of the Lorentz function.

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3. Material for investigations

The material for the investigation was non-annealed commercial CuSn6 alloy, in the form of 0,75×20×130 mm strips. The chemical composition of the CuSn6 alloy is shown in table 1. The strips were processed using a repetitive corrugation and straightening (RCS) station, which consisted of individual sets of tools for working metal by bending and straightening. The strips were deformed in two transverse directions by means of cooperating bending rollers in the form of toothed wheels (Fig. 1).

The strips were processed by means of repetitive corrugation in the rolling direction and cross direction. After each cycle, the strips were rotated by an angle of 180°. For each direction of corrugation, the different pressure settings of the bending tools were applied. The parameters of corrugation were selected, so as to allow performing as many cycles as possible. The strips after the last corrugation cycle were subjected to straightening by means of classic rolling. For comparison purposes, a series of samples subjected only to classic rolling were made.

TABLE 1

The CuSn6 alloy elemental composition (PN-EN 1652:1999)

Material designation		**Elements mass concentration % wt.**								
ISO:	**EN:**	**Element**	**Cu**	**Fe**	**Ni**	**P**	**Pb**	**Sn**	**Zn**	**Other**
CuSn6	CW452K	min.	rest	—	—	0,01	—	5,5	—	—
		max.	—	0,1	0,2	0,4	0,02	7,0	0,2	0,2

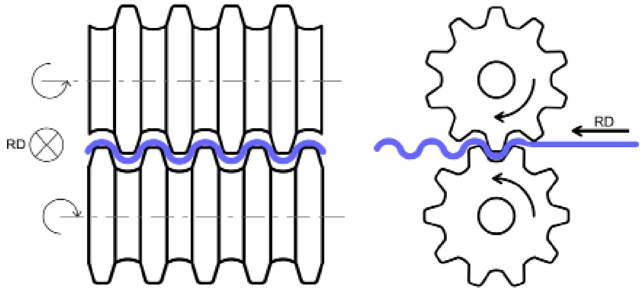

Fig. 1. Layout of the bending tools

4. Results and discussion

As a result of residual stresses analysis (Tab. 2), the presence of compressive stresses for all analysed strips, regardless of the method of plastic working and the direction of measurement, was confirmed. In the classically rolled strips the compressive stresses reached a value of about –305 MPa in the rolling direction and about –261 MPa in the transverse direction. A similar distribution of residual stresses was observed in the strips after 1 cycle of repetitive corrugation. The strips after these kinds of plastic deformation are characterised by higher compressive stresses in the rolling direction. In the strips subjected to 15 cycles of repetitive corrugation, the compressive stresses showed lower values (about –140MPa). The uniform residual stresses distribution effect was observed in the strips subjected to 35 cycles of repetitive corrugation, with the stress values approximately equal to –197 MPa in two orthogonal directions (Figs. 2,3).

TABLE 2

Results of the residual stresses measurement in the analysed CuSn6 alloy strips

Strips		**Value of residual stresses in the rolling direction [MPa]**	**Value of residual stresses in the transverse direction to the rolling direction [MPa]**
Classically rolled		–305.9 ±15.2	–261.3 ±15.9
Repetitive corrugation	1 cycle	–322.2 ±9.8	–281.6 ±10.3
	15 cycles	–141.4 ±14.8	–147.5 ±15.9
	35 cycles	–197.2 ±25.0	–197.9 ±19.3

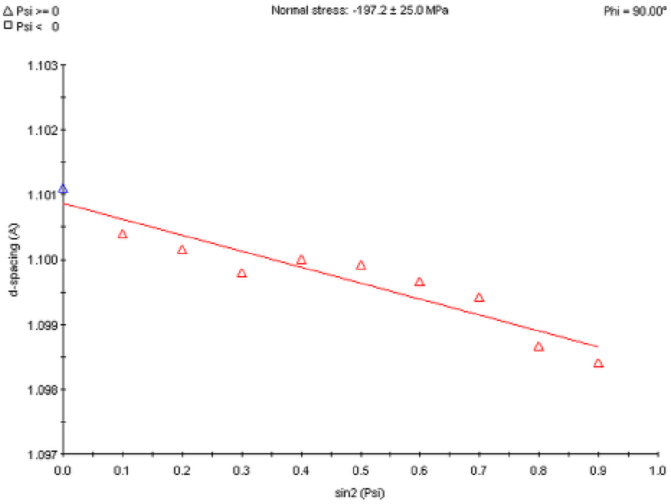

Fig. 2. The results of the residual stresses measurement (rolling direction) in the strip subjected to 35 cycles of the repetitive corrugation

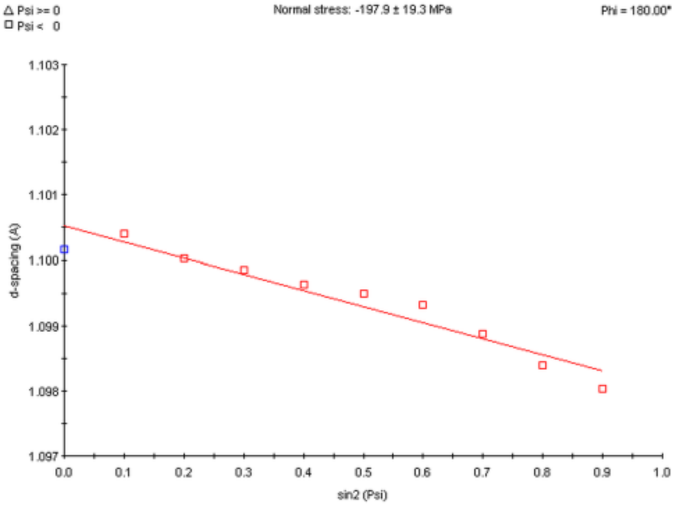

Fig. 3. The results of the residual stresses measurement (transverse direction to the rolling direction) in the strip subjected to 35 cycles of the repetitive corrugation

TABLE 3

Share of the texture components calculated from ODF

Strips		Share of the texture components [%]					
		{110}<112> Brass	**{110}<001> Goss**	**{112}<111> Copper**	**{110}<111>**	**{001}<100> Cube**	**Random**
Classically rolled		24,0	10,1	12,0	7,6	0,8	45,5
repetitive corrugation	1 cycle	22,2	8,4	12,7	8,5	0,5	47,7
	15 cycles	31,7	6,6	6,2	14,6	0,7	40,2
	35 cycles	30,9	3,6	2,2	21,0	0,8	41,5

The performed texture studies showed that in the analysed CuSn6 alloy strips, regardless of the processing method, components with the {110} plane dominated. The maxima configuration in pole figures, as well as in the $\varphi 1$ and $\varphi 2$ orientation spaces of the orientation distribution function (ODF) obtained for the classically rolled strips, indicates the presence of three distinct texture orientations: Brass {110}<112>, Goss {110}<001> and Copper {112}<111>, with the largest contribution of the Brass component, which is confirmed by calculations of the volume shares of components show in table 3. The texture of the strips subjected to one cycle of the repetitive corrugation is not significantly different from the texture of classically rolled strips, while the maxima observed in experimental and calculated pole figures indicate the presence of the same texture components with a distinct {110} plane, and with a similar volume share. In the texture of the strips subjected to 15 and 35 cycles of repetitive corrugation, there dominates the Brass component, with its volume share increased to about 30%. As the number of cycles of repetitive corrugation increases, the proportion of {110} <111> component in the texture of the analysed strips increases, which was confirmed by the calculations of volume shares. The share of the component with the {110} <111> orientation is shown in the CPF (Fig. 4) and NPF (Fig. 5) pole figures obtained for the strips subjected to 35 cycles of repetitive corrugation, in the form of maxima near the centre of the projection, rotated by an angle of 90° with respect to the rolling direction. It can be assumed,

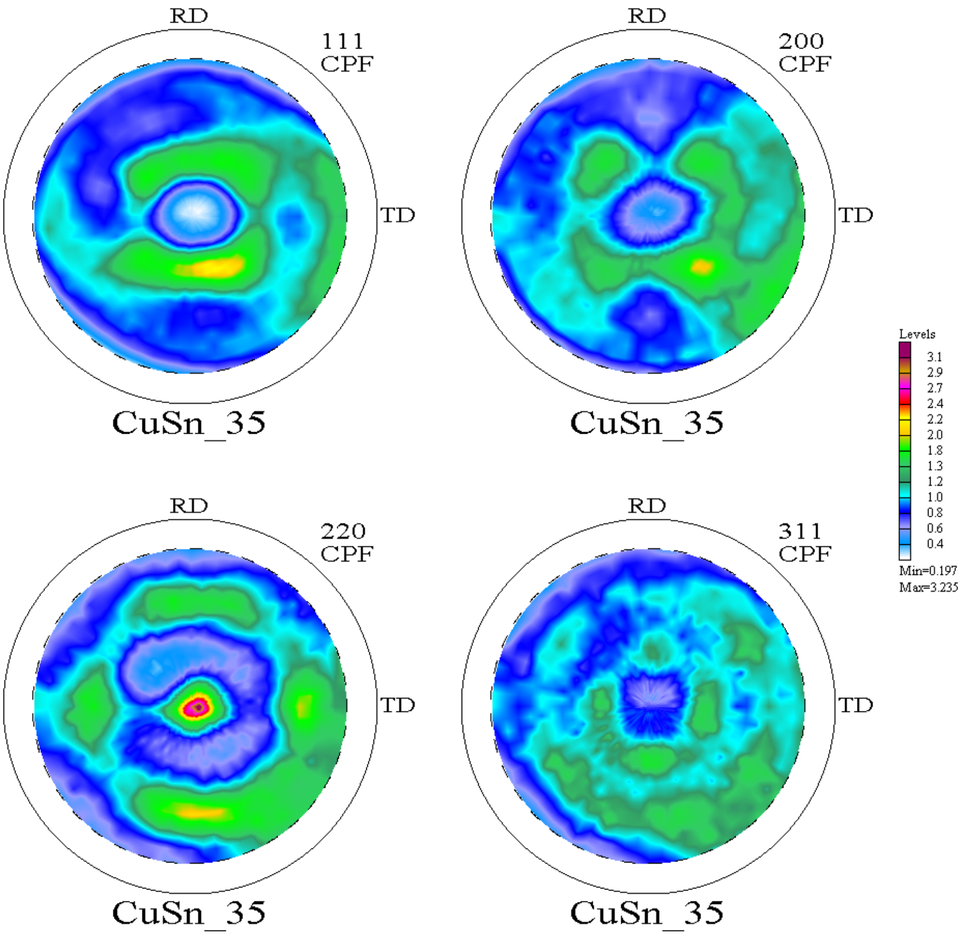

Fig. 4. Experimental pole figures, (111), (200), (220) and (311), of the CuSn6 alloy strips subjected to 35 cycles of the repetitive corrugation

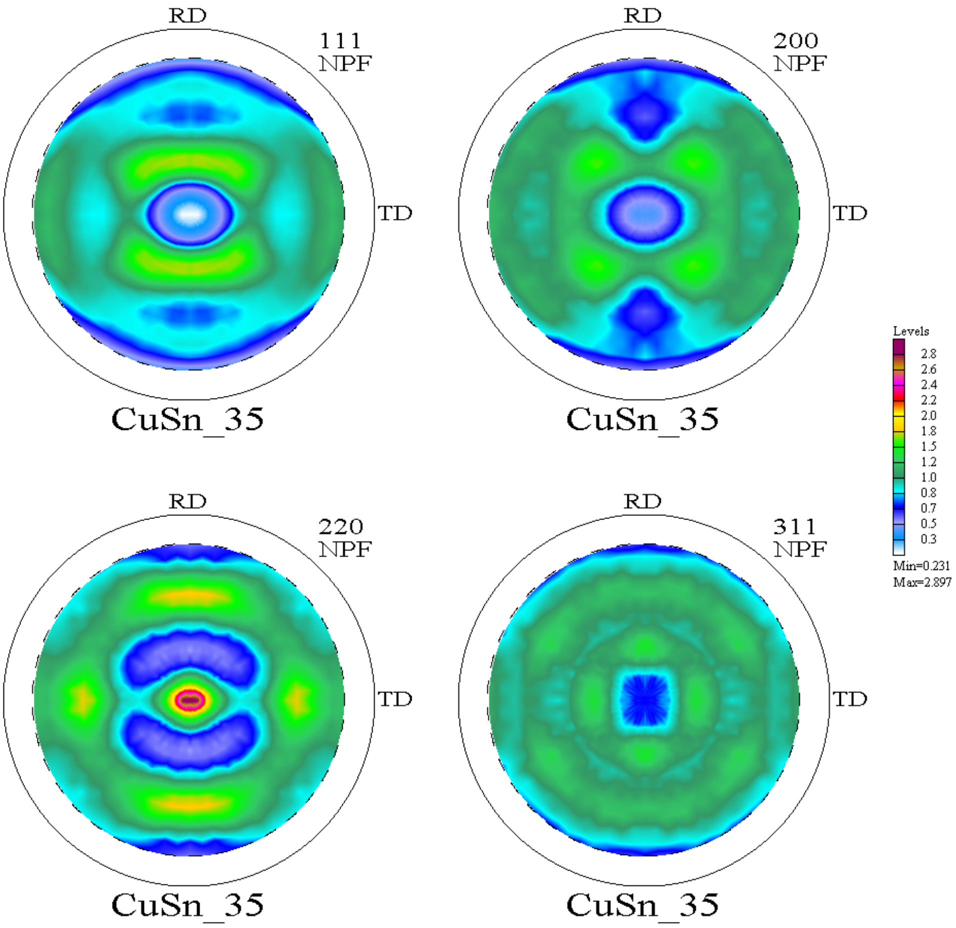

Fig. 5. Normalised pole figures, (111), (200), (220) and (311), of the CuSn6 alloy strips subjected to 35 cycles of the repetitive corrugation

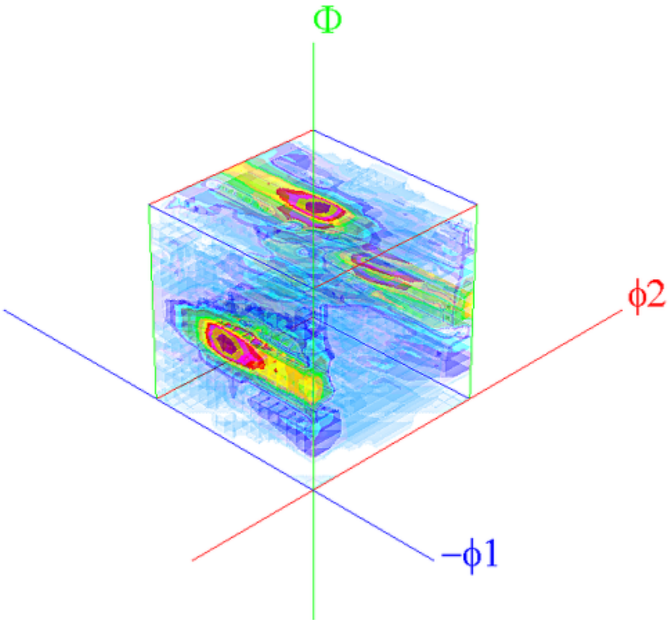

Fig. 6. Orientation distribution function (ODF) of the CuSn6 alloy strips subjected to 35 cycles of the repetitive corrugation

that there is a distinct double texture with the {110} <112> and {110} <111> components (Fig. 6).

Based on the literature data [5,17-19] describing the effect of deformation bands on changes in the texture of metals crystallised in the A1 system, it can be assumed that such significant changes in the texture of the strips subjected to 35 cycles of repetitive corrugation in comparison to the texture of classically rolled strips, are due to the occurrence of shear bands arranged spatially (Figs. 7,8), resulting from a forced change in the direction of the deformation path, which leads to an increase in the flow of material in other directions than the rolling direction.

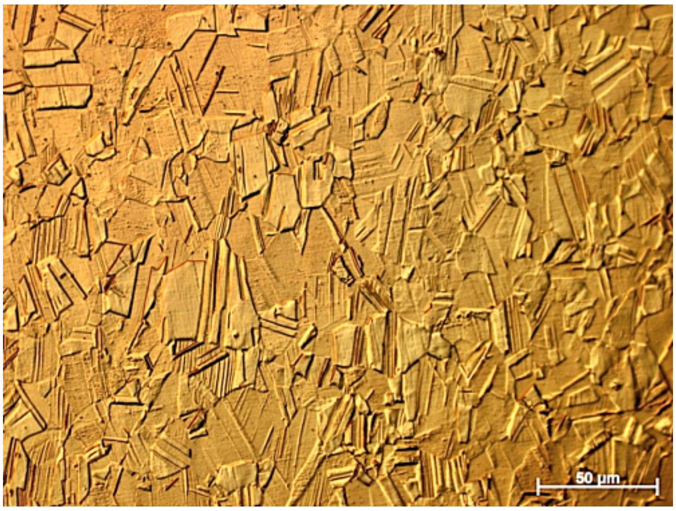

Fig. 7. Structure of CuSn6 alloy subjected to classically rolled; cross section to the rolling direction (magnification 500×, Nomarski differential interference contrast, optical microscope)

Fig. 8. Structure of CuSn6 alloy subjected to 35 cycles of repetitive corrugation; cross section to the rolling direction (magnification 500×, Nomarski differential interference contrast, optical microscope)

5. Conclusion

The residual stresses analysis showed that the distribution and value of stresses depend on the applied plastic deformation process. In the classically rolled strips the residual stresses assume a larger value in the rolling direction (–305 MPa) than in the transverse direction (approx. –261 MPa). It was found that an application of the repetitive corrugation process in several repeating cycles affects the uniform distribution of residual stresses in the CuSn6 strips. It can be hypothesized that this effect is related to the activation of alternating slip bands during the repetitive corrugation process, which affect to distribution of stresses remaining after the plastic deformation.

The analysis of pole figures shows that the plastic deformation with applied repetitive corrugation process induces changes in the texture of CuSn6 alloy. In the classically rolled strip, in addition to the Brass {110} <112> component, there is a Goss {110} <001> and Copper {112} <111> type texture, and with the increasing number of cycles of repetitive corrugation, these components reduce their share in the texture. In the strips subjected to 35 cycles, there is a distinct double texture with the {110} <112> and {110} <111> components. In the considered case, the change of texture occurs gradually, and an application of single cycles of repetitive corrugation does not cause any significant changes in its picture. It can be assumed that in texture after the application of repetitive corrugation process significant differences are induced by changes in deformation paths, which leads to an increased flow of material in directions other than the direction of rolling. In this case, for texture modification, it is necessary to use more than dozen of process cycles, because the evolution of the texture occurs gradually, through the rotation of individual crystals, with a significant share of shear bands induced during the plastic deformation process.

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