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Influence of RCS process on the structure and mechanical properties of CuSn6 alloy

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ABSTRACT

Purpose: The goal of the study is try to find the influence of plastic deformation using the RCS (repetitive corrugation and straightening) process on the structure and mechanical properties of CuSn6 alloy. The influence of process parameters on the above property were investigated. Obtained results were correlated with the results obtained for alloy subjected to cold rolling.

Design/methodology/approach: This study was aimed to investigate structure and mechanical properties non annealed strip of CuSn6 alloy, cold-rolled and the tape subjected to intensive plastic deformation using the RCS method (repetitive corrugation and straightening).

Findings: Research have shown increase compressive stresses and tensile strength in material after RCS process compared to classic rolled. Crystallite size measurement confirmed the presence of nano-scale structures in the studied materials after deformation by RCS process. The used method of plastic deformation is promising for development materials with improved properties.

Research limitations/implications: The research was carried out on samples, not on final elements.

Practical implications: Research is moving towards the development of the materials with finest microstructure, known as ultra-fine-grained materials with improved properties, compared to currently known materials.

Originality/value: This paper presents the results of study of the structure and mechanical properties CuSn6 alloy deformed in the RCS (repetitive corrugation and straightening) process.

Keywords: Copper alloys; RCS - repetitive corrugation and straightening; Plastic deformation; Structure analysis; X-ray analysis; Crystallite size; Stress measurement

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PROPERTIES

1. Introduction

Tin bronze is an alloy of copper and tin with other elements, characterized by good strength, antifriction properties and corrosion resistance. Currently the dominant method of processing of metallic materials is plastic working, so more emphasis placed on the development and refinement of methods belonging to this group. The development of new processing methods is caused by the increasing requirements of modern engineering materials, better properties with optimum production cost are required. One of these newly developed methods of plastic working is the RCS process (*Repetitive Corrugation and Straightening*) belongs to the group of SPD methods (*Severe Plastic Deformation*), whose aim is not to give shape, but the generation of the desired physical and mechanical properties of metal, by fragmentation of the microstructure. The RCS process consists on cyclic bending and straightening plates to obtain a strong accumulation of plastic strain for microstructures fragmentation in the material under investigation. In the processes using the strong accumulation of plastic deformation microstructures can be fragmented by generate a large number of dislocations, which results in formation of grains with low-angle boundaries, that the continued build-up of strain create a homogeneous grain high-angle boundaries. The paper presents results of studies on the effects of RCS process on the structure and mechanical properties of CuSn6 alloy. To produce a series of samples a RCS plastic working station was used. It consists of set of bending rollers and straightening rollers. The bending roller includes a pair of toothed wheels to deformation strip in a direction transverse to the rolling direction (Fig. 1a) and a pair of bending rolls to deformation strip in the direction of rolling (Fig. 1b) [1-13].

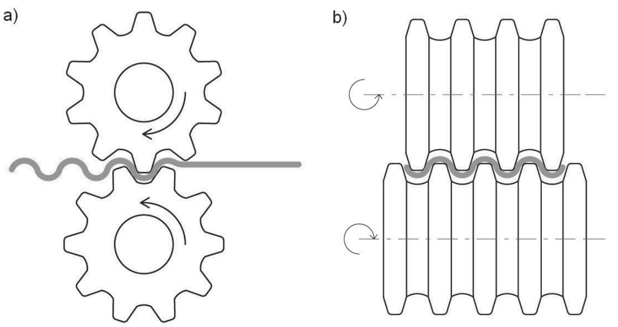


Fig. 1. Layout of bending rolls a) the cross direction to the rolling direction b) the rolling direction.

2. Material for research

The studied material consisted on cold rolled CuSn6 alloy (Table. 1) strips, size 0.8x20x130mm, non annealed, strengthening state (z4).

Table 1.
CuSn6 elemental composition, % wt (PN-92/H-87050)

Material	Tin	Zinc	Phosphorus	Nickel
CuSn6	5.5 - 7	0.3	0.01-0.35	0.3
	Lead	Iron	Other	Copper
	0.05	0.1	0.2	rest

The strips were processed on an alternating forming of bending in the cross direction to the rolling direction and in the rolling direction, rotating tape an 180° after each cycles. Distinct settings of rollers pressure were applied for each direction of bending, to perform as much as possible bending cycles. Selected pressure parameters allowed for performing a series of samples ranging from 1 to 35 cycles. Each strip after the last bending cycle was subjected to straightening by classic rolling. For comparison a set of samples using classic rolling with the same parameters as for the straightening of bended samples was made. Bending processes and classical rolling processes were performed at room temperature.

3. Methodology

X-ray diffraction studies of analyzed samples were performed on the PANalytical X'Pert PRO diffraction system, using filtered radiation from the lamp with copper anode (λ=1.54 Å). X-ray phase analysis was conducted in the Bragg - Brentano geometry using X'celerator strip detector and X'Pert High Score Plus software, used also to determine the average crystallite size and lattice strain. Stress measurements were made with sin2ψ technique using Stress X'Pert Plus software.

Static tensile test of analyzed strips CuSn6 were carried on Instron testing machine 4505/5500 K, using measuring head force-carrying capacity 10kN and the stretching speed equal 2 mm/min.

Structure studies were carried out on the metallurgical microscope Nikon MA200 equipped with an NIS image analysis software.

4. Results and discussion

4.1. XRD

XRD results confirmed presence of the CuSn, regardless of process conditions (Fig. 2). Diffractograms obtained for the strips after classic rolling and for strips after the RCS process in 1, 15 and 35 cycles indicates that the intensity of the diffraction lines decreases with increasing number of RCS cycles (Fig. 3).

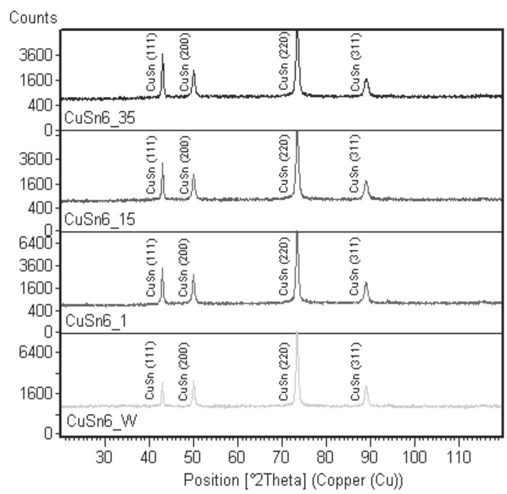


Fig. 2. Diffractograms of CuSn6 strips after classic rolling (W) and after 1, 15 and 35 RCS cycles.

Changing of the intensity and width of diffraction peaks with increasing number of RCS cycles may be caused by the application of cold working. Plastic working may affect the fragmentation of the crystallites and the stress distribution in the analyzed strips. In order to determine which of the reason more or less influence on widening of the diffraction peaks with increasing number of RCS cycles, stress measurements were performed in CuSn6 alloy strips [15].

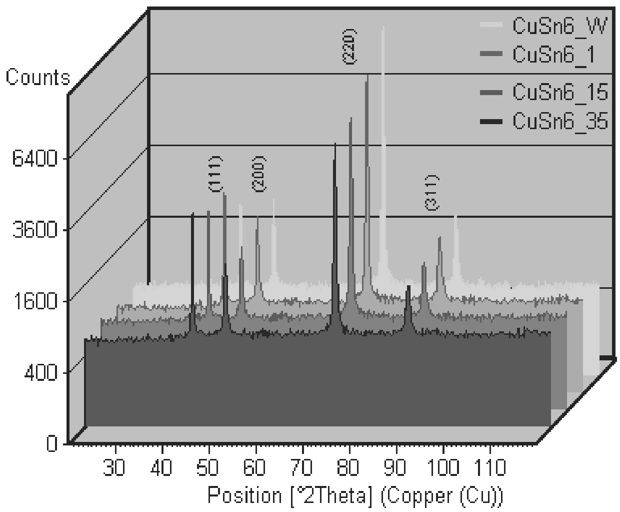


Fig. 3. Statement of diffractograms obtained for CuSn6 strips: after classic rolling (W) and after 1, 15 and 35 RCS cycles

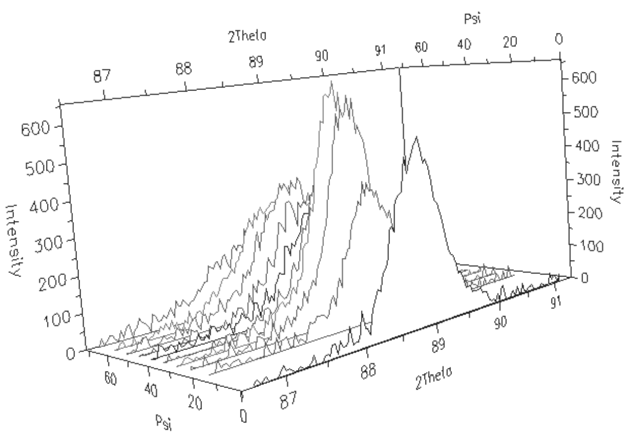
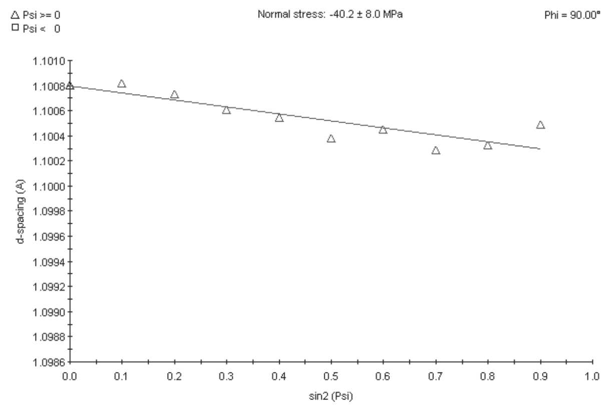


Fig. 4. Changes in the diffraction line position of (311) (CuSn6 strip after classic rolled)

In Figs. 4 to 9 the results of stress measurements in two perpendicular directions for the CuSn6 alloy strips are present. All the measurements showed, regardless of the method of processing, the number of cycles and measuring direction, the occurrence of compressive stresses in the analyzed strips. Analyzing the results (Table 2), was observed a significant increase in internal stress in all the strips in the rolling direction relative to the cross direction to the rolling direction. This is probably due to the initial state of the material (cold rolled, non annealed) and the final step consisting in forming cold rolled all the strips using the same parameters. There was also a slight increase in stress in the strip subjected to plastic working using a RCS process in 35 cycles to compare to the strip only cold rolling [14,15].

a)



b)

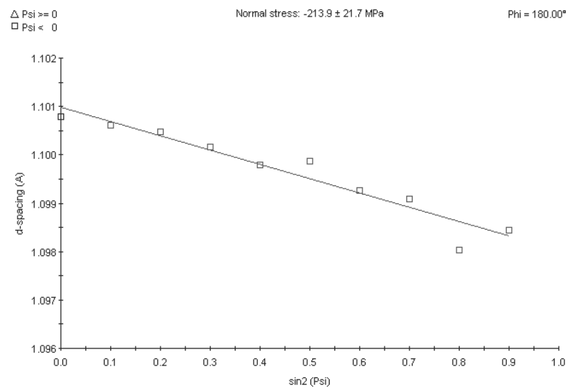


Fig. 5. Results of the measurement stress: a) cross direction to the rolling direction b) the rolling direction (CuSn6 strip after classic rolled, the dependence of *d*-spacing in $sin^2\psi$ function, diffraction line (311))

Table 2.
Statement of the stress in analyzed CuSn6 strips

The treatment process	Stress in a cross direction to the rolling direction [MPa]	Stress in a rolling direction [MPa]
classic rolled	-40.2 ± 8.0	-213.9 ± 21.7
1 cycle of RCS	-79.1 ± 10.4	-239.7 ± 15.7
15 cycles of RCS	-54.2 ± 10.1	-250.8 ± 24.8
35 cycles of RCS	-86.6 ± 7.9	-271.2 ± 16.7

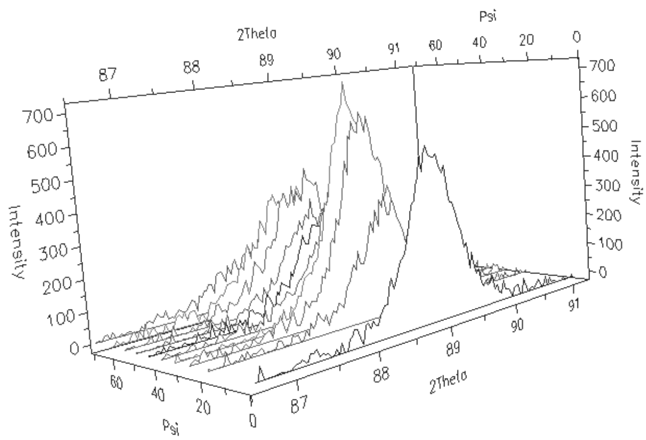
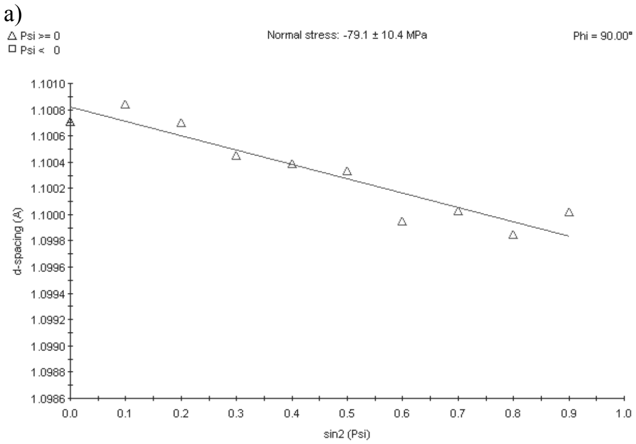


Fig. 6. Changes in the diffraction line position of (311) (CuSn6 strip after 1 cycle of RCS)

a)



b)

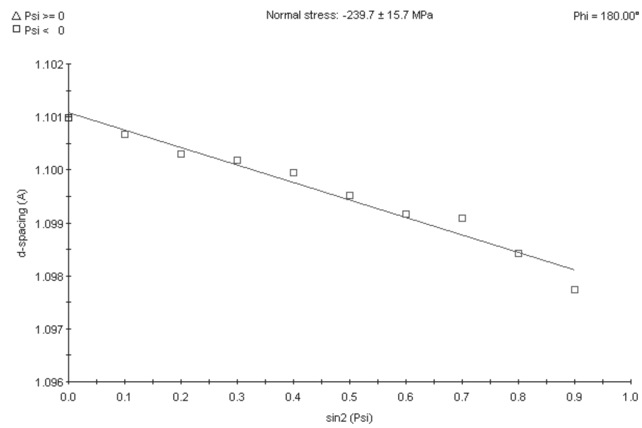


Fig. 7. Results of the measurement stress: a) cross direction to the rolling direction b) the rolling direction (CuSn6 strip after 1 cycle of RCS, the dependence of *d*-spacing in $sin^2\psi$ function, diffraction line (311))

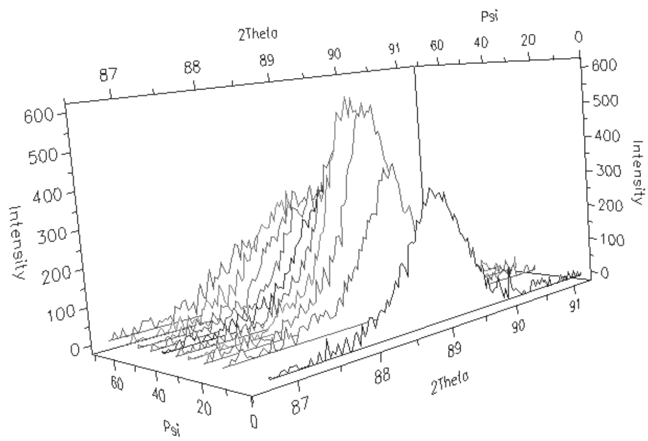
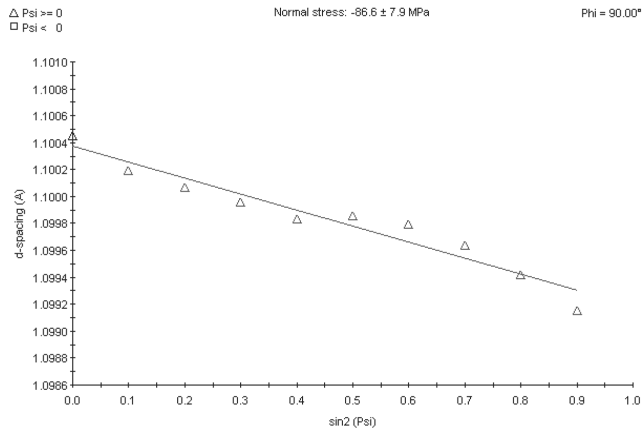


Fig. 8. Changes in the diffraction line position of (311) (CuSn6 strip after 35 cycles of RCS)

a)



b)

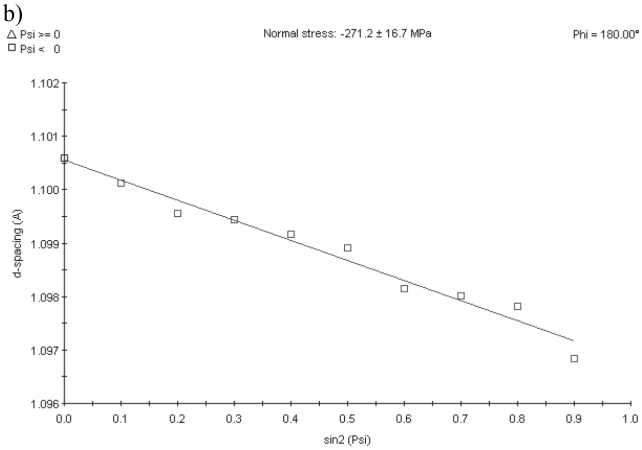


Fig. 9. Results of the measurement stress: a) cross direction to the rolling direction b) the rolling direction (CuSn6 strip after 35 cycles of RCS, the dependence of *d*-spacing in $sin^2\psi$ function, diffraction line (311))

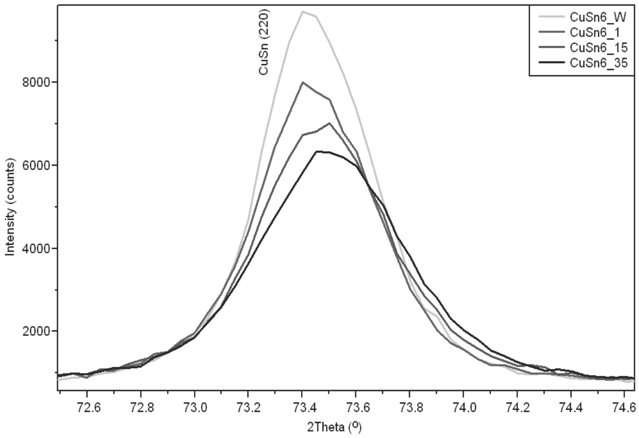


Fig. 10. Graph of CuSn (220) diffraction line widening change from the strip after classic rolled (W) and strips after 1, 15 and 35 cycles of RCS

Total widening of diffraction lines (Fig. 10), crystallite size and lattice strain in CuSn6 alloy strips were determined. Results of the average crystallite size and lattice strain for the different variants of plastic working (classic rolled, RCS: 1, 15 and 35 cycles) was summarized in Table 3.

Table 3.
Average crystallite size and lattice strain of CuSn6 alloy strips after the different variants of plastic working

Sample name	B obs (^{o}2Th)	Crystallite size (nm)	Lattice strain (%)
CuSn6_W	0.48	28.3	0.205
CuSn6_1	0.52	25.4	0.228
CuSn6_15	0.56	23.1	0.251
CuSn6_20	0.61	20.7	0.280
CuSn6_35	0.63	19.8	0.292

Crystallite size measurement by Sherrer method [15], confirmed the presence of nano-scale structures in the studied CuSn6 strips. The average crystallite size decreases from 28 nm in the material after classic rolling, to about 20 nm after the processed with RCS process in 35 cycles. As the number of RCS cycles increase, an increase of lattice strain is observed.

4.2. Mechanical properties

In order to determine mechanical properties of the analyzed strips, static tensile test was conducted and the results are shown in Table 4. The test was conducted at room temperature.

In Fig. 11, the dependency of strip of plastic working on maximum tensile strength is present. A significant (compared to the classic rolled strip) Rm_{max} increase (25%) for strip processed in 35 cycles of RCS, was observed.

After a RCS process yield strength has been growing compared to the classic rolled strips. The greatest value of the yield strength showed a strip after 15 cycles of RCS. Elongation of strips deformation in the RCS process drops significantly compared to the classic rolled strips.

Table 4.
Summary of mechanical properties CuSn6 strip, determined in the static tensile test

Sample	CuSn6_W	CuSn6_1	CuSn6_15	CuSn6_35
Thickness [mm]	0.74	0.73	0.73	0.70
elongation A 20[%]	30.0	21.5	10.5	9.0
Fm_{max} [N]	1414	1436	1662	1650
Rm_{max} [MPa]	472	486	562	590
$Fp_{0,2}$ [N]	1252	1369	1584	1306
$Rp_{0,2}$ [MPa]	417	463	535	467
$Fp_{0,05}$ [N]	1132	1273	1486	1028
$Rp_{0,05}$ [MPa]	378	430	502	367

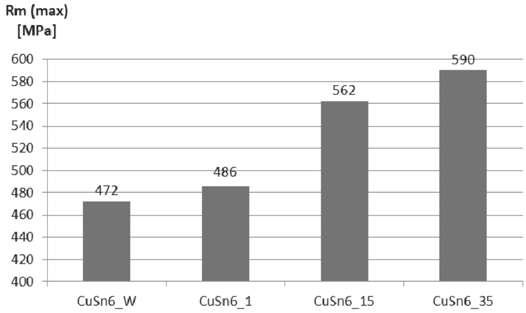


Fig. 11. The maximum tensile strength of strips after classic rolling (W) and strips after 1, 15 and 35 cycles of RCS

4.3. Structures

In order to determine the effect of plastic working on the structure of the examined CuSn6 alloy strips, Nikon optical microscope MA200 using image analysis software NIS were applied. As a result of analysis of the structure in longitudinal section through on examined CuSn6 strips (Fig. 12-15), obtained on the optical microscope at a magnification of 50x was found that the, all the strips regardless of the method of plastic working, have a surface devoid of macro-cracks, for which non annealed CuSn6 strips were exposed during processing.

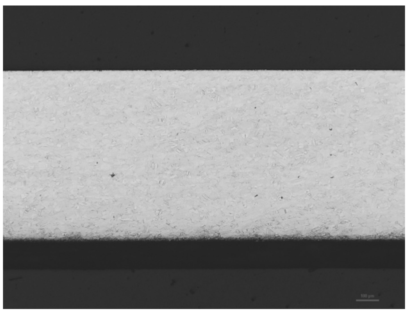


Fig. 12. Longitudinal section through on CuSn6 strip after classic rolling (magnification 50x, optical microscope)

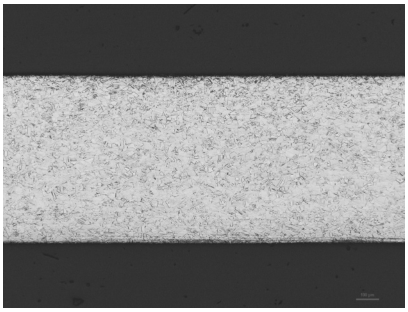


Fig. 13. Longitudinal section through on CuSn6 strip after 1 cycle of RCS (magnification 50x, optical microscope)

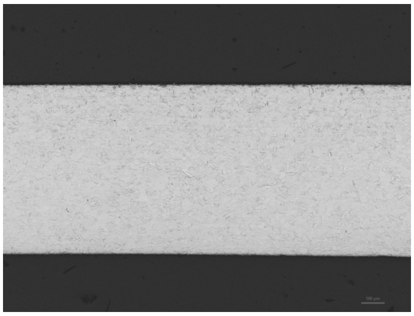


Fig. 14. Longitudinal section through on CuSn6 strip after 15 cycles of RCS (magnification 50x, optical microscope)

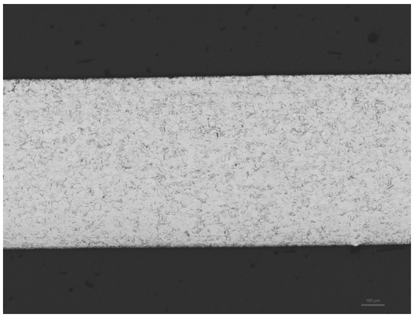


Fig. 15. Longitudinal section through on CuSn6 strip after 35 cycles of RCS (magnification 50x, optical microscope)

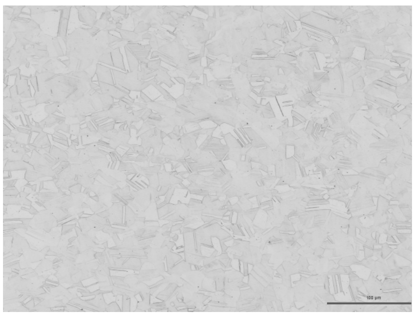


Fig. 16. Structure of CuSn6 strip after classic rolling, cross-section (magnification 200x, optical microscope)

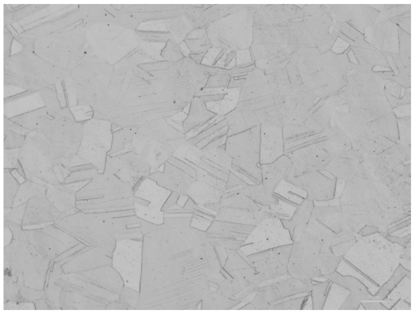


Fig. 17. Structure of CuSn6 strip after classic rolling, cross-section (magnification 500x, optical microscope)

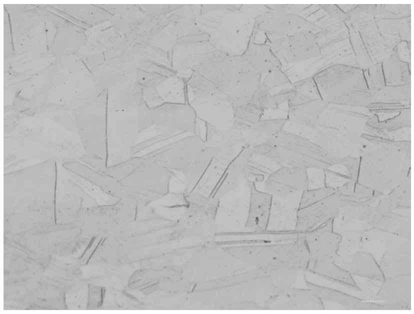


Fig. 18. Structure of CuSn6 strip after classic rolling, longitudinal section (magnification 500x, optical microscope)

Fig. 19. Structure of CuSn6 strip after 35 cycles of RCS, cross-section (magnification 200x, optical microscope)

Fig. 20. Structure of CuSn6 strip after 35 cycles of RCS, cross-section (magnification 500x, optical microscope)

Analyzed structures of CuSn6 strips after plastic working by using RCS process are characterized by significantly larger number of slippage systems visible within the interior of grains (Figs. 19-21) compared to the structures of classic rolled strips (Figs. 16-18) [4-6].

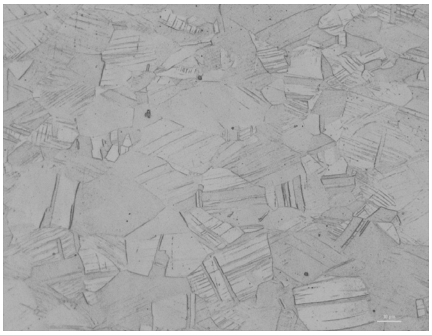


Fig. 21. Structure of CuSn6 strip after 35 cycles of RCS, longitudinal section (magnification 500x, optical microscope)

5. Conclusions

Based on the conducted study it was found that the analyzed material, regardless of the method of plastic working and measuring direction, have a compressive stress. There was a significant increase in internal stress in all the strips in the rolling direction relative to the cross direction to the rolling direction. Strips machined in RCS process was characterized by a small increase in stresses in both directions compared to the classic rolled strips.

Crystallite size measurement by Sherrer method, confirmed the presence of nano-scale structures in the studied CuSn6 alloy strips, within the range from 28 nm for classic rolled strips, to 20 nm for the strips after 35 cycles of RCS.

Strips after deformation in RCS process is characterized by an increase in maximum tensile strength (Rm_{max}) - 590 MPa, in relation to the strength of classically rolled strip - 472 MPa.

Structure of CuSn6 strips after plastic working by using RCS process are characterized by significantly larger number of slippage systems, visible within the interior of grains, compared to the structure of classic rolled strips.

Acknowledgements

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