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INVESTIGATION OF MECHANICAL AND STRUCTURAL CHARACTERISTICS OF SOME ALLOYS IN Ag-RICH CORNER OF Ag-Cu-Sn SYSTEM

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Abstract

Results of investigation of mechanical and structural characteristics of some Ag-rich alloys in Ag-Cu-Sn system are presented in this paper. Starting samples were four small billets with different contents of constituting elements - $Ag_{90}Cu_5Sn_5$, $Ag_{85}Cu_5Sn_{10}$, $Ag_{85}Cu_{10}Sn_5$, $Ag_{80}Cu_{10}Sn_{10}$ *(at%), prepared from p.a. metals Sn, Ag, Cu by melting in electro-inductive furnace under air atmosphere and additional reductant and cast into bars of square shape, dimensions 1x1x10cm. Mechanical characteristics, such as hardness and microhardness, electroconductivity and microstructure, were observed before and after a series of passes through a grooved roll stand (cold rolling).*

Keywords: hardness, microhardness, microstructure, electroconductivity, grooved rolling, Ag-Cu-Sn alloys

1. INTRODUCTION

Since environmental regulations forbid the use of Pb due to the toxicity of Pb, the development of suitable Pb-free solders has been important issue for electronics assembly [1,2].

For more than 4000 years, the soldering technique has been in use by human beings for different purposes [3]. In the modern electronics industry, soldering is the major technique of connecting the electronic devices and substrates. Pb-Sn alloys are the most popular solders. However, in view of the environmental and health hazards, very extensive efforts are being carried out for the development of lead-free solders. Sn-Ag-Cu alloys are among the most promising

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candidates for lead-free solders due to their better thermal resistance, higher mechanical strength, and anti-creep property [3-6], while Cu is the most common substrate in the electronic industry. There is also the opportunity to make a major improvement in joint reliability for challenging operating environments, i.e., high temperatures and stress levels, as well as impact loading situations. To help realize this opportunity, investigations into a promising alloy "family" of eutectic and near-eutectic Sn-Ag-Cu (SAC) solders [7, 8] have increased at many different laboratories, worldwide [9-12]. Sn-Ag-Cu ternary system is one of the most important systems for the electronic packaging industry.

In order to get an insight of a mutual reactivity of this ternary system's components, constitution diagrams of all the constituting binary systems, as well as the ternary Ag-Cu-Sn system [13] have been presented in Fig. 1.

2. EXPERIMENTAL PROCEDURE

Starting samples were four different alloys with following compositions: $Ag_{90}Cu_5Sn_5$, $Ag_{85}Cu_5Sn_{10}$, $Ag_{85}Cu_{10}Sn_5$

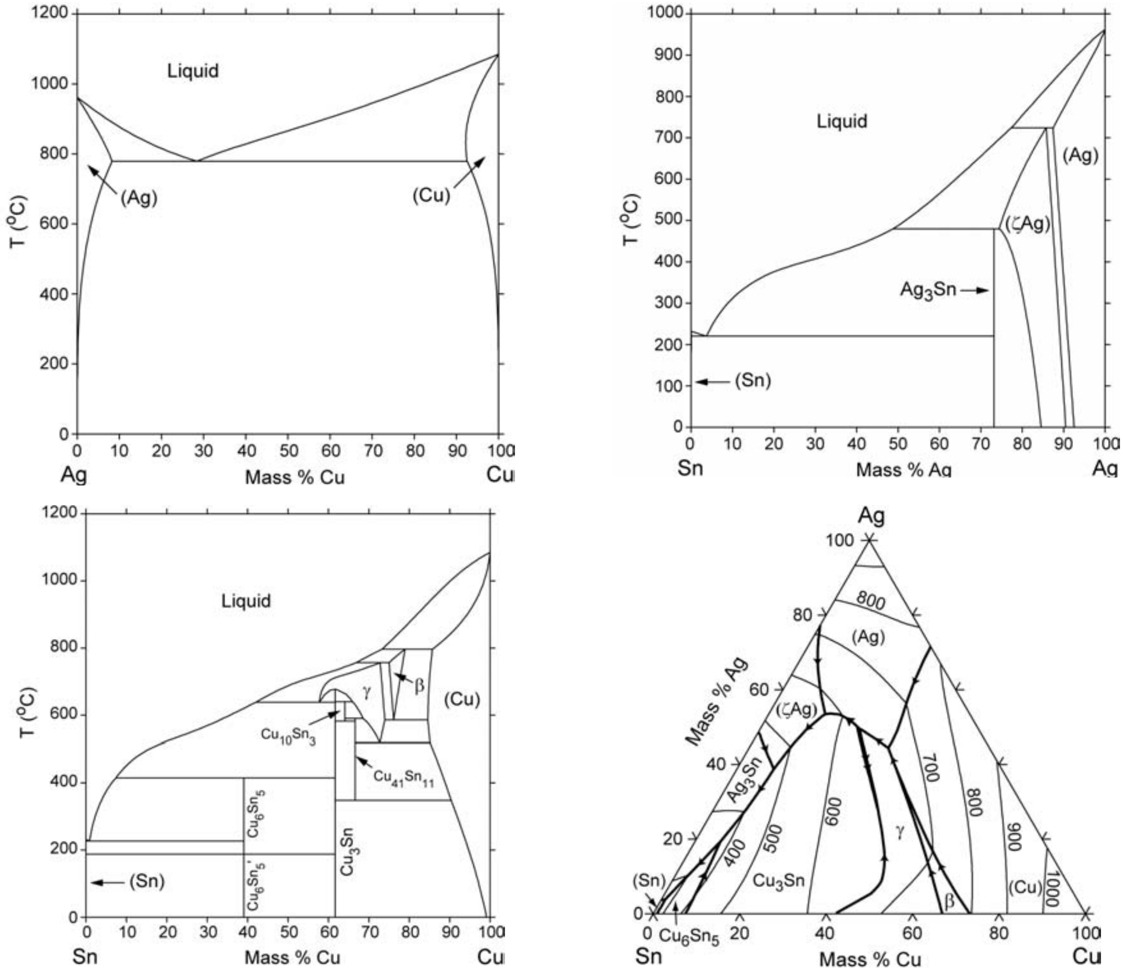

Fig. 1. Phase diagrams of the constituting binary systems and the ternary Ag-Cu-Sn system [13]

and $Ag_{80}Cu_{10}Sn_{10}$ (at %), shown in the ternary Ag-Cu-Sn system in Fig 2. The samples were prepared from p.a. metals Sn, Ag, Cu by melting in electro-inductive furnace under air atmosphere and additional reductant (coal), cast into bars of square shape, dimensions 1x1x10cm, and cooled in the air atmosphere, at room temperature. From each one of them a small piece, 2-3 cm, was cut off from one end and was treated metallographically in order to obtain microstructure, and tested on microhardness.

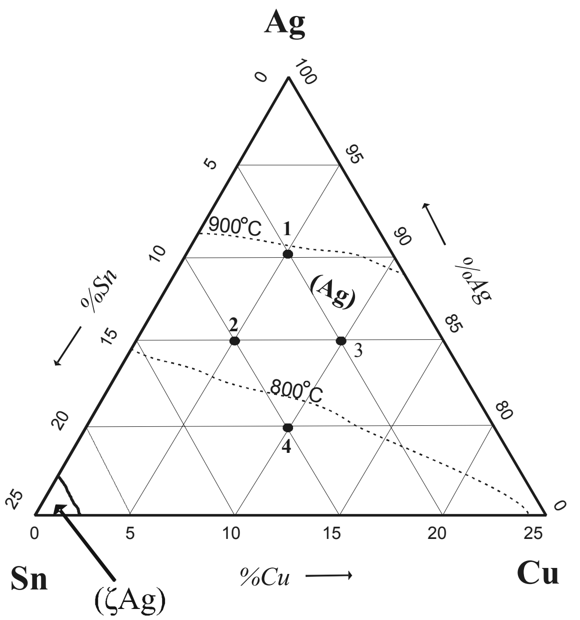

Fig.2. Ag-rich corner of ternary Ag-Cu-Sn system

On the other hand, for the bigger parts of samples hardness and electroconductivity tests were carried out. Those samples were afterwards undergone to a series of passes (five) through a grooved roll stand with all hexagon grooves and the last round one (cold rolling). After each pass values for elongation, cross-section area, hardness and electroconductivity were measured. Should be noted that sample 2 cracked after the second pass and sample 4 cracked after the third pass. Grooves shapes are presented in Fig. 3.

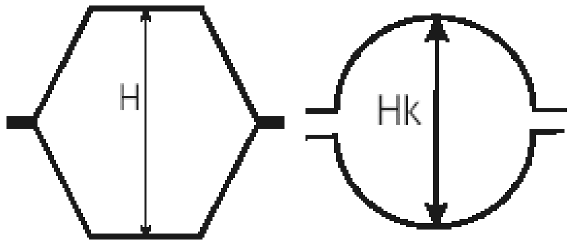

Fig. 3. Grooves shapes, a) hexagonal; b) round

The heights of the grooves used in this experiment were, in chronological order:
H_I = 9,9mm H_{II} = 8,1mm H_{III} = 6,3mm H_{IV} = 4,7mm Hk = 3,8 mm

After the last, fifth pass microstructure and microhardness values were obtained, as well.

The structure of chosen alloys was investigated using metallography, while hardness, microhardness, and electroconductivity were measured using standard techniques.

Schematic presentation of the experimental procedure is shown in Fig. 4.

3. RESULTS AND DISCUSSION

After each pass through the grooved roll stand new values for cross-section area and length of samples were obtained. Those results are given in Table 1.

Relative change of cross-section area and relative elongation have been used as deformation degree parametars:

$$\Psi_i = \frac{S_{i-1} - S_i}{S_{i-1}} \cdot 100 \ \%$$

$$\varepsilon_{l_i} = \frac{l_i - l_{i-1}}{l_{i-1}} \cdot 100 \ \%$$

$$\Psi_{tot\ i} = \frac{S_o - S_i}{S_o} \cdot 100 \ \%$$

$$\varepsilon_{l_{tot\ i}} = \frac{l_i - l_0}{l_o} \cdot 100 \ \%$$

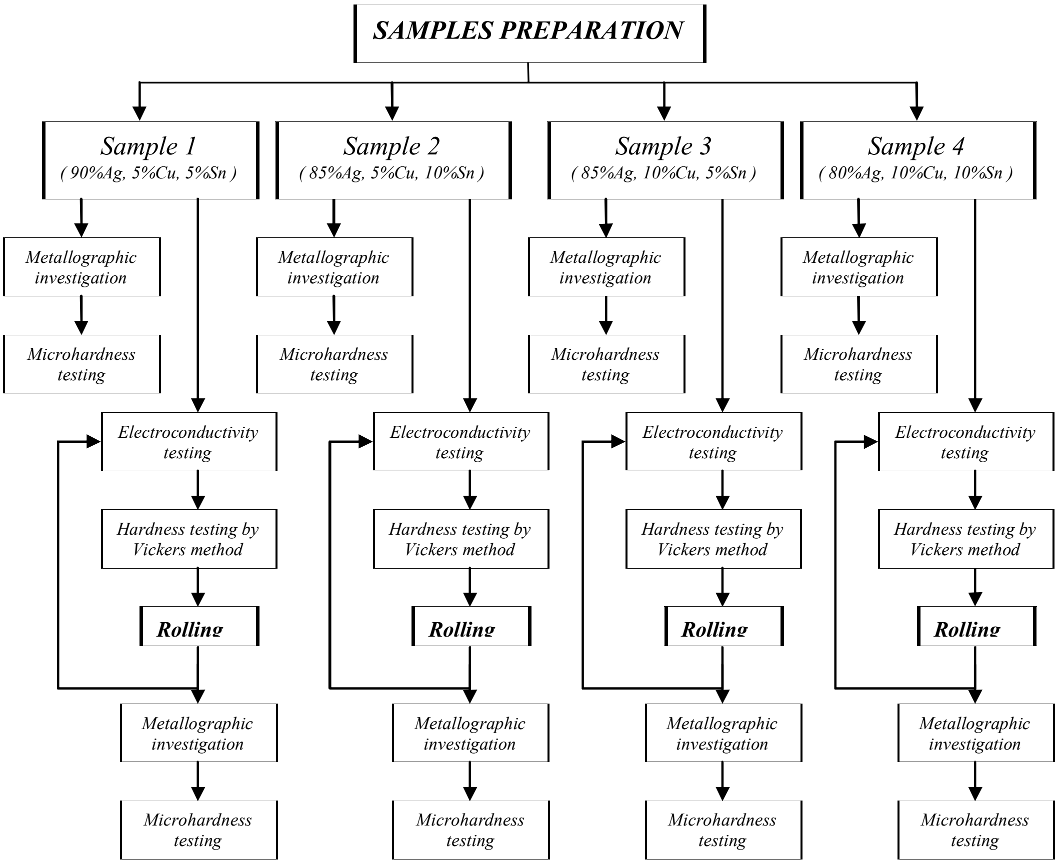

Fig. 4. Schematic presentation of the experimental procedure

Calculated values for those quantities are shown in Table 2. and in Figs. 5. and 6.

From Figs. 5. and 6. it can be seen that both, total cross-section area reduction and total relative elongation increase, as expected, and that the values for samples 3 and 1 are close to each other because of similar phase composition.

Results of hardness testing by Vickers are presented in Table 3. and in Fig. 7.

The results show that hardness values increase with deformation degree, which is also expected according to literature [14, 15], and that values for sample 3 increase more rapidly than for sample 1. Again, samples 1 and 3 have similar values, as for ψ_{tot} and ε_{ltot}.

Table 1. Results of dimensional changes of samples during the rolling

		Starting values	I pass	II pass	III pass	IV pass	Final pass
Sample 1 *(90%Ag, 5%Cu, 5%Sn)*	**S** [mm^2]	100	94,48	79,62	61,54	46,38	33,58
	L [mm]	71,2	75,36	89,42	115,7	153,5	212
Sample 2 *(85%Ag, 5%Cu, 10%Sn)*	**S** [mm^2]	100	94,24	83,28	/	/	/
	L [mm]	79,9	84,78	95,94	/	/	/
Sample 3 *(85%Ag, 10%Cu, 5%Sn)*	**S** [mm^2]	100	93,91	80,59	63,80	44,80	17,62
	L [mm]	80,2	85,4	99,52	125,7	179	240
Sample 4 *(80%Ag, 10%Cu, 10%Sn)*	**S** [mm^2]	100	97,08	/	/	/	/
	L [mm]	77	79,32	/	/	/	/

(S is a cross-section area, and L is a length of a sample)

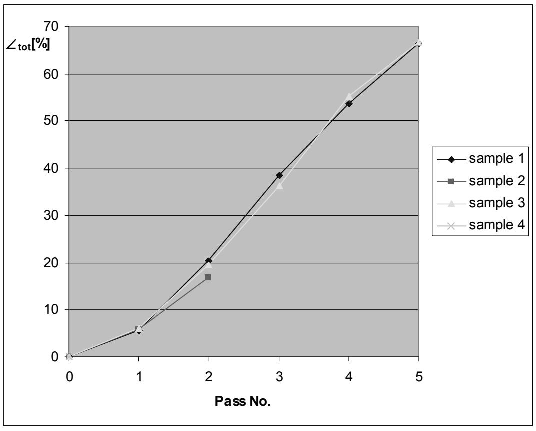

Fig. 5. Dependence of total cross-section area reduction of pass number

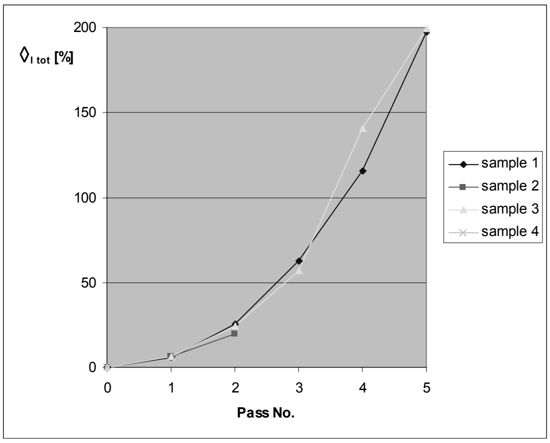

Fig. 6. Dependence of total relative elongation of pass number

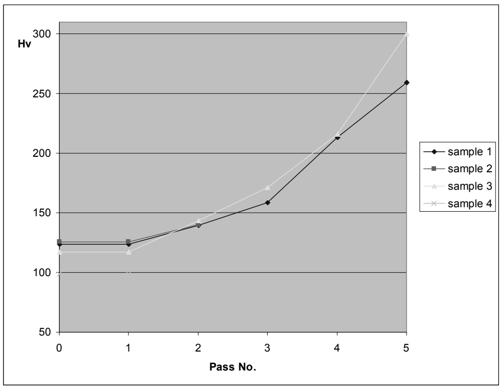

Fig. 7. Dependence of hardness by Vickers of pass number

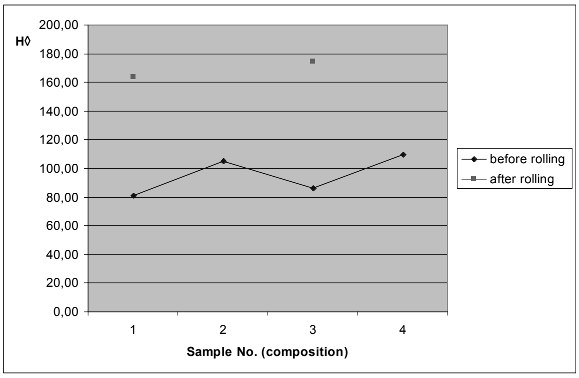

Fig. 8. Dependence of microhardness of sample composition

Table 2. Relative change of cross-section area and relative elongation

		I pass	II pass	III pass	IV pass	Final pass
Sample 1 *(90%Ag, 5%Cu, 5%Sn)*	Ψ[%]	5,52	15,73	22,71	24,63	27,60
	Ψ_{tot}[%]	5,52	20,38	38,46	53,62	66,42
	ε_l [%]	5,84	18,66	29,39	32,67	38,11
	$\varepsilon_{l\,tot}$[%]	5,84	25,59	62,50	115,59	197,75
Sample 2 *(85%Ag, 5%Cu, 10%Sn)*	Ψ [%]	5,76	11,63	/	/	/
	Ψ_{tot}[%]	5,76	16,72	/	/	/
	ε_l [%]	6,11	13,16	/	/	/
	$\varepsilon_{l\,tot}$[%]	6,11	20,08	/	/	/
Sample 3 *(85%Ag, 10%Cu, 5%Sn)*	Ψ [%]	6,09	14,18	20,83	29,78	25,40
	Ψ_{tot}[%]	6,09	19,41	36,20	55,20	66,58
	ε_l [%]	6,48	16,53	26,31	42,40	34,08
	$\varepsilon_{l\,tot}$[%]	6,48	24,09	56,73	140,74	199,25
Sample 4 *(80%Ag, 10%Cu, 10%Sn)*	Ψ [%]	2,92	/	/	/	/
	Ψ_{tot}[%]	2,92	/	/	/	/
	ε_l [%]	3,01	/	/	/	/
	$\varepsilon_{l\,tot}$[%]	3,01	/	/	/	/

Results of microhardness testing are given in Table 4 and in Fig. 8.

Figure 8. shows that microhardness increases with deformation and that samples of similar phase composition have similar values for microhardness (1, 3 and 2, 4).

Results of electroconductivity testing are shown in Table 5. and in Fig. 9.

The results show that values for electroconductivity increase after the second pass (except for sample 2), and after that, as the deformation increases, the values for electroconductivity decrease, as given in literature, also [14,16]. The increase of electroconductivity with deformation occurs because of swerving of grains and gathering of secondary phases grains. In this way the influence of secondary phases with good electroconductivity is increased [17, 18].

Results of metallographic analysis are shown in Figures 10. - 13.

Table 3. Results of hardness testing by Vickers method (average values)

Sample No.	Before rolling	II pass	III pass	IV pass	Final pass
Sample1 90%Ag, 5%Cu, 5%Sn	**123,4**	**139,7**	**158,5**	**213,3**	**259,6**
Sample2 85%Ag, 5%Cu, 10%Sn	**125,4**	**140**	/	/	/
Sample3 85%Ag, 10%Cu, 5%Sn	**117**	**143,5**	**171**	**216**	**300**
Sample4 80%Ag, 10%Cu, 10%Sn	**98,92**	/	/	/	/

Table 4. Results of microhardness testing (average values)

Sample No.	Hì [daN/mm²] Before rolling	Hì [daN/mm²] After rolling
Sample1 90%Ag, 5%Cu, 5%Sn	80,9	163,93
Sample2 85%Ag, 5%Cu, 10%Sn	103,17	/
Sample3 85%Ag, 10%Cu, 5%Sn	86,35	174,67
Sample4 80%Ag, 10%Cu, 10%Sn	109,56	/

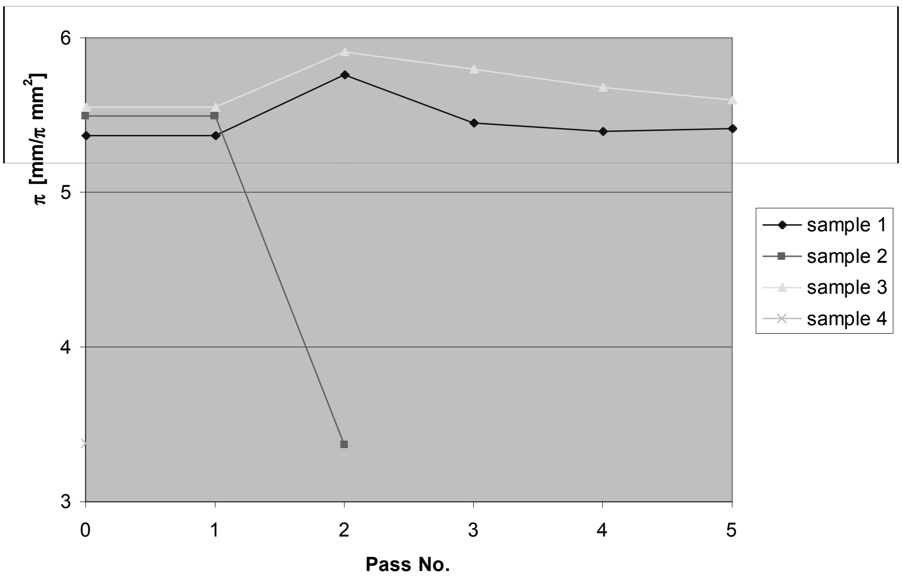

Fig. 9. Dependence of electroconductivity of pass number

Table 5. Results of electroconductivity testing

	Quantity	***Before rolling***	***Pass II***	***Pass III***	***Pass IV***	***Final pass***
Sample1 90%Ag, 5%Cu, 5%Sn	L [mm]	/	50	50	50	50
	U [mV]	/	0,547	0,745	1	1,374
	I [mA]	/	5	5	5	5
	R [Ù]	/	0,000109	0,000149	0,0002	0,000275
	S [mm^2]	/	79,62	61,54	46,38	33,58
	σ[mm/Ùmm^2]	**5,37**	**5,76**	**5,45**	**5,39**	**5,41**
Sample2 85%Ag, 5%Cu, 10%Sn	L [mm]	/	50	/	/	/
	U [mV]	/	0,891	/	/	/
	I [mA]	/	5	/	/	/
	R [Ù]	/	0,000178	/	/	/
	S [mm^2]	/	83,28	/	/	/
	σ[mm/Ùmm^2]	**5,5**	**3,37**	**/**	**/**	**/**
Sample3 85%Ag, 10%Cu, 5%Sn	L [mm]	50	50	50	50	50
	U [mV]	0,450	0,523	0,677	0,983	1,334
	I [mA]	5	5	5	5	5
	R [Ù]	0,00009	0,000105	0,000135	0,000197	0,000267
	S [mm^2]	100	80,59	63,80	44,8	33,42
	σ[mm/Ùmm^2]	**5,55**	**5,91**	**5,80**	**5,68**	**5,60**
Sample4 80%Ag, 10%Cu, 10%Sn	L [mm]	50	/	/	/	/
	U [mV]	0,742	/	/	/	/
	I [mA]	5	/	/	/	/
	R [Ù]	0,000148	/	/	/	/
	S [mm^2]	100	/	/	/	/
	σ[mm/Ùmm^2]	**3,38**	**/**	**/**	**/**	**/**

5. CONCLUSION

Four samples from Ag-rich corner of ternary Ag-Cu-Sn system have been investigated ($Ag_{90}Cu_5Sn_5$, $Ag_{85}Cu_5Sn_{10}$, $Ag_{85}Cu_{10}Sn_5$, and $Ag_{80}Cu_{10}Sn_{10}$), before and after a cold plastic deformation by rolling, on hardness, microhardness, electroconductivity and metallography. The results show that hardness and microhardness values increase with deformation degree, and that electroconducivity firstly increases and after that decreases.

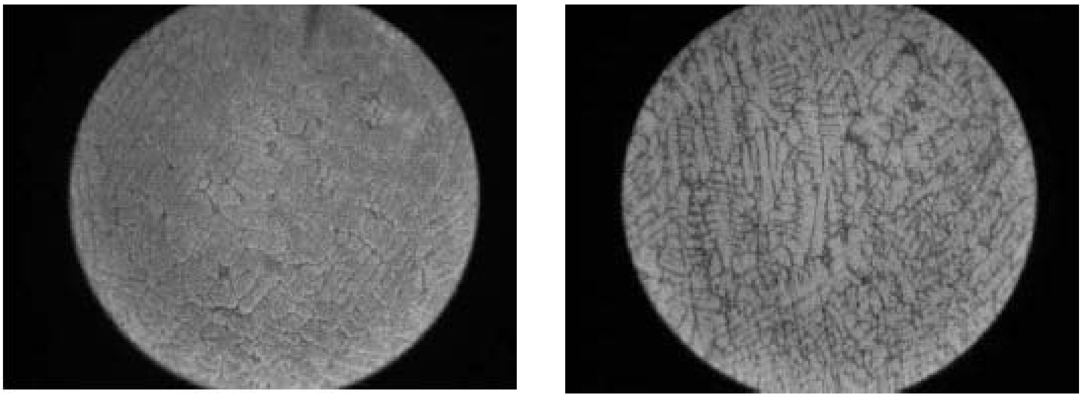

Fig. 10. Microstructure of sample 1 (90%Ag, 5%Cu, 5%Sn) before and after cold rolling (magnification 500x)

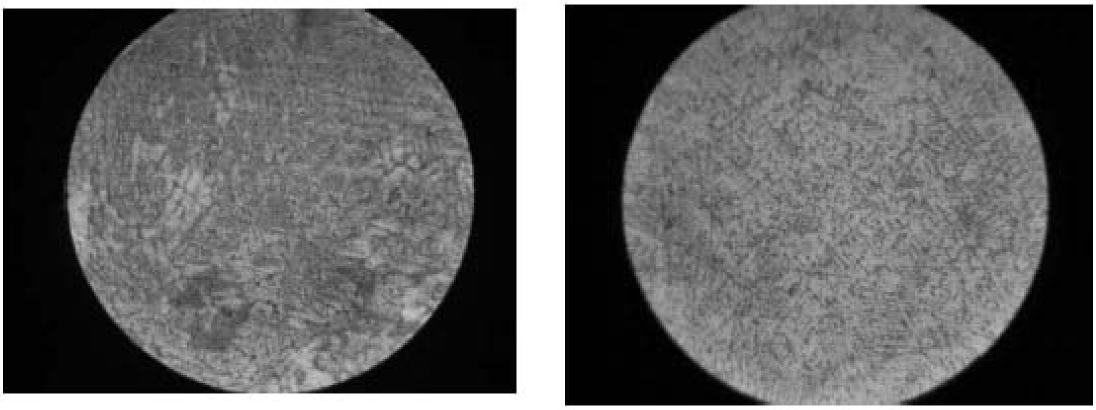

Fig. 11. Microstructure of sample 2 (85%Ag, 5%Cu, 10%Sn) before cold rolling (magnification 500x)

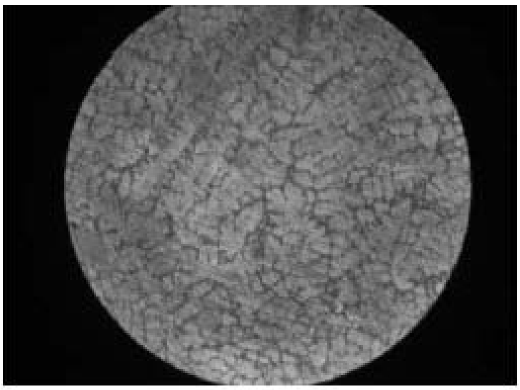

Fig. 12. Microstructure of sample 3 (85%Ag, 10%Cu, 5%Sn) before and after cold rolling (magnification 500x)

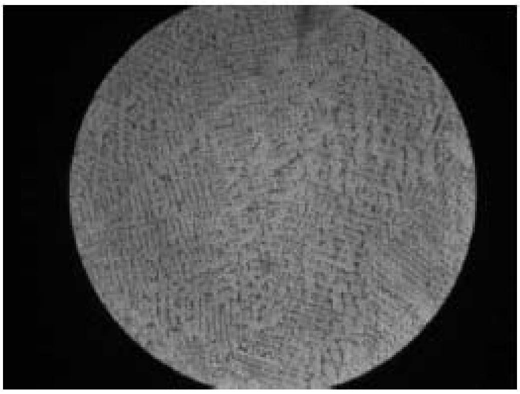

Fig. 13. Microstructure of sample 4 (80%Ag, 10%Cu, 10%Sn) before cold rolling (magnification 500x)

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