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Stability of properties in silver – lanthanum alloy

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Properties

ABSTRACT

Purpose: The objective of the work was to investigate changes in structure and properties of Ag+(0,5%wt)La alloy and its difference to the comparative Ag+(7,5%wt)Cu and pure Ag materials.
Design/methodology/approach: Tests were made with samples obtained by melting and casting in inductive furnace. Further plastic deformation was provided by KOBO® extrusion and drawing. The mechanical properties (at room temperature, elevated temperature and after annealing) and microstructure (by the optical, scanning and transmission electron microscopy) were examined.
Findings: Analysis of the initial microstructure of these materials was made, and its evolution during deformation process was investigated with respect to the changes in the mechanical and electrical properties.
Research limitations/implications: Significant changes in microstructure after extrusion were observed. Alloy with addition of lanthanum had an excellent electrical conductivity close to the conductivity of pure silver. Mechanical properties examination after annealing gave grounds to conclude that also this alloy had increased properties stability at elevated temperature.
Practical implications: Alloy with addition of lanthanum after further investigations could be considered as a material for producing electric or electronic parts which are designed to work in environment of elevated temperature or with a risk of temperature changes.
Originality/value: The paper shows properties stability in new designed silver alloy with addition of lanthanum. Wire made of this material could be easy produced with examined methods, without any annealing process. Having stable properties and excellent electrical conductivity this alloy could be considered as a material for producing advanced electrical or electronic equipment.
Keywords: Metallic alloys; Functional materials; Metallography; Electrical conductivity

1. Introduction

Properties stability is one of more important features of metallic materials. Especially for products assigned to working in environment of elevated temperature or with a risk of periodic temperature changes. Silver has excellent electrical and heat conductivity, good tarnish resistance and fair, glossy look. That is why it is commonly used from electronic and electric industry to jewelry. Majority of the world silver consumption is in electronic and electric industry (40% in 2003) most often as conductors and contacts [1-3]. Mechanical properties of pure annealed silver are very low. The easiest way to improve mechanical properties is cold working. But silver that has been fully work-hardened recrystallizes when left at room temperature, and becomes softer [4]. The better way to obtain good mechanical properties is to use alloy additives, especially causing precipitation [5-11] or dispersion [12-15] hardening. However, it results in lowering of electric conductivity and often decreasing of tarnish resistance.

It is expected that addition of lanthanum in silver based alloys stimulate grain size refinement. In relation to the presence of dispersion hard intermetallic phase particles this structure causes increase of mechanical properties. Presence of particles in grain boundaries slow down their migration and grains growth. Thus, the fine grain structure should became stable at elevated temperature which enable this materials for elevated temperature applications.

2. Experimental procedure

Tests were made with Ag + (0,5%wt) La and Ag + (7,5%wt) Cu (sterling) alloys. Ingots were prepared by typical melting and alloying in an induction furnace in open air with charcoal covering and further casting into graphitoidal mould. Another comparative material (except sterling) was pure silver (Ag100) prepared by powder metallurgy methods. Basing on the assumption that obtained material should have possibly fine structure and dispersive distribution of hardening phases, samples in the shape of rollers, of diameter φ40 mm were extruded on oscillatory turning die press (KOBO®). The samples were not heated before extrusion. Reduction rate after extrusion amounted to S_0/S_1= 178, which corresponds to true strain $\ln(S_0/S_1)$=5,18. Thus a wire of diameter φ1,45 mm was obtained from φ40 mm ingot(S_0/S_F = 761, $\ln(S_0/S_F)$=6,64) without any annealing process.

The microstructure was examined using optical microscope, SEM and TEM.

Tensile tests were conducted at room temperature on testing machine. Wires after drawing were tested also at elevated temperature - 50, 100, 150, 200, 250 and 300°C with maintaining at the temperature for 30 minutes before testing.

Mechanical properties of annealed samples were also determined. The samples were annealed at temperature 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500°C per 1 hour (pure silver up to 300°C). The annealed samples were cooled in the air and tested on a tensile test machine at room temperature.

3. Results and discussion

Sample results of optical microscopy observations are presented in Fig. 1-2, SEM images are presented in Fig.3-4 while structures observed with TEM are presented in Fig.5-6.

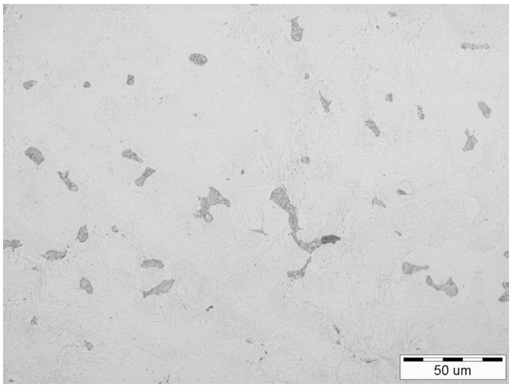

Fig. 1. Sample images of the structure after casting Ag+7,5%Cu, optical microscope, etched sample

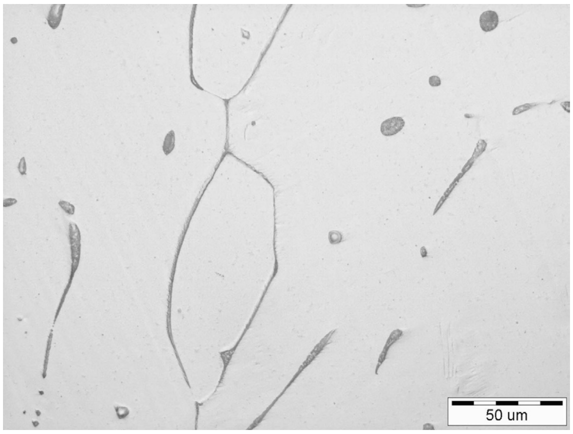

Fig. 2. Sample images of the structure after casting Ag+7,5%Cu, optical microscope, etched sample

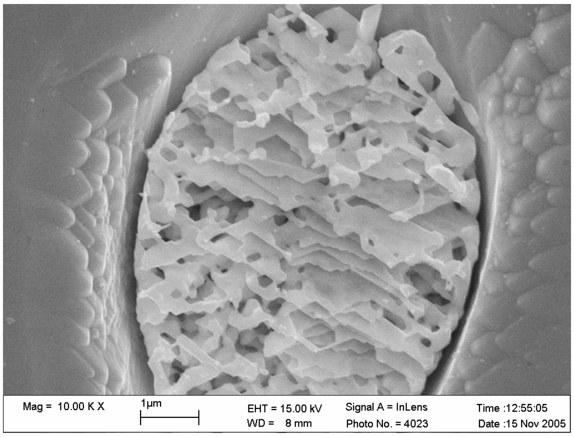

Fig. 3. Particle in Ag+0,5%La alloy SEM after casting, etched sample

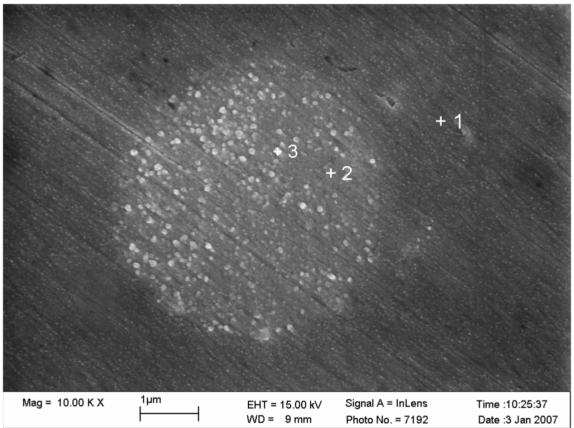

Fig. 4. Particle in Ag+0,5%La alloy SEM after extrusion, polished sample, results of EDS analysis in microareas: 1: Ag=100%; 2: Ag=92,2%;La=7,8%; 3: Ag=90,3%;La=9,7%

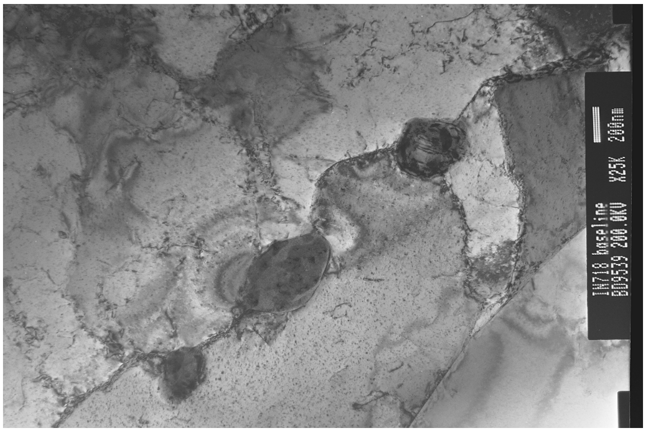

Fig. 5. Structure of Ag+0,5%La alloy examined with TEM

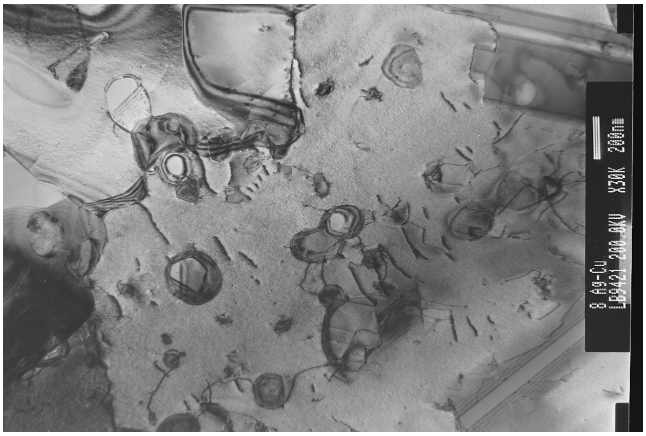

Fig. 6. Structure Ag+7,5%Cu alloy of examined with TEM

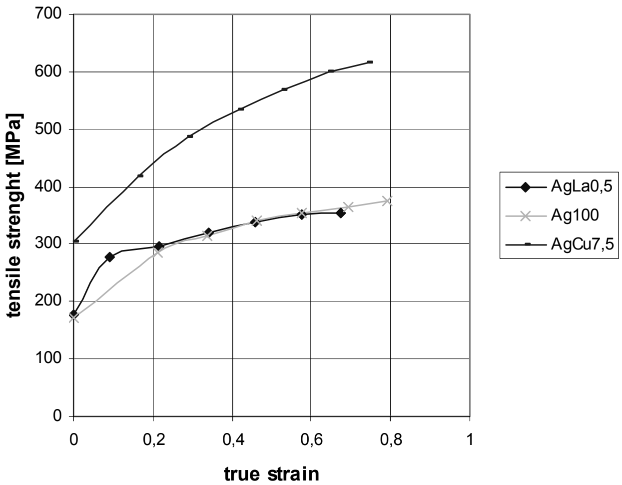

Fig. 7. Tensile strength versus true strain during drawing

The microstructure of Ag-Cu alloy contained considerable amount of eutectic phase precipitations with size of several micrometers. In silver matrix 4-7% of copper were dissolved. Presence of sparse fine copper particles, undissolved in matrix, were observed. In Ag+0,5La alloy presence of eutectic mixture Ag – Ag_5La occurring on pure silver grains was found. This alloy had a typical dendrytic structure.

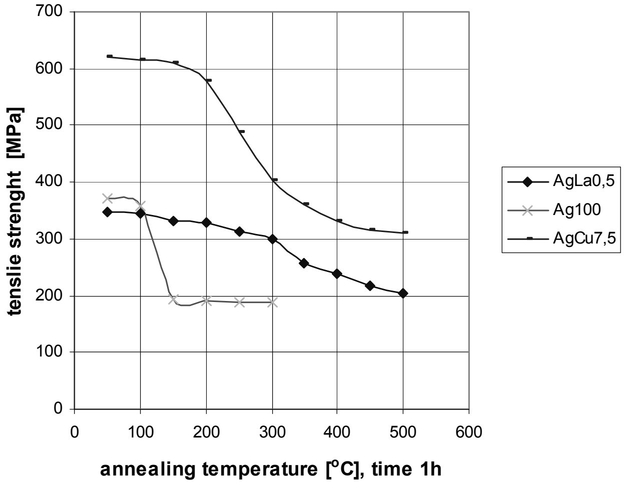

Fig. 8. Tensile strength versus annealing temperature per 1hour.

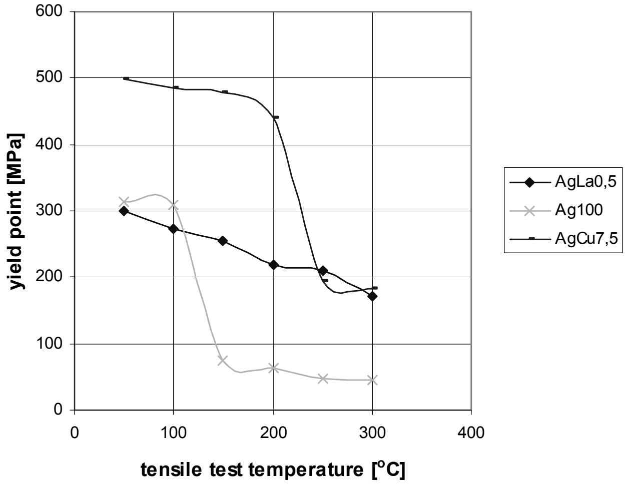

Fig. 9. Yield point versus tensile test temperature.

Significant changes in microstructure after extrusion were observed. Particles had a globular shape and a diameter in range 2-5 μm on a cross-section. These particles were uniformly distributed in a matrix. Plastic deformation by drawing results in further refinement of the structure. Particles size was in range 1-3μm. Microstructure examination revealed that alloys had a fine structure (after extrusion grains size diameter of matrix was in range 1-3μm, and for pure silver in range 5-15 μm). It is important that matrix grains were similar in shape and size on cross-section and longitudinal-section. Particles on parallel microsections form bands, which are longitudinal to the extrusion and drawing direction. After annealing, the start up of recrystalization process was observed. Ag+0,5La alloy behave very similar to pure silver during plastic deformation in drawing process (fig.7). In comparison, Ag+7,5Cu alloy had much higher mechanical properties. Mechanical properties of cold worked pure silver decrease considerably at annealing temperature 150°C and above (fig.8). Mechanical properties of Ag+0,5La alloy remain stable at temperature up to 300- 350°C. The highest mechanical properties had been observed in Ag+7,5Cu alloy but at the annealing temperature of 200°C and above it became decreasing

The curves representing changes of properties in tension tests at the elevated temperature (Fig.9) seem to be moved towards lower temperatures in comparison to curves representing changes of properties of samples which had been annealed and tension tested at room temperature (fig.8). However, the curves for pure silver look very similar in both situations. The yield point of Ag+0,5La and Ag+7,5Cu alloys measured during tension test at temperature 250°C and above had similar value of about 200MPa.

Pure silver had the highest electrical conductivity about 61 MS/m. This value for Ag+0,5La alloy was slightly lowered, to 60 MS/m only. Ag+7,5Cu alloy had electrical conductivity of about 50 MS/m. For all this materials the value of electrical conductivity had been slightly lowered after cold working in drawing process.

4. Conclusions

Significant changes in microstructure after extrusion in KOBO® process were observed. Strengthening particles of globular shape were homogenously distributed in silver matrix. Microstructure examination revealed that alloys had a fine matrix structure. Additionally, size and shape of grains were similar in cross and longitudinal sections. Plastic deformation by drawing results in further refinement of the structure. Particles in longitudinal sections form bands, which are longitudinal to the extrusion and drawing direction.

Electron transmission microscopy investigations revealed presence of particles of diameter in the range of 200-400 nm, which probably favorably influenced mechanical properties and stability.

Alloy with addition of lanthanum had excellent electrical conductivity close to the conductivity of pure silver. Mechanical properties examination after annealing gave grounds to conclude that also this alloy had an increased properties stability at elevated temperature. However, the values of tensile strength and the yield point were close to the values of cold worked pure silver.

Thus alloy with addition of lanthanum could be used for producing electric or electronic parts which are not designed to work under heavy loads but designed to work in environment of elevated temperature or with a risk of temperature changes. It is worth to mention that mechanical properties of this alloy at temperature above 200°C were close to the properties of Ag+7,5Cu alloy, which had much better mechanical properties at room temperature.

This investigation results form a basis for a further research aiming to correlate chemical composition, metal working and heat treatment parameters and microstructure with properties of this alloy.

Acknowledgments

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