INFLUENCE OF SILICON ON CHARACTERISTICS OF STERLING SILVER

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Abstract

The scope of the presented study refers to the mechanical and electrical properties of the sterling silver in relation on silicon content in the alloy. Sterling silver is an alloy of silver containing 92.5% by weight of silver and 7.5% by weight of copper or other metals, whereas in presented research 0.05-0.3% of copper was replaced with silicon. Hardness, compression and electrical conductivity of the sterling silver with silicone addition have been investigated in this study. Electrical conductivity and reduction percentage decrease with increasing content of silicone. The same effect but to a lesser extent was found for the hardness.

***Keywords**: Silicon, Sterling Silver, hardness, conductivity, compression.*

1. INTRODUCTION

Silver is historically known precious metal with characteristics suitable for making jewelry. However, pure silver has low hardness for the fabrication of jewelry items. Therefore, it is common to add other metals to obtain an alloy with increased hardness, tensile strength, and wear resistance [1]. Sterling silver is a silver alloy with 92.5% Ag, and 7.5% of other alloying elements. Usually it is binary silver-copper alloy. Silver sterling Ag-Cu alloy have two phase structure: Ag rich and Cu rich; single Ag rich phase may be achieved only with annealing on high temperature followed with the water quenching, because of the difference in copper solid solubility at different temperatures [2,3]. This feature is used for age-hardening process of the sterling silver to increase hardness [3]. As-cast sterling-silver alloys are very soft (usually less than 60 HB), and the modern alloys with lower copper content are even softer [4]. Modern alloys usually contain Zn, Si, Ge, Ir, and B to achieve improved fire-stain resistance and anti tarnish properties [5].

Tarnishing of metals and alloys, especially sterling silver, is the corrosion process that leads to changing color of the surface of material. It is of utmost importance in the jewelry and dental applications [6,7]. Tarnishing is usually formation of sulfides on the surface of silver by sulfide gases in the atmosphere, such as H_2S or CS_2. Additionally, the physical factors, temperature, humidity of the air (atmosphere) and light, have a great influence on tarnish process [8,9]. The corrosion reactions responsible for the tarnishing oxidize silver and copper in sterling silver by oxygen from atmosphere and atmospheric moisture [10,11].

The addition of elements such as Si or Ge that are capable of forming protective surface films is main method for increasing antitarnish characteristics of sterling silver. Silicon has stronger affinity to oxygen than silver and copper and acts as deoxidizer of the molten alloy and thus prevents the formation of dark copper oxide layers. It decreases the surface tension of the melt and therewith increases fluidity, form filling and reduces surface roughness [12]. Consequently, silicon is often used to improve the properties of silver. Study of an alloy with 95% Ag and sterling silver alloyed with Si showed that with increasing silicon concentration the microstructure had a tendency to be a network structure of Cu-Si rich phase occurring at the grain boundary of the Ag rich phase. As a result, the hardness increased gradually and the ductility decreased significantly even with small concentration (less than 0.1%) of Si in the alloy [13]. The aim of this study was to investigate effect of silicon microalloying of sterling silver in terms of mechanical and electrical properties.

2. EXPERIMENTAL

2.1 Materials and preparation of samples

Constituent metals Ag, Cu and Zn with purity of the 99.99 % were produced by the recycling process [14]. The alloys were prepared by induction melting (induction furnace Eling IP-6, 10 kHz) at a temperature of 950 °C in graphite crucible and vacuum casting into steel mould preheated to 300 °C. Ingots were rectangular in shape and samples weight 350 g ± 3.5 g. Desired composition of alloys is given in the Table 1. Compositions are given in mass percentage. Silver content is planned to be 92.5% for all alloys. Consequently, content of Cu plus Si had to be 7.5%.

Table 1 - Desired chemical composition of alloys of the Ag-Cu-Si system

Alloy	Ag, %	Cu, %	Si, %	Total, %
AgCu7.5	92.50	7.50	0.00	100.00
AgCu7.45Si0.05	92.50	7.45	0.05	100.00
AgCu7.4Si0.1	92.50	7.40	0.10	100.00
AgCu7.35Si0.15	92.50	7.35	0.15	100.00
AgCu7.3Si0.2	92.50	7.30	0.20	100.00
AgCu7.25Si0.25	92.50	7.25	0.25	100.00
AgCu7.2Si0.3	92.50	7.20	0.30	100.00

2.2 Chemical, mechanical and electrical characterization

Silver, copper and silicon were analyzed by AAS (Perkin Elmer 2380). Silver content were within the limits of ±0.1 % for all samples.
Silicone contents for the six alloys are given in the Table 2.

Table 2 - Desired and obtained silicon concentration in the alloys

Desired Si content, mass %	0.05	0.10	0.15	0.20	0.25	0.30
Actual Si content, mass %	0.08	0.11	0.20	0.23	0.28	0.41

Measurement of Brinnell hardness was performed in compliance with SRPS EN ISO 6506-1:2011 standard with use of Brinnell hardness tester produced by „WPM" with steel ball having diameter of 5 mm under load of 1226 N maintained for 15 seconds. The values given for the Vickers hardness are the average of the five measured values. Measurement of the electrical conductivity was performed by a laboratory conductivity meter Foerster SIGMATEST 2.069 at the temperature of 25.6 °C and with 8 mm diameter sensor. Temperature compensation function of the instrument was used to obtain results in IACS%. Measure of sample thickness after compression was used for the compression test. After calculate the surface and thickness of each sample it was obtained the pressure required to compress 5% the samples. Obtained values almost reached 10 MPa, therefore press was set to pressure of 10 MPa. The thickness before and after the compression was been measured in four points, one in each edge, and then it has been calculated the average value.

3. RESULTS AND DISCUSSION

Figure 1 displays the reduction percentage of the as-cast AgCu7.5 alloys with the addition of the silicone from 0.05 to 0.30%. Figure 2 shows dependence of hardness (HB) in relation of the silicon content of the same alloys.

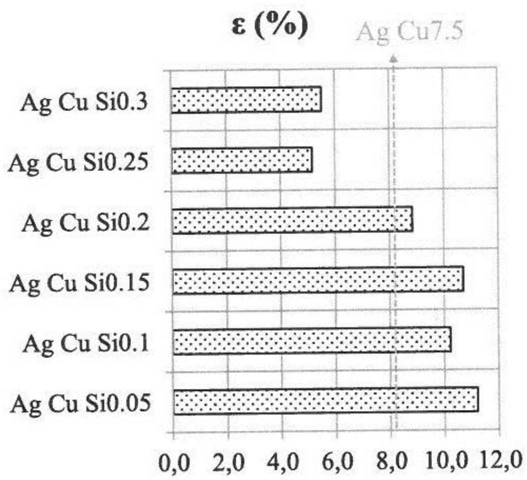

Figure 1 - Reduction after compression with 10 MPa

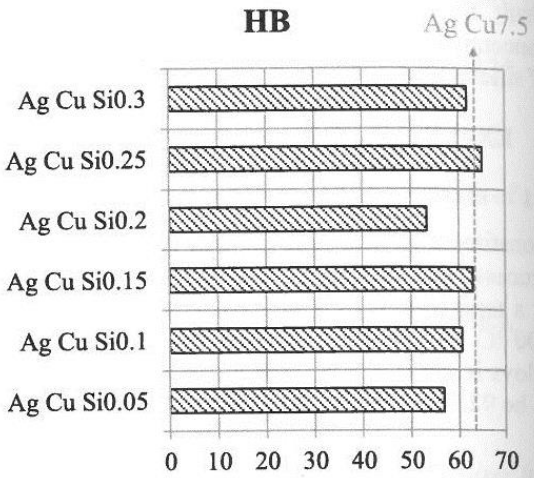

Figure 2 - Hardness of the AgCuSi alloys

Values of reduction of the thickness, as a measure of the compression, have shown that silicon decrease this property and therefore increase the stength of the alloy. Influence is stonger for the higher content of Si (above 0.2%). Sterling silver has nearly the same value as AgCuSi0.2 alloy.

Hardness of the alloys increase with the silicon content but with exceptions for the AgCuSi0.2 and AgCuSi0.3 alloys which showed deviations from this tendency. The lower content of Si even decrease hardness of as-cast alloys. Sterling silver had similar value as the AgCuSi0.15 alloy.

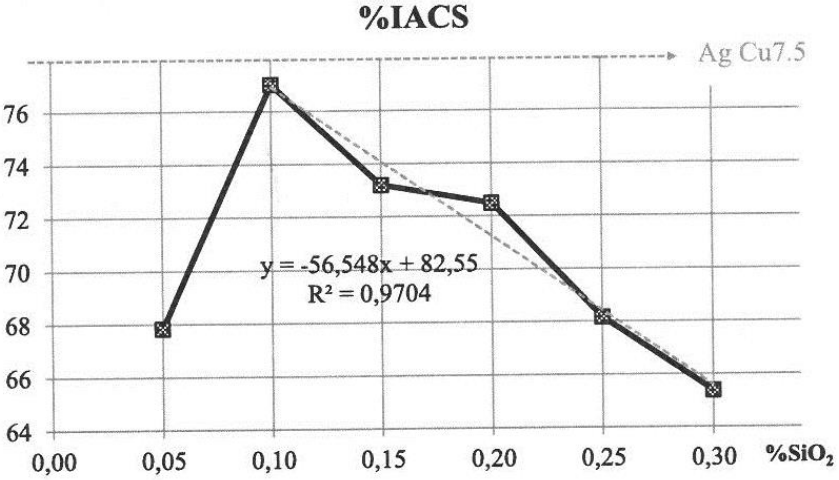

Figure 3 - Electrical conductivity given as percentage of the International Annealed Copper Standard (IACS), 58.0 MS/m at 20 °C, for the AgCuSi alloys

Electrical conductivity of the sterling silver with Si addition is compared in Figure 3. It can be seen that linear dependence with increase of the Si content is obtained. Only exception was observed for the alloy with the lowest (0.05%) content of silicon. Although it is clearly visible from the graph, it was confirmed with high correlation coefficient R^2 and the value of the y-intercept which is very close to the value of the AgCu7.5 alloy (82.55% vs. IACS 77.97%).

4. CONCLUSION

A ternary alloy Ag 92.5 wt%, Cu 7.5 wt% with Si addition from 0.05% do 0.30% with proportionally decrease of cooper was manufactured by melting and casting. The mechanical properties were determined using compression and hardness tests. Electrical characteristics were determined by electrical conductivity measurements. The main results are:

- Silicon has clear and strong influence on electrical conductivity and dependence is linear from the 0.1% to 0.3% Si with good correlation coefficient of 97%.
- Degree of reduction after the applied compression is much lower for the high Si content.
- Effect on the hardness of the alloy is smaller. It was found that copper has strong influence on hardness increase. Higher Cu content had similar effect as addition of Si.
- Silicon improved fluidity of the melt and reduce surface porosity of the sterling silver.
- Results indicate that workability of the Ag-Cu-Si alloys decrease at high Si concentrations.
- Silicone is the alloying component which content in the alloy has to be well optimized to achieve desired characteristics.

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