N. LAMLA, P. KWAŚNIEWSKI, G. KIESIEWICZ, M. SADZIKOWSKI, K. FRANCZAK ISSN 0543-5846
METABK 63(2) 275-278 (2024)
UDC – UDK 669.35.6:669.3.22.5.6:621.791.3:621.317:620.17=111

RESEARCH OF THE ALLOYING ADDITIVES CONTENT IN HIGH-SILVER SOLDERS ON THEIR SUSCEPTIBILITY TO SOLDERING PROCESS AND BASIC PERFORMANCE PROPERTIES

Received – Primljeno: 2023-10-18
Accepted – Prihvaćeno: 2023-12-15
Preliminary Note – Prethodno priopćenje

Copper and its alloys with steel, including stainless steel, are soldered using brazing materials CuAgZn and CuAgZnSn. They are used for making connections in heating, cooling and renewable energy sources (RES) devices. The elements used in the above-mentioned alloys affect wettability, castability, corrosion resistance, impact resistance, plasticity, stress resistance and also increase the melting point of the solder. The article presents the impact of the percentage of alloying additives covered by the EN ISO 17672 standard on performance and susceptibility to soldering brazing materials Ag44 and Ag40Sn.

Keywords: brazing, CuAgZnSn, soldering, electrical properties, mechanical properties

INTRODUCTION

Brazing alloys containing ~40 % silver (Ag) are commonly used in making connections in heating, cooling and renewable energy sources (RES) equipment, including the production of solar collectors and heat pumps, due to their excellent strength, plasticity, corrosion resistance and thermal and electrical conductivity. The properties of these alloys are affected by the addition of such elements as: copper (Cu), silver (Ag), tin (Sn), zinc (Zn) [1-3].

In accordance with EN ISO 17672 [4], brazing materials are most commonly used in these applications. The percentages of each element for the Ag44(Ag244) alloy are the following: 43 % -45 % silver, 29 %-31 % copper, 24 %-28 % zinc and for Ag40Sn(Ag140) 39 %-41 % silver, 29 %-31 % copper, 26 %-30 % zinc and 1,5 %-2,5 % tin. Copper (Cu) increases the thermal and electrical conductivity of the solder alloy, improves corrosion resistance, increases stress resistance and improves plasticity, silver (Ag) causes good wettability, increases corrosion resistance, impact resistance, and increases thermal and electrical conductivity, zinc (Zn) reduces melting temperature of an alloy, tin (Sn) increases the fungibility, improves the capillary effect and lowers the melting point [5-7].

EXPERIMENTAL PROCEDURE

The study examined solder wires with different alloying content and commercial wires were tested for comparison. The soldiers were produced by metallurgical synthesis of Ag44 and Ag40Sn alloys in a continuous casting process (see Figure 1) with the following parameters: liquid metal temperature 1 000 (+/_25) °C, feed/standstill 4 mm/2s, primary cooling 0,24/0,36 l/min, secondary cooling 0,1 l/min. Tests were conducted for solders:

-Ag44 containing 43 %-45 % silver, 29 %-31 % copper, 26 %-28 % zinc.-Ag40Sn containing 40 %-41 % silver, 29 % copper, 28,5 %-29 % zinc, 1,5 %-2,5 % tin.

The chemical compositions are shown in Table 1, and continuous casting on figure 1.

The castings obtained were given drawing on wires of 2 mm diameter with a partial elongation factor of λ = 1,1, using an intermediate heat treatment at 500 °C/1h. The wires produced were subjected to durability tests on a Zwick/Roell Z100-type machine and resistance tests on a Resistomat 2304-type device (to determine the conductivity of the material). The obtained wires were used to create model connections (copper tube in K-20 grade of Ø 8 x 0.5 mm with stainless steel tube in 1,4401 grade of Ø 20 x 2 mm) , which are used in DIS-type solar collectors and monoblock heat pumps. The

Table 1 **List of copper alloys produced on the continuous casting**

Material	Targeted chemical composition / wt. %			
	Ag	Cu	Zn	Sn
Ag45Cu29Zn26	45	29	26	
Ag43Cu31Zn26	43	31	26	
Ag43Cu29Zn28	43	29	28	
Ag41Cu29Zn29Sn1,5	41	29	28,5	1,5
Ag40Cu29Zn29Sn2	40	29	29	2
Ag40Cu29Zn28,5Sn2,5	40	29	28,5	2,5
K Ag44	43/45	29/31	24/28	
K Ag40Sn	39/41	29/31	26/30	1,5/2,5

N. Lamla (e-mail: lamla@agh.edu.pl,), P. Kwaśniewski, G. Kiesiewicz, K. Franczak, M. Sadzikowski, - AGH University of Science and Technology, Faculty of Non-Ferrous Metals, Cracow, Poland

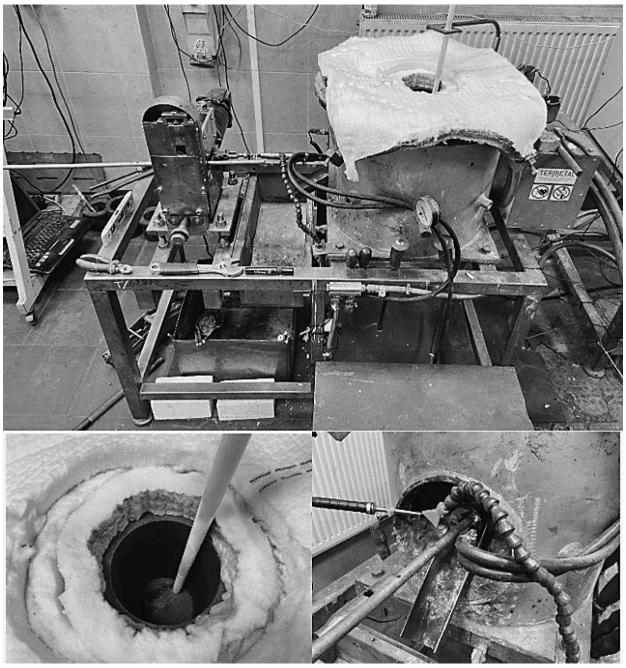


Figure 1 Laboratory line for horizontal continuous casting process used for the metallurgical synthesis and casting of Ag-Cu-Zn-Sn and Ag-Cu-Zn-Sn alloys

obtained model specimens of soldered joints were subjected to pressure evaluation and fatigue strength in a bending test.

Pressure test procedure: the joint was given a pressure test with parameters of pressure 600 kPa, test duration ½ h.

Fatigue test procedure: the joint was given a bending test with parameters of -3,5 mm/+6,5 mm (total stroke of 10 mm) simultaneously, the number of inflections was counted per device constructed for this test.

RESULTS AND DISCUSSION

Tests conducted on solder wires produced under laboratory conditions as well as commercial wires (reference) showed that their conductivity is in the range of 9,27 – 10,97 Ms/m (see Table 2 and Figure.2). A trend is observed that wires containing an increased addition of silver within a specific grade (Ag44 and Ag40 Sn) exhibit increased conductivity. It was also found that

Table 2 **Electrical properties of Cu-Ag-Zn-Sn**

Material	Electrical conductivity / MS/m	IACS / %
Ag45Cu29Zn26	10,26	17,69
Ag43Cu31Zn26	9,69	16,71
Ag43Cu29Zn28	9,84	16,97
Ag41Cu29Zn28,5Sn1,5	10,54	18,17
Ag40Cu29Zn29Sn2	9,51	16,4
Ag40Cu29Zn28,5Sn2,5	9,27	15,98
K Ag44	10,97	18,91
K Ag40Sn	10,83	18,67

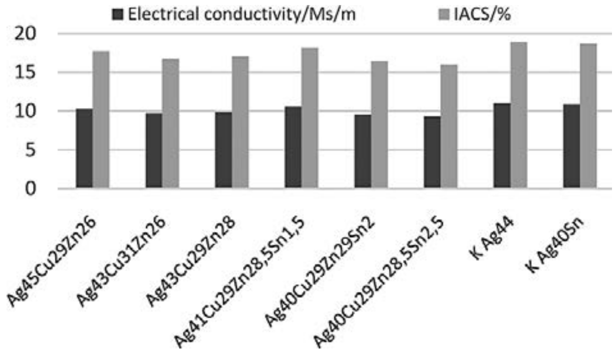


Figure 2 Electrical properties graphical representation for Cu-Ag-Zn-Sn alloys

Table 3 **Mechanical properties of Cu-Ag Zn-Sn alloys**

Material	$R_{p0.2/}$ MPa	$R_{m/}$ MPa	$A_{50mm/}$ %
Ag45Cu29Zn26	700	829,94	1,74
Ag43Cu31Zn26	659	714,17	0,94
Ag43Cu29Zn28	713	769,53	1,18
Ag41Cu29Zn28,5Sn1,5	623	773,54	2
Ag40Cu29Zn29Sn2	700	810,81	1,4
Ag40Cu29Zn28,5Sn2,5	635	727,15	1,78
K Ag44	498	575,28	4,57
K Ag40Sn	505	608,93	8,14

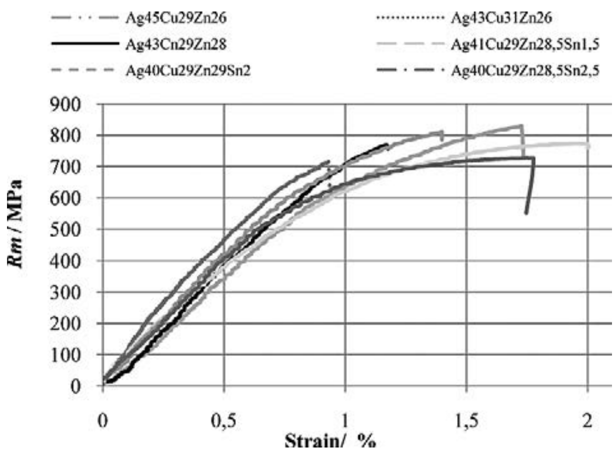


Figure 3 Stress-strain curves obtained in static tensile test for all casted Ag-Cu-Zn- Sn alloys.

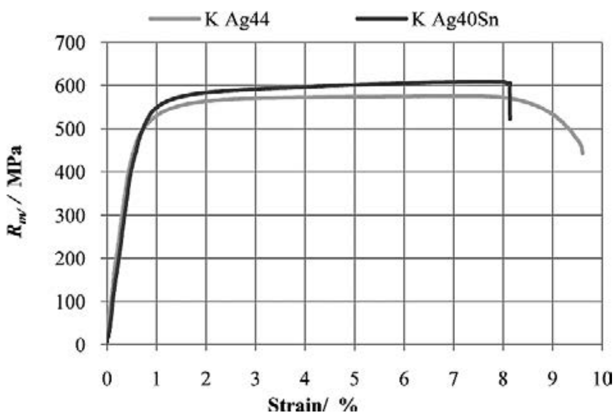


Figure 4 Stress-strain curves obtained in static tensile test for all cadted Ag-Cu-Zn- Sn alloys.

Ag44 and Ag40Sn wires for maximum Ag content have similar conductivity at levels above 10 MS/m, similar to commercial wires.

Table 4 **Pressure and fatigue test for Cu-Ag-Zn-Sn alloys**

Material	Leakage test / 600 /kPa	Number of inflections
Ag45Cu29Zn26	positive	2 967
Ag43Cu31Zn26	positive	3 695
Ag43Cu29Zn28	positive	3 753
Ag41Cu29Zn28,5Sn1,5	positive	3 337
Ag40Cu29Zn29Sn2	positive	4 856
Ag40Cu29Zn28,5Sn2,5	positive	3 710
K Ag44	positive	2 853
K Ag40Sn	positive	2 772

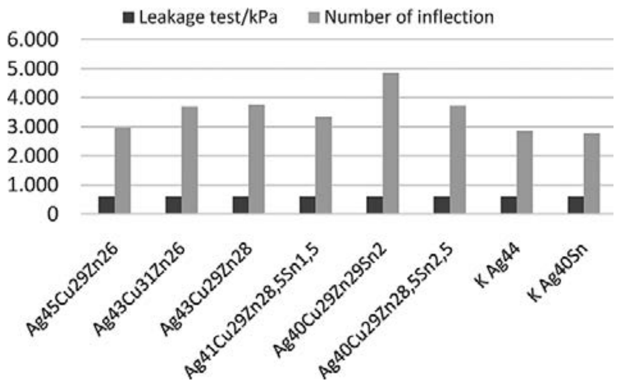
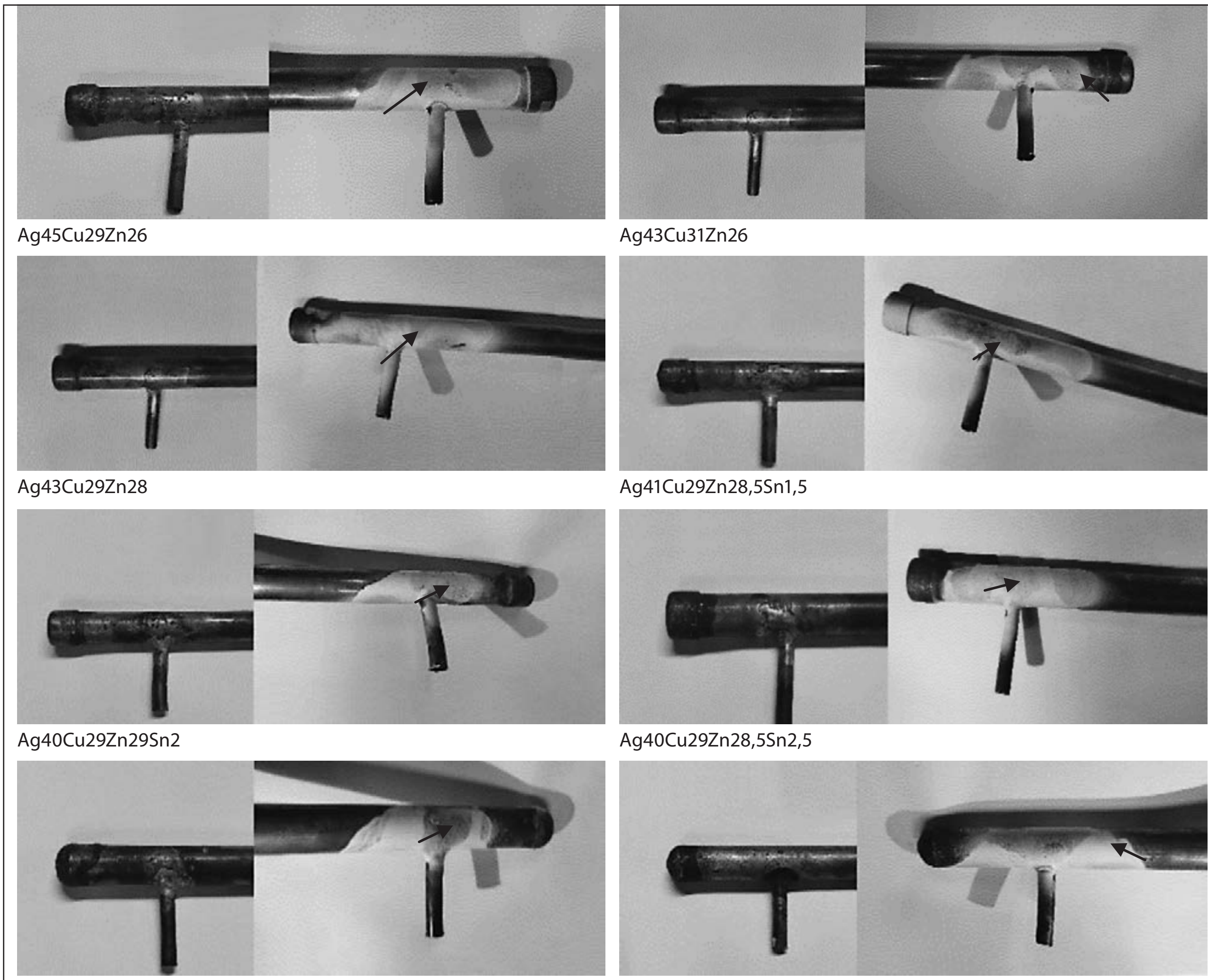


Figure 5 Electrical properties graphical representation for Cu-Ag-Zn-Sn alloys

Table 3 shows the durability properties of the wires tested. Figure 3 shows the tensile curves of the fabricated wires and Figure 4 of the commercial wires. A higher tensile strength of laboratory-made wires was found which is in the range of 714-829 MPa. Commercial wires are characterized by a durability of 575-609 MPa. The contractual yield strength of laboratory-made wires is in the range of 623-713 MPa, and 498-505 MPa for commercial wires, elongation 0,94-1.78 % for laboratory-made wires and 4,54-8,14 % for commercial wires. The study showed that Ag44 wires of Ag45 Cu29Zn26 and Ag43Cu29Zn28 composition have the highest yield strength forming 700 MPa. For Ag40Sn grade, wires with the composition of Ag40Cu29Zn-29Sn2 have the highest yield strength forming at 700 MPa. For performance reasons, there must be no plastic deformation in the product, hence it serves as a criterion for durability.

For the laboratory wires, two intermediate heat treatments were applied, while for the commercial wires the intermediate heat treatment took place shortly before the wire reached the commercial diameter. The degree of strengthening of solder wires is a direct result of the path adopted for their manufacturing technology and



Ag45Cu29Zn26 Ag43Cu31Zn26

Ag43Cu29Zn28 Ag41Cu29Zn28,5Sn1,5

Ag40Cu29Zn29Sn2 Ag40Cu29Zn28,5Sn2,5

K Ag44 K Ag40Sn

Figure 6 Pictures of brazing joints

chemical composition. The mechanical properties of the wires are not of technical importance for soldered joints; however, they fundamentally affect the production costs of the wires (the fewer annealing operations, the lower the cost). Table 4 and Figure 5 show the solder joint leakage test and the fatigue resistance of the solder joint bending process. All soldered connections passed the 600 kPa leakage test, the most resistant connection to bending turned out to be the connection made with laboratory solder type Ag40Cu29Zn29Sn2. All joints meet the expected functional properties, although there is a noticeable trend to use solders with tin content in such cases, which affects good fluidity and improves capillary action, crucial in the presence of cyclic mechanical loads. Commercial solders achieved less bending than laboratory solders during fatigue testing because EN ISO 17672 [4] specifies a percentage tolerance for the chemical composition of the alloy, including the elements silver and copper responsible for plasticity, impact strength, durability and wettability. The fatigue tests conducted showed that the optimal chemical composition for Ag40Sn alloy is Ag40Cu29Zn29Sn2 (number of inflections 4800), while for Ag44 alloy Ag43Cu29Zn28 and Ag43Cu31Zn26 (number of inflections 3 700).

Figure 6 shows the samples after the bending test (photos on the left) and the photos on the right showing where the sample depressurized.

CONCLUSIONS

On the basis of the conducted tests, the following final statement was formulated :

- solders of the Ag44 alloy with chemical composition Ag45Cu29Zn26 have favorably the highest conductivity of 10,26 MS/m
- solders of the Ag40Sn alloy with chemical composition Ag41Cu29Zn28.5Sn1.5 have favorably the highest conductivity of 10,54 MS/m
- the variation of conductivity depending on the content of alloying elements within the studied grades for Ag44 alloy reaches 0,42 MS/m and for Ag40Sn grade 1,27 MS/m
- The highest yield strength for the Ag44 type, shaping at the level of 700 MPa, is exhibited by wires with the composition of Ag45Cu29Zn26 and Ag43Cu29Zn28. Meanwhile, for the Ag40Sn type, wires with the composition of Ag40Cu29Zn29Sn2 possess the highest yield strength.
- Fatigue tests showed that the optimal chemical composition for Ag40Sn alloy is Ag40Cu29Zn29Sn2 (number of inflections 4 800), while for Ag44 alloy Ag43Cu29Zn28 and Ag43Cu31Zn26 (number of inflections 3 700).

REFERENCES

[1] J. Matthey, Silver brazing filler Metals, Zürich, Switzerland ,(2020),2-5
[2] D. Schnee, Principles of brazing and soldering, Principles of brazing and soldering, Braze-Tec-Saxonia-Technical Materials, Hanau, Germany, (2021),15
[3] M. Way, J. Willingham & Russel Goodall, Brazing filler metals, International Materials Reviews, Sheffield University, UK, (2019), 9-12
[4] Norm EN ISO 17672, Table 6
[5] T. Kühne, Brazing Copper and copper alloys, Deutsches Kupferinstitut, Germany, (2021), 8
[6] H. Schmoor, Less silver more brazing, Unicore, Conference, Essen, Germany, (2016)
[7] K. Matsu, Brazing of cemented carbide with low silver content brazing filler metal, Conference Löt 2020, Aachen, Germany, (2020)

Note: The responsible translator for English language is N. Lamla, Cracow, Poland