RESEARCH ON DRAWING PROCESS FOR NEW ALUMINUM BASED ALLOYS OBTAINED IN CONTINUOUS CASTING PROCESS AND DEDICATED FOR ELECTRICAL APPLICATIONS

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Abstract

Steel-aluminum wires, despite their common use, show insufficient operational properties for current needs. Their main disadvantages are high mass and maximum operating temperature limit that guarantees the stability of mechanical properties at 80 °C, which more and more often proves to be insufficient. Current trends in the overhead electrical power engineering in the area of wire materials, include e.g. the improvement of aluminum alloys for electrical purposes, development of composite cores in place of steel in bimetallic conductors and overall improvement of mechanical, electrical and operational properties of the wires. Alloying pure aluminum with other elements results in an inevitable decrease of its electrical conductivity, but at the same time it creates the possibility for the mechanical and operating properties improvement.

The article presents the research results on drawing process for the new aluminum based alloys with the addition of zirconium, silver and molybdenum. Technical aluminum grade was used as a reference material. This paper presents an analysis of the properties of the produced wires dedicated for electrical applications. Wires were obtained in a laboratory continuous casting process with various process parameters.

Keywords: Conductor materials, Al alloys, continuous casting process, drawing process

1. INTRODUCTION

Steel-aluminum wires with a structural core built of high resistant galvanized steel and a conductive layer of pure aluminum in hardened state are commonly used in the domestic energy industry of overhead lines. That type of wires, despite their common use, shows insufficient properties for the current needs. The disadvantageous properties, among others, are high mass and maximum operating temperature that guarantees stability at an insufficient level of 80 °C [1]. The rising level of requirements causes that the technically pure metals are often inadequate. The addition of other elements (e.g. Zr) to pure aluminum causes the inevitable decrease of the electrical conductivity, but allows increase its mechanical and operating properties [2]. In the energy industry, the most commonly used aluminum alloys that show thermal resistance are AlZr alloys. In 2006 the increasing demand for heat-resistant wires of AlZr alloys, resulted in the development of an IEC international standard which standardizes the requirements for properties of these alloys used in the wire production. Four basic types of wires (depending on the application) are distinguished in this standard, namely heat resistant AT1 lead wire designed to operate at temperatures up to 150 °C, heat resistant AT2 lead wire with permissible operating temperature of 150 °C with better mechanical properties, heat resistance AT3 lead wire designed to operate at temperatures up to 210 °C and heat resistant AT4 lead wire with the permissible operating temperature of 240 °C. The properties of these types of alloys are shown in **Table 1** [3, 4].

Table 1 Comparison of the properties for the standard conductive material and for higher heat resistance materials (four types of wires AT1…AT4 are differentiated by distinct tensile strength, resistivity and operating temperature)

Material	Density	Coefficient of linear expansion	Resistivity	Temperature coefficient of resistance	Tensile strength	Elongation	Maximum operating temperature
	(g/cm^3)	(1/K)	(nΩ·m)	(1/K)	(MPa)	(%)	(°C)
Al	2.69	0.000023	28.26	0.0040	160-200	2	80
AT1	2.703	0.000023	28.74	0.0040	159-169	1.5-2.0	150
AT2	2.703	0.000023	31.35	0.0036	225-248	1.5-2.0	150
AT3	2.703	0.000023	28.74	0.0040	159-176	1.5-2.0	210
AT4	2.703	0.000023	29.73	0.0038	159-169	1.5-2.0	230

Based on the data presented in the table above, it can be seen that the mechanical properties of these materials are similar to pure aluminum. Electrical conductivity of Al-Zr alloys is 2 to 10 % lower than for the standard material, their resistance is at least 28.7 nΩ·m, but the operating temperature range is significantly higher. Intentionally introduced alloying additions are used to obtain desired material properties of aluminum alloys [1, 5]. The presence of foreign elements, both purposefully introduced to aluminum and naturally occurring impurities, significantly influence the formation of electrical properties of the material. The degree of change in resistivity of aluminum depends on the location of the foreign elements in the alloy structure, which can be in solid solution or in precipitates. **Figure 1 - 2** show the impact of the elements located in the solid solution and precipitations on the electrical properties of aluminum.

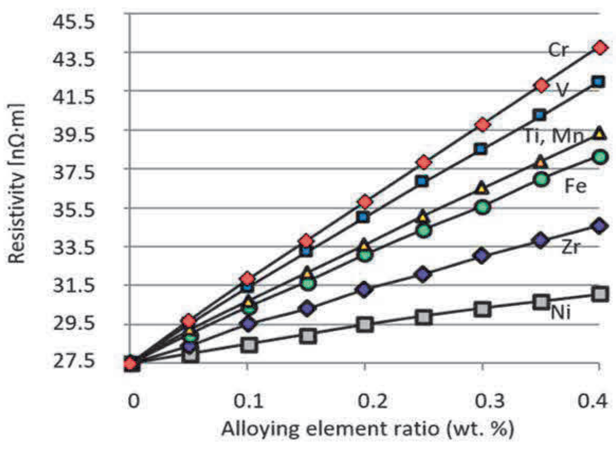

Figure 1 Impact of various alloying elements (localized in solid solution) on aluminum resistivity [3, 6]

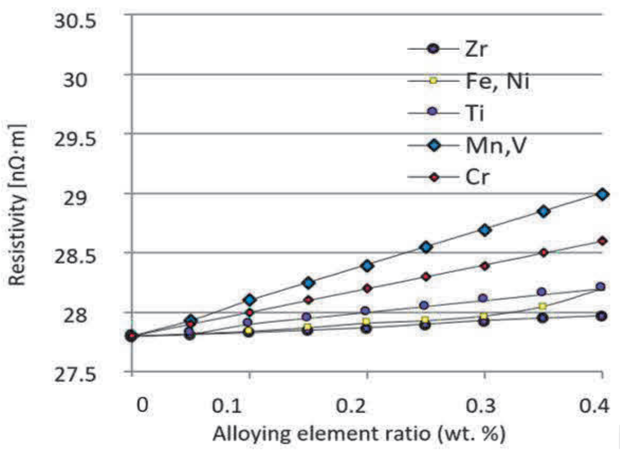

Figure 2 Impact of various alloying elements (localized in precipitations) on aluminum resistivity [3, 6]

Based on the data presented in the above figures it is easy to understand the popularity of the AlZr group as materials used in heat resistance wires. The addition of zirconium to aluminum generates some disadvantages. Zirconium in the solid solution significantly decreases the electrical conductivity of the material and with the quantities used to obtain the desired heat resistance it raises the liquidus temperature up to 750 ºC. Also, zirconium addition can cause the poisoning of AlTiB structure modifier and has a great tendency to segregate. Due to these disadvantages the new alternative alloys with other additives are being investigated [7].

2. MATERIALS AND EXPERIMENTAL WORK

The study was carried out for aluminum alloys with additions of different quantities of zirconium, silver and molybdenum. Materials were made in a laboratory workstation for continuous casting. The reference material was high purity aluminum. The continuous casting process was carried out on an unique casting workstation presented in **Figure 3.**

Figure 3 Laboratory workstation for continuous casting

During the continuous casting process, parameters such as the chemical composition of the material, temperature of the liquid metal, speed and sequences of continuous casting, conditions of cooling in the crystallizer and macrostructure of ingot were recorded. These parameters are shown in **Table 2**.

Table 2 Parameters of continuous casting process (composition in wt.%)

Material	Al	Al-Ag 0.05 %	Al-Ag 0.1 %	Al-Ag 0.15 %	Al-Mo 0.05 %	Al-Mo 0.1 %	Al-Mo 0.2 %	Al-Zr 0.05 %
Feed (mm)	10	4	3	10	10	10	10	10
Stop time (s)	10	4	6	10	10	10	10	10
Casting speed (mm/s)	10	10	10	10	10	10	10	10
Liquid metal temperature (°C)	797.4	783.9	794.4	801.7	820	813.1	780.4	818
Surface temperature of the ingot (°C)	146.6	123	116.3	158	158.8	150	168	127
Water temperature at the entrance (°C)	7.6	6.7	7.1	6	6.8	8.3	6.2	6.3
Water temperature at the finish (°C)	12.6	13.5	18	9.8	12.8	12.6	10.9	12.3
Primary water flow (l/min)	0.66	0.42	0.84	1.32	0.66	0.96	0.72	0.78
Secondary water flow (l/min)	0.31	0.2	0.65	0.65	0.31	0.31	0.11	0.65

Rods (14 mm diameter) with satisfactory surface quality were obtained in the continuous casting process and were subject to chemical analysis using the FOUNDRY-MASTER Xpert spectrometer. The casts were subject to further examination, including Vickers hardness test and the electric conductivity test by eddy current. Subsequently, the rods were drawn to 9.5 mm, to obtain the diameter identical to the diameter of the final wire rod and were subject to heat treatment to obtain a recrystallized structure and to eliminate the casting structure. Then, the recrystallized materials were subject to 9-off extra draws, and as a result 2.4 mm diameter wires were obtained. Drawing process was conducted on the laboratory chain draw bench (**Figure 4**).

The wires obtained in the drawing process were subject to an uniaxial tensile test and the basic mechanical properties of the material were determined. Due to the fact that the new aluminum based materials are designed for use at elevated temperatures, their heat resistance was studied. The thermal resistance of aluminum alloys with different additions was tested by verifying the hardness of the alloys at room temperature and after the heat treatment at specified range of temperatures, which were 100, 150, 200, 250, 275, 300, 325, 350, 400, 450 °C. Each material was heat treated in each of these temperatures for one hour, then the Vickers hardness test was carried out.

Figure 4 The laboratory chain draw bench

3. RESULTS AND DISCUSSION

Table 3 shows the chemical composition of alloys obtained by continuous casting. The level of alloying additives and other additives, especially from the group of heavy metals (Cr, Mn, Ti, Zr) was at the expected level. **Figures 5 - 6** show the results of Vickers hardness under a load of 2 kg and electrical conductivity.

Table 3 Chemical composition of the obtained rods (wt.%)

Alloy	Al	Ag	Mo	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ni	Ti
Al	99.82	0.0007	-	0.05	0.10	0.0005	0.0018	0.0008	0.002	0.0004	0.0002	0.0002
Al-Zr 0.05 %	99.78	0.0009	-	0.06	0.11	0.0005	0.002	0.002	0.001	0.0006	0.0002	0.0002
Al-Ag 0.05 %	99.69	0.057	-	0.12	0.11	0.0005	0.002	0.002	0.002	0.0005	0.0002	0.0002
Al-Ag 0.1 %	99.62	0.11	-	0.13	0.10	0.0005	0.0021	0.003	0.002	0.0004	0.0002	0.0002
Al-Ag 0.15 %	99.61	0.17	-	0.06	0.12	0.0005	0.002	0.003	0.001	0.0003	0.0002	0.0002
Al-Mo 0.05 %	99.68	0.0015	0.044	0.08	0.13	0.0005	0.003	0.001	0.006	0.0007	0.0002	0.0002
Al-Mo 0.1 %	99.68	0.001	0.086	0.081	0.11	0.0005	0.001	0.009	0.003	0.0004	0.0002	0.0002
Al-Mo 0.2 %	99.6	0.001	0.17	0.078	0.11	0.0005	0.002	0.009	0.002	0.0007	0.0002	0.0002

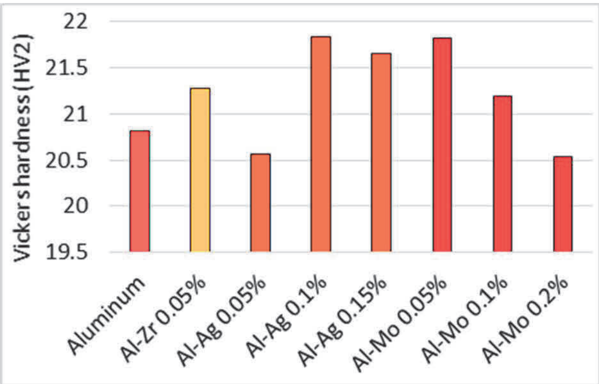

Figure 5 Hardness of the obtained aluminum alloys

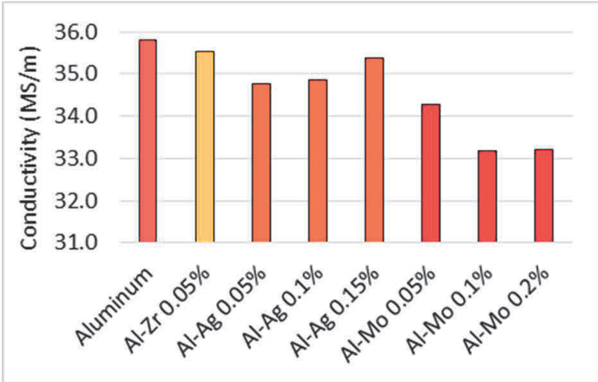

Figure 6 Conductivity of obtained aluminum alloys

The effect of molybdenum and silver on hardness and conductivity in the as-cast state can be easily noticed. With the addition of alloying additives, the hardness of aluminum is increasing, while the electrical conductivity of is reduced. Molybdenum, especially in large quantities, has greater effect on the electrical conductivity of aluminum. The observed electrical properties suggest that molybdenum and silver are mainly concentrated in solid solution, and the mechanical effects of the solution strengthening are not as noticeable. By analogy to the AlZr alloys used, the level of strength comparable to aluminum is sufficient. **Table 4** presents the basic mechanical properties of wires in a hardened state obtained in the drawing process.

Table 4 Basic mechanical properties of aluminum wires with different amounts of alloying additions

	Al	Al-Zr 0.05 %	Al-Mo 0.025 %	Al-Mo 0.05 %	Al-Ag 0.025 %	Al-Ag 0.05 %	Al-Ag 0.1 %
Yield strength (MPa)	135	135	140	147	129	139	142
Tensile strength (MPa)	143	143	142	147	136	146	148
Elongation (%)	2.9	3.2	2.8	1.6	2.8	3.4	3.7

Mechanical and plastic properties of aluminum alloys with zirconium, molybdenum and silver are at a similar level, which is sufficient provided the desired electrical properties are met. The research results on thermal resistance of aluminum alloys are presented in **Figure 7**. It can be seen that the mechanical properties of aluminum decrease at the approximate temperature of 240 °C, while addition of molybdenum increases the heat resistance of the material. The mechanical properties of AlMo alloy decrease at temperature of 280 °C.

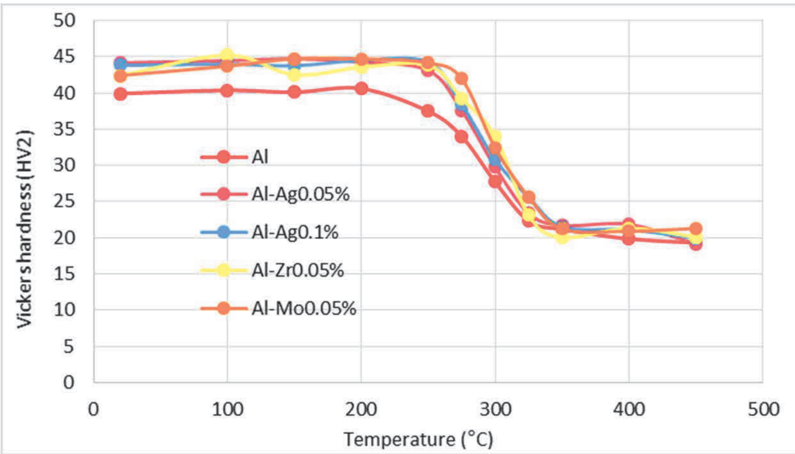

Figure 7 Thermal resistance of aluminum alloys

4. CONCLUSION

As a result of experimental test, aluminum alloys with different content of zirconium, silver and molybdenum were obtained in a continuous casting process. They show satisfactory quality and reproducible properties. This is a prerequisite to the conclusion that the materials considered in the research are not materials that require special methods in casting technology. The addition of zirconium, silver and molybdenum in aluminum alloys in the as-cast state causes increase in hardness and decrease in electrical conductivity relative to pure aluminum (99.8 % purity). Preliminary studies on the heat resistance of the alloys show that zirconium, molybdenum and silver slightly increase the initial recrystallization temperature, which allows increase the current structural capacity of the conductor.

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