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RESEARCH ON MECHANICAL AND ELECTRICAL PROPERTIES OF ENAMEL WINDING WIRES CONNECTIONS MADE WITH THE USE OF SHARK-AL® TECHNOLOGY

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Preliminary Note – Prethodno priopćenje

The results of the research that have been presented in this article include the analysis of basic exploitational properties of connections made with the use of new family of Shark-Al connectors, which are the first in the industry strictly dedicated for connecting the enamelled aluminium wires. In particular, the test results include the analysis of the contact resistance and tensile strength of connections prepared with the various types of connectors and various configurations of used enamelled wires. Results of this work enabled to verify the correctness of performed connecting process and also allowed to verify the connectors design.

Keywords: Shark connectors, Cu alloys, enameled Al wires, mechanical properties, electrical properties

INTRODUCTION

The article presents the results of research on a newly developed innovative SHARK-Al connection system for enameled aluminium wires [1]. The genesis of the topic on the development of the above-mentioned new connection system lies in the new trends observed in recent years in the field of ever-increasing requirements for power equipment and systems. All economic, environmental and technological activities are aimed at reducing the weight of electrical devices, reducing costs and electricity transmission losses and broadly understood aspects of ecological and green energy [2-4].

The attractive ratio of aluminium specific weight in relation to copper and at the same very good electrical properties makes the weight of a aluminium wire with given length and resistance two times lower than the weight of analogical copper wire. The above mentioned phenomenon, as well as significant differences in copper and aluminium prices, initiated in the previous decade a technological revolution in the area of substitution of copper by aluminium in many areas of its use, especially for electrical applications [5-7].

Nowadays wires are connected using various types of screw connectors and by the use of crimping, soldering and welding processes. With regard to enameled wires being the subject of this article, these methods have various side effects essential not only for the connected wires and the connection itself, but also for the working environment and the natural environment. Innovative on a global scale, the SHARK-Al system which is dedicated to the connection of aluminium enameled wires consists of connectors with mechanically aggressive surfaces in the form of micro-blades (teeth), whose task is to puncture the electrical insulation layer and to penetrate deep into the wire, creating an effective electro-mechanical connection. The use of a modern system for connecting enameled aluminium wires eliminates the troublesome and energy-intensive removal of the enamel before the connection process. In addition, the connection technology using the SHARK-AL type connector is environmentally friendly, as it eliminates the emission of harmful fumes and dust, and reduces noise, which is an integral part of typical connection methods i.e. welding or soldering [8].

EXPERIMENTAL PROCEDURE

Connection resistance testing

The electrical properties tests of enameled wires connections were carried out for various connector materials, i.e. CuSn0.15 and CuAg0.1 alloys. During the tests, Al-R, Al-RD, Al-SRD, Al-RM and Al-RT type connectors were used (see manufacturer's catalogue [1]). In addition, the tests were carried out using different diameters of the crimped enameled wire (see Table 1). Variants of performed connection resistance tests are presented in Table 1. Main goal of the contact resistance tests was to verify if the material of the connector has an significant influence on the contact resistance value,

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Table 1 **List of types of tested connectors, connector materials and diameters of connected wires used to carry out tests of contact resistance and tensile strength**

Connector Type	Connector material			
	CuSn0.15		CuAg0.1	
	Enameled wire diameter / mm			
Al-R	1,5	2,65	1,5	2,65
Al-RD	2,8	4	2,8	4
Al-SRD	2,8	4	2,8	4
Al-RM	1	2	1	2
Al-RT	1	1,5	1	1,5

which should allow to chose the optimal material for the newly developed SHARK-Al connectors.

The Burster RESISTOMAT® 2304 device and the 4-point resistance measurement method were used to carry out the connection resistance tests (see Figure 1). For each of the tested variants 3 measurements were made for three independent samples. The article presents the arithmetic mean of the resistance results obtained.

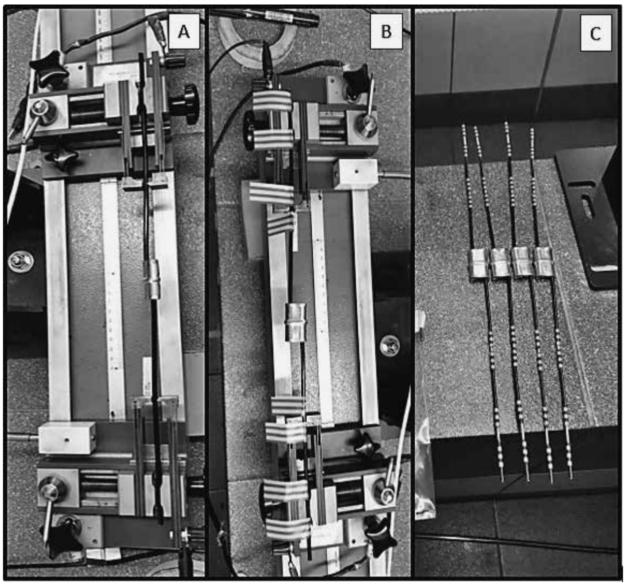

Figure 1 Electrical resistance set-up and methodology: A and B – initial fitment checking and indication were to remove enamel from wires in order to install them on the measuring table, C – samples after testing

Connection mechanical strength testing

Mechanical strength test of previously prepared wire connections were carried out also for the same amount of samples presented as part of connection resistance tests (see Table 1). The tests were carried out with the use of Zwick/Roell Z020 testing machine. In total 3 tensile tests were carried out for each of the analysed sample variants. Below in Figure 2 exemplary photos of the tests carried out were presented. Mechanical strength analysis was done in order to verify if all prepared samples, which were connected with the use of SHAR-Al technology meet the requirement of minimal breaking load of 40 N/mm^2 which was and initial design criterion based on actual standards, technical guidelines and own technological knowledge.

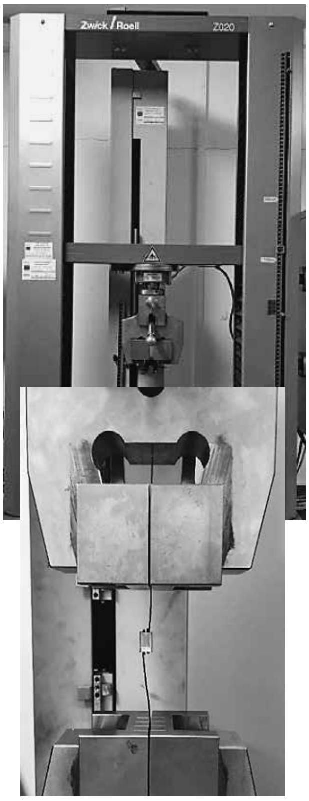

Figure 2 Static tensile test method used to test mechanical strength of enameled wire connections: A – Zwick/Roell testing machine set up and B – exemplary sample during static tensile test

RESULTS AND DISCUSSION

Comparison of obtained contact resistance test results for fittings made of two different materials, i.e. CuSn0.15 and CuAg0.1, allows to state that all obtained measurement results are characterized by relatively similar values. The greatest difference in measurements is observed for the Al-RM connector clamped on aluminium enamel wire with a diameter of 1 mm. For the CuSn0.15 material, the average value from 3 samples after 3 measurements made on each connection was 8,7143 mΩ, and for the CuAg0.1 material – 8,7321 mΩ. The difference between above mentioned is 0,0178 mΩ. Similarly, comparing the resistance results for the previously mentioned materials and other types of connectors with different wire diameters, we observe only slight differences in the range of about 0,0053 mΩ to 0,0008 mΩ. Table 2 summarizes the results of resistance tests for all analysed samples.

The analysis of the mechanical strength tests results involving tensile breaking of the enameled wires connected with the newly developed SHARK technology allows to conclude that for all types of connections, the obtained results ranges from 49,95 N/mm^2 to 92,73 N/mm^2. Figure 3 shows an exemplary stress-strain curve for Al-RD connector made out of a CuAg0.1 alloy clamped on a aluminium wire with a diameter of 4 mm.

Table 2 **A summary of the contact resistance measurements for all analysed aluminium enameled wires connections**

Connection type	Contact Resistance / mΩ	
	CuSn0.15	CuAg0.1
Al-R; ϕ1,5 mm	3,8644	3,8677
Al-R; ϕ2,65 mm	1,2042	1,2049
Al-RD; ϕ2,8 mm	1,0344	1,0318
Al-RD; ϕ4 mm	0,5131	0,5098
Al-SRD; ϕ2,8 mm	1,1209	1,1217
Al-SRD; ϕ4 mm	0,5057	0,5110
Al-RM; ϕ1 mm	8,7143	8,7321
Al-RM; ϕ2 mm	2,4626	2,4548
Al-RT; ϕ1 mm	8,7116	8,7174
Al-RT; ϕ1,5 mm	3,9251	3,9259

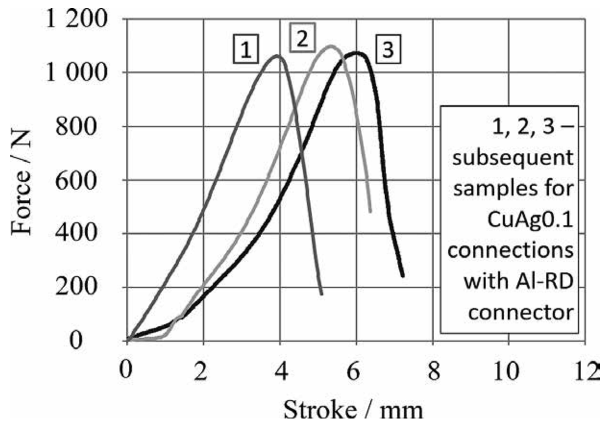

Figure 3 Exemplary characteristic of connections tensile test results with the use of Al-RD connector made of CuAg0.1 alloy clamped on a enameled wire with a diameter of 4 mm

The average stress at breaking point of the tested types of joints for the CuSn0.15 material was 80 N/mm^2, while for the CuAg0.1 material it was 77 N/mm2 which is slightly higher. The table 3 below summarizes the obtained test results in the form of maximum destructive force and breaking stress of winding wires connected with the new technology.

Table 3 **A summary of the resistance research results for all prepared connections with the use of aluminium enameled wires**

Connection type	Connector Material			
	CuSn0.15		CuAg0.1	
	F_{max} / N	σ / N/mm^2	F_{max} / N	σ / N/mm^2
Al-R; ϕ1,5 mm	163	92	158	89
Al-R; ϕ2,65 mm	379	68	391	72
Al-RD; ϕ2,8 mm	491	79	504	81
Al-RD; ϕ4 mm	1 083	86	1076	85
Al-SRD; ϕ2,8 mm	468	76	495	80
Al-SRD; ϕ4 mm	1 119	89	1096	87
Al-RM; ϕ1 mm	57	73	50	63
Al-RM; ϕ2 mm	230	73	188	60
Al-RT; ϕ1 mm	68	87	64	82
Al-RT; ϕ1,5 mm	118	66	113	64

CONCLUSIONS

The results of the conducted analyses show that there are no significant differences in the connection resistance values between the connector materials used and show that the connections made in ERKO with the use of SHARK technology are characterized by high repeatability from their electrical properties point of view. In addition, the analysis of the mechanical strength results of connections made with the use of newly developed technology allows to conclude that for all types of connections subjected to the tests, the obtained results are above 40 N/mm^2. Therefore, the conclusion of the research carried out is that the developed technology fully meets the requirements for this type of connection and the guidelines developed as part of the project.

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Note: The translator responsible for English language: Justyna Grzebinoga, Krakow, Poland