Streszczenie Rozprawy Doktorskiej w języku angielskim

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pt. “Research on the development of technology for the production of multimetal wires with a multifilament structure for applications in welding and additive processes.”

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In this study, efforts were made to develop a novel technology for the production of welding materials that cannot be obtained using classical methods such as continuous casting. The influence of selected alloying elements on casting properties is very important as it sometimes makes it impossible to obtain a full-quality material with an increased content of alloying elements. In this study mainly copper-based materials containing more than 10 wt.% of aluminum in their composition were examined. Additionally, attempts were made to obtain materials enriched with nickel. The developed technology is based on the bundling of pure metals - aluminum and aluminum with nickel - into a copper tube, and then subjecting this bundle to plastic processing operations in order to obtain a material of suitable diameter to enable its use in 3D printing technology by Wire Arc Additive Manufacturing (WAAM).

A detailed literature review was conducted, based on which the current state of the issue was described. Currently used welding materials, 3D printing methods and materials produced by non-standard techniques are presented and discussed in this study. The paper includes a breakdown of 3D printing techniques in metals and using plastics, describing in detail the principles of each method. Special attention was paid to 3D printing technology using the WAAM (Wire Arc Additive Manufacturing) method, its principle of operation and its application in the production of machine components. The prospects of using this technology in materials engineering and architecture are also discussed. The paper presents the development of 3D printing technology on the basis of studies and foresight reports, which

indicate its dynamic progress. It was pointed out that the development of 3D printing technology requires simultaneous progress in the field of materials with high mechanical strength, corrosion resistance and impact resistance. The importance of the development of military technology, in which 3D printing and modern materials are increasingly used in innovative projects, was also noted.

Based on the analysis of the literature and the results obtained in the work preceding the doctoral project, the thesis of the work assuming the development of a technology for manufacturing multifilament welding wires was proposed. The technology is aimed at obtaining competitive material solutions that will be characterized by higher mechanical properties, structural homogeneity, mechanical isotropy and linear elasticity within a certain strength range. The developed material, thanks to these features, is expected to become competitive with solutions available on the market.

On the basis of own research, a detailed course of action was developed to obtain new materials with improved performance properties. For the study, materials such as Cu-ETP copper tube, aluminum wires and nickel wires were selected and bundled in different variations to obtain multifilament materials: CuAl1, CuAl3, CuAl8, CuAl12 and CuAl10Ni10. After plastic processing, these materials were obtained in the form of wires with a diameter of 2.15 mm and were subjected to preliminary TIG welding tests on steel sheet, creating spatial objects (wall model). Current-voltage parameters were developed at which the materials showed suitable welding properties for further testing. An analysis of the chemical composition of the obtained multifilament wires was also carried out to verify their compatibility with the composition assumed in the manufacturing process.

Simultaneously, attempts were made to produce CuAl12 and CuAl10Ni10 materials with a diameter of 1.00 mm, for use in the WAAM printer equipped in the Manufacturing and Application Laboratory at the Łukasiewicz Research Network – Institute of Non-Ferrous Metals. The 3D printing trials carried out were successful, yielding materials that can be subjected to further research.

The obtained materials were subjected to macroscopic studies using a digital microscope and microscopic studies using light microscopy. The next step was research using scanning electron microscopy (SEM). Spot analyses were carried out in three areas: the upper part of the sample (the face of the padding weld), the middle part of the sample and the lower part of the sample (the root of the padding weld), and the content of individual elements at the measuring points was determined. Maps of element distribution and images obtained from secondary electrons (SE) were made.

This was followed by Vickers hardness test, using a diamond quadrilateral pyramid with a vertical angle of 136° and a load of 98.07 N. A compression test was also performed using a universal testing machine. Three cylindrical specimens of each type of material were prepared for the test, with a diameter to height ratio of 1:1, with the dimensions of the specimens varying according to the thickness of the padding weld. The yield strength, percentage shortening and compressive stress corresponding to the first permanent deformation of the specimens (the "barrel" shape or the appearance of cracks on the specimen surface) were determined.

In the next stage of the research, a pin-on-disc sliding wear test was performed, which determines the sliding wear of friction pairs in the sample-countersample system (most frequently a steel ball or Al2O3). CuAl8 MigWeld (commercial material), CuAl8, CuAl12, CuAl10Ni10 materials were tested after TIG welding, as well as variants of CuAl12 and CuAl10Ni10 materials after WAAM printing.

NSS neutral salt spray corrosion tests were also conducted in accordance with PN-EN ISO 9227:2017-06, analyzing samples made from multiwire and commercial wire. The samples were tested for a 14-day cycle, after which their weight was determined, according to the standard. Prior to each weighing, the samples were thoroughly washed, dried, and then re-treated with salt spray to continue testing.

Phase analysis was then performed with a Seifert-FPM XRD7 X-ray diffractometer, using Cu Kα radiation and a Ni filter. Measurements were carried out in Bragg-Brentano geometry, with angles of 2Θ ranging from 10° to 100°, corresponding to interplane distances d_{hkl} from 0.8838 to 0.10064 nm. Phase analysis of CuAl12 WAAM and CuAl10Ni10 WAAM samples was performed in three areas: the face of the padding weld, its center and the bottom. Interpretation of the results was based on Seifert and Match! software, and the 2023 ICDD PDF-4+ database.

The aim of the paper was achieved, and the thesis set forth was confirmed.