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Quality Analysis of Welded and Soldered Joints of Cu-Nb Microcomposite Wires

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Quality analysis of welded and soldered joints of Cu-Nb microcomposite wires has been performed. Quality and mechanical characteristics of joints as ultimate tensile stress limit and elongation at break were measured with an universal testing machine and controlled visually using an optical microscope. Two wires joints were soldered with silver and copper solders and put into steel and copper sleeve respectively. Another two wires joints were soldered with silver solder and welded without any reinforcement. Joints soldered with the silver solder and steel sleeve have demonstrated the best mechanical characteristics: ultimate tensile stress limit of 650 MPa and elongation at break of 0.85 %. Joints soldered with the copper sleeve have no advantages comparing with the soldered butt joint. Ultimate tensile stress limit and elongation at break were in 300 MPa – 350 MPa and in 0.35 % – 0.45 % ranges respectively. Two welded joints had ultimate tensile stress limit of 470 MPa and elongation at break of 0.71 %. In all joints the microstructure of Nb filaments was destroyed and mechanical properties have been specified by mechanical strength of copper and sleeve materials only.
Keywords: defect detection, microcomposite wire, welded and soldered joints, pulsed magnet.

1. INTRODUCTION

Electromagnetic fields have been widely used in science and industry because of their high efficiency, economic benefits and cleanness [1]. The design of high power actuators, transformers, magnets require a careful estimation of pulsed, cyclic overloads [2]. The construction should be able to contain magnetic forces without undue deformation and stresses in winding. Therefore advanced materials as high strength pure copper [3], Cu-stainless steel macrocomposite [4], Cu-Ag, Cu-Nb microcomposite [5] conductors combined the high electric and mechanical characteristics are applied in pulsed equipment. Microcomposite conductors have high mechanical strength (>1 GPa), high conductivity (>65 % I.A.C.S - International Annealed Copper Standard), good elongation, forgiving plastic behavior, long fatigue life (>10 000 cycles), high resistivity ratio (ratio of resistivity at room temperature and liquid nitrogen temperature). Mechanical properties of such conductors depend on various factors as internal structure, the dimensions of the cross-sections, drawing technology, intermediate heat treatment between stages of the plastic deformation [6].

In general there are two methods of production of microcomposite conductors as "meld-and-deform" and "bundle-and-deform" [7]. The advantage of the first method is a relatively simple way to obtain the random distribution of rather small dendrite of Nb in large ingots of Cu-Nb alloy. The second method allows to form a more regular arrangement of continuous Nb filaments altogether with higher level of electro conductivity due to elimination of the melting process and the contamination of Cu matrix [8]. As a result metal matrix microcomposite wires with cross section of 5 mm^2 – 20 mm^2, ultimate tensile strength limit of 1.05 GPa – 1.3 GPa, 61 % – 74 % IACS, resistivity ratio 4.2 – 5.4 have been commercially available for pulsed magnet and other high power applications [9]. In pulsed magnetic fields of 50 T mechanical stresses of order 1000 MPa are induced [10]. A prototype of microcomposite metal matrix Cu-Nb wire wound and reinforced with steel container and Zylon-epoxy composite pulsed coil was tested in Vilnius Magnetic field Centre [11]. For technological purposes it was interesting to check a possibility to connect two conductors working under heavy electrical and mechanical conditions. Welding, soldering processes in combination with various sleeve constructions are applicable to connect separate wires. But as to junctions of microcomposite wires the main problem is the fact that there is no technology that guarantees the uniform structure of Nb filaments responsible for high mechanical strength. The structure of microcomposite Cu-Nb wire is shown in Fig. 1.

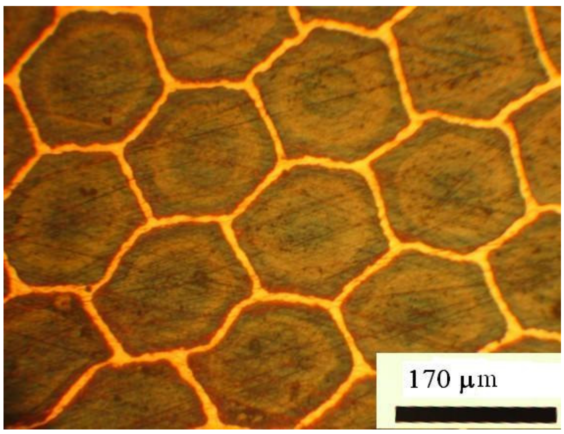

Fig. 1. The microstructure of microcomposite Cu-Nb wire

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Independently from chosen technology the microstructure of wire will be destroyed and as a result mechanical strength should be decreased significantly. Therefore the main goal of these investigations is to find an acceptable compromise of available joints.

2. METHOD AND MATERIALS

Numerical analysis of magnetic field distribution, magnetic forces distribution, deformations analysis of pulsed solenoids was done. The pulsed coil is comparable to a high-pressure adiabatically heated vessel [10]. Due to construction symmetry the simplified 2-D structure can be analyzed. Initial properties of the Cu-Nb wires for pulsed coil are presented in Table 1.

Table 1. Mechanical and electrical properties of Cu-Nb wire

Material	Cross-section, mm	% IACS	$\sigma_{0.2}$, MPa	σ_B, MPa
Cu-Nb (82 %–18 %)	4.2×2.4	63	830–850	1120

Total magnetic force acting on bodies contained in particular surface is [12]:

$$F = \frac{1}{2}\oint\left(\vec{H}\left(\vec{n}\cdot\vec{B}\right)+\vec{B}\left(\vec{n}\cdot\vec{H}\right)-\vec{n}\left(\vec{H}\cdot\vec{B}\right)\right)d\vec{s}\ , \tag{1}$$

where $\vec{H}$ is the magnetic field intensity, $\vec{B}$ is he magnetic flux density, $\vec{n}$ denotes the vector of the outward unit normal.

Total deformations at each point can be expressed as the sum of elastic, plastic and thermal deformations [13]:

$$d\{\varepsilon\} = d\{\varepsilon^{e}\} + d\{\varepsilon^{p}\} + d\{\varepsilon^{th}\}, \tag{2}$$

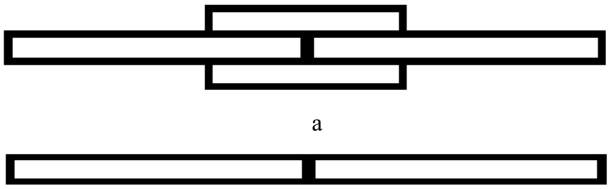
where $\{\varepsilon^e\}$ is the elastic strain, $\{\varepsilon^p\}$ is the plastic strain, $\varepsilon^p\}$ is the thermal strain.

The plastic behaviour of a material, characterized by non-recoverable strain, begins when the stresses exceed the material's yield point, i. e. correspond the von Mises yield criteria as [14]:

$$F(\{\sigma\},k) = \bar{\sigma} - \sigma_T(k) = = \sqrt{\frac{1}{2}\left(\sigma_x-\sigma_y\right)^2+\frac{1}{2}{\sigma_x}^2+\frac{1}{2}{\sigma_y}^2+3{\tau_{xy}}^2} - \sigma_T(k) = 0\ , \tag{3}$$

where $\sigma_T(k)$ is the yield strength limit, the value on which depends the parameter of hardening, $\bar{\sigma}$ is the equivalent stress parameter, k is the plastic work.

If maximum stress in inductor does not exceed the yield strength of the weakest material or joint, inductor will not fail mechanically. Therefore welded and soldered joints should be investigated. A schematic view of Cu-Nb wires joints of is shown in Fig. 2. Only (4.2×2.4) mm cross-section Cu-Nb wire was used for all the experiments. For the first experiment a soldered joint with steel sleeve was made. Two Cu-Nb wires were soldered using silver solder CI-302 (DIN 8513, L-Ag30Sn, 680 °C – 765 °C), flux „Amasan Hartlötpaste HS“ (DIN 8511, Type F-SH1, DVGW-GW7, 550 °C – 800 °C). For the second experiment a soldered joint with cooper sleeve was made. Two Cu-Nb wires were soldered with cooper solder „Amasan Hartlot 94“ (DIN 8513, L-CuP6, 710 °C – 880 °C), „Amasan Hartlötpaste HS“ flux (DIN 8511, Type F-SH1, DVGW-GW7, 550 °C – 800 °C). For the third experiment a soldered joint without reinforcement was made. Microcomposite Cu-Nb wires were soldered using a copper solder „Amasan Hartlot 94“ (DIN 8513, L-CuP6, 710 °C – 880 °C), flux „Amasan Hartlötpaste HS“ flux (DIN 8511, Typ F-SH1, DVGW-GW7, 550 °C – 800 °C). And finally microcomposite Cu-Nb wires were welded. Butt joints were formed by resistance welding machine MCC-901. Mechanical properties of four different joints of Cu-Nb microcomposite wires were investigated. Mechanical characteristics of joints as ultimate tensile stress limit and elongation at break were measured with an universal testing machine Tiratest 2300. In addition quality of welded and soldered joints was controlled visually using an optical microscope Nikon Eclipse MA200.



a

b

Fig. 2. A schematic view of joints: a – joints with sleeve; b – butt joints

3. RESULTS AND DISCUSSION

Simulation results of distribution of Von Misses stress in multilayer microcomposite Cu-Nb wire wound pulsed coil is presented in Fig. 3. In the range of maximum allowable stresses the magnetic field flux density reaches 40 T.

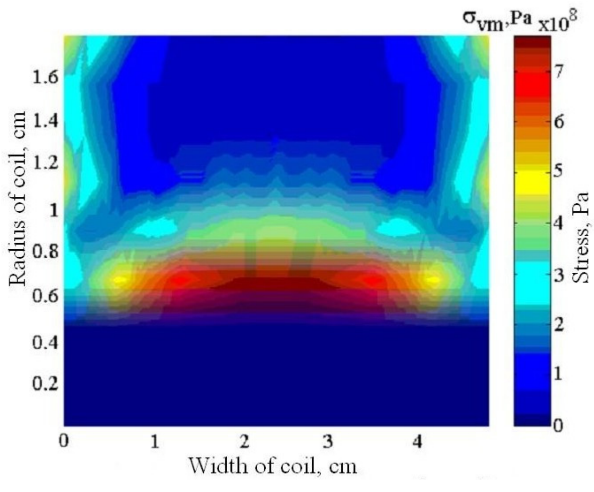
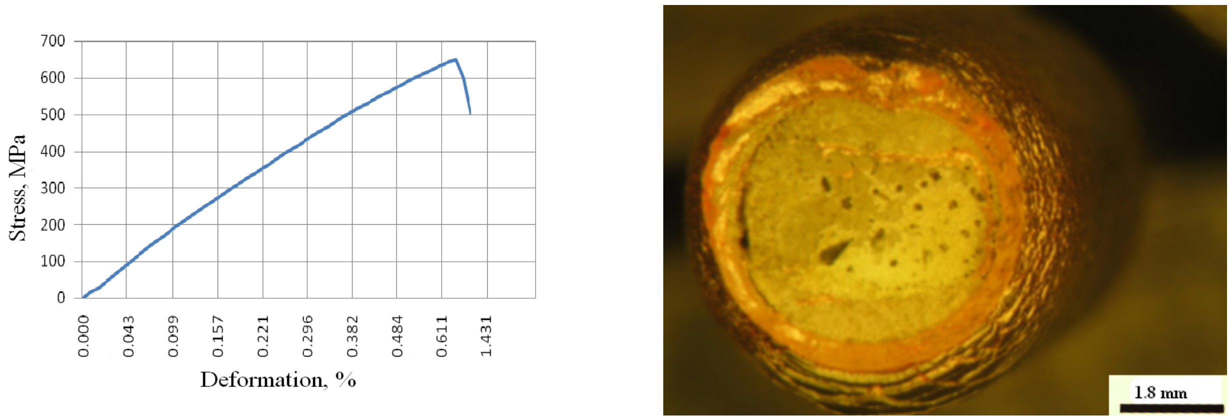


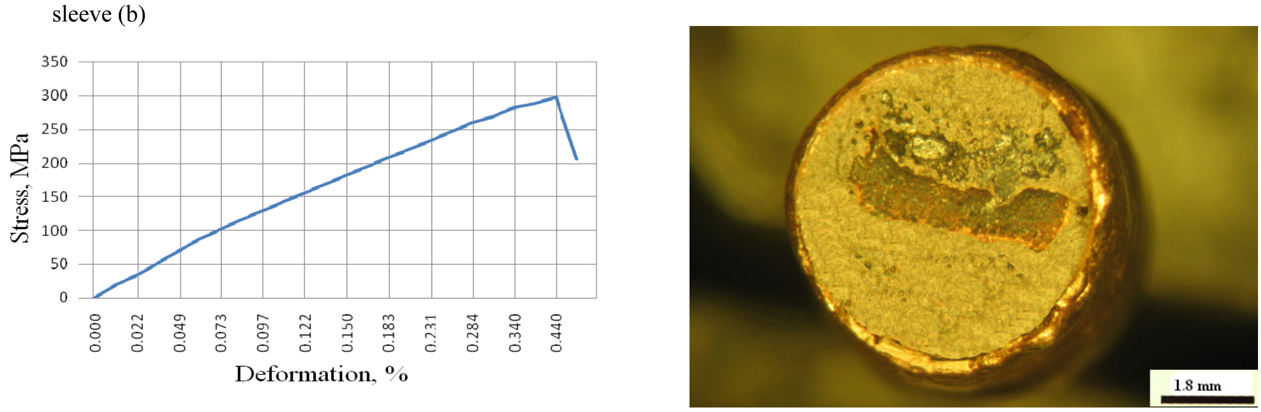
Fig. 3. Distribution of Von Misses stress in multilayer microcomposite Cu-Nb wire wound pulsed coil

Mechanical properties of the soldered joint with steel sleeve were established during the first experiment. Tensile characteristic and view of tested joint is shown in Fig. 4. Ultimate tensile stress limit of such joint is about 650 MPa and elongation at break of 0.85 % respectively. It is two times less than uniform microcomposite wire. Mechanical properties of the soldered joint with copper sleeve were established during next experiment. Ultimate tensile stress limit of such joint was in 300 MPa area and elongation at



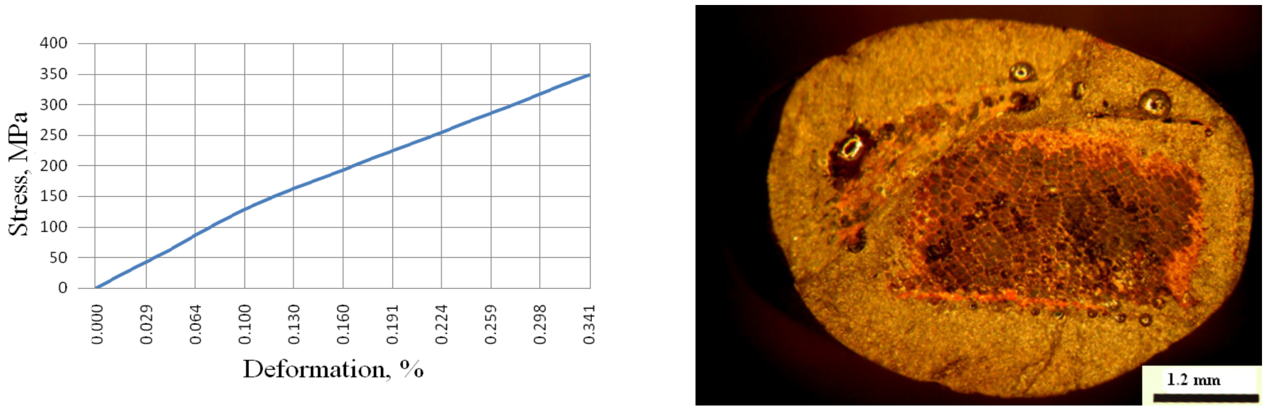
a b

Fig. 4. Tensile characteristic (a) and view of microcomposite Cu-Nb wires soldered joint. Soldering supplies: silver solder and steel sleeve (b)



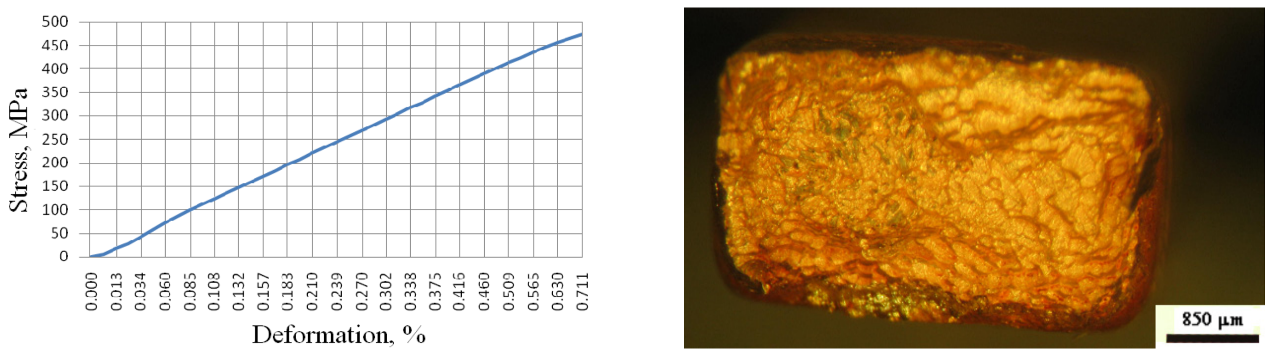
a b

Fig. 5. Tensile characteristic (a) and view of soldered joint cross-section. Soldering supplies: cooper solder and cooper sleeve (b)



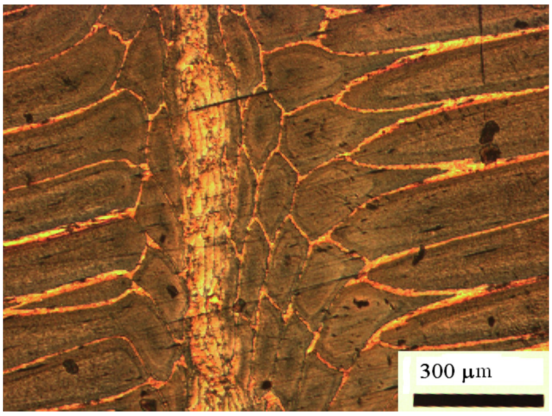
a b

Fig. 6. Tensile characteristic (a) and a view of microcomposite Cu-Nb wires soldered joint. Soldering supplies: cooper solder reinforcement (b)



a b

Fig. 7. Tensile characteristic (a) and a view of microcomposite Cu-Nb wires welded joint (b)



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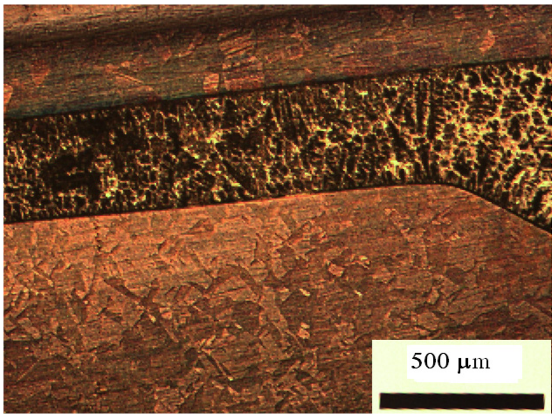

b

Fig. 8. Microstructure of microcomposite Cu-Nb joints: a – welded; b – soldered with sleeve

break of 0.44 %. The tensile characteristic and a general view of soldered wires are shown in Fig. 5.

Mechanical properties of soldered joint without reinforcement were established during third experiment. The obtained results demonstrated the ultimate tensile stress limit of 350 MPa and elongation at break of 0.34 %. Tensile characteristic and a general view of soldered wires are shown in Fig. 6.

And finally mechanical properties of welded joint were established during last experiment. Results of butt joint tensile tests are shown in Fig. 7. Registered value of ultimate tensile stress limit was about 470 MPa and elongation at break of 0.71 % respectively.

All tested joints demonstrated worse mechanical properties than uniform wires. Microstructure of welded and soldered joints is shown in Fig. 8. Worse mechanical properties took place because the microstructure of Cu-Nb wire was destroyed. Therefore total mechanical strength of joint depended on mechanical strength sleeve and solder. Microstructure of Cu-Nb has no effect and such microcomposite wire can be described as traditional common used copper conductor.

4. CONCLUSIONS

Joints soldered with silver solder and steel sleeve have demonstrated the best mechanical characteristics: ultimate tensile stress limit of 650 MPa and elongation at break of 0.85 %. Joint of wires with copper sleeve has no advantages comparing to wires soldered one. Ultimate tensile stress limit and elongation at break is in (300 – 350) MPa and in (0.34 – 0.45) % ranges respectively. A butt joint of two welded wires had ultimate tensile stress limit of 470 MPa and elongation at break of 0.71 %.

No joints have demonstrated mechanical strength close to uniform microcomposite wires. It has happened because the matrix of Nb filaments in microcomposite Cu-Nb wires was destroyed and main mechanical properties have been specified by mechanical strength of solder and sleeve materials only.

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