Featured Measurements of Mechanical Properties of Electrotechnical Materials for Pulsed Magnets

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Abstract. *The measurements of mechanical properties of electrotechnical materials applied in pulsed magnet design are described. Tensile strength, the elongation at break of Cu-Nb micro-composite wire and Zylon filament was measured experimentally and the influence of cyclic cooling and heating on material mechanical properties was investigated. Experimental data was compared with standard static mechanical properties.*

Keywords: pulsed magnet, Cu-Nb micro-composite wire, Zylon filament, tensile strength, elongation at break.

1. Introduction

Recently the demand of pulsed magnetic systems applicable for material science measurements increased very much. The total reliability of magnetic field system strongly depends on pulsed coil reliability and its construction should be determined very carefully. An increase in magnetic field is accompanied by a quadratic increase in mechanical and thermal loads [1]. Therefore, the possibility to increase the maximum available magnetic field is limited by the thermal and mechanical strength of applicable materials in general. The coil construction should be able to contain the magnetic forces without undue deformation and stresses in wires and reinforcements should not exceed the ultimate tensile stress limit [2]. In order to contain the mechanical loads the coil has to be designed carefully using high strength materials. Moreover, the good conductivity needs to be combined with mechanical strength because of reduced electric conductivity is caused increased thermal loads and thus leads to a strong coupling of mechanical and thermal loads. In this way micro-composite conductors as Cu-Nb, Cu-Ag made by co-melting are very attractive for pulsed magnet design [3]. By the other way, the mechanical strength of pulsed magnet can be improved by the coil reinforcement with glass, carbon and other fibres composites. Non-conductive composite is more favourable because does not require additional electric insulation of coil winding. Last time Zylon filament (poly p-phelylene-2,6-benzobisoxazole) combined high mechanical and electrical strength has been used for the advanced reinforcement of pulsed magnets [4].

In present paper we would like to offer results of featured measurements of tensile strength and elongation at break of micro-composite Cu-Nb wire and Zylon filament applied in pulsed magnet design in High Magnetic Field Laboratory of Vilnius Gediminas Technical University. The measurement goal was to clear the influence of cyclic cooling and heating of applied materials on the material mechanical properties and total reliability of the pulsed magnet.

2. Subject and Methods

Pulsed magnetic field induces mechanical, thermal and electric overloads of the magnet construction and a mechanical stress is a most destructive factor of pulsed coils. Therefore material ultimate tensile strength determines the value of maximal available non-destructive magnetic field. The peak field for soft-copper is 22 T, work-hardened copper – 33 T. At a magnetic field of 50 T a pressure in the order of 1 GPa acts on the winding and traditional materials become not applicable in pulsed magnet design [5]. In measurement science the non-destructive pulsed magnet operation is extremely important and induced overloads should be estimated to insure the safety of experimentation. The analysis of the behaviour of the coil construction in pulsed magnetic field is a complicate task and it can be solved using numerical methods and computational technologies for multi-physical phenomena [6]. In High Magnetic Field Laboratory first estimations of mechanical and thermal overloads of pulsed coils were done using ANSYS software in FEM framework [7], [8]. The main tendencies may be illustrated by computational results of the pulsed coil as shown in Fig. 1, where radial variation of the von Misses stress in mid-plane at 45 T magnetic field and time evolution of temperature are presented.

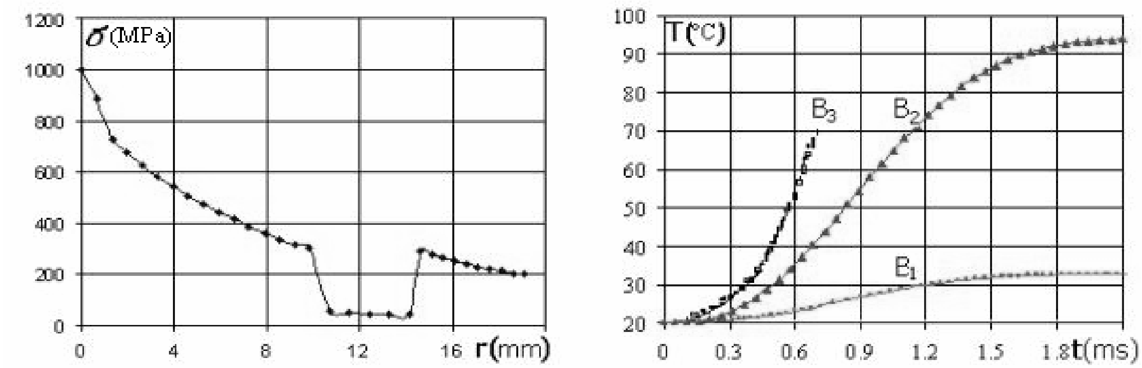

Fig. 1 The radial variation of the von Misses stress (a) and temperature evolution (b) of pulsed coil.

Analysed pulsed coil was wound with micro-composite Cu-Nb wire, armoured Zylon 545HM filament and epoxy wet impregnated. Zylon Poly p-phenylene benzobisoxazole or PBO filament demonstrates very high modulus and strength values, far in excess of almost all other high-performance fibres [9]. Micro-composite Cu-Nb wires are known due to their high ultimate tensile strength combined with high electrical conductivity [10]. Applied Zylon 545HM filament according to TOYOBO Co. certificate has ultimate tensile strength of 5,8 GPa and elongation at break of 2,5%. Micro-composite Cu-Nb wires with cross-section of 1,70 mm x 0,8 mm according to Bochvar Institute of Inorganic Materials certificate has ultimate tensile strength of 1,1GPa, elongation at break of 4,0%. All parameters were certificated at normal conditions. Dynamic and cyclic overloads were not valuated. Really pulsed coil constructing materials are pre-cooled with liquid nitrogen and heated adiabatically due to Joule heating during the pulse. The measurements of tensile strength and the elongation at break of applied materials were done to clear the probable influence of thermal overloads on material mechanical properties and further pulsed coil reliability.

3. Results

Tensile testing of the single specimens was carried out by universal testing machine Tiratest 2300, which provides testing at temperatures from –160 ºC to +260 ºC. The measurements of tensile strength and elongation at break were done at 20 ºC using a 1 N load cell and are shown in Fig.2

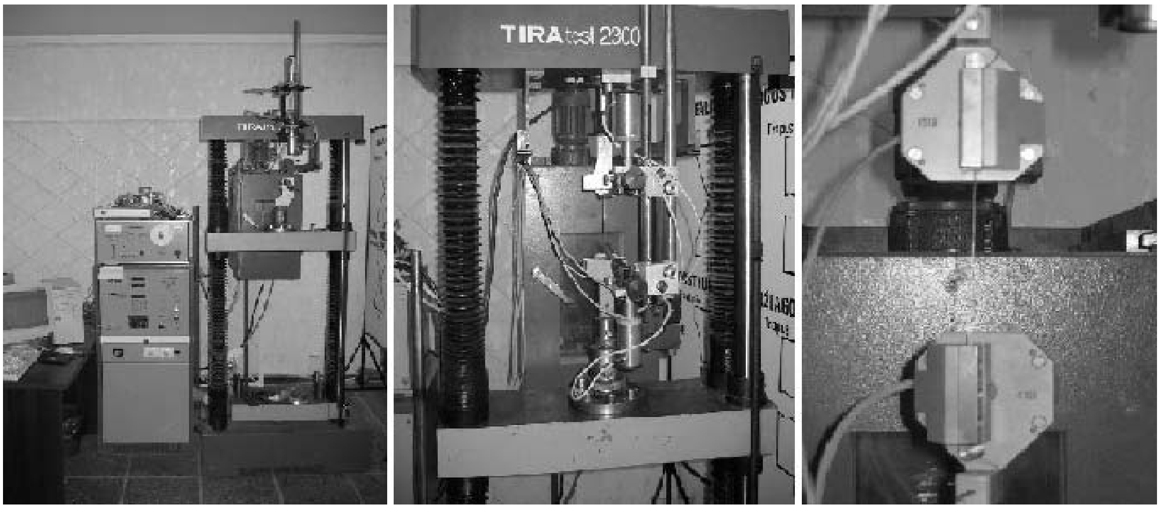

Fig.2 Measurements of tensile strength of Cu-Nb wire and Zylon filament with testing machine Tiratest 2300

The testing of Cu-Nb micro-composite wire was carried out in a standard atmosphere at tension speed of 2 mm/min. Recommended gauge length according to ISO 6892 is (100± 0,1) mm. The testing of Zylon filament was carried out in a standard atmosphere at tension speed of 18 mm/min, using samples preliminary pre-conditioned for a minimum of 48 hours. The filament samples were fixed in a place using special mechanical and pneumatic grips applicable for chemical and textile filaments. It is necessary to note, that different filament properties can be obtained using the different testing equipment and methods of sample fixing. Therefore is useful to verify filaments breaking load and elongation by different test methods according to the standards GOST 10213.2, GOST 23362, GOST 26171, ISO 5079. The recommended gauge length is (20± 0,1) mm. The studies of another researchers are shown that both Young's modulus and tensile strength are gauge length sensitive [11]. After some tentative tests we found, that more reliable and replicable experiment results can be obtained using grips with flat jaws then with semicircle grips.

Cu-Nb micro-composite wire and Zylon filament mechanical properties were measured before and after thermal overload. Zylon filament and Cu-Nb wires were tested at normal conditions using 100 mm gauge length at least 10 samples at each variety. Then, simulating real operation conditions, 10 samples of wire and filament are thermally affected: cooled in liquid nitrogen, heated in climatic chamber at 260ºC temperature. Every operation was repeated at 20 (cooling and heating) cycles. Measuring data of tensile strength and the elongation at break is shown in Fig.3.

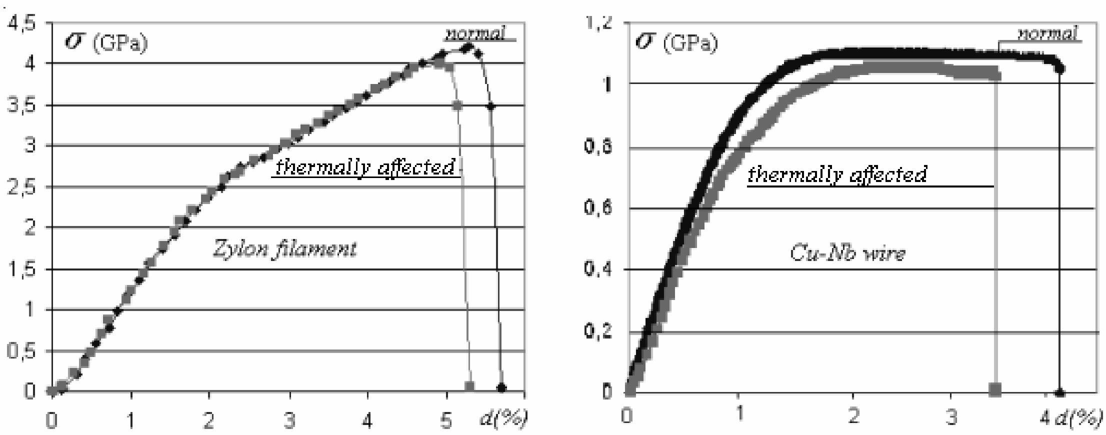

Fig.3 Measurement of tensile strength, the elongation at break of Zylon filament

4. Conclusions

Mechanical properties of electrotechnical materials applied in pulsed magnet design were investigated. The change of tensile strength and elongation at break was measured under condition close to real pulsed coil operation conditions, which were simulated by cyclic cooling to – 160 ºC and further rapid heating up to 230 ºC temperature.

It was found that the tensile strength and elongation at break of micro-composite Cu-Nb wire depend on thermal overloads. After cyclic thermal loading the tensile strength of wire decreased at least 5% and elongation at break is increased at 20% in tensile strength limit area.

It was found that the tensile strength and elongation at break of Zylon filament does not depend on thermal overloads took place in pulsed coils. The tolerance of measured mechanical properties of Zylon filament took place due to testing method particularities and disadvantages of grips.

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