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STRESS ANALYSIS AND MICROSTRUCTURE OF THE $AL_2O_3/Cu/MgB_2$ WIRES

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ABSTRACT

The effect of annealing process on the properties of the mechanical and microstructure of $Al_2O_3/Cu/MgB_2$ wires have been studied. The stress calculation was analytically determined for1 mm diameters of Cu/MgB_2 wires, which were fabricated by using powder in-tube process. Al_2O_3 ceramic insulations were coated on Cu/MgB_2 wires. The stress distribution, microstructure and superconducting properties of the $Al_2O_3/Cu/MgB_2$ wires are presented.

Keywords: MgB_2; Stress-Strain; Superconducting wire

1. INTRODUCTION

Many studies associated with the physical and mechanical properties of MgB_2 exist, but very few are related with the residual stress. The residual stress suffers from failure due to flaking and cracking which results from the thermal and elastic mismatch, the plastic flow stress of the metal sheath, and the relative MgB_2 superconducting core. Moreover, failures in MgB_2 depend on the sheath materials and temperature. The residual stresses can be computed using many different methods using numerical, analytical or experimental methods such as layer removal, curvature, neutron, X-ray diffraction and etc.

The aim of the present work is to investigate the residual stresses and microstructure of Al_2O_3 insulation coating on Cu/MgB_2 wires for MgB_2 coils. The residual stresses which arise during the annealing process due to cooling from formation temperature.

2. EXPERIMENTAL PART

The monofilament MgB_2 wires were fabricated by using powder in tube process. Diameter of the Cu/MgB_2 wires was 1.0 mm. The Al_2O_3 solutions were synthesized by sol-gel process. The details of the preparation of Al_2O_3 solutions were discussed in the previous work [1]. The sample was heat-treated using optimum annealing profile under 4% H_2-Ar gas flow microstructure and surface analyses of the samples were characterized by using Scanning Electron Microscopy (SEM).

Table 1. Properties of the materials

	Index no	*E (GPa)*	ν	α *(10^{-6}/K)*
MgB_2	*1*	151	0.18	8.3
Cu	*2*	120	0.32	16.7
Al_2O_3	*3*	318	0.22	5.6

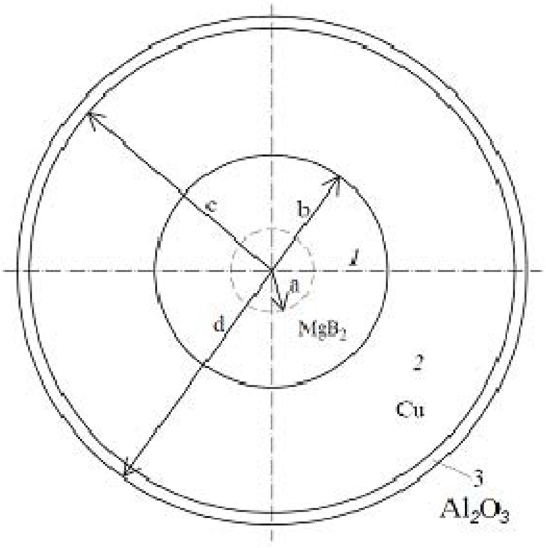

Figure 1. Sketch of axially symmetric $Al_2O_3/Cu/MgB_2$ wire.

Residual stress analysis of Cu/MgB_2 wires

Al_2O_3 coated Cu/MgB_2 wire samples were annealed at 700 °C for 30 min with 5.8 °C/min heating rate under %4 H_2-Ar gas flow which is obtained optimum annealing process [1, 2]. When it is cooled down to the room temperature, residual stress may cause crack or fracture in the $Al_2O_3/Cu/MgB_2$ wires. In this study, the residual stress is examined for the axially symmetric $Al_2O_3/Cu/MgB_2$ wires. Material properties at the room temperature and dimensions of the investigated sample are given in Tables 1 and 2, respectively.

Table 2. Dimensions of the structure

b	*309* µm
c	*515* µm
d	*523* µm

Lamé's solution [3] can be used to calculate the state of stress in this cylindrical rod which is composed of ($Al_2O_3/Cu/MgB_2$). The materials filling the regions in the structure are indexed as shown in Figure 1. The relavant solution of the problem is obtained using the continuity condition among the regions of the structure. It is as follows:

Displacement between the region in the centre (MgB_2), indexed by *1* and the second region (Cu), indexed by *2*

$$u_1 = u_2 \quad \text{at} \quad r=b \tag{1}$$

and displacement between the region in the second region (Cu), indexed by *2* and the third region (Al_2O_3), indexed by *3*

$$u_2 = u_3 \quad \text{at} \quad r=c \tag{2}$$

According to Lamé's solution, the expression of displacement is

$$u = \frac{1-2\nu}{E}\frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} r + \frac{1+\nu}{E}\frac{r_i^2 r_o^2}{r}\frac{p_i - p_o}{r_o^2 - r_i^2} \tag{3}$$

where ν and E denote the Poisson's ratio and modulus of elasticity, respectively. r_i and r_o represent the internal and external radii of the cylinder, and p_i and p_o are the uniform internal and external pressures acting on the boundaries.

If equation (2) is written for the condition mentioned above, the following expression is obtained.

$$\frac{1-2\nu_1}{E_1} p_b b + b\alpha_1 \Delta T = \frac{1-2\nu_2}{E_2} p_b b + b\alpha_2 \Delta T \tag{4}$$

where α_i ($i=1$,2 and 3) is thermal expansion coefficient belong to the associated material and ΔT is the difference of temperature. It should be noted that the formulation mentioned above is valid for plane stress problems. Therefore, Poisson's ratio, modulus of elasticity and thermal expansion coefficient should be substituted in the formulations as $\nu/(1-\nu)$, $E/(1-\nu^2)$ and $\alpha(1+\nu)$, respectively, for plane strain problems. The solution of equation (3) gives the radial stress component among the regions, represented by p_b, occur during the cooling process. Stress components can be calculated in the parts of the relevant structure using Lamé's stress formulation given below because p_b is known value any more.

$$\sigma_r = \frac{r_i^2 r_o^2 (p_o - p_i)}{r_o^2 - r_i^2} \frac{1}{r^2} + \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} \tag{5}$$

$$\sigma_\theta = -\frac{r_i^2 r_o^2 (p_o - p_i)}{r_o^2 - r_i^2} \frac{1}{r^2} + \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} \tag{6}$$

$$\sigma_z = \nu(\sigma_r + \sigma_\theta) - \alpha E \Delta T \tag{7}$$

where σ_z is the stress component along the length. The p_b is obtained as -261 MPa. The displacements are obtained as -2.52 μm and -2.52 μm where r = 309 μm and r = 515 μm. Values of stress components are -604 MPa at the region of MgB_2, -327 MPa at the copper after MgB_2 and -1026 MPa at the copper on boundary of Al_2O_3 and 1010 MPa at the region of Al_2O_3.

3. RESULTS AND DISCUSSION

The samples of Cu/MgB_2 were annealed at 700 °C for 30 min with 5.8 °C/min heating rate under 4% H_2-Ar gas flow. Diameter of the Cu/MgB_2 wire, about 1.0 mm, and the cross sectional area of superconducting cores were found to be 2.9 x10^{-3} cm^2 from SEM picture as shown in Figure 2. Circumferential stress components are in compression behavior. Maximum circumferential stress component magnitude was obtained at region of Al_2O_3.

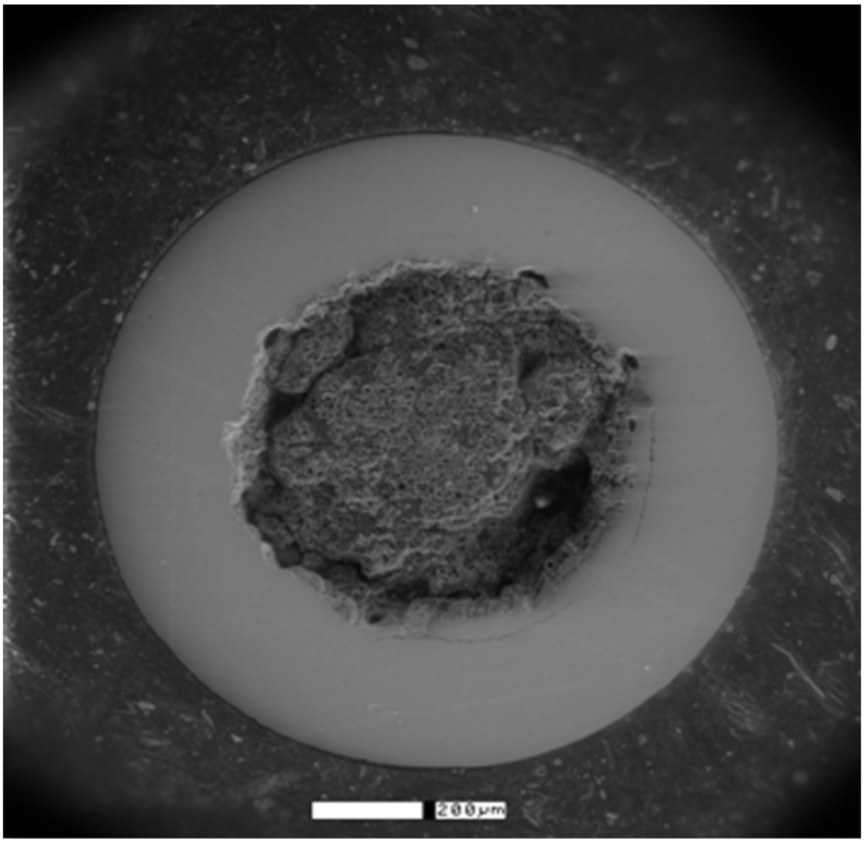

Figure 2. Typical SEM micrographs of Cu/MgB_2 wire

4. CONCLUSIONS

The stress calculation was analytically determined for 1.0 mm diameter of MgB_2 wires, annealed at 700 °C for 30 min with 5.8 °C/min heating rate under %4 H_2-Ar gas flow. Residual stress analysis of Cu/MgB_2 wires is investigated in temperature change for 1.0 mm diameter using Lamé's formulation in axially symmetric wire. Maximum circumferential stress component magnitude was obtained Al_2O_3 region.

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5. REFERENCES

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