STUDY ON THERMOMAGNETIC COUPLING FRACTURE OF HIGH TEMPERATURE SUPERCONDUCTOR MULTILAYER STRUCTURES

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Abstract

Most studies on the fracture of bulk or ribbon superconductors are based on superconducting critical state models that do not consider temperature changes. Most of the research objects of the thermal-mechanical-electric-magnetic model only focus on the distribution of magnetic field current and stress, while the thermal-mechanical-electric-magnetic model with cracks is rarely involved. The research in this paper will be based on a generalized critical state model that considers both temperature and magnetic field effects to investigate the effects of thermal and magnetic effects on cracks in superconducting structures.

1. Introduction

Multilayer superconducting structures consisting of superconducting layers and other supporting layers such as buffer layers, hastelloy, silver, and copper are commonly used in superconducting cables. The multilayer structure composed of a central superconducting layer and an external reinforcing layer represents the general structural form of a multi-layer high-temperature superconducting cable structure, which has great application potential in space solar power stations. The fracture problem of this multilayer superconducting structure is even more important. Superconductors must operate at liquid nitrogen temperature. There is heat transfer between liquid nitrogen and superconductors, and there may also be heat transfer between refrigeration and the external environment. Due to inevitable temperature fluctuations, especially during the cooling or heating process, large thermal stresses can occur. We will construct an analytical model to consider the effects of thermal mechanical electrical magnetic coupling and temperature on the stress distribution.

2. Results

The thermal stress problem of interfacial cracks between orthotropic functionally graded superconducting materials and functionally graded materials is studied.

a. The temperature boundary condition uses convective heat transfer boundary conditions, and there is thermal conductivity and resistance in the crack region.
b. The temperature distributions of the superconducting layer and the functionally graded layer are obtained.
c. The expressions of displacement, stress, and stress intensity factors are obtained by solving non homogeneous partial differential equations.
d. The numerical solution was carried out using the Gauss-Chebysheve integral formula and Laplace numerical inversion method, and the variation curves of the crack surface and crack extension line temperatures and the mode I and II stress intensity factors were obtained.
e. The effects of time, thermal resistance, thermal conductivity parameter ratio, crack distance from the heating boundary, thermal expansion parameter ratio, hardness parameter ratio on temperature and thermal stress intensity factor were analyzed.
f. The effects of hardness parameters and thickness of functionally graded layers on stress intensity factors during different magnetization processes were studied.

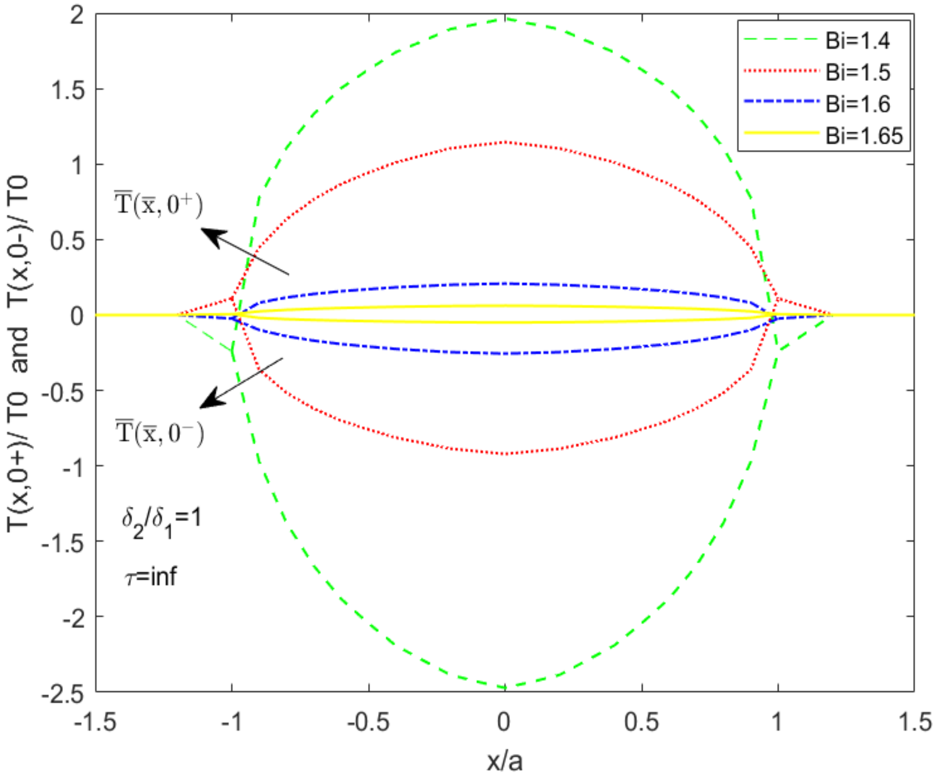

Fig.1 Variation of temperature on crack surface and extension line with dimensionless thermal resistance

The results show that an increase in the ratio of heating time to thermal conductivity parameters has the same effect on the temperature change of the crack surface, that is, the temperature change of the crack surface is significant, while the effect of changes in dimensionless thermal resistance and superconducting plate thickness on the temperature change is opposite to the effect of factors such as heating time. Under zero field cooling magnetization, the stress intensity factor usually exhibits a trend from negative to positive, and gradually increases with the decrease of the magnetic field. Increasing the hardness parameter of the functionally graded layer slows down the increase rate of the stress intensity factor. Under the field cooling magnetization method, the decrease of the magnetic field causes the stress intensity factor to first increase to a peak value and then decrease. The smaller the hardness parameter of the functionally graded layer, the more obvious the impact on the stress intensity factor, and the larger the peak value.

3. Conclusions

When designing a structure, the value of the elastic modulus ratio needs to be compromised. Material properties have a significant impact on the heat conduction and magnetization processes of superconducting multilayer structures. The thermal-mechanical-electrical and magnetic coupling models established in this paper are very helpful for analyzing the application of high-temperature superconducting multilayer cables in space solar power stations.

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