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Rheological Behavior and Cryogenic Properties of Cyanate Ester/Epoxy Insulation Material for Fusion Superconducting Magnet

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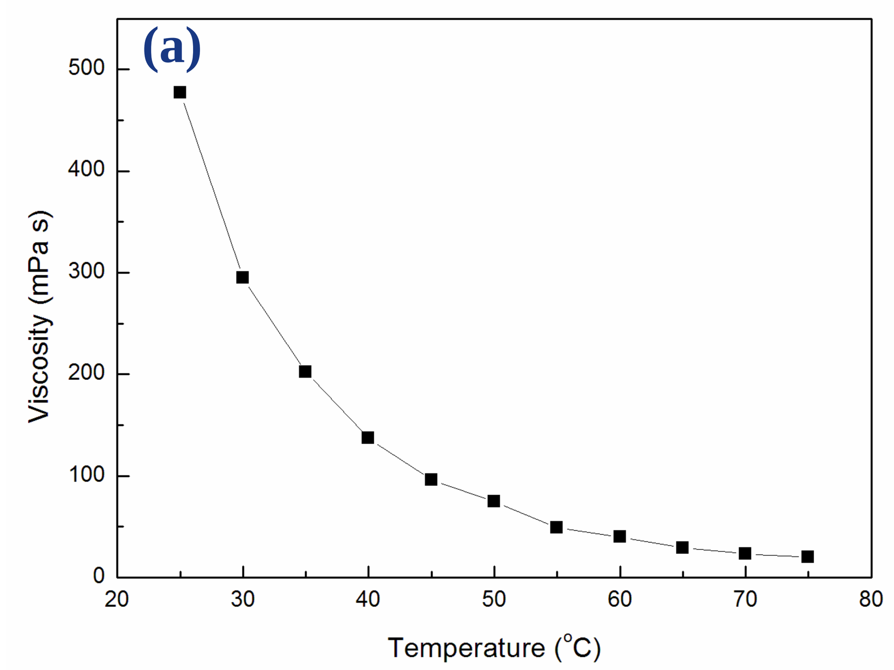
Abstract

In a Tokamak fusion reactor device like ITER, insulation materials for superconducting magnets are usually fabricated by a vacuum pressure impregnation (VPI) process. Thus these insulation materials must exhibit low viscosity, long working life as well as good radiation resistance. Previous studies have indicated that cyanate ester (CE) blended with epoxy has an excellent resistance against neutron irradiation which is expected to be a candidate insulation material for a fusion magnet. In this work, the rheological behavior of a CE/epoxy (CE/EP) blend containing 40% CE was investigated with non-isothermal and isothermal viscosity experiments. Furthermore, the cryogenic mechanical and electrical properties of the composite were evaluated in terms of interlaminar shear strength and electrical breakdown strength. The results showed that CE/epoxy blend had a very low viscosity and an exceptionally long processing life of about 4 days at 60 °C.

Introduction

The vacuum pressure impregnation (VPI) process is applied to fabricate the insulation materials for superconducting magnets, therefore the resin matrix should have a rather low viscosity and a long working life in order to ensure an efficient impregnation over long distances. Recent studies showed that cyanate ester (CE) has an excellent resistance against the gamma ray and neutron irradiation which is expected to be a candidate insulation material for a fusion magnet. In the present work, the mixture with 40% cyanate ester and 60% epoxy resin was used as the resin matrix and acetylacetone cobalt(II) was used as the catalyst. The processing characteristic of the resin system was assessed with non-isothermal and isothermal viscosity experiments. In addition, mechanical and electrical properties of the glass fiber reinforced composites were investigated in terms of the interlaminar shear strength and the electrical breakdown strength as well as the surface flashover strength.

Rheological Property



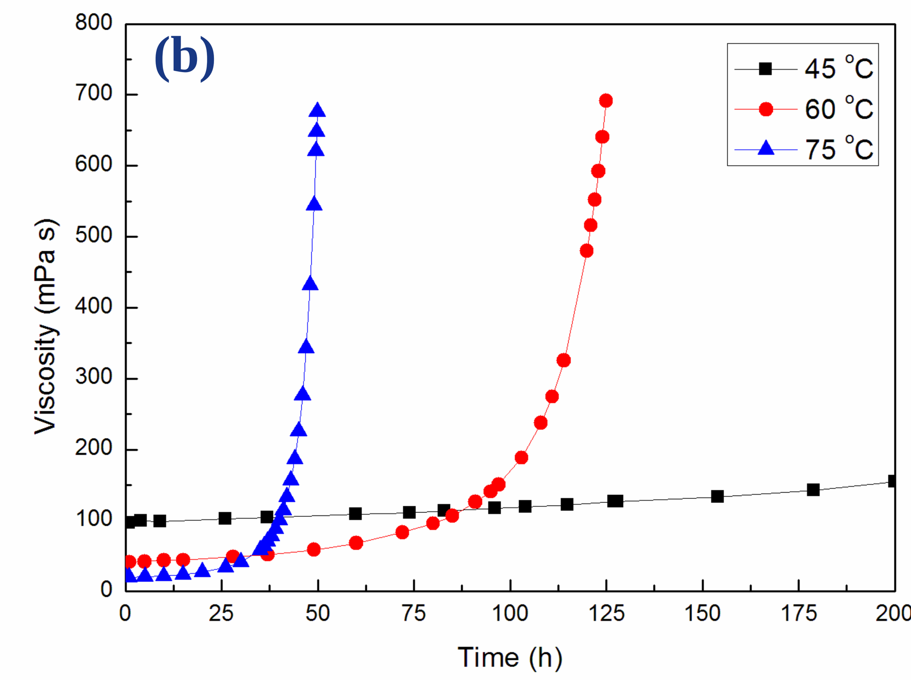
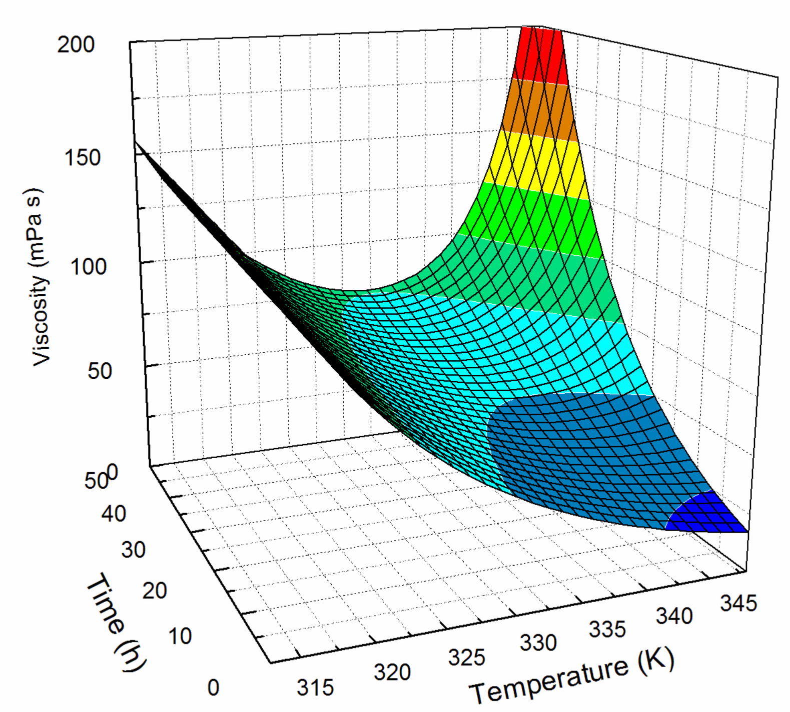
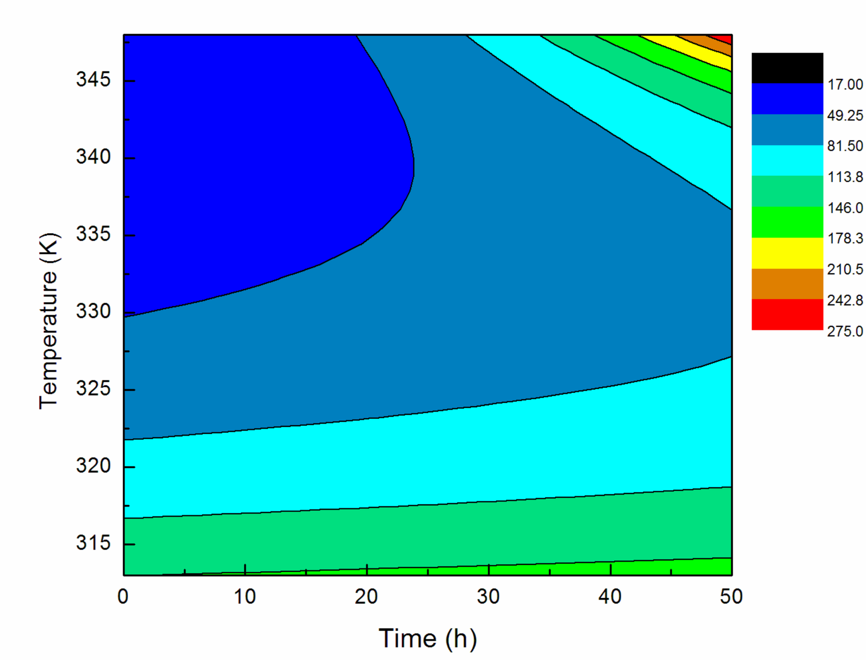


Figure 1. (a) Initial viscosities of CE/EP resin system as a function of temperature; (b) Viscosity of CE/EP resin system as a function of time at different temperatures

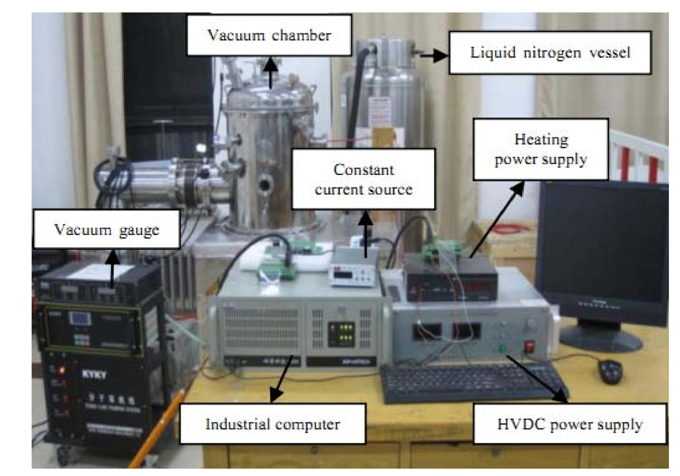
Rheological Model

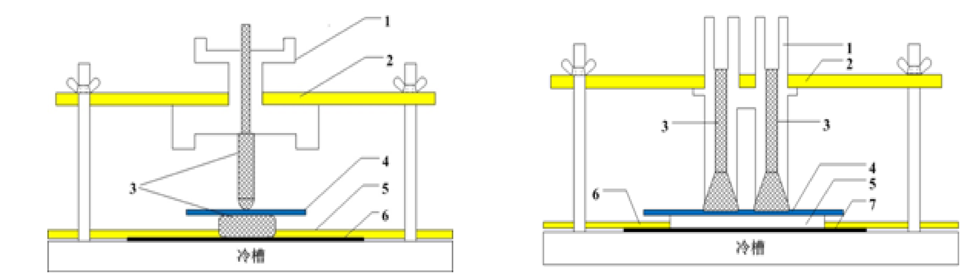
$$\ln\eta(T,t) = -16.36 + \frac{6680}{T} + t\cdot\exp(30.053 - \frac{11464}{T})$$





Mechanical and Electrical Properties





1-Insulating bushing; 2, 5- Insulating board; 3-electrodes; 4-test sample; 6-Insulation layer
(a) Electrode system for electrical breakdown test

1-Insulating bushing; 2, 6- Insulating board; 3-electrodes; 4-test sample; 5-copper plane plate; 7-Insulation layer
(b) Electrode system for flashover test

TABLE 1. Mechanical and electrical properties of the composite at 300 K and 77 K

Temperature (K)	ILSS (MPa)	Electrical Breakdown Strength (kV/mm)	Surface Flashover Strength (kV/mm)
300	69.5	58.3	4.19
77	85.6	63.8	4.32

Conclusions

- The CE/EP blend resin system containing 40% CE exhibits a lower viscosity and longer working life compared to the traditional epoxy resins.
- The chemorheological model was developed, which could be used effectively to predict the viscosity change of the resin system during the impregnation process.
- The ILSS, breakdown strength and surface flashover strength of the CE/EP composite at 77 K were 85.6 MPa, 63.8 kV/mm and 4.32 kV/mm.

Acknowledgment

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