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Processing characteristic and radiation resistance of various epoxy insulation materials for superconducting magnets

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HIGHLIGHTS

- We studied the processing properties of various epoxy matrices.
- We studied the radiation resistance of TGPAP-based and DGEBF-based composites.
- TGPAP-based systems are more suitable for VPI process than DGEBF-based systems.
- TGPAP systems present more radiation resistant than DGEBF systems.

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ABSTRACT

Glass fiber reinforced epoxy-based composites were developed as insulating materials for fusion superconducting magnets. The processing properties of various epoxy matrices were investigated in terms of the isothermal viscosity at 45 °C. The interlaminar shear strength (ILSS) at 77 K and the thermal expansion coefficient (CTE) of the composites were assessed before and after gamma irradiation at ambient temperature up to 10 MGy. It is found that the TGPAP-based systems showed lower initial viscosities, longer working life and higher radiation resistance compared to the DGEBF-based systems with the same modifier. Furthermore, there was no significant effect of the irradiation dose on the CTE of the composites.

1. Introduction

With the rapid developments in magnetic confinement fusion reactors such as the International Thermonuclear Experimental Reactor (ITER), glass fiber reinforced polymer composites (GFRPs) have drawn much attention and are expected to be used as structural supports and electrical insulation for superconducting magnets of fusion devices because of their excellent mechanical strength, good electrical insulating and adhesive properties. However, these materials are inherently sensitive to environmental factors such as cryogenics and exposure to irradiation, which significantly affects their performance and useful life. On the other hand, the composites used as the insulation of superconducting magnets are usually fabricated by a vacuum press impregnation (VPI) process which requires that the resin matrix should have a rather low viscosity and long pot life in order to ensure an efficient impregnation over long distances. In the past few years, extensive work [1–11] has been done to explore and optimize the candidate impregnating resins and some advanced resin matrices with improved processing and radiation resistance properties were introduced into the fusion field. Recent studies [10,11] showed that cyanate ester (CE) has an excellent resistance against the gamma ray and neutron irradiation, but it is too expensive compared to traditional epoxy resins.

Diglycidyl ether of bisphenol-F (DGEBF) and triglycidyl-p-aminophenol (TGPAP) are di-functional and tri-functional epoxy resins with a low viscosity, both of which have been widely used as impregnating resins for superconducting magnets. However, they are rather brittle, especially at cryogenic temperatures. Thus, it is necessary to enhance their toughness in order to broaden their applications. Generally, the effective methods for improving

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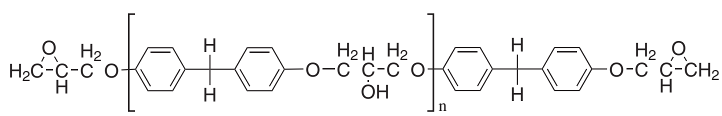
epoxy resin toughness are to incorporate organic polymers and inorganic particles into epoxies. Yang et al. [12] used the hyperbranched polymer (H30) to improve the cryogenic mechanical properties of diglycidyl ether of bisphenol A (DGEBA) and found that the cryogenic tensile strength, ductility and impact strength of DGEBA were enhanced simultaneously. Zhang et al. [13,14] synthesized a low-viscosity liquid epoxidized aromatic hyperbranched polymer (HTDE-2) and found that the impact toughness of DGEBA was improved about three times as 9–12 wt% HTDE-2 was introduced into DGEBA. Sawa et al. [15] found the fracture toughness of DGEBA at cryogenic temperature could be improved by mixing with tetraglycidyl-meta-xylenediamine (TGMXDA). Our previous study [16] indicated that isopropylidenebisphenol bis[(2-glycidyloxy-3-n-butoxy)-1-propylether] (IPBE) could improve cryogenic toughness as well as the pot life of the epoxy resins. Although the toughness was achieved successfully, their processing and irradiation resistance properties are unknown.

In the present work, DGEBF and TGPAP were used as the baseline epoxies. HTDE-2 and IPBE were selected as the modifiers. The aim of the present work is to investigate the effect of baseline resins and modifiers on the processing and irradiation resistance properties of the insulating materials. The processing characteristic of these systems was assessed. In addition, mechanical and thermal properties of the glass fiber reinforced epoxy composites were investigated in terms of the interlaminar shear strength and the thermal expansion before and after irradiation with various doses. Some new epoxy insulation materials based on DGEBF and TGPAP were developed as radiation stable impregnating systems for superconducting magnets.

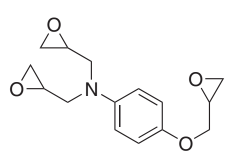
2. Experiment

2.1. Materials

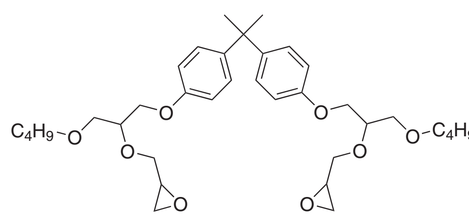
The epoxy resins used in this study were diglycidyl ether of bisphenol F epoxy resin (DGEBF, GY285, Huntsman Advanced Materials) and triglycidyl-p-aminophenol (TGPAP, MY0510, Huntsman Advanced Materials), respectively. The curing agent was diethyl toluene diamine (DETD, HY5200, Huntsman Advanced Materials). The modifiers were isopropylidenebisphenol bis[(2-glycidyloxy-3-n-butoxy)-1-propylether] (IPBE, PY 4122, Huntsman Advanced Materials) and a liquid aromatic hyperbranched epoxy resin (HDTE-2, E102, Suzhou HyPerT Resin Science &Technology Co. Ltd., China). The chemical structures are given in Fig. 1. The reinforcement was boron-free glass fiber cloth (RW220-90, Sinoma Science and Technology Co., China) treaded with a silane coupling agent.



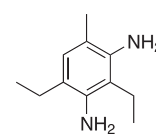
DGEBF (GY285)



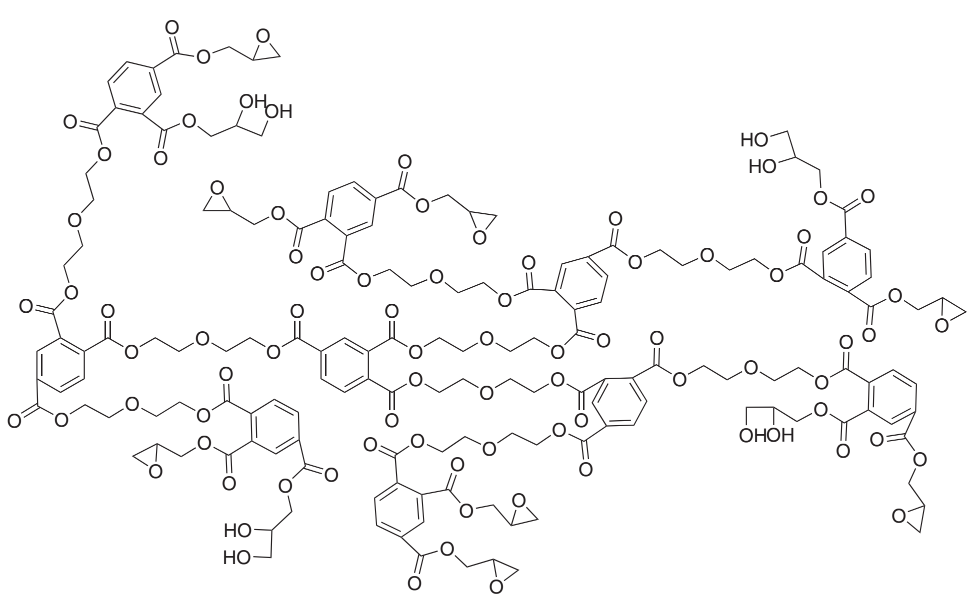
TGPAP (MY0510)



IPBE (PY4122)



DETD



Aromatic hyperbranched epoxy resin (E102)

Fig. 1. Chemical structures of DGEBF, TGPAP, DETD, IPBE and HTDE-2.