RESEARCH ON NEW HIGH-STRENGTH STRUCTURAL MATERIALS FOR LOW-TEMPERATURE APPLICATIONS IN THE NEXT GENERATION OF FUSION REACTORS

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Abstract

Increasing magnetic field intensity in limited space is an important strategy to obtain high parameter plasma and improve the fusion power. The next generation of fusion magnets will have a peak magnetic field greater than 17 T, such as China Fusion Engineering Demonstration Reactor (CFEDR). The development of high strength and high toughness jacket has become one of the challenges in the application of high-field cable-in-conduit conductors (CICC) for CFEDR. 0.2% proof stress of jacket should be over 1500 MPa at 4.2 K for CICC, thus 316LN and JK2LB jackets developed by ITER do not meet the requirements.

The austenitic stainless steel CHSN01 (formerly N50H) jacket developed for China's future fusion reactor shows excellent high strength and high toughness. The yield strength of the CHSN01 jacket at 4.2 K exceeds 1500 MPa, which is about 40% higher than that of the ITER 316LN jacket. The jacket not only needs to have good matching strength and toughness, but also needs to take into account excellent safety service performance. The jacket eventually served in liquid helium for a long period of time. The effect of long-term cryogenic treatment on the microstructure and properties of jacket materials is unknown. In this paper, the actual preparation and service conditions of the jacket are simulated by experiments. The material was immersed in a liquid helium Dewar for long-term heat preservation treatment. Firstly, the effects of liquid helium immersion of different durations on the mechanics of the jacket were investigated. Secondly, the changes in the microstructure of the material were characterized by means of SEM, XRD, EBSD and TEM experiments. Furthermore, this paper discusses the feasibility of employing CHSN01 as a cryogenic structural material capable of withstanding high-magnetic fields in next-generation fusion reactors.

Keywords

CHSN01, CICC jacket, Cryogenic mechanical properties, Fusion reactor

This study focuses on the circle-in-square jacket of BEST toroidal field coil, which has an initial size of 37.7 mm (square size) × 29.5 mm (inner hole diameter). The CHSN01 jacket of BEST is shown in Figure 1.

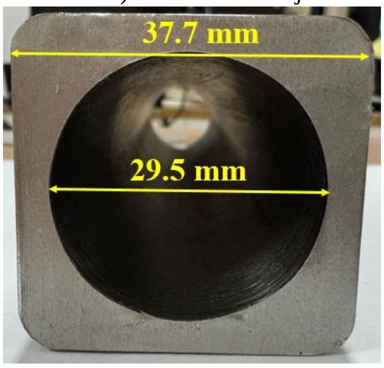

Fig. 1. Schematic diagram of jacket section dimensions.

The prepared mechanical samples were soaked in liquid helium dewar for different times, specifically 5 minutes, 5 hours, 10 hours, 50 hours and 100 hours. Under each soaking condition, 2 tensile samples and 2 fracture toughness samples were prepared, and a total of 10 tensile samples and 10 fracture toughness samples were prepared. The jacket sample preparation process is shown in Figure 2.

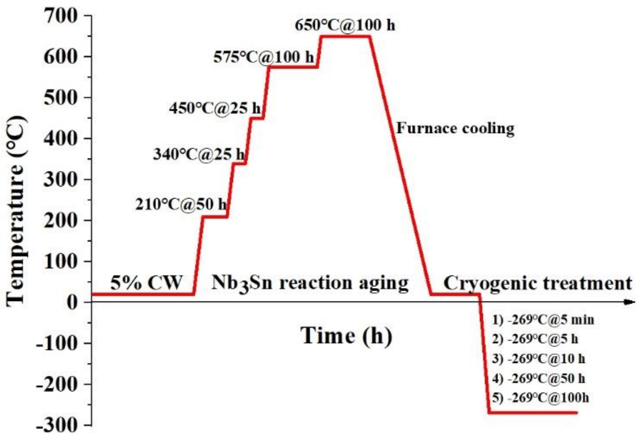

Fig. 2. The curve of 5%CW+Nb_3Sn aging treatment+ liquid helium aging treatment under different duration.

The batch preparation of CHSN01 jackets has been successfully achieved in China. Experimental simulations replicated the working conditions of the jacket under actual service environments. The mechanical properties of the jacket remained stable after prolonged exposure to liquid helium, with no degradation observed. At liquid helium temperatures, the yield strength of the jacket exceeds 1500 MPa, demonstrating excellent plasticity and toughness, and confirming its capability for long-term low-temperature service. However, further studies are required to fully verify the fatigue properties of the jacket.

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