Fatigue and Fatigue Crack Growth Properties of 316LN and Incoloy 908 Below 10 K

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Introduction

The cyclic loading characteristics of Tokamak type thermonuclear machines demand for an answer towards the fatigue response of the materials used in critical components. As one of the main outstanding parts of such a device the large superconducting magnets and their superconductors will operate under cyclic mechanical stress conditions. The present paper is biased towards the current superconductor design of the NET (Next European Torus) model coil concept. The superconductor of this coil will be a cable-in-conduit Nb3Sn type with an enveloped stiff external jacket structure. The wall thickness of the jacket structure is within the range of 4-5 mm in accordance with the recent structural mechanics calculations. The manufacturing of the jacket lengths for several hundred meters require an appropriate joining process due to the prefabricated section pieces available only in short lengths of 5-7 meters. At the ongoing technical discussions the recently anticipated solution favors the flash butt welding technique, which seems to be quite reasonable considering the present industrial practice. The performance of the superconductors jacket will strongly depend on the material selection and the proper structural design according to the existing low temperature structural materials data base. The wind and react Nb3Sn-manufacturing process must also account the materials properties after ageing. To envisage all these aforementioned factors a material test program was set up to elucidate the fatigue-life behavior and fatigue crack growth rate (FCGR) of the recently selected two candidate materials. These materials were the AISI 316LN with a specified low carbon content to avoid the embrittlement after the ageing process and the material Incoloy 908. Both materials were investigated in aged condition. In addition, the 316LN material in the as received condition was also tested with respect to its fatigue-life for specimens bearing predefined flaws and cracks. For more practical engineering relevance the propagation of surface cracks at 12 K and at 295 K was characterized with non standard specimens. All these tests were performed in a newly developed cryogenic dynamic test facility under helium gas environment between

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7 K and 20 K. Using the reference growth laws obtained from all these measurements the total crack propagation starting with the initial crack length of the specimen could be predicted by numerical computation.

EXPERIMENTALS

Materials and Specimens

The 316LN material with a carbon content of 0.015 wt.% (details of the chemistry are given in 3) was supplied by Böhler company, whereas the procurement of Inconel 908 was undertaken by Inco, Alloys, USA. The base metals and the flash butt welded plates of ~ 10 mm thickness of both materials were aged (50 hours at 700°C in air) in form of appropriate sized blocks prior to specimen machining. The fatigue life specimens were 100 mm long smooth cylindrical type with a reduced section of 20 mm length and 3.5 mm Ø. Both ends of the specimen had threads of M10 x 1.5. The specimens for the FCGR measurements were standard compact tension (CT) type of 63 x 60 x 6 mm with a starting a/W (a = crack length, W = specimen width) ratio of 0.34. The crack positions in the flash butt welded CT-specimens (narrow weld profile of ~ 0.2 mm) were in the center of the weldment in welding direction, and in transverse longitudinal plate orientation. The weldments of the fatigue-life investigations were located in the center of the 100 mm long specimens. In addition, fatigue-life tests were carried out with flaw bearing specimens of standard as received 316LN material. The size of these flawed specimens were similar to those of smooth cylindrical ones. The centerly located flaw of these specimens was machined by electro discharge method (EDM) and it was possible to machine predefined semi-circular flaws in the range of ~ 0.2 mm depth. For the surface crack growth characterization specially machined 100 mm long specimens with rectangular cross section (4 mm thick and 10 - 7 mm width) were used. Similar semi-circular flaws as in the case of the fatigue-life specimens were located in the center of the width to initiate the crack by fatigue loading.

Test Equipment

All these cyclic investigations were conducted in a helium flow cryostat with a test chamber dimension of 265 mm Ø x 210 mm depth, equipped with a servohydraulic tensile machine of ± 25 kN capacity (MTS, Modell 810). Details of this test facility are given in 3.

Test Procedure

Prior to these tests the temperature stability during the cycling was examined using specially prepared specimens with a 0.5 mm Ø horizontal bore in the high stress region with a Ni/NiCr thermocouple. For the fatigue-life measurements the specimens were sinusoidal loaded at the load ratio R = 0.1 with a frequency of 20 Hz after reaching the test temperature (e.g. 7 K). No temperature increase was detected during the cyclic loading well beyond the yield strength (~1.1 x \(\sigma_y\)) of the 316LN material. Considering this observation 20 Hz frequency was taken as a standard for all smooth specimens. The cyclic loading until failure was performed at constant load condition.

The flawed specimens for the fatigue-life tests were loaded at R = 0.1 with a higher frequency than the previous one (30 Hz), because of the lower nominal stress condition. During cycling the EDM-notch was directly observed with a built-in fiberscope (magnification 22x) to record the beginning of the crack emanation. Beside this a high resolution clamp-on extensometer mounted on the specimen was used to monitor the displacement situation on a 2 channel oscilloscope to determine the strain condition in