S-N Fatigue Tests of 9% Nickel Steel Weldments

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ABSTRACT

A series of S-N fatigue tests was conducted on weldments of nine percent nickel steel, which is often used in cryogenic applications. The objective was to confirm that the fatigue behavior conformed to that assumed in structural designs involving carbon steel weldments. The specimens were similar in configuration to those used to develop the D-, F-, and W-Curves, which are found in UK practice and generally recognized by other structural design standards worldwide. The specimens were left as-welded. The tests were performed at room temperature. This condition is the basis for the carbon steel S-N curves and indicated by the literature to be conservative for crack propagation at cryogenic temperatures. Testing at room temperature also greatly simplified the test set-up. A sufficient number of tests were conducted, at varying stress range levels and for each connection type, in order to perform a regression analysis. The regression demonstrated that the lower bound from the test results is at or above the lower bound of each pertinent design curve. Thus, the usual S-N curves for carbon steel weldments can be applied with confidence to nine percent nickel weldments.

KEY WORDS: 9% Nickel Steel, Fatigue, Welds, S-N Curves, D-Curve, F-Curve, W-Curve

INTRODUCTION

Low nickel ferritic steels, such as nine percent nickel steel, were first introduced in the early 1940’s as an economical option for storage and transportation of liquefied natural gas (Armstrong and Gagnebin, 1940). With high yield strength (85-90 ksi) and good low-temperature toughness (30 J @ -192 °C), these steels have been used to fabricate hundreds of on-land storage tanks and a few Kvaerner-Moss spherical LNG ship tanks (Wiersma, 1990).

Published studies comparing fatigue crack-growth rates of nine percent nickel at room and cryogenic temperatures indicate that fatigue crack-growth is reduced at lower temperatures (Sakai, Takashima, Tanaka, and Yajima, 1974; McBabe, Sarno, and Feddersen, 1974). However, data confirming the applicability of fatigue design practices based on carbon steel fatigue curves, such as BS7608-1993, for nine percent nickel structures is limited. To that end, a test program was conducted using weldments of nine percent nickel steel specimens, similar in configuration to those used to develop the D-, F-, and W-Curves found in BS7608.

TEST PROGRAM

The test program consisted of testing three different specimen configurations, as shown in Fig. 1:

- butt welds associated with the D design curve (10 specimens)
- non-load-carrying cruciform joints associated with the F design curve (9 specimens)
- load-carrying cruciform joints associated with the W design curve (10 specimens)

The configurations are consistent with those used to establish the reference curves for carbon steel weldments. All specimens had a minimum of 4 strain gauges positioned 10 mm from the weld toe. An additional 4 gauges, located at 50 mm from the weld toe, were used on 9 of the 10 D-Curve specimens (Fig. 2) because these specimens had a large degree of distortion. This second set of gauges facilitated extrapolation of the stress range to the weld toe. Due to the gauge positions, this extrapolation is conservative when compared the usual hotspot design approach [DNV 2005]. Extrapolation was not needed and thus not performed for the F- and W-Curve specimens since they satisfy the design target without it. In all cases, local stress ranges were calculated by multiplying the strain-gauge data by the room temperature elastic modulus for the nine percent nickel steel ($E_{\text{measured}}=190$ GPa). The stress range closest to the point of crack initiation was used for plotting and data analysis.

As discussed in BS7608, load-carrying fillet weld fatigue calculations account for potential root cracking through the use of the W-curve. However, they must be based on the engineering shear stress ranges present in the weld throat. For the W-Curve specimen configuration, the engineering shear stress ranges can be calculated using the following equation: