

## **Cryogenic Fatigue Tests of 9% Nickel Steel Weldments**

*P. C. Gioielli, ExxonMobil Upstream Research Company, Houston, TX  
N. Zettlemoyer, ExxonMobil Development Company, Houston, TX*

### **ABSTRACT**

S-N fatigue tests were carried out on weldments of 9% nickel steel, which is often used in cryogenic applications. The objective was to confirm that the fatigue behavior at cryogenic temperature was at least as good as that at room temperature. The cruciform specimens were similar in configuration to those used to develop the F-curve, which is found in UK practice and generally recognized by other structural design standards worldwide. The specimens were left as-welded. Three tests were conducted at both room and cryogenic temperature and at two different stress range levels. Comparison of the results showed that the cryogenic condition improved the life noticeably at both stress range levels. This finding was not unexpected based on literature evidence as to the reduction in crack growth rate at lower temperatures for this particular material. Prior work demonstrated that 9% nickel weldments can be safely analyzed by the usual S-N curves for carbon steel weldments when at room temperature. Hence, this latest finding means the same conclusion applies to 9% nickel weldments at cryogenic temperatures.

**KEY WORDS:** 9% Nickel Steel, Cryogenic 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).

Prior work (Gioielli and Zettlemoyer, 2007) demonstrated that 9% nickel weldments can be safely analyzed by the usual S-N curves for carbon steel weldments when at room temperature. However, data confirming fatigue design practices at cryogenic temperature is limited. To that end, a test program was conducted at both room and cryogenic temperature and at two different stress range levels. Comparison of the results showed that the cryogenic condition improved the life

noticeably at both stress range levels. This finding was not unexpected considering 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 (Nishioka, Hirakawa, and Kitaure, 1973; Sakai, Takashima, Tanaka, and Yajima, 1974; and McKabe, Sarno, and Feddersen, 1974).

### **TEST PROGRAM**

Four 9%Ni steel plates were gas metal arc welded (GMAW) using NO6625 consumable. Each welded plate consisted of a 20mm thick base plate with 16mm thick welded attachments on each side, as indicated in Figure 1. Four 50mm wide specimens were cut from each plate and subsequently machined.

Twelve of the sixteen specimens were tested using stress ranges of 300 and 200MPa, at both ambient temperature and -165°C, according to Table 1. For tests carried out at -165°C, temperature was controlled using a cryogenic chamber fed with liquid nitrogen. Prior to testing all specimen edges were dressed to avoid edge-crack initiation.

Table 1 Summary of specimen testing conditions

Number of Specimens Total = 12		Stress Range	
		200MPa	300MPa
Temperature	Ambient	3	3
	-165 °C	3	3

Standard servo-hydraulic testing machines were used to apply constant amplitude sinusoidal fatigue loading under load control. A four point bend loading arrangement was utilized, with the outer and inner spans being 300 and 120mm respectively. The cyclic loading frequency was 2-3Hz and tests were carried out using a constant high maximum stress (of approximately 400MPa) to simulate the presence of a highly tensile residual stress. Each specimen subjected to cryogenic conditions was instrumented with two thermocouples to confirm the temperature of the specimen during the test. A schematic illustration of the experimental set-up is provided in Figure 2.