Fundamental Aspects of Fatigue of Steel in Arctic Applications

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ABSTRACT
Over the past decade, it has been a continuously growing interest in exploration of oil and gas in the arctic region. The harsh, cold climate imposes challenging tasks which concern the structural integrity of steels and their weldments. Specific knowledge of metals behavior in such conditions is therefore mandatory in order to provide sufficient robustness. Within this framework, the present paper focuses on the fatigue properties of steels with the intention to provide a comprehensive review of the open literature about the effect of low temperature on the different aspects of the fatigue life of steels and their weldments. The main objective is therefore to provide a reliable basis for suggestions of necessary testing of low temperature fatigue in steels.

KEY WORDS: Fatigue; Low Temperature; Steels; Welds

INTRODUCTION
The arctic region is assumed to possess a large share of the remaining oil gas reserves. One estimate indicates that 13% of the world global oil reserves and 30% of the remaining gas is located in the northern regions (Gautier et al., 2009). With the world's increasing demand for these natural resources, it is reasonable to predict that offshore activities will continue to grow in Alaska, North Canada, Greenland, the Norwegian and Russian parts of the Barents Sea, as well as eastern parts of Russia (Layus et al., 2013). Coherently, as the offshore industry is moving north, the challenges related to materials and structural integrity arises due to the extreme climate. The most obvious is the low temperature and the inherent risk of unexpected brittle fracture. All structural steels will suffer from reduced fracture toughness at low temperatures due to the ductile-to-brittle transition behavior that is characteristic for ferritic steels. This behavior can be mitigated by nickel alloying and even if cryogenic grades are readily available, they are not competitive in price. (Hauge, 2012). A first comprehensive joint industry R&D project was launched in 2008 to develop basic knowledge and understand the methods for assessment of the fracture resistance of structural steel. In this project, systematic investigation of different steels and their weldments was conducted at lower temperatures with most experimental testing performed at -60°C (e.g. (Akselsen et al., 2011; Akselsen et al., 2012; Welsch et al., 2012; Jørgensen et al., 2013), which was assumed to be the lowest design temperature. However, fracture toughness was the main target in these studies, and there is also a need to examine the fatigue properties at ambient temperature. When it comes to regulations and standards, no particular reference is made to low temperature conditions, and the current procedures for materials qualifications are supposed to be valid for any operating temperature below room temperature. This is in accordance with the general assumptions that lower temperature will not have detrimental effect on the fatigue properties of steels. In this sense, a review of the experimental data available in literature has been made. The effect of low temperature on the overall steels fatigue life is first investigated through S-N curves while the crack initiation and the three regimes of crack propagation are then distinguished to provide particular insight to the physical mechanisms. The results will serve as basis for further low temperature assessment of fatigue properties.

LOW TEMPERATURE EFFECTS
The most obvious challenge for materials to be employed in the arctic region is the low ambient temperature. The literature review indicated that most of the research about low temperature fatigue was conducted during 70s and 80s, mainly in relation to cryogenic applications. However interest toward fatigue at low temperature is growing again in the last period, due to the increasing demand of performing materials in arctic conditions. The review of the fatigue properties of iron-based alloys dependency on low temperature is structured in three parts: the effect of low temperature is firstly reviewed in terms of S-N curve variations. Hence, the dependency of the mechanisms of crack initiation as well as the different stages of fatigue crack propagation on temperature decrease is summarized. Because of the high number of parameters characterizing fatigue testing conditions (e.g. steel composition/strength/microstructure, ΔK, R-ratio, cycle frequency/waveform, and testing temperature), direct data comparison from literature are generally not straightforward. Nevertheless, the intervals of the different testing parameters can be summarized as follow: waveform: sinusoidal; R-ratio: 0.05-0.1; frequency: 10-40 Hz; temperatures and microstructures instead will be indicated for each particular case. Therefore, the approach adopted in this paper is to try to rule out some consistent recorded variation in the fatigue-related behavior at low temperature by focusing on body-centered cubic (bcc) and face-centered cubic (fcc) based metals.

FATIGUE LIFE AND ENDURANCE
Low temperature effects on metals fatigue were initially made focusing on the variation of fatigue life and fatigue strength. The first thorough experimental campaign was made by McCammon and Rosenberg (1957) who measured the variations of the number of cycles at failure with low temperature (at four temperatures between 293 and 4.2 K) of pure metals, e.g. copper, silver, gold, aluminium zinc, iron and...