Material Challenges for Arctic Offshore Applications, a Reliability Study of Fracture of a Welded Steel Plate Based on Material Toughness Data at -60°C

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ABSTRACT
A five year Arctic material research project supported by The Research Council of Norway, oil companies, offshore suppliers and contractors is run by Sintef. The main goal of the project is to establish criteria and solutions for safe and cost-effective application of materials for hydrocarbon exploration and production in Arctic regions. One main task for the project is to carry out material and toughness testing of carbon steel at -60°C in order to qualify steel for low temperature applications. The obtained toughness results so far shows large scatter and with some results below code requirements set by e.g. ISO 19902 for fixed steel offshore structures and DNV-OSF-101 for seam welds for offshore pipelines and risers. It must be mentioned that the test program is comprehensive and not required by any of the recognised international codes discussed in this paper. This paper will address the qualification of materials and welding procedures in recognised offshore codes today, their limitations and challenges they can cause when applied at very low design temperatures. In addition, a case study where the annual probability of failure for a welded steel plate has been evaluated based on the achieved material test data at -60°C from the Arctic Material R&D Project.

KEY WORDS: brittle fracture, toughness, probabilistic fracture mechanics

INTRODUCTION
There is a lack of rules and standards that provide guidelines for material selection and qualification of materials for offshore and onshore structures in Arctic areas. Some actions have been taken to develop new standards e.g. within ISO19906, however the guideline does not specify material requirements except for the statement that material shall have adequate toughness in order to behave ductile at low temperatures. Today, recognized material codes are applied when qualifying material for Arctic applications. But these codes are not developed for low temperature applications, and the test temperature for toughness testing vary significantly from code to code and the definition of these temperatures may have a large cost impact and may affect the feasibility of a project in the Arctic region where the design temperature can be very low.

The oil and gas industry is looking for recommendations and guidelines for material selection and design for low operating temperatures. Low temperature is not only a concern for the operation phase but must also be considered for the construction and installation phases. Welds and base materials need adequate toughness to minimize the risk of brittle failure and work carried out by Karlsen at al. recommends that further efforts should focus on improving weld metal toughness of steels for low temperature applications. Material test results not fulfilling specified minimum toughness requirements either set by the codes or the designer / operators will have to be treated with care by e.g. a fit for purpose analyses in order to ensure a specified target safety level for the structure or component in question.

In order to investigate the significance of the material properties for the structural integrity, a probabilistic fracture mechanics analyses have been carried out on the basis of the test results achieved by the Arctic Material R&D Project. The case study has evaluated data for a 420 MPa welded steel plate, where different hypothetical surface flaws have been analysed. The effect of constraint for critical flaw size has been evaluated and it is seen that the failure probability vary significantly with the specimen geometry SENB (Single edge notch bending) and SENT (single edge notch tensile) and with the crack tip location (weld metal or fusion line).