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Thermal analysis of marine structural steel EH36 subject to non-spreading cryogenic spills: Part III: structural response assessment

Woongshik Nam[a], Odd Sture Hopperstad[b] and Jørgen Amdahl [a]

[a]Department of Marine Technology, Centre for Autonomous Marine Operations and Systems (AMOS), NTNU – Norwegian University of Science and Technology, Trondheim, Norway; [b]Department of Structural Engineering, CASA – Centre for Advanced Structural Analysis, NTNU – Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT

An experimental study that allows for thermal-structural analysis of steel structures subject to non-spreading cryogenic spills is described. A local, non-spreading cryogenic spill was replicated by building a liquid nitrogen pool in the middle of six EH36 steel plates with a central crack of different length. The results of the temperature measurement and the thermal analysis are reported in the first and second part of this three-part companion paper. The computational study reported herein comprises stress analysis based on temperature-dependent von Mises plasticity combined with the SED failure criterion. Comparison of experimental and numerical results for stresses, fracture initiation and crack path shows satisfactory agreement. The numerical study indicates that the SED failure criterion is a useful concept for practical design of ship and offshore structures subjected to sub-zero temperatures and thus exposed to the risk of brittle failure when exposed to cryogenic spills .

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Cryogenic spill; experimental-structural analysis; brittle fracture criterion; strain energy density

1. Introduction

The global demand for Liquefied Natural Gas (LNG) as a clean source of energy has been increasing in recent years. LNG transport is mostly performed using LNG ocean carriers. They are also widely used for the transportation of other liquified gases such as liquefied hydrogen. The liquified gases are cooled down below about −150°C. Leakage from cargo containments or fuel tanks of ships, as well as during bunkering of liquefied gases to vessels or offshore power plants, is a potential risk to the structural integrity of stiffened steel plates in ship hulls and offshore structures by embrittling them at cryogenic temperatures. Stress concentrations at micro-cracks may initiate brittle fracture that could progress into a catastrophic failure (cascading damage). Analysis of crack initiation and propagation by the finite element method requires generally very small solid elements. This represents a severe constraint to simulate the fracture initiation, crack propagation, and the transition from ductile to brittle fracture in those studies. A fracture criterion capable of predicting the ductile-brittle fracture transition in steel structures using shell elements was proposed by Nam et al. (2018). The strain energy density (SED) in shell elements was used as a criterion for the onset of fracture and the critical SED of the high-strength steel DH36 was determined at sub-zero temperatures. The SED failure criterion was evaluated as a practical and robust formulation to predict the ductile-brittle fracture transition using large shell elements.

This is the third part of a three-part companion paper and deals with the structural analysis of the pool boiling test. Part I (Nam et al. 2021) and Part II (Mokhtari et al. 2021) described the execution of the experiments and the finite element analysis of the heat transfer, respectively. The present paper addresses the stress field, fracture initiation and crack propagation in the EH36