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Investigation of fatigue performance for new membrane-type LNG CCS at cryogenic temperature

Dong-Jin Oh[a], Nam-Kyu Kim[a], Sang-Woo Song[a], Yang-Do Kim[b], Myung-Hyun Kim[b,*]

[a] Department of Joining Technology, Korea Institute of Materials Science, Changwon, 51508, South Korea
[b] Department of Naval Architecture and Ocean Engineering, Pusan National University, Busan, 46241, South Korea

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ABSTRACT

In recent years, various membrane-type liquefied natural gas (LNG) containment systems have been developed to improve the performance related to the insulation system and boil off rate (BOR). In this respect, investigations into the mechanical properties and fatigue strength of the welded joints in a new LNG cargo containment system (CCS) are required to ensure the structural integrity of LNG carriers. In this study, a series of fatigue tests were carried out for five different types of test specimens manufactured using Invar alloy and SUS 304L at ambient and cryogenic temperatures, respectively. It was clearly observed that the fatigue strength at cryogenic temperature is higher than that at ambient temperature. Finally, the FAT value and slope for the welded joints in the new LNG CCS were suggested based on the effective notch stress approach.

1. Introduction

The demand for liquefied natural gas (LNG) carriers as a means of transporting large quantities of LNG to satisfy strict environmental regulations has been recently increasing [1,2]. These LNG carriers, which operate under repeated fatigue loading in severe environments, are exposed to a risk of fatigue fracture. In particular, LNG is carried inside a cargo containment system (CCS) at cryogenic temperature, which is detrimental to the structural integrity. In this respect, a fatigue strength assessment for LNG CCS under a sloshing impact and thermal load is an important issue. During the operation period of an LNG carrier, an LNG inner tank is always maintained at a cryogenic temperature typically $-163\,^{\circ}C$ for liquefying the natural gas. Therefore, the use of low-temperature materials, which have high strength, ductility, and toughness in a cryogenic environment, is essential in the manufacturing of LNG CCS [3].

LNG CCS fabricated in recent years can be classified into two types of CCS, a membrane type and an independent type, according to differences in the process used to prevent a possible LNG leakage [4]. Mark-III and No. 96 developed by Gaztranspot & Technigaz (GTT) are common types of LNG CCS manufactured by shipyards [5]. Such membrane LNG CCS consists of an insulation system with two types of barriers, primary and secondary barriers, to reduce the possibility of an LNG leakage. The primary barrier manufactured using thin sheets of SUS 304L or Invar alloy is used to ensure the integrity of an LNG cargo tank. In addition, the secondary barrier, which has a function for preventing the leakage of LNG after a failure of the primary barrier, is produced using a thin composite material or Invar alloy for Mark-III and No. 96 types, respectively. According to the international maritime organization (IMO) standard, there are three different types of LNG CCS, Types A, B and C, considering the design pressure inside LNG tanks. Types A and B need a full or partial secondary barrier to prevent a leakage risk. In addition, Type C has no secondary barrier because it has a lower

* Corresponding author.
E-mail address: kimm@pusan.ac.kr (M.-H. Kim).

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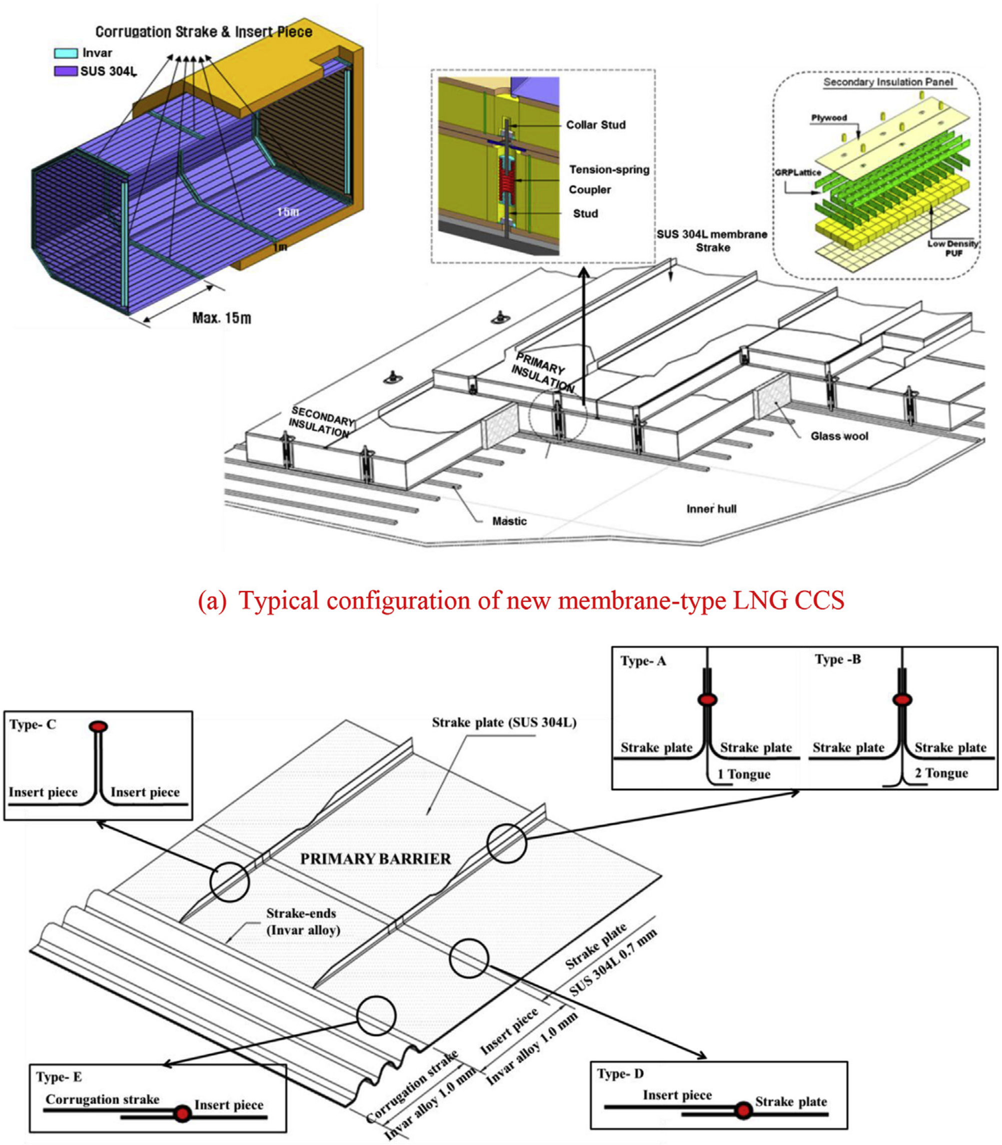

(a) Typical configuration of new membrane-type LNG CCS

(b) Welded joints in new membrane-type LNG CCS

Fig. 1. New membrane-type LNG CCS.

Table 1
Chemical composition of Invar alloy [9].

Material	Chemical composition (wt, %)						
Invar	Ni 36–36.5	C ≤0.04	Si ≤0.25	Mn ≤0.2	S ≤0.0015	P ≤0.008	Fe Bal.

Table 2
Chemical composition of SUS 304L [12].

Material	Chemical composition (wt, %)							
SUS 304L	Ni 8.63	C 0.016	Si 0.376	Mn 1.451	S 0.0251	P 0.028	Cu 0.5	Cr 18.2