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Reliability evaluation of a LNGC insulation system with a metallic secondary barrier

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ABSTRACT

This study examined the fatigue performance of a LNG (Liquefied Natural Gas) insulation system with a newly developed metallic secondary barrier used in Mark-III type LNG carriers. In particular, the conventional secondary barrier used in Mark-III type carries a risk of leakage and fatigue failure owing to the thermal and cyclic loads. In this respect, the secondary barrier requires superior tightness, high strength, and fatigue performance at cryogenic temperatures. To improve the tightness and strength, the metallic secondary barrier was constituted of two aluminum foils, 0.08 mm in thickness, covered with glass fabric. A series of fatigue tests for the newly secondary barrier was carried out at room and cryogenic temperatures. In addition, the durability of the new secondary barrier was confirmed by a comparison of the fatigue performance of the conventional secondary barrier with that of the new proposed secondary barrier.

1. Introduction

Recently, there has been a growing demand for Liquefied Natural Gas (LNG) worldwide because of the environment issues and the increase in shale gas production. LNG is an inexpensive and clean energy compared to other energy resources. These advantages have led to an increase in the consumption and demand for LNG. In this regard, the size and number of LNG carriers are also increasing because the LNG trade mainly relies on the sea transportation [1–4]. LNG is liquefied by refrigeration to −163 °C and above 10% atmosphere pressure before the cargo is loaded onto the LNG carriers. To ensure the safety and the integrity of LNG cargo tank under cryogenic conditions, a unique cargo containment system (CCS) is applied to the manufacture of LNG carriers [5,6].

According to the international maritime organization (IMO) code, a LNG cargo tanks are divided mainly into two tank types, such as independent tank and membrane tank, as shown in Fig. 1 [7]. The independent tanks do not form a part of the ship's hull and are not essential to the hull strength. As defined in the IMO code, there are three different types of independent tanks for LNG carriers, Type 'A', 'B' and 'C', depending on the design pressure. Types A and B require a full or partial secondary barrier, respectively, to prevent the potential release of LNG, whereas Type C has no secondary barrier because of the lower leakage risk [8]. Recently, the membrane types, which have space efficiency, light weight and low construction cost, have been used widely for the manufacture of LNG carriers [4] and [9]. There are two normal types of cargo containment systems, Mark-III type and No. 96 type, which were developed by Gaztransport & Technigaz (GTT). The cargo containment systems of the membrane type are composed of two different type barriers, primary barrier and secondary barrier, to prevent LNG leakage. The primary barrier is made mainly of thin plate SUS 304L or Invar alloy to secure the structural integrity of the LNG cargo tanks under cryogenic condition (−163 °C). Located between the primary barrier and ship's hull structure, the secondary barrier related to the low temperature region (−100 °C to −135 °C) is manufactured from a composite material and Invar alloy for Mark-III and No. 96 types, respectively. If there is an accident involving the leakage of gas in the primary barrier due to the thermal fatigue loading and sloshing impact, the secondary barrier should play a significant role in preventing the leakage of LNG.

All components in LNG CCS, such as the primary barrier, secondary barrier and insulation panel, undergo fatigue loading due to the loading-unloading of LNG cargo and hull girder bending. In this respect, the fatigue performance of the main components in LNG CCS is one of the key parameters for securing the safety of LNG carriers. Many studies presented the fatigue performance of low temperature materials and LNG insulation system used for LNG applications considering the cryogenic temperature. Oh

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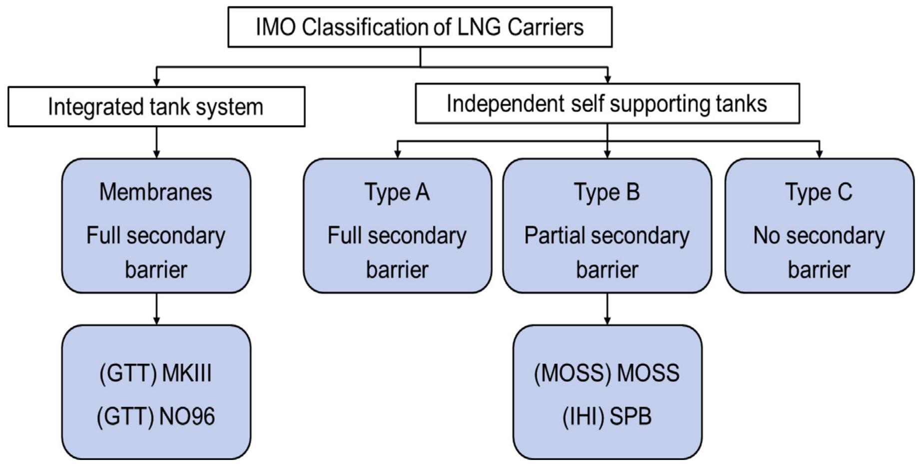

Fig. 1. Specifications of LNG carriers according to the IMO code [7].

et al. [10] reviewed and summarized the fatigue performance of Al 5083, 7% nickel steel, Invar alloy and SUS 304L, which are used in the LNG cargo tank. Kim et al. [9] carried out a series of compressive fatigue tests for Mark-III type LNG insulation system. They showed the fatigue performance of reinforced polyurethane foam (R-PUF) at the highly loaded regions around the mastic supports and the slit region on the R-PUF. They considered only the fatigue strength of the low temperature materials associated with the primary barrier and or R-PUF with mastic and did not consider the secondary barrier. Recently, Kim et al. [11] performed an assessment of the fatigue performance of a LNG insulation system, including the secondary barrier in Mark-III type. They demonstrated that the fatigue performance of high density foam is better than that of low density foam in a LNG insulation system.

Many researchers investigated the fatigue performance of the key assembly in a LNG insulation system as well as the mechanical properties of the low temperature materials used in the design of LNG carriers. On the other hand, there is no mention of an improvement related to the secondary barrier in a LNG insulation system in terms of the tightness and strength in recent studies. In this respect, this study proposes a new metallic secondary barrier (MSB) that can be applied to Mark-III type LNG CCS. In contrast to the general secondary barrier, the metallic secondary barrier used two aluminum foils, 0.08 mm in thickness, covering both sides with glass fabric. This metal composite barrier is a key function for improving the performance of the LNG insulation system. To evaluate the fatigue performance of the newly developed secondary barrier, a series of fatigue tests were performed on the new secondary barrier at room and cryogenic temperatures, respectively. In addition, the fatigue performance of the LNG insulation system with the newly secondary barrier was compared with that of the conventional secondary barrier.

2. Components of membrane type LNG CCS

As shown in Fig. 2, the Mark-III type membrane LNG carrier is configured in such a manner that LNG CCS maintains the functions of tightness and insulation under a range of loading conditions at cryogenic temperatures. In general, there are three different components comprising a cargo containment system in membrane type LNG carriers: the primary barrier, the secondary barrier and the insulation panel [6]. The primary and secondary barriers function as a protective wall to prevent gas leakage, and the insulation box/panel work to maintain the cryogenic environment within the

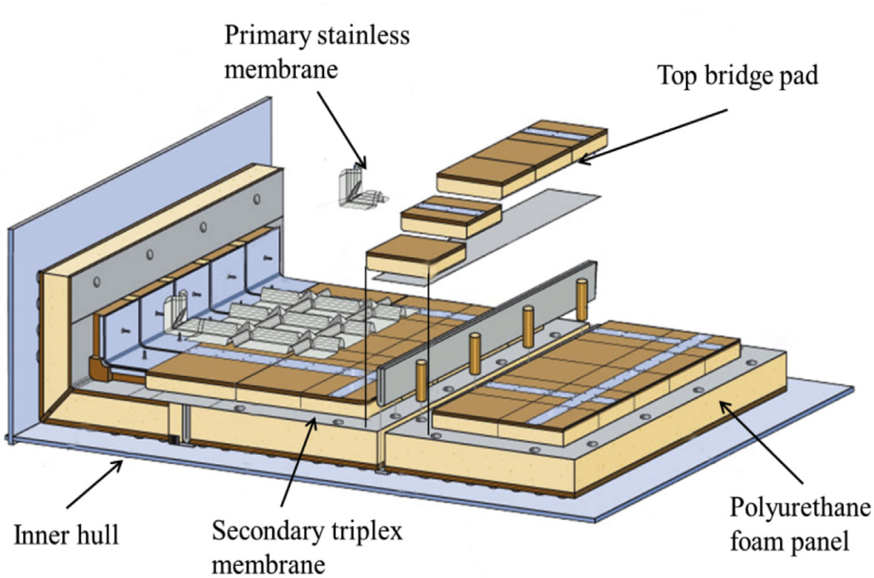

Fig. 2. Schematic diagram of Mark-III type LNG CCS.