Low-temperature Mechanical Behavior of Reinforced Polyurethane Foam

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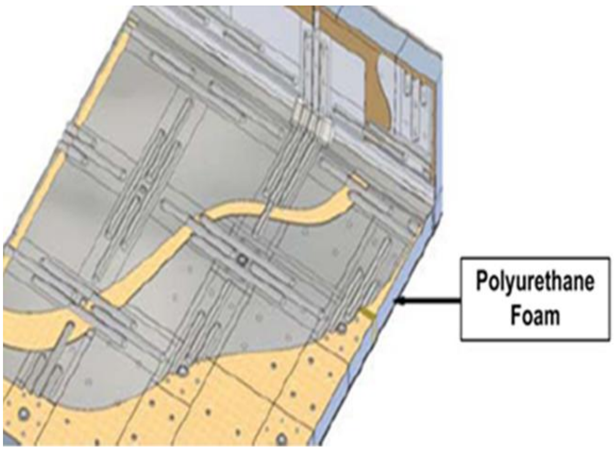
Abstract: - Polyurethane foam has been adopted not only as an insulating material in LNG storage tanks for LNG carriers but also in fuel tanks for LNG fueled ships owing to its high mechanical strength compared to other types of insulating materials. They are required to adopt an insulating material with high mechanical strength in order to withstand sloshing impact load because LNG storage and fuel tank systems are operated at cryogenic temperatures. Polyurethane foams which have closed cell structure are used in the applications especially liquefied natural gas storage system with superior mechanical characteristics at low-temperatures. In addition, carbon nanotubes are known for its excellent mechanical properties and low density. However, they cannot be adopted solely in liquefied natural gas storage system because carbon nanotubes are nanomaterials. In this study, reinforced polyurethane foams were fabricated by adopting carbon nanotube reinforcement material. Compression tests were then conducted in order to compare the mechanical properties of polyurethane foam composites at room and cryogenic temperatures. Finally, the cellular structure effects of additives were investigated.

Key-Words: - Polyurethane foam, reinforced insulation, low-temperature, mechanical strength

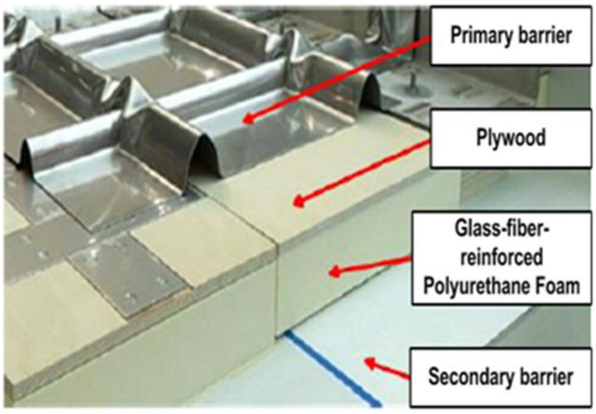
1 Introduction

Polymer foams have attracted a great attention in industries owing to its many strong points such as the low density, significant weight reduction, and low heat transfer characteristics [1-2]. For these reasons, they are commonly used in a wide range of applications such as cushion, thermal insulator, and core materials in sandwich composites. Polyurethane foams which have closed cell structure are used in the applications especially liquefied natural gas insulation system with low production costs and superior mechanical characteristics at low-temperature environments. Because liquefied natural gas is stored at -163℃, insulation material should endure severe environmental conditions such as sloshing and sloshing-based impact loads. Hence, mechanical characteristics and insulation performances are very important for LNG insulation material [3-4]. In the past decades, a number of investigations have been reported for improving the mechanical and thermal properties of materials by adding nanoparticles such as titanium dioxide, carbon nanofiber, nanoclay, graphite, graphene-oxide, silicon carbide, and silica aerogel [5-10]

In this study, reinforced polyurethane foam samples were fabricated using carbon nanotube to understand the effect of carbon nano materials on mechanical characteristics of polyurethane foam. In addition, samples were tested at ambient and low-temperature conditions. Finally, failure characteristics were investigated using macro and microscopic approach.



`(a)



(b)

Fig. 1 (a) Schematic and (b) photograph of the liquefied natural gas insulation system

2 Sample Preparation

In this study, carbon nanotube based polyurethane foams were fabricated. The carbon nanotubes used as fillers in carbon nanotube polyurethane foams were poured into polyol system and dispersed at 8,000Hz for 15 minutes by an ultrasonicator. To determine the effects of carbon nanotubes on the mechanical properties of polyurethane foams, samples having three different carbon nanotubes contents were prepared, 0.02, 0.1 and 0.3 wt.%. A water cooling system was adopted to prevent rapid temperature rising in the polyol system. Polyol system and isocyanate were mixed in the ratio of 1:1.1 and 5000RPM using a homogenizer. Each mixture was poured into a rectangular mold and foamed for 24 hours at room temperature. After the foaming process, carbon nanotube polyurethane foam samples were prepared in rectangular shapes (50×50×25mm3) following Korean Industrial Standards (KSMISO 844).

Fig. 2 Photographs of the foaming process of the polyurethane foam

3 Experiments

For performing cryogenic compression test, as indicated in Fig. 3, a cryogenic chamber was connected to a liquid nitrogen tank and was filled with nitrogen gas to maintain the cryogenic temperature. Test specimens were exposed to cryogenic temperature followed by cooling down for 30 min. Tests were performed at two different temperatures 20℃, and -163℃. To investigate the effects of carbon nanotubes on the mechanical properties of polyurethane foams, the only strain rate of 0.00167s-1 was considered as a representative strain rate. By referring to the ASTM standard, this value was determined by considering the test specimen thickness (ASTM D1621). In order to obtain reliable test results, five specimens were tested under each experimental condition.

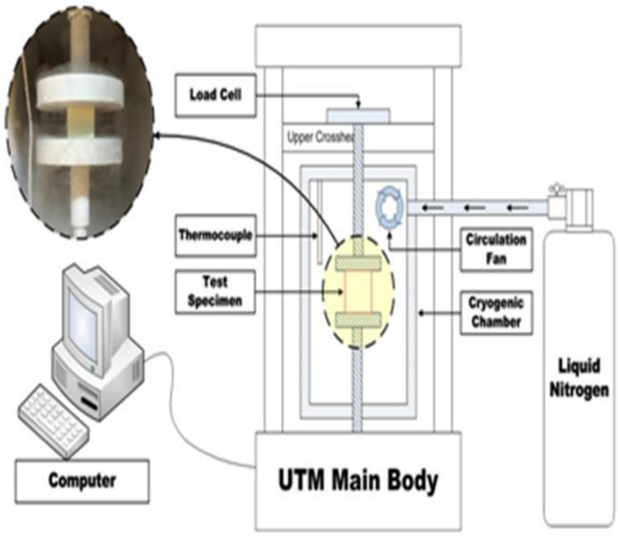


Fig. 3 Schematic diagram of the experimental apparatus for the low-temperature compression test

4 Results and Discussion

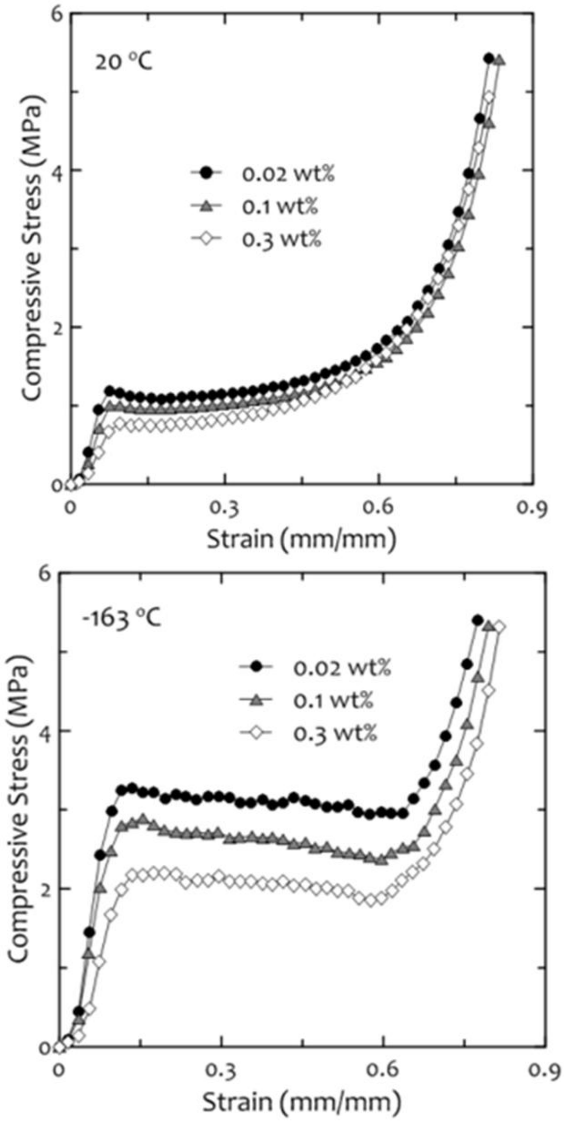


Fig.4 Temperature dependent compression test result of carbon nanotube polyurethane foam

Fig.4 shows compression test results for carbon nanotube polyurethane foams at different temperatures. At room temperature, all the carbon nanotube polyurethane foam samples exhibited similar compressive strength values. However, at the cryogenic temperature, the compressive strength of carbon nanotube polyurethane foam (0.02 wt.%) was 1.5 times higher than that of carbon nanotube polyurethane foam (0.3 wt.%). To cellular structure of the carbon nanotube polyurethane foam, field emission scanning electron microscope (FE-SEM) was used. As the amount of carbon nanotubes added to polyurethane foam increased, greater deviations in the cell size and the amount of holed cell walls were observed. Carbon nanotubes interrupted the foaming process of closed-cells, and fully closed cells were not obtained. This effect was intensified as the amount of carbon nanotubes was increased. Thus, as the amount of carbon nanotubes in the carbon nanotube polyurethane foam increased, the compressive strength was decreased, as shown in Fig.4.

5 Conclusion

In this study, effects of carbon nanotubes on the mechanical properties of polyurethane foams were examined by comparing the compressive strength values of carbon nanotube polyurethane foams. Compressive tests were performed for examining the mechanical properties of carbon nanotube polyurethane foam. Furthermore, FE-SEM images of carbon nanotube polyurethane foam were analyzed to understand decrease in compressive strength with increasing carbon nanotube amounts. The results of this study are summarized below.

- The 0.02 wt% of carbon nanotube addition showed an abrupt decrease in cell size of the samples.
- The compressive strength at -163℃ was higher than that of results at -90 and 20℃.
- The compressive strength at the amount of 0.02wt% of carbon nanotube was higher than that at 0, 0.1, and 0.3wt% of carbon nanotube

However, not only the compressive strength but also the insulating performance of carbon nanotube polyurethane foams should be investigated before adopting the material in LNG carrier cargo tanks.

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