A Study on Mechanical Behavior of Deformation Experienced Polyisocyanurate Foam under Compressive Load

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Abstract: - In this study, compression tests for the polyisocyanurate foam which is recognized as an insulation material for a storage tank of the liquefied natural gas (LNG) were performed to investigate a material behavior of the deformation experienced polymeric foam. A couple of engineering strain levels was selected as the test condition which controls the extent of the experienced deformation for the polyisocyanurate foam. After applying the initial deformation to the specimen, specimen recovered at the ambient temperature for over twenty-hours. And then, typical compression test was carried out for deformation-recovery experienced specimen. Deformation recovery ratio according to the various deformation levels and the mechanical behavior of deformation experienced foams were obtained experimentally in this study. The test results were analyzed based on the test condition, namely the initially experienced deformation level. Based on the test results, it was found that the polymeric foam can be considerably degraded when it experiences a certain level of deformation which is located at the densification region in the stress-strain relation curve of polymeric foam under compression.

Key-Words: - Polyisocyanurate foam, Deformation Recovery, Compression Test, Liquefied Natural Gas (LNG), Insulation material

1 Introduction

The demand for natural gas which is recognized as an environmental-friendly fuel for ships and offshore structure increases, and natural gas is commonly stored and transported in a liquid state at -163 ℃ cryogenic temperature to reduce a volume of gas for its storage. Ship's LNG insulation system is known as a key structure of LNG carrier and the LNG fueled ship. Therefore, assessment of structural integrity for LNG insulation system comprised of a metallic barrier for LNG leakage, non-metallic insulation material, and the bonding material is essential to robust design. In particular, for the insulation material, insulating performance has been recognized as the most important index for estimation and selection of the insulation system. However, sufficient mechanical strength is also required when insulation material undergoes various loads such as sloshing and vapor and liquids pressures.

MARK-III LNG insulation system has been widely used for LNG carrier, and polymeric foam such as reinforced polyurethane foam is mainly used in MARK-III system as the insulation material. Therefore, mechanical characteristic of polyurethane foam is previously reported based on the experimental investigation. Siegmann, et al. performed a material test for polyurethane foam to obtain mechanical properties under tension and compression [1]. Han, et al. carried out a study on the investigation to characteristics of mechanical behavior for the reinforced polyurethane foam under cyclic impact loading [2]. Polymeric foams consist of numerous cells, and it is recognized that this characteristic can effect on its mechanical behavior. Especially, under compression, polymeric foams partially recover from the deformation when applied load is eliminated [3]. However, literature related to recovery and material behavior of the polymeric foam which experience the deformation has not sufficiently reported yet. Considering loading histories of LNG carrier (cargo loading – transportation - unloading), it is essential that characteristics of the recovery and mechanical behavior for the deformation experienced polymeric foam are precisely investigated.

Therefore, in this study, extensive material compression tests for polyisocyanurate foam were carried out to investigate a material behavior of the deformation experienced polymeric foam. A couple

of engineering strain levels was chosen as the applied deformation which polyisocyanurate foam initially experiences and were applied to un-deformed test specimens during the 1st compression test. Compressive loads were eliminated after intended initial deformation was applied to the each specimen (1st compression test), and then, compressed specimens recovered from its deformation at ambient temperature in order to observe a characteristic of the deformation recovery according to extent of the initially experienced deformation. Finally, the 2nd compression test was carried out for deformation-recovery experienced specimens similar with the conventional compression test, and the mechanical behavior as well as stress-strain relation curve was obtained experimentally with regard to the amount of the initially experienced deformation during the 1st compression test.

2 Experimental Method and Specimen

In this study, experimental tests were prepared to investigate the mechanical behavior of poly-isocyanurate foam which experienced compression. A number of strain levels that were applied to the specimen as the initial deformation were selected considering three regions in constitutive relation of polymeric foam, namely region of linear elasticity, plateau and densification as shown in Fig. 1 [3,4].

As the test result, extents of the deformation recovery according to the applied strain levels during the 1st compression test were analyzed in this study. Fig. 2 shows the schematic definition of recovery ratio which is defined as a ratio between compressive deformation and amount of recovery.

Characteristics of material behavior for deformation experienced polyisocyanurate foam according to the extent of the initial deformation were investigated based on analyzing the compressive stress-strain relation.

In this study, polyisocyanurate foam with 42kg/m3 mass density was selected for the compression test and brick type specimen was fabricated in size of 50(B) x 50(W) x 50(H) mm [5]. Compression test was carried out regarding the foaming direction, and the specimen was compressed between upper and lower stainless jigs during the test.

Fig. 3 shows the dimension of test specimen and test apparatus. Universal testing machine for the composite material (model: KSU-5M) was applied to perform the compression test. During the test, compressive strain of the specimen was measured by a laser extensometer in a right side in the Fig. 3

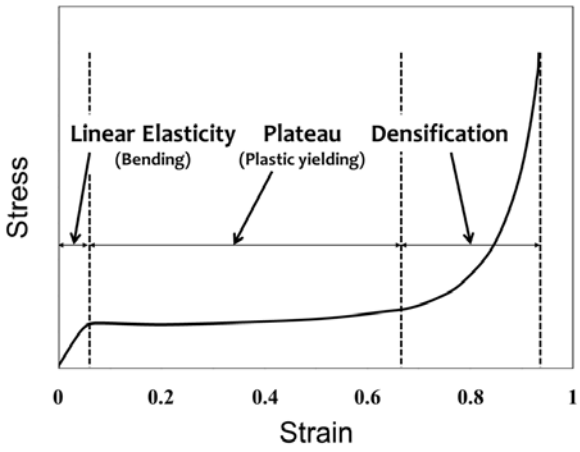

Fig. 1 Typical stress-strain relation of polymeric foam under compressive loading

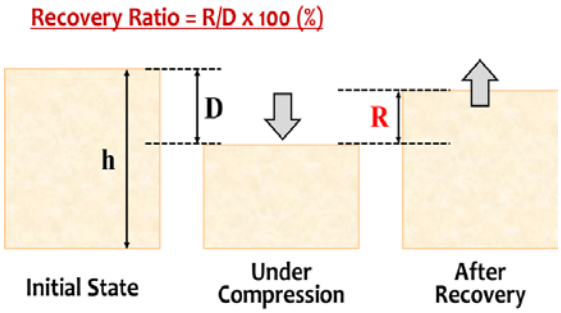

Fig. 2 Schematic definition of recovery ratio

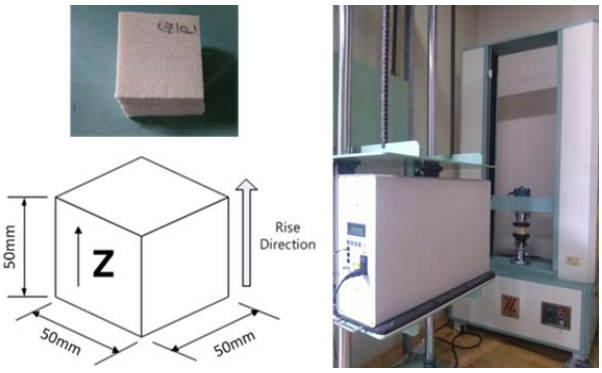

Fig. 3 Test specimen and test apparatus

3 Experimental Results and Discussion

As the representative result of the 2nd compression test, compressive stress-strain relation of poly-isocyanurate foam according to the initially applied strain level is presented in Fig. 4. As shown in Fig. 4, although quantitative extents of the plateau stress were similar according to the initially applied strain levels, points of reaching the plateau stress were moved backward in accordance with increase of applied strain level. It means that some specimens

that reveal a delayed reaching the plateau stress in the Fig. 4 were degraded by the initially experienced deformation. As similar with the characteristics on the mechanical behavior, regarding the amount of deformation recovery, it was revealed that an increase of the experienced deformation level for polyisocyanurate foam decreases the recovery ratio of it. In particular, in the case of that applied strain level is in the densification region, recovery ratio is substantially decreased different from other cases. Considering cellular structure of the poly-isocyanurate foam, these results were induced by that the cells yielded during the 1st compression test didn't recover after applied loading was eliminated, and foam partially recovers by uncollapsed cells. Therefore, during the 2nd compression test, uncollpased cells dominantly sustained the loading before the reaching the plateau stress (uncollapsed cells were also yielded).

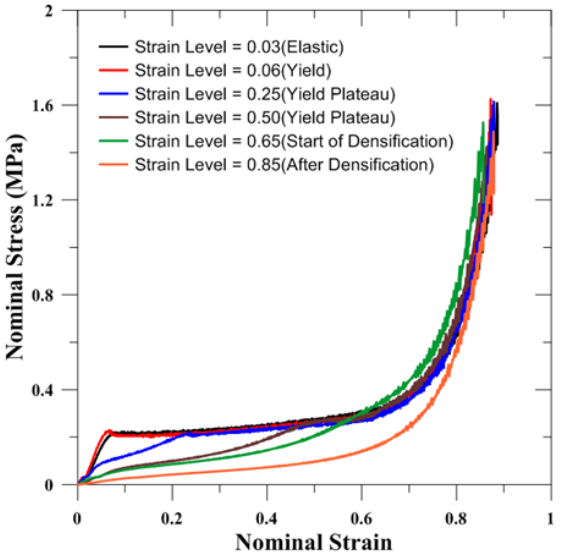

Fig. 4 Stress-strain relations after initial deformation and recovery of polyisocyanurate foam

4 Conclusion

In this study, characteristics of mechanical behavior for deformation experienced polyisocyanurate foam which is known as the polymeric foam and used as the insulation material were investigated based on the experimental observation. For the experiments, brick type specimen was deformed and recovered by intended test condition, and typical compression test was carried out using recovered specimen. It was found that the polyisocyanurate foam was degraded when it experiences a certain level of deformation which is located at the densification region in the stress-strain relation curve of polymeric foam under compression. Amount of the deformation recovery decreased in the specimens that experienced the compressive strains over 0.6. As well as the recovery, degradation of deformation experienced foam could be found in the stress-strain relation curve of the 2nd compression test.

Based on test results, the experimental backgrounds that are required to assess the feasibility of polymeric foams including polyisocyanurate foam to the insulation system of LNG carriers and LNG fueled ships were provided in this study.

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