A Study on Effect of Immersion on the Mechanical Characteristics of Polyurethane Foam

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Abstract: - Polyurethane foam composites is widely used in insulation industry. Since the material is exposed the cryogenic environment for a certain period of time, it is essential to estimate the mechanical properties of the material. In this study, compression tests for the polyurethane foam which is recognized as the insulation material for the storage tank of the liquefied natural gas (LNG) were carried out for investigation of the material characteristic of mechanical behavior. To investigate the effect of immersion of cryogenic liquid on polyurethane foam according to immersion time, each compressive test was conductive at five times for reliability, and the test results were obtained by eliminating the maximum and minimum values to reduce experimental error. As a results, Deformation recovery ratio according to the various initial deformation levels were estimated and the mechanical behavior of foams that are experienced compressive deformation was also obtained experimentally. The test results were analyzed based on the conditions of initially applied strain level and engineering strain rate. In addition, the microstructure of the test specimen after the test was analyzed to investigate the relationship between mechanical behavior and immersion time.

Key-Words: - Liquefied natural gas, Leakage, Immersion, Polyurethane foam, Deformation recovery, Compression test

1 Introduction

It is well known that International Maritime Organization (IMO) regulated the emissions of Sulfur Oxides (SOx) and Nitrogen Oxides (NOx) in vessels and offshore fields after 2015/16 according to “Worldwide Sulphur Limitation for Marine Fuels” regulation. In this regulation, the sulfur contents should be limited to 0.1% weight (% m/m) from 2015 onwards in Sulphur emission control areas and 80% of NOx reduction is mandatory in these locations by 2016. For this reason, it is required to switch to cleaner fuels such as Liquefied Natural Gas (LNG), and to install sulfur scrubbers and exhaust gas recirculation, etc.

Since environmental regulations have been strengthened, demands for the LNG are expected to increase sharply because the matter of emission of sulfur and reduction of nitrogen oxides can be solved and the Energy Efficiency Design Index (EEDI) index associated with Carbon dioxide (CO2) can be reduced by 20 percent by applying LNG fuel supply system to the ships [1]. Accordingly, the LNG is extensively and sharply adopted as an alternative fuel in marine industry and LNG vessels have specialized cryogenic handling equipment and cargo containment systems for carrying LNG.

The insulation material used in Mark III-type LNG cargo containment system and independent- type LNG fuel tank structure is polyurethane foam (PUF). Polyurethane foam composites is widely used in insulation industry because of low thermal conductivity, good mechanical properties, light weight and low water absorption/permeability etc. [2]. If the LNG leakage caused by the damage of cargo containment system or independent type LNG fuel tank, polyurethane foam is exposed to the cryogenic liquid. When this happens, since the material is exposed the cryogenic environment for a certain period of time, it is essential to estimate the mechanical properties of the material.

In the past, compressive test of glass fiber reinforced polyurethane foam at different strain rates was conducted [3] and Compressive test of polymeric foams for ships and offshore structures under the low temperature was conducted [4]. But no studies have been conducted on the investigation of mechanical behavior for the material exposed in the cryogenic liquid.

In addition, polyurethane foam does not change in accordance with different temperature range [5, 6], In other words, it hold the significant size stability. Immersion time can affect the mechanical characteristics of the PUF because it changes the microstructure of the polymeric foam.

In this study, to investigate the effect of immersion of cryogenic liquid on polyurethane foam according to immersion time. As a results, the compression test was carried out using universal testing machine at cryogenic temperature and analysis the microstructure of the test specimen after the test to investigate the relationship between mechanical behavior and immersion time.

2 Test Preparation

In this study, the characteristics of microstructure and mechanical behavior were investigated by performing immersion of cryogenic liquid on polyurethane foam. Compression tests of the PUFs were carried out in accordance with Korean standard KS M 3809 [7]. And fig. 1 shows the test specimens for the cryogenic compression test. The specimens were formed into rectangular cubes with dimensions of 50mm x 50mm x 25mm.

The compressive stress-strain curve of general porous foam material as shown in Fig. 2 was considered in order to reflect the hysteresis of the load element. As shown in the Fig. 2, compressive stress–strain curves of porous foam material simply consist of three regions: a linear elasticity region, a plateau region, and a densification region.

After initial deformation was applied by performing the first compressive test, sufficient deformation recovery was advanced. Subsequently, immersion was carried out to perform the second compressive test. Also, the test scenarios for the cryogenic compressive test at three strain level of first test(0.05,0.25,0.5) and four prior condition of second test(1,2,4,8 hour immersion) under the quasi-static strain rate of 10^{-2}/s were composed. Each compressive test was conductive at five times for reliability, and the test results were obtained by eliminating the maximum and minimum values to reduce experimental error.

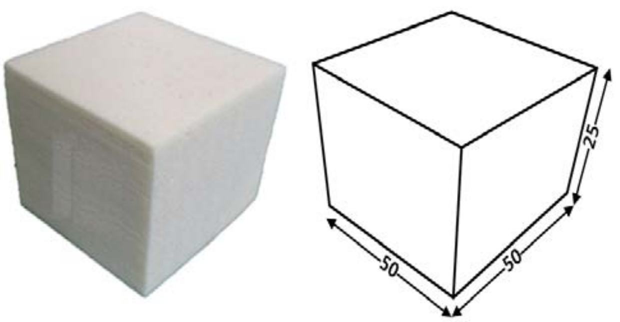


Fig. 1 Photographs of Polyurethane foam specimen

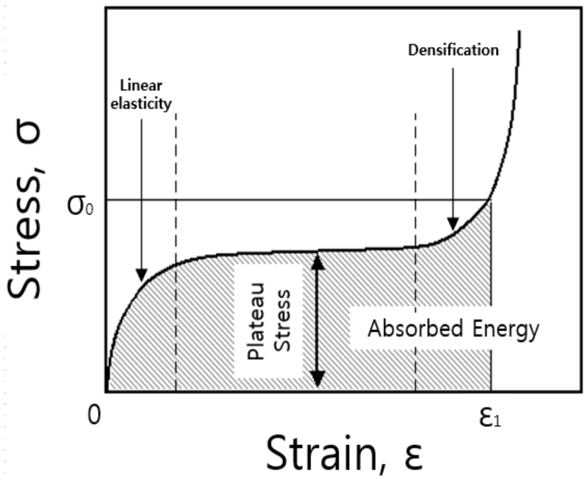
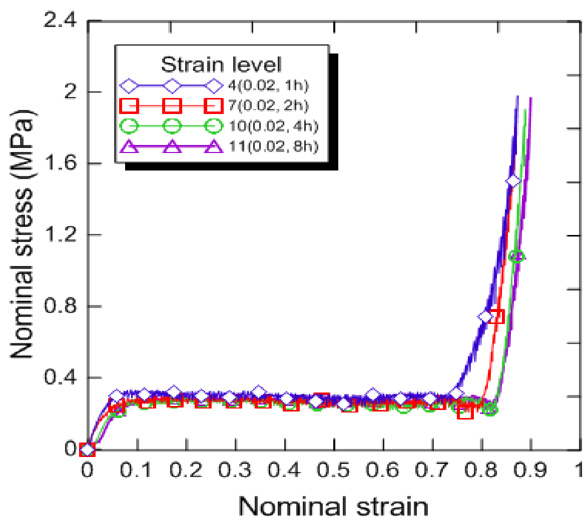


Fig. 2 Compressive stress- strain curve of porous foam material

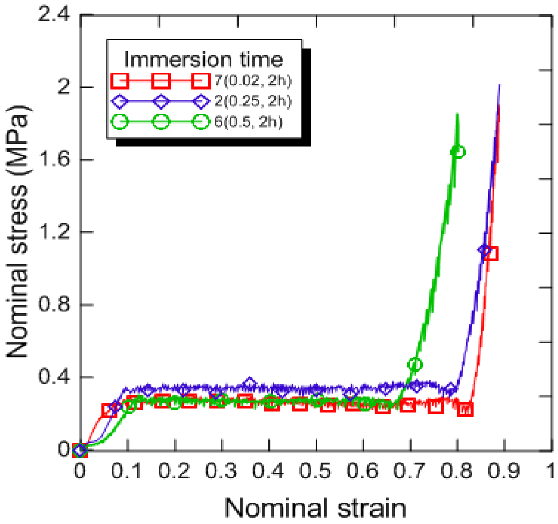
3 Test Results and Discussion

In this study, the stress-strain relationship according to initial strain was analyzed through the series of experiments, and the stress-strain relationship according to immersion time was investigated. In addition, the microstructure of test specimen after the test was observed.

Fig. 3 (a) shows the immersion time-dependent stress-strain relationships of the tested polyurethane foams at strain rates of 10^{-2}/s. the results of all tests show that the stress values are similar in the plateau region, and the slope of the elastic modulus does not show a large difference regardless of the initial strain. And, Fig. 3 (b) shows the strain level-dependent stress-strain relationships of the tested polyurethane foams at strain rate of 10^{-2}/s. in all tests, the longer the time of immersion, the more delayed the start of densification region.



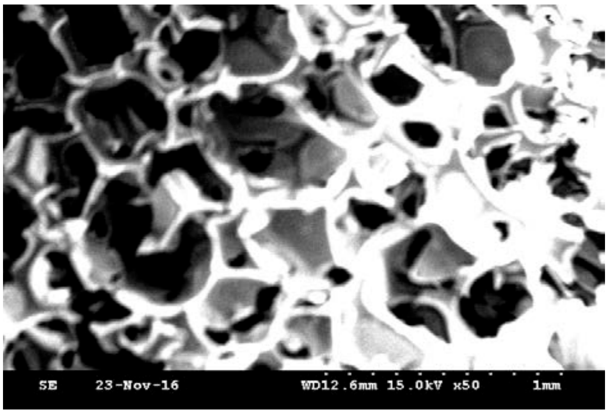
(a) Compression test results at different immersion time



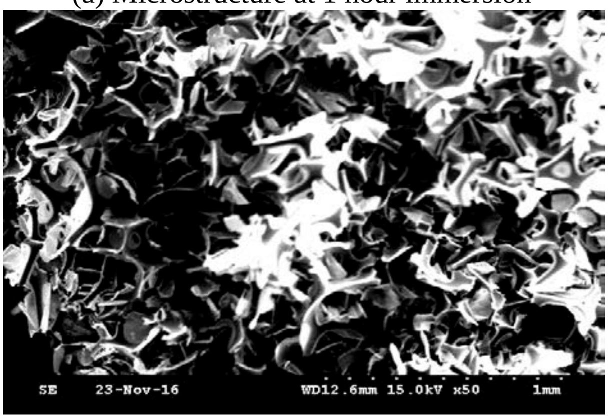
(b) Compression test results at different strain level

Fig. 3 Compression test results of Polyurethane foams

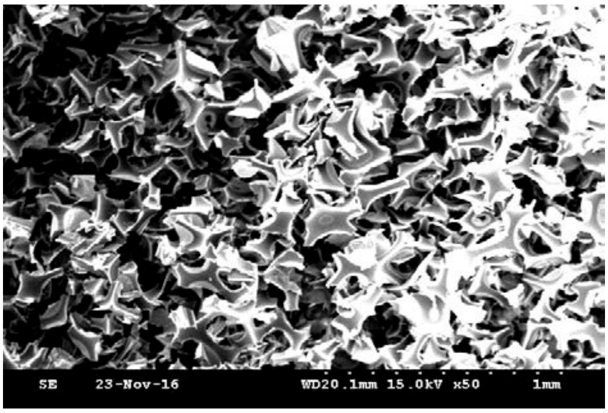
Fig. 4 presents scanning electron microscopy (SEM) images of PUF at 1μm scale, after the compression test, with respect to the loading direction. The foam structure of the PUF specimens tested at different immersion time were observed. As a result, as the immersion time increases, the structure of the specimen after the test is more broken.



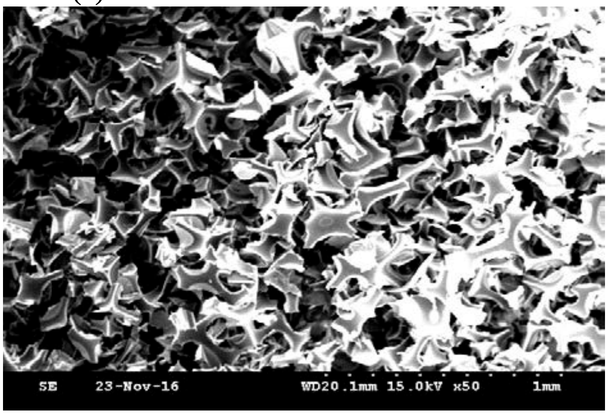
(a) Microstructure at 1 hour immersion



(b) Microstructure at 2 hour immersion



(c) Microstructure at 4 hour immersion



(d) Microstructure at 8 hour immersion

Fig. 4 Microstructure of polyurethane foams after the test at different immersion time

4 Conclusion

In this study, a series of tests were conducted using universal testing machine at cryogenic environment to investigate the effect of immersion of cryogenic liquid on polyurethane foam according to immersion time. And, the microstructure of the test specimen after the test was analyzed to investigate the relationship between mechanical behavior and immersion time.

As a results, the stress-strain relationship according to initial strain and immersion time was investigated through the series of experiments.

The results of all tests show that the stress values are similar in the plateau region, and the slope of the elastic modulus does not show a large difference regardless of the initial strain. Also in all tests, the longer the time of immersion, the more delayed the start of densification region.

As a result of scanning electron microscopy (SEM) images of PUF at 1μm scale, after the compression test, with respect to the loading direction. The foam structure of the PUF specimens tested at different immersion time were observed. As the immersion time increases, the structure of the specimen after the test is more broken.

Therefore, in the future study, the influence on bending strength of progressive damage of the polyurethane foam will be examined. Also, the additional fusion studies of polyurethane foam will be carried out to ensure the strength of polyurethane foam based on the results of this study.

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