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Development of Hydraulic Compressor for Hydrogen Station

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수소스테이션용 유압 압축기 개발

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ABSTRACT

Major producers have already built compressors since World War I and have been monopolizing all domestic and overseas markets based on the accumulated technology, and the dependency of the manufacturers over the entire industry is deepening. Therefore, it is expected that the technological gap with developed countries will be larger without development of the related technology. Therefore, it is necessary to develop a unique technology for a new type of high efficiency compression system. In this study, we present localization of Hydraulic Compressor which can meet the technical trends such as cost reduction, efficiency improvement, environmental friendliness, wide operating range, low capacity / high capacity compatibility, size reduction, easy operation and easy maintenance.

Key Words : Hydrogen Station(수소충전소), Hydraulic Pressure(유압), Compressor(압축기)

1. Introduction

South Korea is currently striving to accelerate the growth of the domestic green vehicles market, restructure the automotive industry around a high value-added one, and develop new and renewable energy technologies. To satisfy these objectives, competitive green vehicles are being developed to promote consumer sales, low-cost/high-efficiency charging infrastructure is being expanded, the use of green vehicles is being increased, and more hydrogen charging stations are being built[1].

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Compressors, storage tanks, and dispensers account for 54 to 86% of the construction costs for hydrogen charging stations. These components mostly depend on imports from other countries. However, the manufacture of some of these components is undergoing localization. At this stage their reliability cannot be secured due to lack of verification.

As a resource poor country, South Korea is directly affected by the depletion of fossil fuel resources. The use of compressors is necessary to obtain gases from the natural environment and utilize them for energy sources (as a next step after the development of solar heat and wind power) [2,3].

Major manufacturers in other countries are monopolizing the Korean and overseas markets based on compressor technologies that have been developed since World War I. The industry-wide reliance on these companies is deepening. South Korea's technology gap with advanced countries will only increase unless highly efficient compression systems are developed independently.

This study aims to perform localization development for a hydraulic compressor that can meet the following requirements: cost reduction, efficiency improvement, eco-friendliness, broad operation range, compatibility for low- and high-capacities, size reduction, simple operation, and easy maintenance.

2. Selection of Appropriate Materials and Properties Test

2.1 Selection of Appropriate Materials

The compressors in hydrogen stations are used to compress and store hydrogen in storage containers or dispensers connected to them. The hydrogen flows inside a cylinder through the inlet and is then compressed with a piston. During the compression process, the hydrogen decreases in volume and forms a high-density gas. As a reaction to this, an environment of high pressure and temperature is formed inside the compressor with cylinders and pistons. Hence, the internal working conditions of the cylinder were considered when selecting the material for the compressor developed in this study. As a result, two types of materials were selected,. SCM440 and SUS316, which are chromium-molybdenum steel and austenitic stainless steel, respectively.

2.2 Properties Tests

First, a tensile test was carried out on the SCM440 to be applied to the cylinder and piston parts. A tensile tester was used that can apply a load of up to 300kN and a tensile speed of 0.02 to 6000 mm/s. To measure the strain, images were taken with a high-speed camera and the correlations of the digital images were analyzed. For the specimens, dog-bone types fabricated by wire cutting were used to concentrate cracks at the central part. Five specimens were measured at a strain rate of 0.01/s. The following results were obtained for the specimens: a tensile strength of 1000 MPa, a modulus of elasticity of 204 GPa, a Poisson's ratio of 0.28, and a tensile elongation of 13%(see Fig. 4).

Next, a tensile test was carried out for SUS316. The results were a tensile strength of 520 MPa, a modulus of elasticity of 194 GPa, a Poisson's ratio of 0.33, and a tensile elongation of 40%(see Fig. 6).

Fig. 1 Mechanism of compressor for hydrogen station

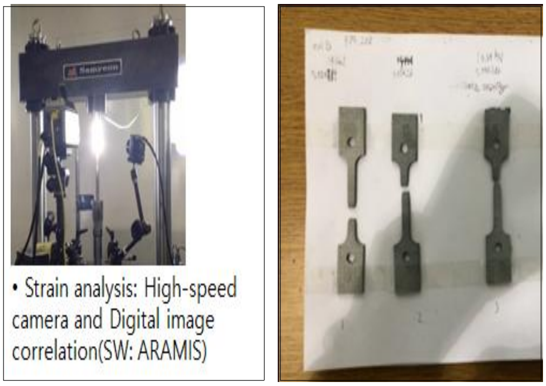


Fig. 2 Machine for tensile test

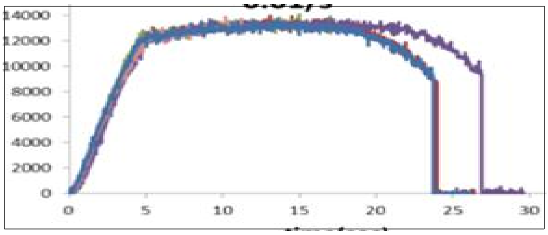


Fig. 3 Tensile specimen for SCM440

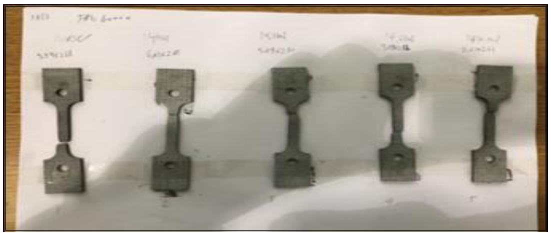


Fig. 4 Tensile test result of SCM440

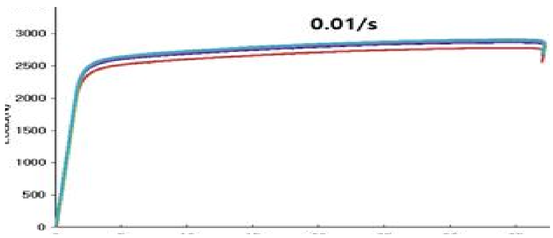


Fig. 5 Tensile specimen for SUS316

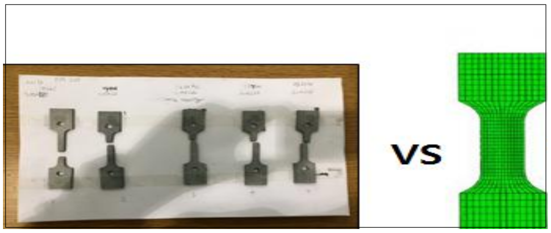


Fig. 6 Tensile test result of SUS316

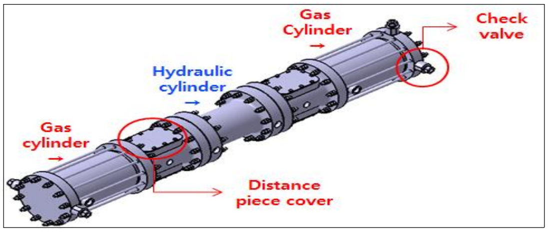
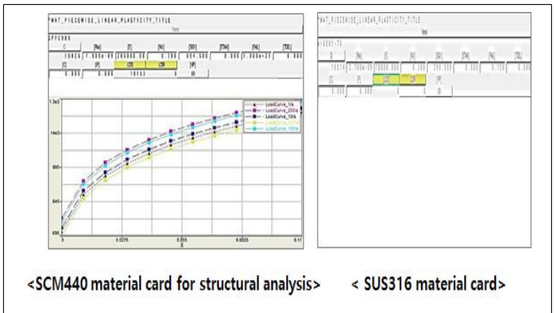
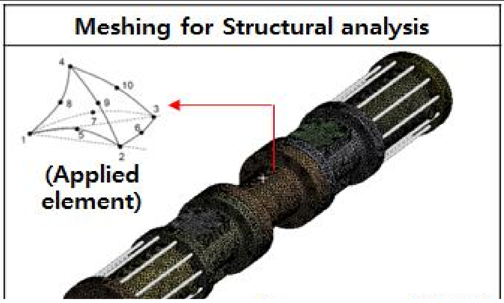


Fig. 7 Correlation result of tensile test vs simulation



<SCM440 material card for structural analysis>



<SUS316 material card>

Fig. 8 material card for structural analysis

2.3 Establishment of Properties for Structural Analysis

The same shapes as the specimens used for the properties tests were modeled. A correlation analysis was performed by comparing the modeling results with the properties measured in the tests. The theoretical formulation to calculate each element during structural analysis was selected, and the tensile test results were converted from nominal stress and strain to true stress and strain. Then while applying them to the structural analysis, the parts mismatched with the test results were modified. After this correlation analysis, the test and structural analyses obtained very similar load-displacement curves (see Fig. 7). Sufficient reliability in the measurements of the properties for structural analysis werewas obtained. Finally, the property cards for structural analysis were established(see Fig. 8).

3. Design and Analysis of a Hydrogen Compressor

3.1 Design of a Hydrogen Compressor

Advanced countries (such as the U.S., Japan, and Germany) use hydrogen compressors that are capable of compression at ~50–300 Nm3/hr to 45 MPa at the minimum and up to a maximum ultra-high pressure of 70–100 MPa.

This high-pressure hydrogen compressor maximizes power efficiency by hydraulically moving the piston inside the cylinder without rotational drives(such as crank shaft, piston rod, and impeller), which are applied for compressing the gas in general 30 MPa compressors. This study constructed a system that compresses and discharges hydrogen using a cylinder and piston with no rotational driver. A two-step compression structure was applied in which a 30 MPa pressure is applied in stage 1 and then a 50 MPa pressure is applied in stage 2. The modules are interconnected with highly rigid stud bolts(see Fig. 9).

3.2 Analysis of the Hydrogen Compressor

The hydrogen compressor cannot use a hexagonal element that has a high degree of freedom for strain because it has an asymmetric shape due to the piece cover. To improve the deficiencies of tetra elements (which are likely to generate high stress and stress resistance), the quadratic solid element to which a quadratic equation was applied among the elements in ANSYS was used[4,5].

The bolts and nuts for connecting the modules are highly rigid materials and can be replaced with 1-D shaped beam elements. Consequently, the bolts were simplified to rigid line shapes to shorten the calculation time during structural analysis (see Fig. 10). Under the assumption that every module is firmly bound by stud bolts, a bond adhesion condition that disables slipping and separation was applied to the contact surfaces between modules.

In addition, a friction contact condition that allows free sliding and separation between the parts was applied [6~8] under the assumption that sliding motions can occur between the cylinder and the inner parts. A default coefficient of friction of 0.2 was applied (see Fig. 11). A pressure of 50 MPa was applied to the liner and inner wall of the hydraulic cylinder that is in direct contact with the piston inside the cylinder.

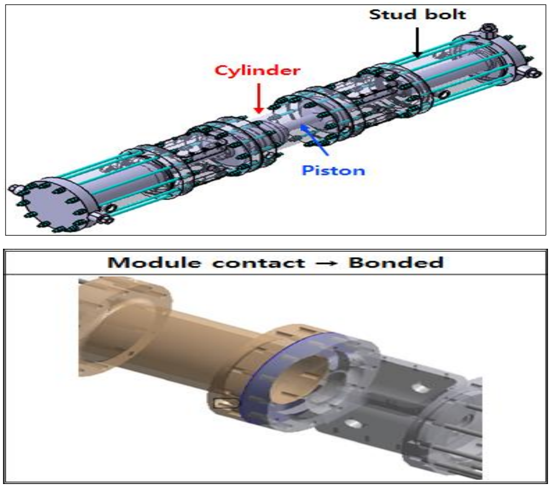


Fig. 9 Basic mechanism of hydraulic compressor

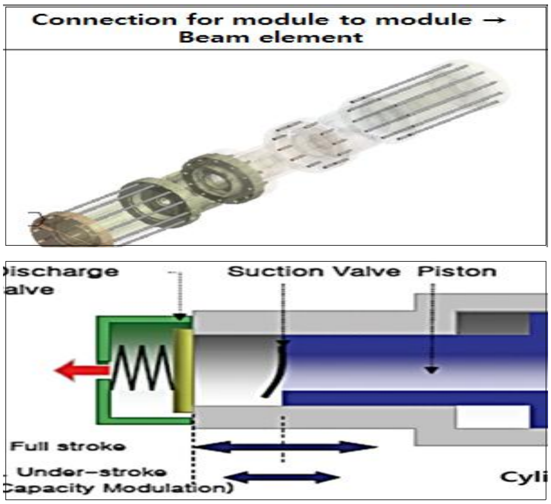


Fig. 10 FE model of hydraulic compressor

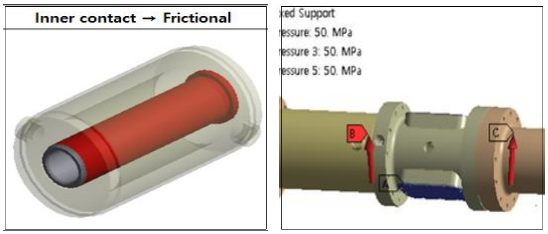


Fig. 11 Contact model of hydraulic compressor

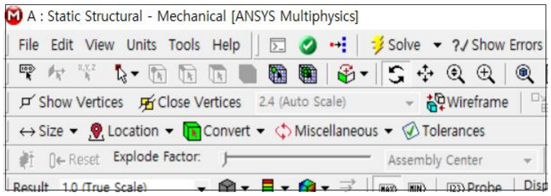


Fig. 12 Boundary condition of hydraulic compressor

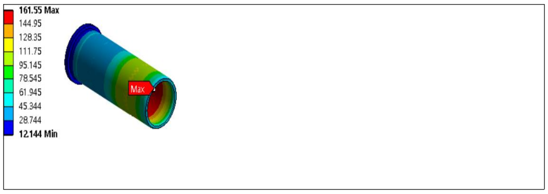


Fig. 13 Stress contour of full model under SCM440, Pressure 50MPa

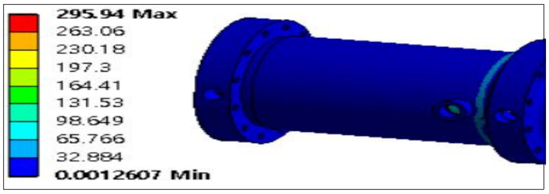


Fig. 14 Stress contour of liner under SCM440, Pressure 50 MPa

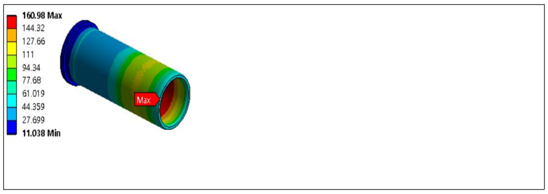


Fig. 15 Stress contour of full model under SUS316, Pressure 50 MPa

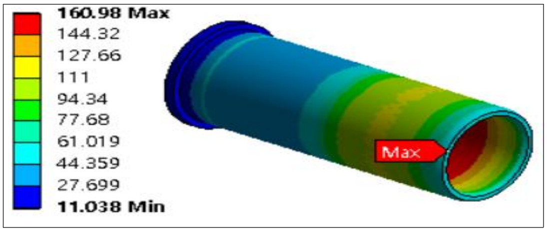


Fig. 16 Stress contour of liner under SUS316, Pressure 50MPa

Furthermore, the total degree of freedom was fixed for the outside of the distance cover that has a large plate shape, considering the characteristic of the product which is fixed to a surface plate or floor (see Fig. 12).

The performance of the developed model was examined for two materials (SCM440 and SUS316), which were selected in the appropriate material selection step in Section 2.1.

When SCM440 was used, the maximum stress occurred in the hydraulic cylinder (see Fig. 13). This was 30% the level of the tensile strength of the material (confirming a sufficient safety margin). Furthermore, a very low stress of 162 MPa occurred in the liner (which is in direct contact with the piston) due to the expansion suppression effect caused by the external cylinder (see Fig. 14).

When SUS316 was used, a stress similar to that of SCM440 occurred (see Fig. 15). However, due to the low tensile strength of SUS316 (56% the level of that of SCM440) the safety margin was lower than for SCM440. The stress of the liner of SUS316 was similar to that of SCM440, as shown in Fig. 16.

Finally, SCM440 was selected as the material for hydraulic compressors because it can suppress expansion due to its high tensile strength and low elongation.

5. Conclusion

A new design for a hydraulic high-pressure compressor has been presented. The compressor is capable of compressing hydrogen up to 50 MPa. The pressure is obtained by directly operating a piston with a hydraulic pressure with no rotational drivers (such as a crankshaft). This product was designed with a two-step compression structure to generate a maximum compressive force of 50 MPa. SCM440 was selected as the material. It showed excellent mechanical performance in the structural analysis among the materials appropriate for a high temperature and pressure environment. In future work, we plan to fabricate a prototype of this product on which to carry out performance tests. Subsequently, the product may be used as a reduced prototype for developing a 100 MPa ultra-high-pressure compressor (after matching it with structural analysis results).

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