SIMULATION STUDY ON THE SUCTION PERFORMANCE OF A RUBBER SEAL UNDER MARIN CONDITIONS

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ABSTRACT

The automatic mooring system is an unmanned and automated solution designed to securely anchor ships to quay walls. A key component of this system is the vacuum suction pad, which utilizes a rubber seal to maintain vacuum contact with the ship's hull. This study investigates the mechanical behavior of rubber seals in marine environments to identify an optimal material for durability and adhesion. Finite element analysis was conducted using material parameters derived from the strain energy density function, informed by mechanical properties tests including uniaxial and biaxial tensile tests. Through experiments that assessed the rubber’s property variations with temperature and ozone exposure, we analyzed the seal’s contact state, reaction force, maximum stress, and strain. Based on these findings, we propose an optimal material to prevent detachment of the rubber seal from the ship surface under marine conditions.

KEY WORDS

Rubber seal, Suction performance, Finite element analysis, Marine conditions

1. INTRODUCTION

Traditional mooring methods, relying on manual systems such as mooring lines and winches, pose challenges in terms of safety, extended operation times, and associated costs. In response, automated mooring solutions aim to enhance safety and efficiency in the mooring process. Significant research and commercialization of automated mooring devices—such as vacuum and magnetic pads and hydraulic tension systems—have been pursued primarily in advanced countries. However, in Korea, development is still at an early stage, resulting in a limited understanding and application of such systems.

An automatic mooring system typically consists of a detachable vacuum suction pad coupled with a hydraulic drive mechanism, coordinated via a multi-control system to secure the vessel stably to the quay.[1] The vacuum suction pad’s rubber seal is the initial contact point with the ship, necessitating a material capable of maintaining a reliable vacuum and providing shock absorption. Due to continuous exposure to marine environments, the design of the rubber seal must consider environmental factors like temperature and ozone. This study investigates the behavior of rubber seals in marine environments, specifically focusing on the effects of temperature and ozone exposure, to select optimal materials for use in automatic mooring systems. Mechanical property changes in rubber materials due to environmental factors were measured through controlled experiments. Using the obtained material properties, finite element analysis (FEA) was conducted to simulate the performance of the rubber seal under operational conditions. In these simulations, a vacuum-sealed rubber seal was attached to a steel plate, and its contact state, stress distribution, and strain were analyzed by varying the direction of the applied load. These results provide insights into selecting rubber materials that maintain adhesion and durability in marine applications.

2. RUBBER MATERIAL TEST

2.1 Rubber materials

Common marine-grade rubbers include natural rubber (NR) and chloroprene rubber (CR). Natural rubber offers advantages in workability, elasticity, and flexibility but is less resistant to heat and environmental factors. Chloroprene rubber, in contrast, exhibits strong adhesive properties and superior ozone resistance, making it suitable for marine applications.[2] In this study, natural rubber (NR), chloroprene rubber (CR), and a blended rubber with a 4:6 ratio of CR to NR were selected as the primary materials for analysis.

Table 1: Chemical compositions of rubber materials

Ingredients	CR	Blend CR:NR =4:6	NR
Polymer	53.5	51.9	52.7
Carbon black	21.4	26.0	26.3
Fillers & Others	22.2	17.9	17.2
Vulcanizing agent	2.9	4.2	3.8
Total	100	100	100

2.2 Mechanical property tests of rubber material

In this study, temperature, a key variable in marine environments, was set to three levels: -20°C, 23°C, and 60°C, reflecting typical port conditions. The ozone exposure conditions were defined based on marine environment guidelines for rubber components, with an ozone concentration of 50 pphm, a temperature of 40°C, and a pre-strain of 20%, applied over a period of 72 hours. Mechanical property tests were conducted under each temperature condition, either by utilizing an environmental chamber or at room temperature following the 72-hour ozone exposure period. The rubber specimens were prepared according to ISO 37 which uses the dumbbell type 1A. These settings were chosen to simulate realistic conditions and evaluate the durability and performance of rubber materials in maritime applications.

3. FINITE ELEMENT ANALYSIS

Material constants were obtained from the stress-strain (s-s) curves generated under various environmental conditions through mechanical property testing. A 3D quarter-symmetry model of the rubber seal and base plate was created to analyze the seal's deformation and contact state under applied vacuum pressure. Specifically, a vacuum pressure of -80 kPa was applied to evaluate the deformation and contact quality of the rubber seal. Additionally, the model was subjected to loads in the x and y directions on the base plate to assess the behavior of the seal under different loading conditions and to verify its sealing integrity.

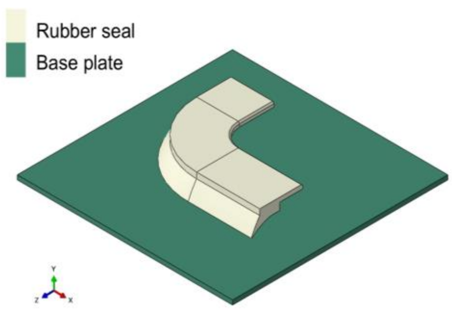

Fig.l: 3D structures of finite element model

4. CONCLUSION

The rubber seal of the vacuum suction pad in an automatic mooring system is continuously exposed to harsh marine environments, requiring a material with strong resistance to temperature variations, ozone exposure, and other environmental factors. This study investigated the mechanical behavior of a CR/NR blended rubber under different temperature and ozone conditions, utilizing finite element analysis to compare the seal's performance. Future research will focus on combined temperature and ozone exposure experiments, as well as assessments of seawater resistance, to identify materials that are optimally suited for long-term durability in marine applications.

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