Research on a sealing solution using O-rings in the design and manufacture of underwater observation devices

Tran Xuan Tien[1], Le Van Hoang[2*]

[1]Academy of Military Science and Technology, 17 Hoang Sam, Cau Giay, Ha Noi, Vietnam;
[2]Institute of Military Equipment, Academy of Military Science and Technology, 17 Hoang Sam, Cau Giay, Ha Noi, Vietnam.
[*]Corresponding author: lehoang103@gmail.com

Received 1 Mar. 2025; Revised 23 Apr. 2025; Accepted 2 Jun. 2025; Published 25 Jun. 2025.
DOI: https://doi.org/10.54939/1859-1043.j.mst.104.2025.122-129

ABSTRACT

This paper presents a comprehensive study on the design of pressure-resistant seals for underwater observation devices operating in seawater environments. The unique challenges posed by seawater, including its high salinity and corrosive elements, necessitate innovative material selection and precise engineering techniques to ensure the durability and efficiency of the seals. This research focuses on identifying corrosion-resistant elastomers and coatings suitable for withstanding high pressures and temperature fluctuations in the harsh marine environment. Additionally, the study delves into the impact of meticulous assembly practices on the long-term performance and reliability of the sealing components. The research team calculated and designed a prototype of the underwater observation device's shell and successfully conducted a water pressure test at a depth of up to 80 meters. The sealing limit primarily depends on the mechanical properties of the gasket material. When using metal gaskets, the sealing limit can reach up to 5000 psi, equivalent to a depth of 3400 meters, which is also the current testing equipment limit.

Keywords: Sealing solution; O-rings; Underwater observation devices.

1. INTRODUCTION

Sealing gaskets are crucial components in hydraulic systems and pipelines operating in marine environments [1]. For underwater observation devices, ensuring water resistance and the ability to withstand water pressure within the operational depth range necessitates meticulous calculation and precise mechanical design of the gaskets [2].

Designing and manufacturing watertight mechanical housings capable of withstanding pressure and corrosion in seawater environments is a significant research topic in marine engineering, particularly in the design and manufacture of underwater equipment. Seawater's high salt content and corrosive factors pose substantial challenges, requiring innovative solutions and rigorous scientific calculations. This is especially critical in the design of underwater equipment to ensure it can withstand pressures at desired depths [3, 4]. Ensuring the integrity and longevity of underwater equipment necessitates prioritizing the efficiency of sealing components.

In the field of underwater sealing, rubber O-rings with super-elastic mechanical properties are currently used for sealing structures that contact seats and windows, deforming under water pressure. Numerous studies have investigated the sealing performance of various O-ring shapes for different applications. For example, Zhou et al. [5] examined the sealing performance of D-rings in high-pressure hydrogen testing equipment. He et al. [6] experimentally studied the leakage in large carbon steel flange O-rings under pressure. Cao et al. [7] used numerical methods to analyze how a baffle affects the sealing performance of O-rings in deep-sea underwater gliders, demonstrating the baffle's effectiveness in improving sealing. Qiao et al. [8] investigated the impact of different metal material properties on O-ring sealing performance, highlighting material as a crucial factor in O-ring sealing structures. Davies et al. [9] conducted tests on nitrile rubber joints for a deep-sea vehicle. However, no prior study has comprehensively addressed material selection, O-ring size calculation for optimal mechanical design, high-pressure resistance, simplified assembly processes, and high stability during assembly.

This paper investigates pressure-resistant O-ring sealing solutions. The research concentrates on material selection, O-ring dimension calculation, and the required mechanical design principles for manufacturing water-resistant housings capable of withstanding high pressures and suitable for prolonged operation in harsh marine environments. Additionally, the study examines the impact of precise assembly processes on seal performance and long-term reliability.

2. PROBLEMS

2.1. Sealing solutions using O-ring gaskets

Gasket sealing solutions, particularly O-rings, ensure system integrity under extreme conditions. They effectively prevent leaks, withstand high pressures, and resist corrosion, making them ideal for applications in industries such as marine engineering and aerospace. Optimal performance relies on precise material selection, accurate sizing, and meticulous mechanical design and assembly [4, 10].

2.1.1. Sealing tasks for underwater observation devices

The research scope specifies that the underwater observation equipment is designed to operate at sea depths of 0 to 50 meters, within the surface water layer (<200 meters). Consequently, the rubber sealing gaskets must withstand environmental impacts and temperature and pressure variations within this operational range.

Operating Temperature Range: The temperature range of the surface water layer in the East Sea of Vietnam varies between 18°C and 29°C, based on data recorded during the period 2011–2020 [11].

Pressure Range Impacting the Equipment: Underwater equipment is subjected to the pressure of the water column and the atmospheric pressure acting directly on the surface of the sea.

The pressure of the water column P, caused by the weight of seawater, is determined by the formula:

$$P = \rho \, . \, g \, . \, h \tag{1}$$

Where ρ is the density of seawater (approximately 1025 kg/m^3), g is the acceleration due to gravity (9.8 m/s^2), and h is the depth of water (in meters).

When considering atmospheric pressure P_K (1atm), the absolute pressure P_a is determined by the formula:

$$P_a = \rho \cdot g \cdot h + P_k \tag{2}$$

Table 1 presents the absolute pressure values, in kPa, atm, and psi, acting on the underwater observation equipment within the sea depth range of 0 ÷ 50 m, calculated using formula (2).

Table 1. *The absolute pressure values correspond to sea depth.*

h (m)	0	10	20	30	40	50
P (kPa)	0	100.45	200.90	301.35	401.80	502.25
P_a (kPa)	101.3	201.78	302.23	402.68	503.13	603.58
P_a (atm)	1.00	1.99	2.98	3.98	4.96	5.96
P_a (Psi)	14.70	29.30	43.80	58.40	73.00	87.50

Absolute pressure increases proportionally with the working depth of underwater equipment, rising approximately 1 atm for every 10 meters of depth. Therefore, for equipment operating at a depth of 50 meters, the sealing gasket and mechanical sealing design must withstand a water pressure of approximately 600 kPa.

2.1.2. The selection of gasket materials

Designers select specialized gasket materials with suitable mechanical properties, and chemical and heat resistance, based on the specific working environment. This ensures optimal gasket performance and durability under the required conditions. For equipment operating at great ocean depths, materials must resist deformation under high pressure while maintaining flexibility and elasticity within a specific temperature range. These materials must also withstand the chemical corrosiveness of the marine environment. Materials suitable for marine environments include PTFE (Polytetrafluoroethylene), PEEK (Polyetheretherketone), and NBR (Nitrile Butadiene Rubber).

NBR is a widely used synthetic rubber for gaskets due to its oil resistance and good mechanical strength. While it may not be as elastic as PTFE or PEEK in extreme conditions, NBR is cost-effective and capable of withstanding moderate pressure and temperature variations. NBR rubber exhibits a low oil swelling coefficient (20 ÷ 30%) and operates within a temperature range of -40 °C to +120 °C, with a recommended working range of -30 °C to +100 °C to minimize aging. NBR O-rings can withstand pressures up to 1500 psi [2], with tensile strength ranging from 3 MPa to 15 MPa and hardness from 60 to 90 Shore A.

Figure 1 shows the results of water swelling tests conducted on various O-rings made from different materials after 1 to 2 years of immersion. The dimensional change ranges from 5-13%, depending on the NBR grade (N0398-70, N0103-70, N0219-70), [4].

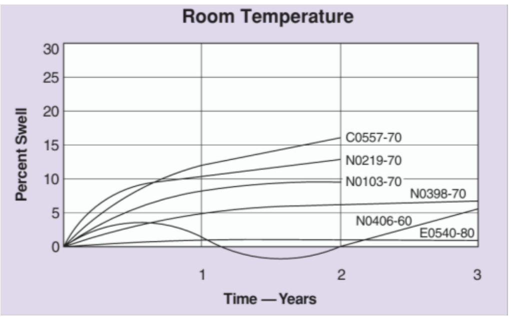


Figure 1. *Chart of the operating temperature range.*

It has been observed that NBR rubber gaskets exhibit low expansion rates and operate within temperature ranges suitable for the requirements of the underwater observation devices under development by the research team.

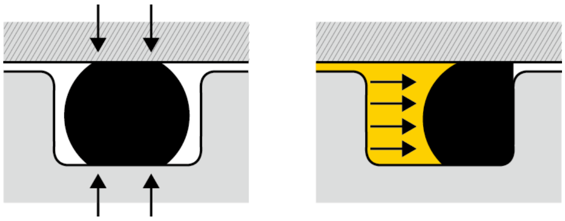
2.1.3. Selection of gasket types

Gaskets are classified by their cross-sectional shapes, which include circular, flat, square, triangular, X-shaped, D-shaped, V-shaped, U-shaped, T-shaped, and H-shaped. The circular cross-section, or O-ring, is the most popular and widely used. The selection of an appropriate cross-sectional shape depends on the application, specifically whether the gasket will experience static or dynamic loads, and whether friction needs to be increased or decreased.

Deep-sea equipment frequently employs a combination of various gaskets/seals, each serving specific functions within the system. For underwater observation equipment, which primarily operates under static load conditions, circular cross-section O-rings are the preferred choice. These O-rings offer significant convenience in selecting materials and sizes that align with the design parameters of the device housing.

2.1.4. Calculating the size of an O-ring

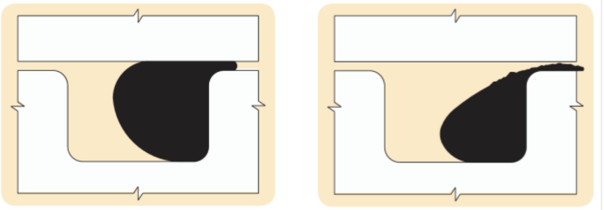
Key mechanical properties of materials to consider include constant tensile stress, elongation at break, deformation at break, and the stress-strain curve, collectively defining tensile strength. This encompasses the maximum tensile stress a sample can withstand before failure (breaking, fracturing, or loss of elasticity). Furthermore, hardness, reaction force, and elastic recovery under compression are crucial evaluation factors. The typical working states of rubber O-rings are illustrated in figure 2.



a) b)

***Figure 2.** Typical working states of O-rings: (a) Loose installation state; (b) Tight installation state; (c) Deformed state under the effect of pressure (gas/liquid).*

In figure 2(a), the O-ring is shown compressed and deformed by mechanical pressure exerted by surrounding components. In Figure 2(b), the O-ring is illustrated under pressure from external forces (e.g., fluid or gas), whereby sealing effectiveness is achieved due to the elastic properties of the rubber material.



a) b)

***Figure 3.** The working states of the gasket under critical pressure load: (a) State of the gasket at critical deformation; (b) State of the gasket at destructive deformation.*

When the threshold pressure is excessively high, the rubber O-ring can deform completely, with portions extruding into the gap between mechanical components, as illustrated in figure 3(a). Under pressure exceeding its strength limit, this over-extrusion results in gasket structure failure (tearing), as shown in figure 3(b), where excessive pressure leads to structural failure (tearing or permanent damage). Consequently, the O-ring loses both its elasticity and sealing efficiency. The allowable extrusion limit is dependent on the O-ring's cross-sectional diameter (thickness), as detailed in table 2 [1].

***Table 2.** Maximum diametral clearance of O-ring gaskets.*

O-ring cross-section (mm)	1.60	1.78	2.40	2.62	3.00	3.53	5.33	5.70	6.99	8.40
Maximum diametral clearance (mm)	0.12	0.13	0.14	0.14	0.15	0.15	0.18	0.18	0.20	0.20

When the extrusion limit is exceeded, additional backup gasket solutions should be calculated and implemented, or gasket materials with higher hardness should be selected. This ensures the sealing system maintains its integrity and effectiveness under extreme pressure conditions [2]. However, in practical working conditions, assembling an O-ring becomes more challenging as rubber hardness increases. Therefore, lower-hardness rubber is preferred to facilitate installation.

Companies specializing in gasket manufacturing, such as Parker Seal Company, USA, permit O-ring expansion up to 50% in static load applications but limit shrinkage to 3%. O-ring shrinkage invariably reduces sealing capability. Shrinkage often increases hardness and leads to compression set (non-recoverable deformation), resulting in a smaller, harder, and less elastic O-ring cross-section. Given the negative effects of shrinkage on hardness and compression set, the shrinkage ratio must be significantly lower than the initial compression ratio of the installed O-ring's cross-section [4].

Gasket grooves are designed to accommodate the expansion or contraction of O-rings. While most

O-rings experience slight expansion, even when sealing compatible fluids, grooves can be widened to accommodate seals with significant expansion in situations requiring material compromises [1].

2.2. Mechanical Design

2.2.1. Gasket groove design considerations

Groove design for rubber O-rings requires careful consideration of the following criteria: groove dimensions, compression ratio, surface finish, and tolerances. Specific design parameters are provided in table 3 [1].

Table 3. *Groove design criteria for Elastomer O-rings.*

Tolerance on groove depth (*h*)	0.25 mm
Tolerance on groove outside diameter (*D*)	0.5 mm
Flange load to compress the seal	150 ÷ 800 N
Surface finish	0.8 μm Ra

The underwater observation device's housing requires sealing at the junctions where the front and rear covers attach to the main body. Additionally, the optical window must be sealed to the front cover. Consequently, the underwater observation device utilizes two types of rubber O-rings for face-sealing structures, with parameters specified in table 4.

Table 4. *Mechanical design parameters for face-sealing structures.*

Groove ID	Groove W	Groove OD	Groove depth	O-ring ID	O-ring CS	
264-h11	4.50	272-H11	2.62	265.00	3.50	*front and rear cover sealing*
67-h11	3.50	74-H11	2.25	67.50	3.00	*optical window sealing*

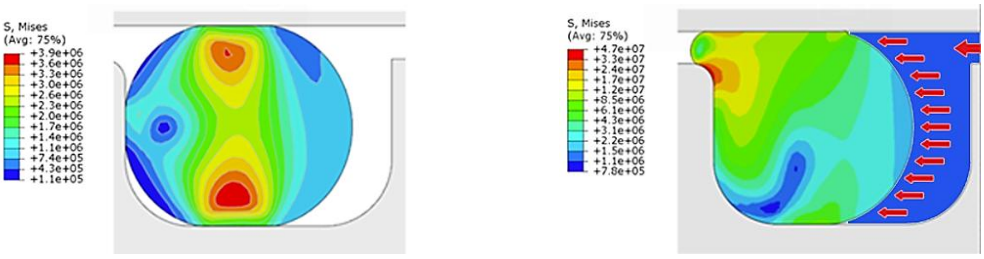
Theoretically, a larger O-ring CS results in improved compressibility and higher water pressure tolerance. However, the O-ring diameter must be optimized to achieve the simplest and most efficient mechanical design, thus reducing overall size and manufacturing costs. Specifically, a 3 mm O-ring is used for optical window sealing, and a 3.5 mm O-ring is used for sealing the front and rear covers. The O-ring ID dimensions are selected to correspond to the mechanical diameters required by the components and closely match standard O-ring sizes, thereby facilitating procurement.

Figure 4. *3D image of the underwater observation device housing after assembly.*

The 3D design model of the housing for the underwater observation device, illustrated in figure 4, was created using Autodesk Inventor Professional 2024 software.

2.2.2. Simulation of sealing effectiveness

The impact of seawater pressure on an NBR O-ring with a 3 mm cross-sectional diameter (CS) was simulated using DS Simulia Suite Abaqus 2024 software, and the results are presented in figure 5. In figure 5(a), the O-ring is shown within its housing under assembly pressure in the absence of fluid pressure. In figure 5(b), the O-ring is depicted within its housing, subjected to approximately 8 atmospheres (atm) of fluid pressure.



a) *b)*

Figure 5. *Simulation of an NBR O-ring seal subjected to the pressure of a fluid, using DS Simulia Suite Abaqus 2024 software: (a) O-ring in housing without the pressure of a fluid; (b) O-ring in housing under about 8atm pressure of a fluid.*

3. RESULTS AND DISCUSSION

3.1. Prototyping and testing of the device

The mechanical components of the underwater observation device's body assembly, after manufacturing, are assembled with the following technical requirements:

- ***Surface inspection***: Ensure that the contact surface of the O-ring and other components is clean, free of cracks, or damage. All O-rings must undergo quality inspection to ensure compliance with MIL-STD-413 standard. The objective of this standard is to ensure the acquisition of elastomeric O-rings with a surface quality level adequate for their intended use.
- ***Gasket surface quality check***: Verify that the gasket meets quality standards before assembly.
- ***Assembly pressure***: The assembly pressure must be evenly distributed to avoid damaging or deforming the gasket. The required compression force to install a rubber O-ring with a cross-sectional diameter of 2.5 to 3.0 mm at a 20% compression rate ranges from 2 to 5 N/mm of circumference.
- ***Leakage inspection***: After assembly, the system must be checked to ensure there are no leaks.

Adherence to the assembly technical requirements ensures the device's waterproof performance. Incorrect assembly procedures can damage the gasket or otherwise harm the device.

3.2. Waterproof testing

Methods: Waterproof testing was conducted using the TKN-GĐCL-19 device, provided by the Department of Standards, Metrology, and Quality, General Staff. The pressure was simulated to replicate the device diving to depths of 0 to 50 meters underwater, with the maximum pressure maintained for 2 hours. Subsequently, the underwater observation device was removed for inspection. If no water ingress was detected, the test was deemed successful. The experimental setup and procedure are illustrated in figure 6.

a) *b)* *c)*

Figure 6. *Some images of real-world tests of the waterproofing capabilities of the underwater observation device: (a) Placing the product into the tank; (b) Preparing the pressure pump; (c) Applying a pressure of 800 kPa.*

Following the comprehensive waterproof testing, the results demonstrated that the device is fully capable of withstanding seawater at a depth of 50 meters. Similar experiments were conducted at the maximum depth the test equipment could simulate, equivalent to 80 meters, and the device's water resistance performance continued to meet the required standards.

3.3. Results and comments

The underwater observation device was also disassembled for inspection. The surfaces of the O-ring gaskets remained in excellent condition, exhibiting normal elasticity without any signs of deformation or surface damage. These findings indicate that the selected O-ring solution meets the design and manufacturing requirements of the underwater observation device. Actual test results demonstrated that the device is fully capable of withstanding seawater at a depth of 80 meters (figure 6).

The designed compression ratio is 25%, with an additional 13% water swelling after two years, resulting in a cumulative effect of 38%, which remains below 50%. Consequently, the gasket's sealing performance is expected to last two years, assuming other influencing factors are disregarded.

To achieve a higher sealing test pressure, equivalent to a greater maximum test depth, a housing capable of withstanding higher pressure must be designed and fabricated. The device, as currently designed, is rated for a maximum depth of 100 m (50 m is recommended).

The assembly process must be strictly followed. A torn gasket, unclean component surfaces, uneven or insufficient bolt tightening can all affect the gasket's compression ratio, preventing the sealing performance from meeting expectations.

4. CONCLUSIONS

This paper presents research aimed at developing a solution for selecting O-rings and designing mechanical seals for the housing of an underwater observation device. Leveraging gasket sealing theory, a solution was developed using cost-effective NBR material, coupled with calculations and simulations to evaluate sealing performance under water pressure up to 800 kPa. The research team proposed a sealing solution for underwater observation devices operating at depths up to 80 meters. Practical testing confirmed the prototype's water resistance effectiveness. The use of NBR O-rings helps reduce product costs and offers significant convenience for maintenance and replacement when necessary. However, in the future, sealing gaskets made from environmentally friendly materials, such as silicone, could be studied for application in sealing underwater observation devices. However, due to their lower hardness, their pressure resistance is also limited.

The objective of this research is to enhance the water resistance of underwater observation devices. This design solution can be directly applied to deep-sea exploration applications, including Remotely Operated Vehicles (ROVs), underwater sensors, and communication systems. Furthermore, the research outcomes may contribute to the development of underwater equipment designed for long-term operation.

Acknowledgement: *This work is thanks to the funding support of the project "Research, design and manufacture underwater observation equipment to protect important areas and search and rescue at sea" Institute of Technical Physics, AMST.*

REFERENCES

[1]. Robert Flitney, “*Seals and Sealing Handbook 6th edition*,” Butterworth-Heinemann, (2014).
[2]. Leonard J. Martini, “*Practical Seal Design,*” Routledge, (1984).
[3]. Leonard J. Martini, “*Seals for the Ocean Environment,*” PN, (1972).
[4]. “*The Parker O-Ring Handbook ORD 5700,*” Parker Hannifin Corporation, (2021).
[5]. C.L. Zhou et al., “*Finite element analysis of sealing performance of rubber D-ring seal in high-pressure hydrogen storage vessel,*” J. Fail. Anal. Prev. 18, 846–852 (2017).
[6]. T. He et al., “*Analysis on performance of sealants for large carbon steel flange O-ring leakage blocking with pressure,*” Chem. Propel. Polym. Mater. 5, 82–85 (2017).

[7]. S. Cao et al., "*Numerical analysis of seal structure of underwater glider in deep sea environment,*" Lubr. Seal. 45, 56–60 (2020).

[8]. L.N. Qiao et al., "*Three-dimensional finite element analysis of O-ring metal seals considering varying material properties and different seal diameters,*" Inter. J. Press. Vessels Pip. 176, 103953 (2019).

[9]. P. Davies et al., "*Testing of nitrile rubber joints for a deep submergence vehicle,*" Polym. Test. 90, 106630 (2020).

[10]. *"Visual inspection guide for rubber elastromeric o-ring,"* MIL-STD-413C, (1980).

[11]. Nguyen Ngoc Tuan, "*Xu thế phân bố nhiệt độ nước biển tầng mặt vùng Biển Đông từ dữ liệu viễn thám*," The National Conference on GIS Application, (2022) (in Vietnamese).

TÓM TẮT

Nghiên cứu xây dựng giải pháp làm kín sử dụng gioăng O-ring trong thiết kế chế tạo thiết bị quan sát dưới nước

Bài báo này trình bày một nghiên cứu toàn diện về thiết kế cơ khí sử dụng gioăng làm kín chịu áp suất cho các thiết bị quan sát dưới nước, hoạt động trong môi trường nước biển. Những thách thức đặt ra khi hoạt động trong môi trường nước biển sâu, chẳng hạn như độ mặn cao và các yếu tố ăn mòn, đòi hỏi phải lựa chọn vật liệu sáng tạo và kỹ thuật chính xác để đảm bảo độ bền và hiệu quả của gioăng. Nghiên cứu tập trung vào việc xác định các tham số kích thước quan trọng của gioăng cao su tròn O-ring và tính toán thiết kế kích thước kết cấu cơ khí phù hợp để chịu được áp suất cao, biến động nhiệt độ trong môi trường biển khắc nghiệt. Ngoài ra, nghiên cứu cũng chỉ ra tác động của quy trình lắp ráp đến hiệu suất và độ tin cậy lâu dài của các thành phần làm kín. Nhóm nghiên cứu đã thực hiện tính toán thiết kế chế thử sản phẩm thân vỏ thiết bị quan sát dưới nước và tiến hành thực nghiệm thử kín áp suất nước thành công ở độ sâu tới 80 m. Để tăng giới hạn làm kín có thể chọn vật liệu làm gioăng có cơ tính phù hợp, khi sử dụng gioăng kim loại giới hạn làm kín có thể đạt tới 5000 psi, tương đương độ sâu 3400 m, cũng là giới hạn thiết bị thử nghiệm hiện nay.

Từ khoá: Giải pháp làm kín; Gioăng cao su tròn O-ring; Thiết bị quan sát dưới nước.