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Evaluation of Scratch Characteristics of Diaphragm for Application of Hydrogen Compressor Parts

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Abstract – Diaphragm compressors play a crucial role in safely compressing large volumes of high-purity hydrogen gas without contamination or leakage, thereby ensuring quality and reliability. Diaphragm compressors use a thin, flat, triple-layered diaphragm plate that is subjected to repetitive piston pressure for compression. They are usually made of metallic materials such as stainless steel or Inconel owing to their high-pressure resistance. However, since they are consumable components, they fail due to fatigue from repetitive pressure and vibration stress. This study aims to evaluate the scratch characteristics of diaphragms in operational environments by conducting tests on three different samples: Inconel 718, AISI 301, and Teflon-coated AISI 301. The Inconel 718 sample underwent a polishing process, the AISI 301 sample used raw material, and the Teflon coating was applied to the AISI 301 substrate at a thickness of 50 µm. To assess the scratch resistance, reciprocating motion friction tests were performed using a tribometer, utilizing 220 and 2000 grit sandpapers as the counter materials. The results of the friction tests suggested that the Teflon-coated sample exhibited the lowest initial friction coefficient and consistently maintained the lowest average friction coefficient (0.13 and 0.11 with 220 and 2000 grit, respectively) throughout the test. Moreover, the Teflon-coated diaphragm showed minimal wear patterns, indicating superior scratch resistance than the Inconel 718 and AISI 301 samples. These findings suggest that Teflon coatings may offer an effective solution for enhancing scratch resistance in diaphragms, thereby improving compressor performance in high-pressure hydrogen applications.

Keywords – Diaphragm compressor, Hydrogen gas, Friction, Surface polishing, Surface coating

1. Introduction

In recent times, there has been a growing importance in the development and implementation of efficient and reliable energy storage systems[1]. Hydrogen gas has emerged as a prominent candidate for such systems due to its high energy density and environmentally friendly characteristics[2]. Among the essential components required for handling high-pressure hydrogen gas, the diaphragm compressor stands out as it allows the compression of large volumes of gas to high pressures while ensuring purity and reliability without contamination or gas leakage[3]. As shown in Fig. 1, the operation of a diaphragm compressor is based on the principle that when a repetitive piston pressure acts on a thin, flat, triple-layered diaphragm plate, the defor-mation of the diaphragm results in the compression of gas volume proportional to the deformation amount[4].

Diaphragms used in such compressors are crucial components for storing and charging high-pressure hydrogen. They are typically made of metals capable of withstanding higher pressures compared to those used in general industrial applications. Most diaphragms are manufactured in a circular plate form[5]. However, being consumable parts, diaphragms are susceptible to damage due to fatigue caused by repetitive pressure and vibration stress. Therefore, to withstand high

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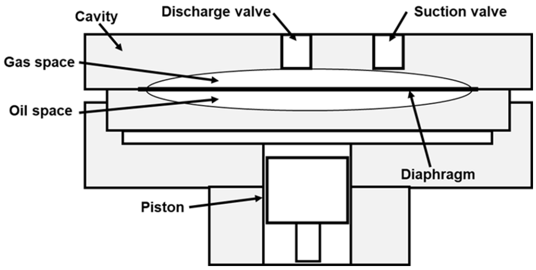

Fig. 1. Structure of diaphragm compressor.

Table 1. Tribo-test conditions

Tribo-test	
Tip material	Sandpaper (200, 2,000 grit)
Normal load	100 mN
Sliding speed	4 mm/s
Sliding stroke	2 mm
Sliding cycle	5,000 cycles

pressures and potential exposure to external substances or contaminants that may cause damage, many diaphragms are made from materials such as stainless steel or Inconel[6].

As a result of the repetitive deformation experienced by diaphragms, micro-contact phenomena occur, leading to surface scratches. These scratches, formed on the diaphragm surface, can impact the compressor's sealing integrity, making research on this matter imperative.

This study aimed to compare the scratch charac-teristics of diaphragm materials in their operational environments. Through this research, the scratch behavior of diaphragms under various materials and operational conditions was evaluated, with the ultimate goal of contributing to the development and optimization of diaphragm compressors for high-pressure hydrogen gas storage and charging.

2. Materials and Experiments

In this study, three types of diaphragm samples, Inconel 718, AISI 301, and Teflon-coated AISI 301, were prepared to evaluate the scratch characteristics under various operating conditions. The Inconel 718 sample was polished to form a smooth surface, while the AISI 301 sample was used in its original state. The Teflon coating with a thickness of 50 µm was applied to the AISI 301 substrate.

To assess the scratch characteristics of the diaphragm samples, a reciprocating motion friction tester was employed. This equipment allowed for controlled loading and velocity to simulate the repetitive scratches experienced by the diaphragm within the compressor. Two different grit sizes of sandpapers, 220 and 2,000 grit, were selected as the counter materials, and the test conditions are summarized in Table 1. The friction test was performed with a linear speed of 4 mm/s and a load of 100 mN on the sample. The sliding distance was set at 2 mm to represent the range of diaphragm deformation during the compression process. To evaluate the effects of repetitive loading and micro-scratches on the diaphragm, the test was conducted for a total of 5,000 cycles. To ensure the reliability of the experimental results, the scratch test was performed for each specimen at least three times or more. After the friction test, the wear patterns of the diaphragm were analyzed using an optical microscope.

3. Results and Discussion

Fig. 2 are optical microscope images showing the surfaces of Inconel 718, AISI 301 and Teflon coating samples. The polished surface of Inconel 718 appeared to be the smoothest, while the Teflon coating exhibited a relatively rough surface due to the presence of micro-sized coating particles. In contrast, AISI 301 was found to have a slightly rougher surface than Inconel 718. Fig. 3 provides quantitative surface roughness (R_a) values for the three samples. The roughness value of the surface was determined using arithmetic mean roughness. For the diaphragm compressor, the main concern is the sealing performance and the contact between the diaphragm and the mating surface. R_a

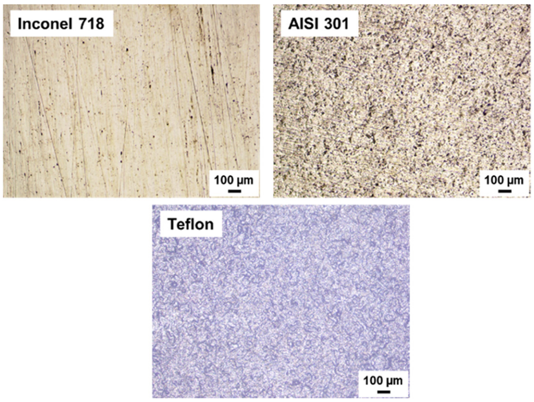

Fig. 2. Optical microscope images of Inconel 718, AISI 301 and Teflon coating surfaces.

provides a useful measurement of average roughness that can be associated with sealing performance and surface interaction in such applications. The average roughness values for Inconel 718, AISI 301, and Teflon coating samples were measured as 0.09, 0.15, and 0.97, respectively. The surface roughness of Inconel 718 was the lowest, while the Teflon-coated surface showed the highest R_a value. This indicates that the surface roughness varies depending on the surface polishing and coating conditions, with the micro-sized Teflon coating particles having the most significant impact on the surface roughness[7].

The results of the reciprocating sliding scratch tests performed on Inconel 718, AISI 301, and Teflon-

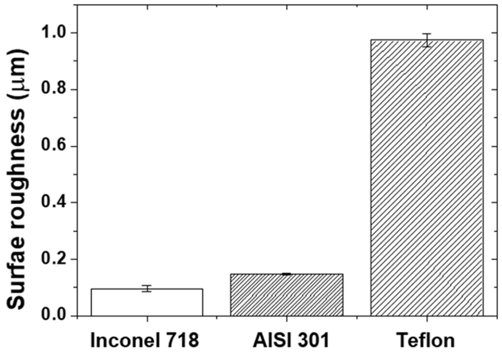

Fig. 3. Surface roughness of Inconel 718, AISI 301 and Teflon coating.

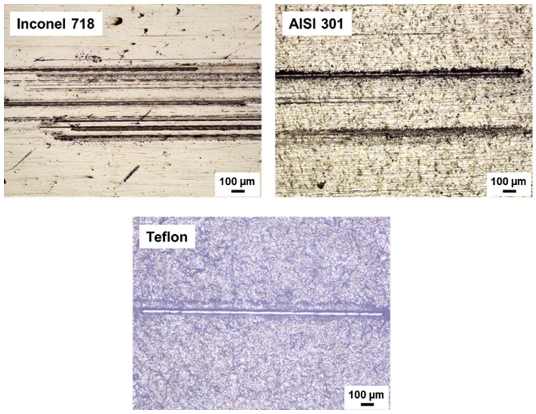

Fig. 5. Microscope images of wear track of Inconel 718, AISI 301 and Teflon coating

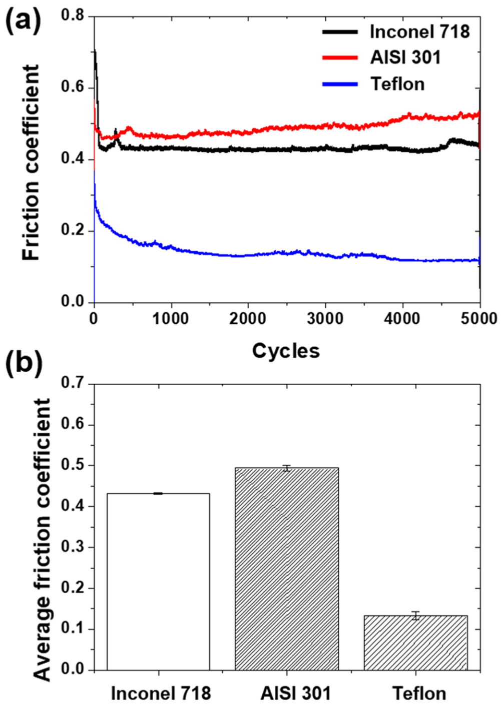

Fig. 4. Friction characteristics of Inconel 718, AISI 301 and Teflon coating: (a) friction coefficient history, and (b) average friction coefficient.

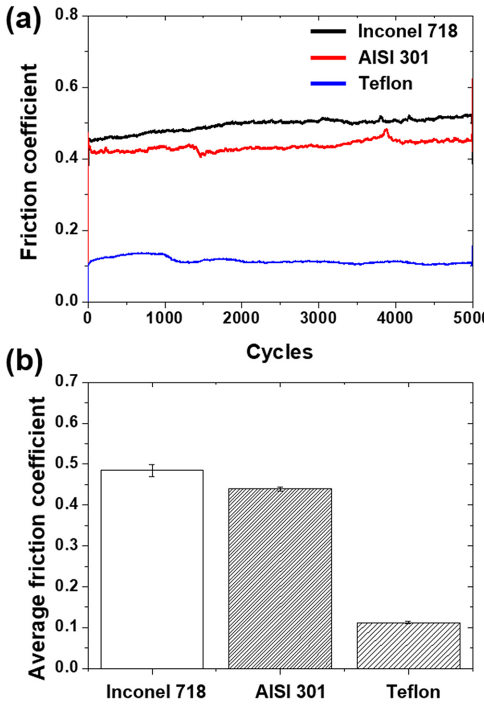

Fig. 6. Friction characteristics of Inconel 718, AISI 301 and Teflon coating: (a) friction coefficient history, and (b) average friction coefficient.

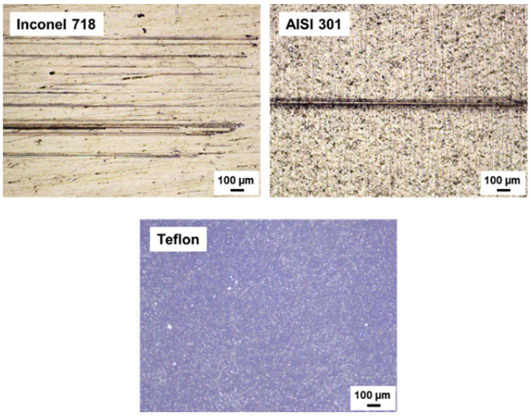

Fig. 7. Microscope images of wear track of Inconel 718, AISI 301 and Teflon coating.

coated samples are shown in Fig. 4(a). During the friction test with the 220 grit sandpaper, Inconel 718 initially exhibited a friction coefficient of 0.7, which subsequently stabilized at 0.45 without significant changes. AISI 301 showed an initial friction coefficient of 0.5, which slightly decreased before increasing again, reaching a friction coefficient of 0.53. In contrast, the Teflon-coated sample demonstrated the lowest initial friction coefficient of 0.3, which then exhibited a decreasing trend, eventually reaching a low friction coefficient of 0.12. Fig. 4(b) illustrates the average friction coefficients of Inconel 718 and AISI 301 as 0.43 and 0.49, respectively, which were relatively higher compared to the Teflon coating (0.13).

4. Conclusion

In this study, three different samples of diaphragm materials, Inconel 718, AISI 301, and Teflon-coated, were utilized to evaluate their scratch characteristics for high-pressure hydrogen gas compressors. Reciprocating motion friction tests were conducted using a friction tester under various counter materials and experimental conditions to assess the durability of each sample over 5,000 cycles of scratch testing. The research findings demonstrated that the Teflon coating exhibited superior scratch resistance compared to Inconel 718 and AISI 301. The Teflon-coated sample started with a low initial friction coefficient and maintained the lowest average friction coefficient. Moreover, the Teflon coating displayed the mildest scratch patterns, indicating excellent durability in addressing scratch-related issues that may directly impact the overall lifespan and reliability of the diaphragm. The conclusions drawn from this study are expected to significantly contribute to the improvement of diaphragm compressors, a critical component in the development of hydrogen gas production and storage technology.

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References

[1] Kuthiala, T., Thakur, K., Sharma, D., Singh, G., Khatri, M., Arya, S. K., "The Eco-friendly Approach of Cocktail Enzyme in Agricultural Waste Treatment: A Comprehensive Review", *Int. J. Biol. Macromol.*, Vol.209, pp.1956-1974, 2022.

[2] Arsad, A. Z., Hannan, M. A., Al-Shetwi, A. Q., Mansur, M., Muttaqi, K.M., Dong, Z.Y., Blaabjerg, F., "Hydrogen Energy Storage Integrated Hybrid Renewable Energy Systems: A Review Analysis for Future Research Directions", *Int. J. Hydrog. Energy*, Vol.47, pp.17285-17312, 2022.

[3] Zou, J., Han, N., Yan, J., Feng, Q., Wang, Y., Zhao, Z., Fan, J., Zeng, L., Li, H., Wang, H., "Electrochemical Compression Technologies for High-Pressure Hydrogen: Current Status, Challenges and Perspective", *Electrochem. Energy Rev.*, Vol.3, pp.690-729, 2020.

[4] Ren, S., Jia, X., Jiang, J., Zhang, S., Zhao, B., Peng, X., "Effect of Hydraulic Oil Compressibility on the Volumetric Efficiency of a Diaphragm Compressor for Hydrogen Refueling Stations", *Int. J. Hydrog. Energy*, Vol.47, pp.15224-15235, 2022.

[5] Li, X., Chen, J., Wang, Z., Jia, X., Peng, X., "A Non-Destructive Fault Diagnosis Method for a Diaphragm Compressor in the Hydrogen Refueling Station", *Int. J. Hydrog. Energy*, Vol.44, pp.24301-24311, 2019.

[6] Lee, S. J., Kim, C. L., "Evaluation of Friction and Wear Characteristics of Carbon-based Solid Lubricant Films for Surface Application of Compressor Parts", *Tribol. Lubr.*, Vol.38, No.5, pp.222-226, 2022, https://doi.org/10.9725/kts.2022.38.5.222

[7] Peng, S., Zhang, L., Xie, G., Guo, Y., Si, L., Luo, J., "Friction and Wear Behavior of PTFE Coatings Modified with Poly(methyl methacrylate)", *Compos. Pt. B-Eng.*, Vol.172, pp.316-322, 2019.

[8] Lee, S. J., Sohn, Y. C., Segu, D. Z., Kim, C. L., "An Evaluation of the Tribological Characteristics of Diaphragm Plates for High-Pressure Hydrogen Gas Compressor Applications", *Lubricants*, Vol.11, pp.411, 2023.