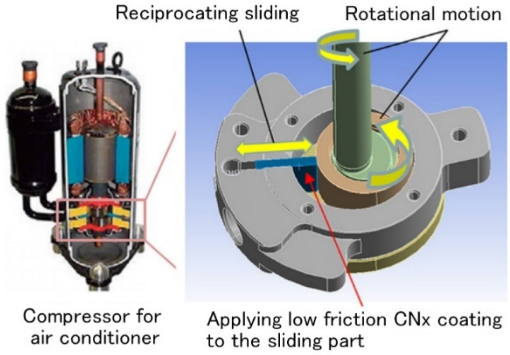
Sliding Surface Improvement Technology Using Low Friction Surface Treatment to Reduce Friction Loss and Improve Efficiency of Products



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Using ta-CNx coatings deposited by the IBA-FAD (Ion Beam Assisted Filtered Arc Deposition) method, we conducted friction tests. The test results showed that the friction coefficient in dry friction of refrigerant environment was about 0.02 and the friction coefficient in mixed environment of refrigerant and refrigerating oil was 0.03 or less. The ta-CNx coatings expressed low friction coefficients about one-third or less of the friction coefficients of current DLC coatings (Diamond Like Carbon Coatings), which are generally about 0.1. Compared with the DLC coatings of other companies (which have been used for automobile engines) and no coating, which exhibits friction coefficients of 0.1 to 0.15, the ta-CNx coatings we developed showed significantly lower friction coefficients. Furthermore, in the environment of engine oil, under the condition where an additive agent was additionally mixed with the oil, the ta-CNx coating showed a low friction coefficient of 0.04. We observed the sliding faces after friction tests and analyzed them with reflectance spectroscopy. As a result, we found that there was tribo-film formed on the friction surface and clarified the low friction mechanism of ta-CNx coatings. In addition, as one example, we applied the developed ta-CNx coatings to the sliding parts of a compressor of an air conditioner and confirmed that the efficiency was improved by about 1%.

1. Introduction

Various energy conservation measures of machine products have been undertaken by each company. One such energy conservation measure is the reduction of friction loss of sliding parts. In recent years, it has been reported that carbonaceous hard coatings expressed low friction coefficients and among them, ta-CNx (tetrahedral amorphous Carbon Nitride) coatings showed friction coefficients of 0.01 or less in dry nitrogen environment(1)(2). However, there have been no reports about the friction properties of ta-CNx coatings in refrigerant environment. Therefore, we developed a sliding surface improvement technology using low friction surface treatment to reduce friction loss and improve the efficiency of machine products. In this report, we evaluate the friction properties of ta-CNx coatings in refrigerant environment and suggest the low friction expression mechanism. We also report one example where we applied the developed sliding surface improvement technology to a compressor of an air conditioner aiming at the further improvement of efficiency.

2. Method of element sliding test, results and consideration

2.1 Method of sliding test of elements

Figure 1 shows the outline of the IBA-FAD system owned by Nagoya University with which we have conducted joint research, the deposition conditions of ta-CNx coating deposited using a gridless ion beam generation system and the specimen. The ring-on-disk friction tester used in friction tests is shown in **Figure 2**. The friction tests were conducted in dry friction with refrigerant gas, in mixed environment of refrigerant and refrigerating oil and in engine oil environment, while

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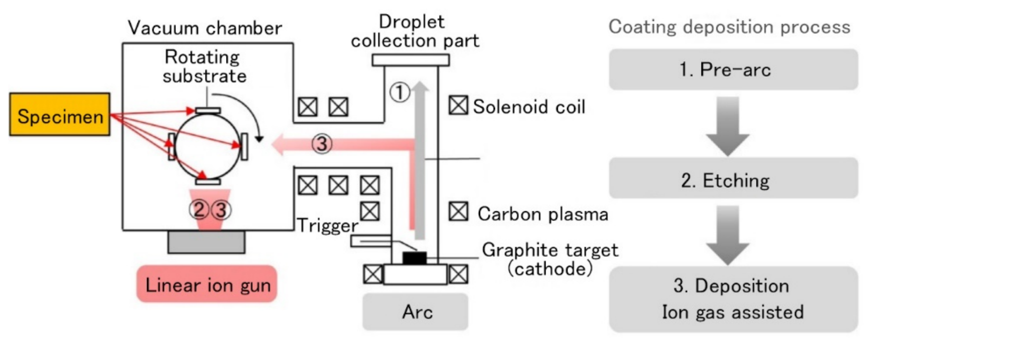
the load was increased at certain intervals. A reflectance spectroscopy analyzer was used for the analysis of the sliding surfaces after the friction tests.



Deposition conditions		
Deposition method		FCVA (PVD) + Nitrogen ion beam
Deposition conditions	Substrate	SUJ2
	Vacuum pressure	4.5x10^{-4} Pa
	N2 ion beam	Nitrogen flow rate (5 to 40 sccm)
	Arc current value, A	50
	Bias voltage, V	−100
	Voltage/Arc current	30 to 100V/50A

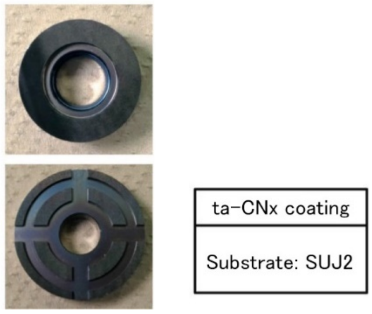


Figure 1 Outline of IBA-FAD system, coating deposition conditions and ta-CNx coating specimen

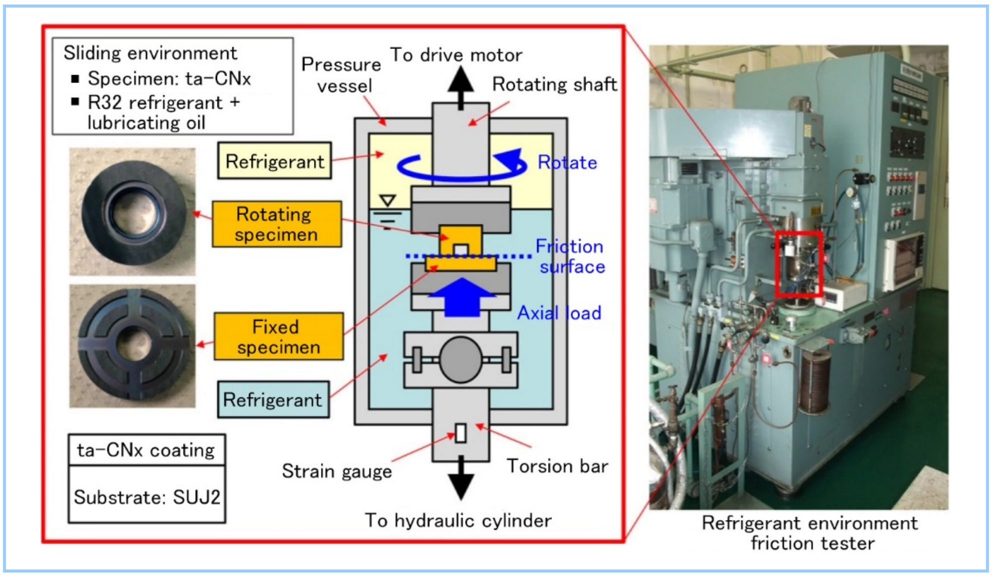


Figure 2 Ring-on-disk friction tester

2.2 Results of element sliding test

(1) Evaluation and study of application to compressor for air conditioner

The results of the dry friction test in R32 refrigerant environment are indicated in **Figure 3**. Although the friction coefficient immediately after the test started was high, it fell below 0.03 in about eight minutes. After that, while the load was increasing, low friction coefficients were maintained.

Tre results of the friction tests in mixed environment of refrigerant and refrigerating oil are given in **Figure 4**. The friction coefficient of no coating was 0.1 or more and although not shown in the figure, the friction coefficient of the current DLC coating was about 0.1, on the other hand, the friction coefficient of ta-CNx coating was one-third or less of 0.1.The application of ta-CNx coatings reduced friction coefficients by about 70% under boundary lubrication.

(2) Evaluation and study of application to engine

The results of the friction tests in engine oil environment are shown in **Figure 5**. The friction coefficient in current oil is about 0.06. Under the condition where an additive agent was additionally mixed with the current oil, the friction coefficient was reduced to 0.04.

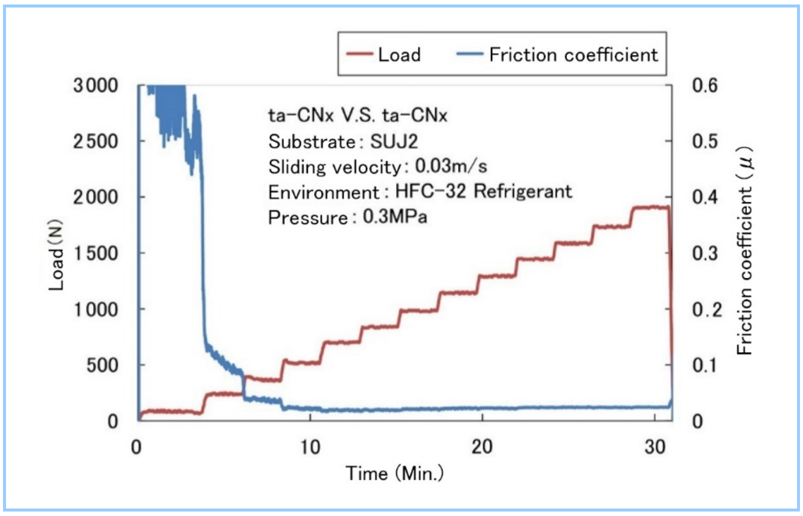


Figure 3 Results of dry friction test in R32 refrigerant environment (friction trend graph)

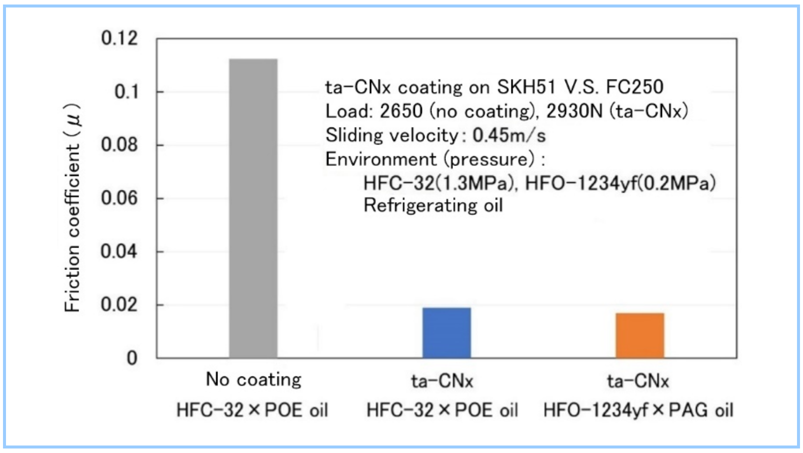


Figure 4 Results of friction tests in mixed environment of refrigerant and refrigerating oil

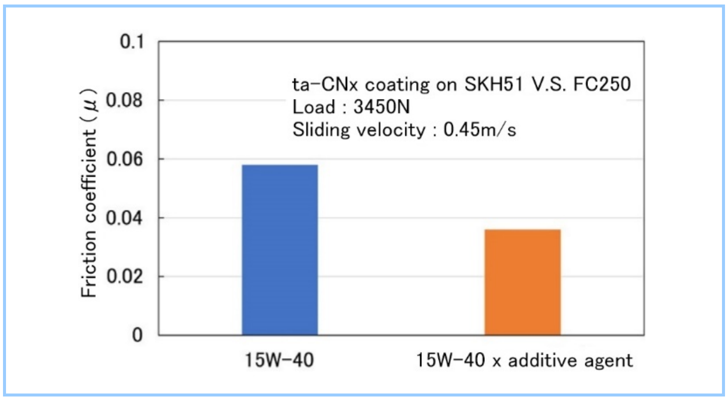


Figure 5 Results of friction tests in engine oil environment

2.3 Clarification of low friction expression mechanism of ta-CNx coating in refrigerant environment

The observation results of the sliding surface after the dry friction test in R32 refrigerant environment are presented in **Figure 6**. Tribo-film formed on the sliding surface was observed. The tribo-film was about 270 to 370 nm thick at the thickest portion. The results of the reflectance spectroscopy analysis for the sliding surface are given in **Figure 7**. The refractive index, n, of the tribo-film was 2 or less and the extinction coefficient, k, was 0.15. According to the classification reported by Hiratsuka, et al.[3][4], the obtained values are equivalent to those of polymer-like carbon. Accordingly, we considered that soft tribo-film[5][6] was formed on the sliding surface and the thin-film solid lubrication with a low shear strength achieved low friction coefficients.

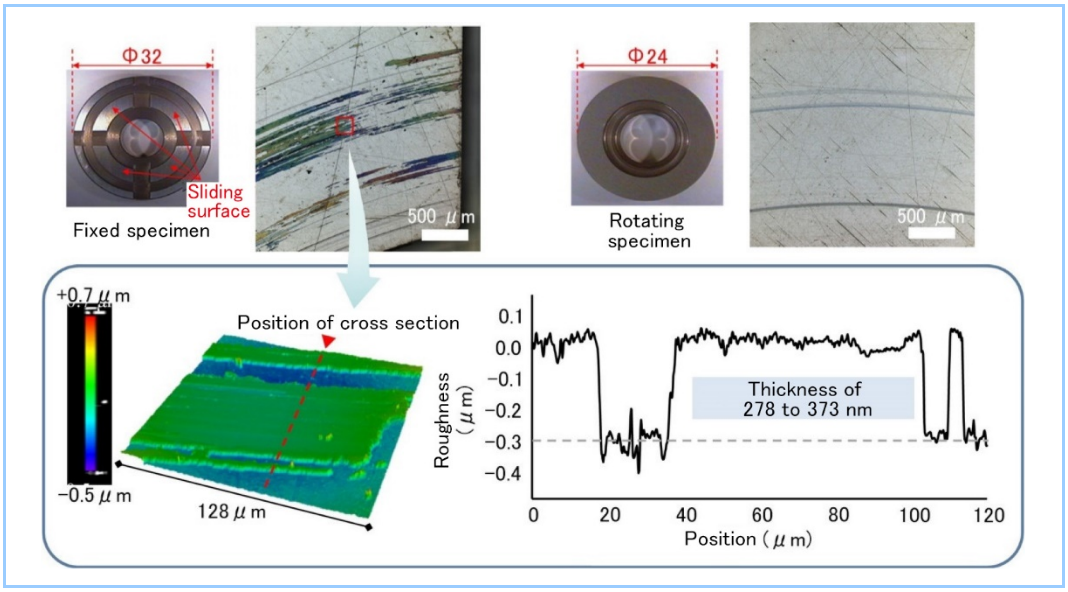


Figure 6 Results of sliding surface observation after dry friction test in R32 refrigerant environment (state of formation of tribo-film)

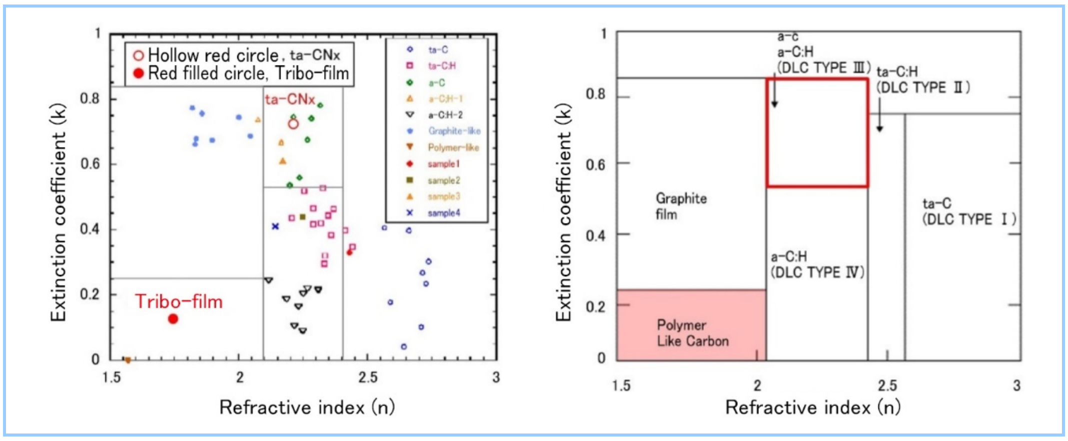


Figure 7 Results of reflectance spectroscopy analysis for sliding surface (study of proposed low friction expression mechanism)

3. Verification results for efficiency improvement of compressor for air conditioner

The developed ta-CNx coating was applied to the sliding parts of a compressor of an air conditioner and the performance was evaluated. The results are shown in **Figure 8**. Compared with current DLC coating, the developed ta-CNx coating improved the average efficiency ratio of the electricity charge by about 1%. Low friction coatings reduce friction loss and allow for improved efficiency. Therefore, it is expected that as a result of the reduction in the power consumption of machine products with sliding parts, running costs can be reduced and as a result of the downsizing of motors by the degree of improved efficiency, parts costs, etc., can also be lowered. There is also a possibility that the use of ta-CNx coatings will contribute to environmental protection through energy saving, decarbonization, etc. We will clarify the durability and long-term reliability of ta-CNx coatings in the future.

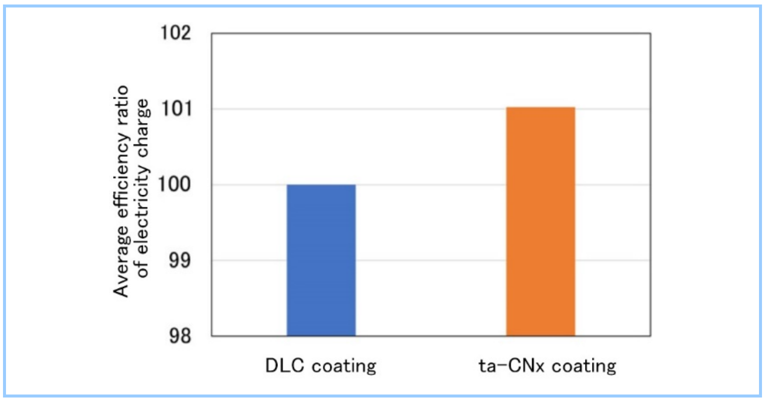


Figure 8 Results of performance test of compressor for air conditioner

4. Conclusion

The ta-CNx coating we developed is a surface treatment using carbon nitride as the main component. Nitrogen is added to conventional DLC coating to soften the coating. By optimizing the level of nitrogen content, which controls coating hardness, as well as the coating thickness, we derived the specifications of a coating that achieved both low friction coefficients and wear resistance.

ta-CNx coatings reduce friction loss and improve the efficiency of machine products. Therefore, ta-CNx coatings are expected to be used for compressors for air conditioner.

In the future, we will promote research about durability, lower costs and the stable supply of ta-CNx coatings as well as evaluations of extended product applications. Toward application to engines, we will aim to develop a friction/wear sliding surface control technology for low friction coefficients in oil environment and apply it to the piston pins, piston rings, etc., of engines, thereby making a contribution to environmental conservation through energy saving and decarbonization in machine products.

With the increase of electrically operated machine elements, lower noise is required. Therefore, we will create new value from lower friction toward the reduction of noise and vibration.

References

(1) Kato, K., Umehara, N., and Adachi, K., “Friction, wear and N2-lubrication of carbon nitride coatings: a review”, Wear, Vol. 254, No. 11 (2003), pp. 1062-1069.

(2) Tokoroyama, T., Goto, M., Umehara, N., Nakamura, T., and Honda, F., “Effect of nitrogen atoms desorption on the friction of the CNx coating against Si3N4 ball in nitrogen gas”, *Tribology letters*, Vol. 22, No. 3 (2006), pp. 215-220.

(3) Hiratsuka, Optical classification pattern of DLC film, Mechanical Surface Tech, 4 (2017)

(4) Hiratsuka, M., Nakamori, H., Kogo, Y., Sakurai, M., Ohtake, N., and Saitoh, H., “Correlation between optical properties and hardness of diamond-like carbon films”, *Journal of Solid Mechanics and Materials Engineering*, Vol. 7 (2013), pp. 187-198.

(5) Takayuki Tokoroyama, Noritsugu Umehara, Hirotsugu Tomita, Yukinori Takenoshita, Effect of Surface Roughness and Transfer Layer of Mating Ceramic Parts for Ultra Low Friction Phenomena in Sliding between CNx and Ceramics, Transactions of the Japan Society of Mechanical Engineers. Series C, Vol. 69, No. 686 (2003), pp. 2824-2829.

(6) Yi-yung Lee, Norihisa Horaguchi, Ishimoto Takao, Noritsugu Umehara, Realization of Low Friction in Refrigerant Environment Using ta-CNx Film, Japanese Society of Tribologists Annual Meeting (Autumn 2020)