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A Study on Improving the Enhanced Durability of Cylinder Liner according to Cavitation Influence of Combat Equipment Engine

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전투장비 엔진의 캐비테이션 영향에 따른 실린더 라이너의 내구성 강화 방안에 관한 연구

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ABSTRACT

Cylinder liners used in diesel engines of combat equipment are prone to cavitation due to wet cooling. The damage caused by erosion and corrosion due to cavitation has a fatal effect on the performance and lifespan of a diesel engine. Therefore, a study was conducted to improve the durability of cylinder liners. Two surface treatment techniques were proposed: nitriding and chrome plating. It was observed that the amount of erosion on the surface of nitride-treated cylinder liners was high because the surface-treated part eroded due to its weak impact resistance against the bubble explosion generated by cavitation. In contrast, the chrome-plated cylinder liner had a lower amount of erosion among the specimens subjected to the accelerated test. These results verified that the resistance of chrome-plated liners against cavitation is high. Therefore, it can withstand the impact of bubble explosion. If the chrome plating thickness is set with reference to the KS standard, an exceptional durability of abrasion, wear resistance, and corrosion resistance can be obtained. If the thickness is set between 120~250㎛, it is expected that the durability of the cylinder liner can be improved. Although a recovery method for corroded cylinder liners is suggested, the proposed method has an inherent risk of crack generation. Therefore, further research is required to solve this problem.

Keywords : Accelerated Test(가속시험), Durability(내구성), Corrosion(부식), Erosion(침식)

1. Introduction

It is crucial that the combat equipment used by the military has a high-speed and high-performance, and it should operate under harsh conditions. Accordingly, the demand for high-performance sub-assemblies and parts mounted on combat equipment is also increasing. Therefore, related research institutes and companies are actively

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conducting research to fulfill this demand. The engines used in combat vehicles are a crucial equipment and its durability is an important factor. Therefore, it should be ensured that the parts of an engine are highly reliable because it might lead to defeat in a combat in the event of a problem. Therefore, it is necessary to analyze the cause and perform measures to prevent its recurrence.

Cylinder liner erosion is a type of engine damage that causes a fatal problem in the engine and an appropriate solution for this problem is absent. The erosion phenomenon damages the cylinder liner, and if the phenomenon progresses, it might erode the liner and form a hole. The erosion of the cyliner liner is known as 'cavitation', and is has been confirmed that it causes severe damage to the diesel engine.

Cavitation is a phenomenon in which the static pressure of a fluid reduces below the saturated vapor pressure of the fluid resulting in the formation of bubbles. When these bubbles collapse, they erode the protective oxide layer present on the metal surface. According to the literature, when the piston is lowered by the explosive pressure in a high-power diesel engine, it leads to the occurrence of piston slap on the side of the cylinder liner due to the impact of the piston. Additionally, piston liner might also be impacted by the gap between the piston and the liner, and the gap between the liner and the cylinder block. It has been verified that cavitation of the cylinder liner occurred when receiving.[1]

Erosion caused due to cavitation and the damage caused to cylinder liners due to corrosion have a fatal effect on the engine performance and lifespan of combat equipment.

In this study, techniques were proposed to improve the durability of cylinder liners that are eroded or corroded due to the occurrence of cavitation. The surface of the cylinder liner is subjected to nitriding treatment and chrome plating. The amount of erosion was compared and analyzed through accelerated testing to determine the magnitude of damage caused due to cavitation.

2. Cylinder liner damage analysis

2.1 Engine operating time and erosion

The cylinder liners of three engines used in combat equipment with an operation time of greater than 1500 h were tested for damage. Twenty-four cylinder liners were tested, and the liner with the most damage for each equipment was selected for analysis. Initially, a visual test was conducted to determine the erosion on the surface of the cylinder liner. Subsequently, the erosion depth was measured using an X-ray 3D scanner.

Table 1 shows the amount of erosion and operating time of the cylinder liner which had the highest amount of erosion in comparison with that of the three cylinders. A significant correlation between the operating time and the amount of erosion was not found. However, since engine idling was operated higher than that of the basic requirement of 78%, it was hypothesized that the correlation between idling requires further verification.

2.2 Flow analysis

Flow analysis was performed to analyze the flow of

Table 1 Cylinder liner erosion measurement

Item	Sample #1	Sample #2	Sample #3
New cylinder liner Size	t : 4.65mm		
Depth of erosion(mm)	3.29	1.96	2.90
Amount of erosion(%)	71	42	62
Operation time(H)	1,534	1,569	1,600
Idle ratio *nomal: 78	93.4	94.2	94.0

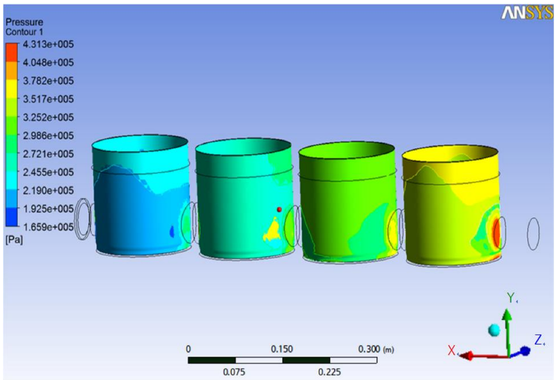


Fig. 1 Fluid domain pressure distribution

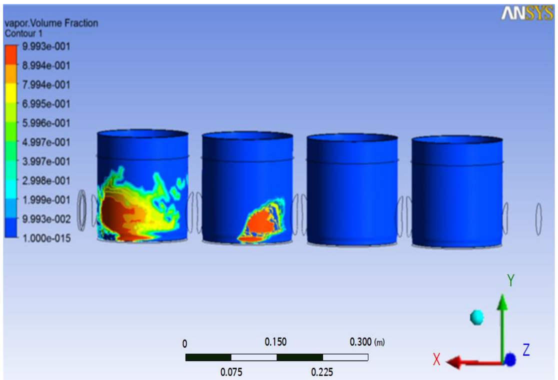


Fig. 2 Bubbling distribution in the cylinder liners

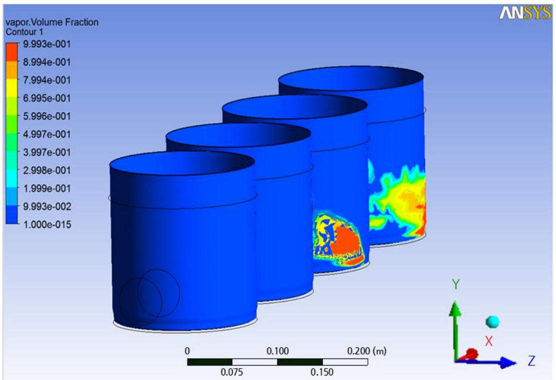


Fig. 3 Vibration generation part - Bottom right

coolant passing through the cylinder liner. ANSYS Fluent 18.0 version was used for the analysis, and volume of fluid and evaporating models were used. The steady-state equation was used to derive the calculation results under a steady-state flow, and the analysis was performed by applying the enhanced wall law and the energy equation.

The engine coolant inlet was located on the output side of the power, and the sensor value of the performance test room was checked to measure the coolant inlet pressure. Therefore, it was confirmed that the fluid pressure at the coolant inlet side at the rated rotation was 4.3 bar and the pressure at the outlet side was 1.7 bar, and when the coolant pump discharge amount was 3000 rpm, it was confirmed to be approximately $0.84m^3/min$.

Fig. 1 represents the pressure distribution of the coolant flow, and it was confirmed that the pressure decreased as the fluid moved from cylinder 1 (the inlet side on the right) to cylinder 4 (the outlet end on the left).This indicates that the probability of generation of bubbles increases with a decrease in the pressure.

Fig. 2 shows location of the formation of bubbles. Assuming that the external temperature of the cylinder liner is 130℃ and the vapor pressure is 2.7 bar, it can be seen that bubbles are generated. The generation of bubbles increases with an increase in the temperature.

According to the study conducted by Mustafa, the cause of cavitation in the wet liner is due to the slap phenomenon and vibration of the piston. It was stated that the vibration generating part due to the piston slap phenomenon is the side part of the cylinder liner, and erosion and corrosion occur on the side part. According to the data studied by Sang-Tae et al., when viewed from the direction of the main output stage, the direction of engine rotation is the opposite of clockwise rotation.

Fig. 3 indicates the occurrence of vibration of the cylinder liner. Considering previous studies, it is expected that cavitation erosion and corrosion will occur in the lower right-side part of the cylinder. Due to the characteristics of combat equipment, it is difficult to solve the cause of increased engine idle operation time and lateral pressure in a short period of time. Therefore, a different solution is required to prevent cylinder liner damage caused due to cavitation.[2,3]

3. Cylinder liner durability enhancement plan

3.1 Surface treatment and accelerated testing of cylinder liners

The test apparatus was configured as shown in Fig. 4 to conduct the accelerated test according to the surface treatment method. In this experiment, erosion of the specimen was induced by cavitation with a high-frequency generator for the specified specimen and solution. Accordingly, it was possible to determine the amount of erosion by exposure time due to vibration.

To reduce the damage caused to the cylinder liner due to cavitation, a surface treatment method was used. The cylinder liner of the engine was fabricated using Cr-Mo alloy centrifugal casting, but the surface was not treated. However, it was confirmed that the manufacturer increased the durability of the cylinder liner by surface-treating the hard chrome plating, and a cylinder liner of similar combat equipment was plated with chrome or nickel. Hard chrome was considered as a suitable durability enhancement method because the plating layer can obtain a high hardness (Hv700~1000), and it has excellent wear resistance, heat resistance, and corrosion resistance.

An accelerated test was performed to verify the durability of the cylinder liner. An accelerated test is conducted under stringent conditions compared with that of standard conditions for the purpose of reducing the test time.

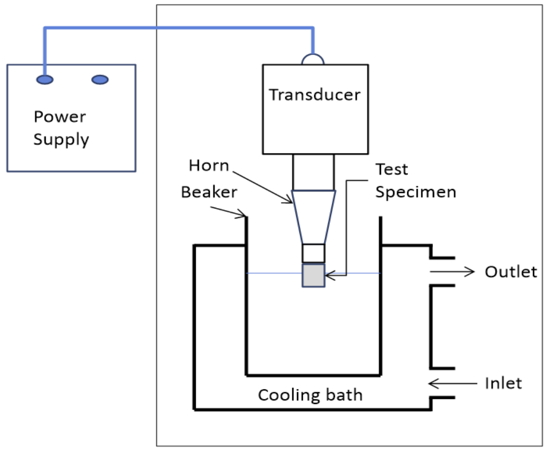
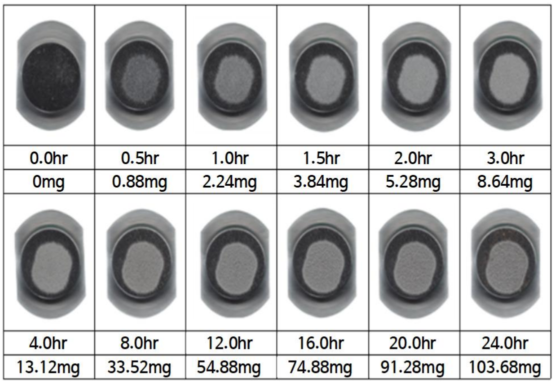
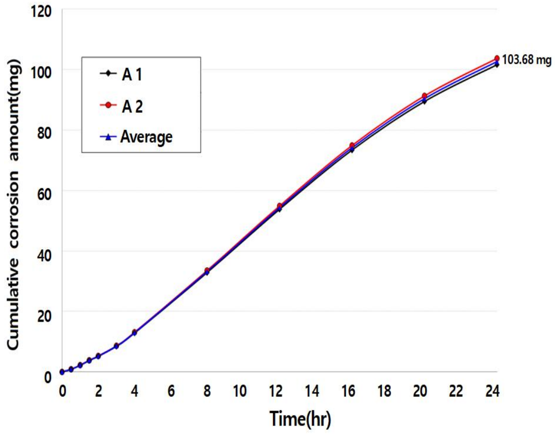


Fig. 4 Schematic of vibratory cavitation erosion apparatus



(a) Corrosion amount shape of ‘A’



(b) Corrosion amount graph of ‘A’

Fig. 5 Accelerated test of ‘A’ specimen

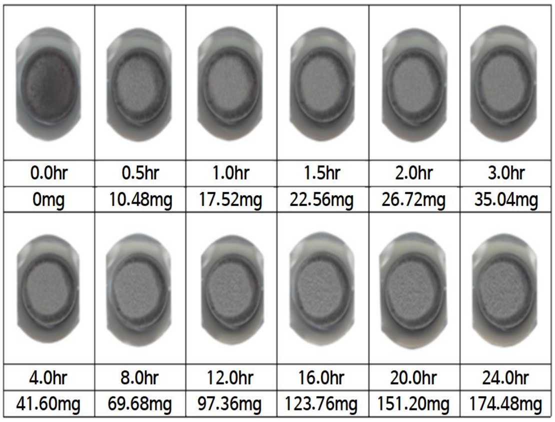
ASTM G32 was used for the test rule, and the test method caused cavitation with a high-frequency exciter with respect to the specified specimen and solution to induce erosion on the surface of the specimen. In addition, the degree of damage to cavitation was determined by measuring the amount of erosion over time by exposure to vibration.

Three types of test specimens were used for the experiment: a non-surface-treated cylinder liner specimen (which was raised), and a nitride specimen, and a chrome-plated specimen with a surface hardness of Hv 700 or greater. The cylinder liner specimen without surface treatment was denoted as 'A', the nitrided cylinder liner was denoted as 'N', and the chrome-plated cylinder liner specimen was denoted as 'C'.

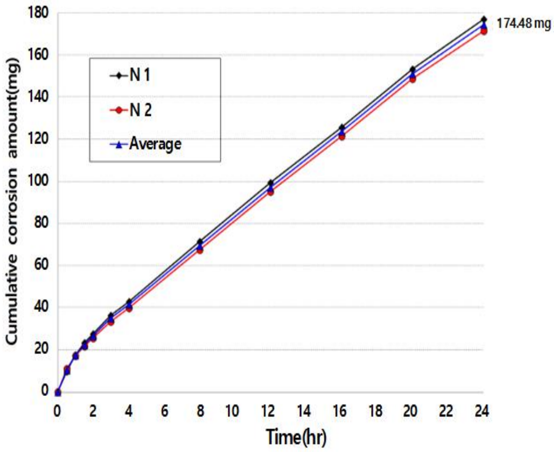
Fig. 5 shows the results of the accelerated test of two 'A' specimens, and it was confirmed by mass measurement that an average of 103 mg of erosion occurred after 24 h. Since the values of the two specimens were not significantly different, the average values were considered similar.

Fig 6 represents an accelerated test of two 'N' specimens, and it was observed that an average of 174 mg of erosion occurred after 24 h. The erosion observed on the surface of cylinder liner 'N' was greater than that of 'A' because the nitriding compound layer had weak impact resistance and was initially peeled off due to the impact of strong bubble explosion.

Fig. 7 shows the chrome-plated cylinder liner, and it can be observed that the amount of erosion after the accelerated test was significantly lower than that of the previous two samples. After 24 h, the amount of erosion was approximately 15 mg. This indicated that approximately 14% of the erosion was generated compared with that of the untreated cylinder liner, and approximately 8.6% of the erosion was generated compared with that of the nitride specimen. It was observed through this accelerated test that the durability of the chrome-plated cylinder liner was excellent.

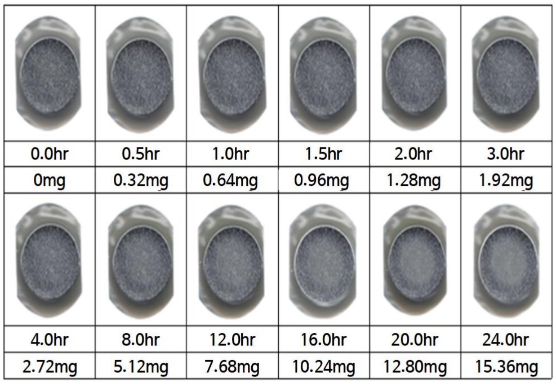


(a) Corrosion amount shape of ‘N’

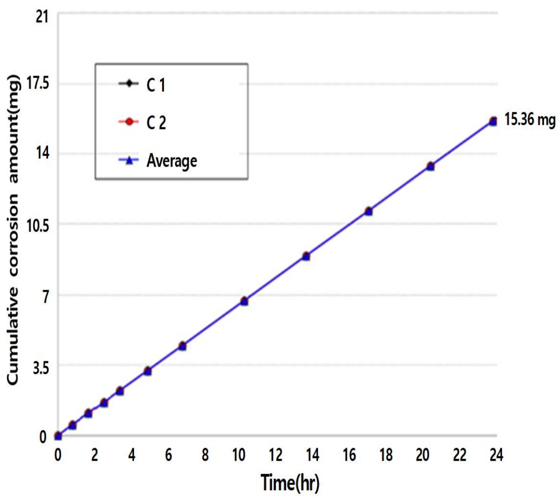


(b) Corrosion amount graph of ‘N’

Fig. 6 Accelerated test of ‘N’ specimen



(a) Corrosion amount shape of ‘C’



(b) Corrosion amount graph of ‘C’

Fig. 7 Accelerated test of ‘C’ specimen

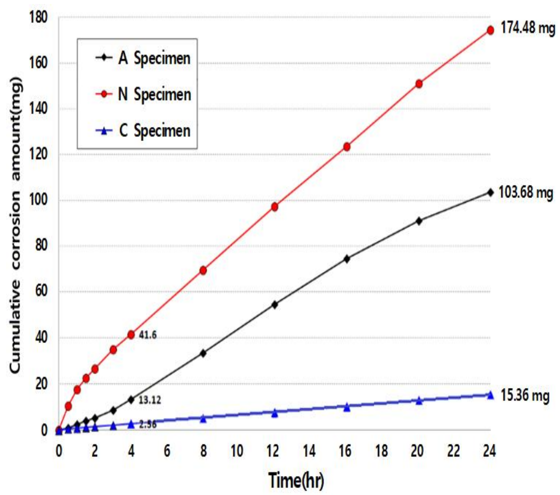
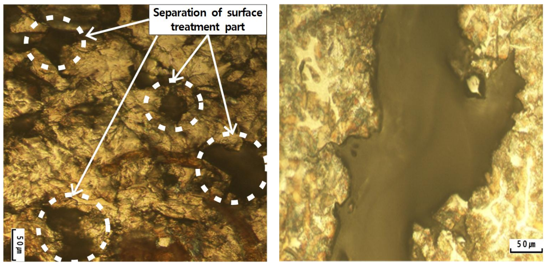


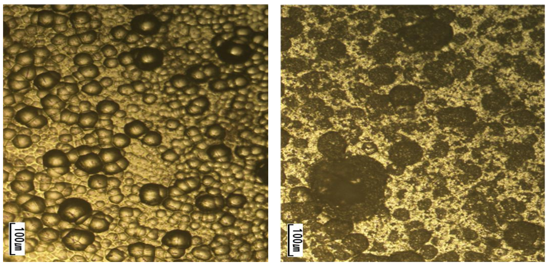
Fig. 8 Accelerated test result

Fig. 8 is a graph of the results of obtained after conducting the accelerated test of the three types of specimens. Initially, as a result of comparison based on 4 h, the erosion amount of the nitrided cylinder liner was 28.48 mg higher than that of the non-surface-treated cylinder liner, and the chrome-plated cylinder liner was 10.56 mg lower than that of the non-surface-treated liner.



(a) Surface After 24h (b) Cutting surface

Fig. 9 Corrosion surface after 24h test of ‘N’



(a) Surface After 24h (b) Cutting surface

Fig. 10 Corrosion surface after 24h test of ‘C’

As shown in the graph, it was confirmed that the amount of erosion of the nitrided cylinder liner was significantly high within the initial 30 min, and slight erosion occurred on the chrome-plated cylinder liner. Since the impact resistance is weak due to the property of nitriding treatment, it was confirmed that the amount of early erosion of the chemical layer occurred (similar to Fig. 9), and the surface treated part eroded.

Fig. 10(a) shows the surface of the chrome-plated cylinder liner after conducting the accelerated test for 24 h. It was confirmed that unlike the surface of the nitride-liner, surface damage due to erosion did not occur significantly. Therefore, it was confirmed that major erosion did not occur in Fig. 10(b), which is shown by cutting the surface of the cylinder liner.

3.2 How to recycle damaged cylinder liners

Brazing is a method of joining metals and non-metals by heating the joint to melt the filler metal without melting the base material. Welding and brazing were performed on the eroded surface of the untreated cylinder liner to verify its suitability as a repair method. Welding was performed with SUS series and carbon steel series, and it was determined that it was unsuitable as a regeneration method due to the generation of internal cracks due to welding heat. Internal cracks and cracks on the surface were not observed due to surface turning after brazing. However, the thin thickness of the cylinder liner has inherent risks of cracking due to explosion and vibration caused by engine operation, and rapid thermal expansion and contraction. Therefore, it is hypothesized that additional research is required to apply the brazing method. Recently, several direct energy deposition (DED) methods using metal 3D printing have been studied. This is a method of irradiating a high-power laser beam on the surface to be processed and simultaneously supplying metal powder and laminating it in real time, and it is emerging as an efficient repair method. However, there is a lack of data or references applicable to the erosion surface of the cylinder liner. Therefore, further research should be conducted before utilizing this method,.

4. Conclusion

Cylinder liners of diesel engines used in combat equipment are prone to cavitation due to wet cooling, which results in severe damage. Therefore, in this study, two surface treatment methods were applied to the cylinder liners to prevent this phenomenon. The following conclusions were obtained from the experiments.

Erosion of the nitride cylinder liner was the highest, which is a characteristic of nitridation treatment with weak impact resistance. Since the surface-treated compound layer eroded at the beginning of the test due to the impact of bubble explosion caused by cavitation, the amount of erosion observed was high. The chrome-plated cylinder liner exhibited the lowest amount of erosion among the three specimens subjected to accelerated testing. It was confirmed that the chrome-plated specimen has a high resistance against cavitation and it can withstand the impact of bubble explosion.

Since the Korean Industrial Standard stipulates that the thickness of industrial chrome plating should be in the range of 120~250㎛ for abrasion resistance, wear resistance, and corrosion resistance, it would be effective to use this to set the plating thickness to improve durability of the cylinder liner. Brazing and DED methods of metal 3D printers were discussed as a method to regenerate cylinder liners that have undergone erosion. However, due to the risk of cracking due to vibration and thermal expansion caused by engine explosion and exhaust process, it was stated that the DED method should be applied after conducting additional research.

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