ISSN: 0974-5823 Vol. 6 No. 3 October-December, 2021

International Journal of Mechanical Engineering

A Study on Remanufactured Hydraulic Cylinders for Construction Equipment

Yong Kyu Chae

Graduate Student Mechanical Engineering, Daejin University, Pocheon, Korea, brucechae@naver.com

Doo-Sung Baik*

Professor, Mechanical Engineering, Daejin University, Pocheon, Korea, dsbaik@daejin.ac.kr

Abstract—

Recently, due to mass production and mass consumption in industrial society, global warming is induced not only by depletion of finite resources but also by continuous use of fossil fuels, thereby rapidly deteriorating the global environment. Therefore, foreign countries are leading the effort to solve the problem technically through resource circulation. In Europe, the Waste Vehicle Disposal Directive has been enforced, requiring producers to achieve at least 85% recycling of their waste vehicles by weight annually, including reuse and recycling rates of at least 80% by weight, since January 2006. The EU's Waste Vehicle Disposal Guidelines restrict the use of hazardous substances to promote the recycling of wastes, and the use of four heavy metals such as mercury, lead, cadmium, hexavalent chromium has been banned in automobiles launched in July 2003. Many types of heavy construction equipment are used for construction heavy equipment. However, the use of hydraulic cylinders, which is a key component among them, is rapidly increasing. This paper aims to contribute to the environment and depleted resources by securing standardized hydraulic cylinder remanufacturing technology by quantitatively evaluating the hydraulic performance of the used hydraulic cylinder.

Keywords— Aftertreatment Hydraulic Control System, Cushion Peak Pressure, Hydraulic Cushioning Cylinder Recycling, Remanufacturing

1. INTRODUCTION

As of April 2021, Korea owns about 24.5 million automobiles and produces 4.34 million vehicles annually in Korea. For these reasons, considering the environment of the domestic automobile industry, active measures are required for automobile-related environmental regulations in developed countries. However, the registration status of domestic construction equipment is 518 thousand units and about 10,000 units are registered every year. However, there are no guidelines for disposal of waste construction equipment in Korea, and the Act on Resource Circulation of Electrical and Electronic Equipment and Vehicles (No. 17848, 2021.01.105) was published as a law. Although this law requires that the recycling rate of scrap cars be observed at 95%, in reality, it is at the level of 90%. The Agency for Technology and Standards (www.kats.go.kr), an organization related to the remanufacturing of construction machinery, introduced the construction machinery remanufacturing trend in the Construction Equipment Industry Status and Standardization Trend (KATS Technical Report No. 59, 2013.12.31). After that, the standard for testing method for remanufactured hydraulic cylinders for excavators (KSI 4038, 2019) and quality certification standards for remanufactured hydraulic cylinders for excavators (REMAN 304, February 2020) were established [1-3].
Representative methods of resource circulation include recycling, remanufacturing, and reuse. Recycling refers to reusing raw materials for new materials and parts through processes such as dissolving, pulverizing, and crushing used product or process scrap. Remanufacturing means restoring the product to the performance level of a new product through processes such as disassembly, cleaning, inspection, repair/adjustment, and reassembly

after use. Reuse refers to the reuse of used parts, which is used for the rest of its life after simply passing through the exterior cleaning process.

The most efficient resource recycling method is remanufacturing because recycling consumes more energy and costs more than remanufacturing. In the case of reuse, the difference in quality is severe and it is impossible to know when a failure will occur, so the efficiency of resource circulation is lower than that of remanufacturing.

A number of products are being remanufactured around the world to improve resource circulation efficiency. Among them, automobile parts account for more than 70-90% of remanufactured products, but the status of remanufacturing of construction equipment is not even known.

Remanufactured quality certification standards for construction machinery have been established in National Institute of Technology Notice No. 2020-0075 (April 20, 2020), and quality verification has been performed on remanufactured hydraulic cylinders.

In Korea, remanufactured parts account for more than 60% of automobile parts, such as alternators, starting motors, constant velocity joints, automatic transmissions, and injectors. However, hydraulic cylinders of construction equipment are distributed as second-hand products that are closer to reuse than remanufacturing. Despite the excellent resource circulation efficiency of the product through the remanufacturing of hydraulic cylinders, consumers tend to be reluctant to purchase the remanufactured product due to the reliability problem of the product, and the reasons are as follows.

First, quality certification standards for remanufactured products have been established when repairing construction equipment, but the absence of an agency that issues certification is an obstacle to market revitalization.

Second, because the inspection, adjustment, and processing processes of individual products for remanufacturing are not systematically established, the performance of the final assembled remanufactured product is significantly lower than that of a new product, resulting in a tendency to decrease consumer confidence.

Third, failure mode analysis between remanufacturing processes is not systematic, and failure defects that occur during operation of construction equipment are fed back to the remanufacturing production site and are not reflected in process improvement. It is negative for the lowering of reliability and perception of remanufactured products.

Currently, in the domestic remanufacturing industry, a systematic standard process for remanufactured products has not been established or researched, and quality control is not performed properly due to the absence of evaluation equipment. To this end, the government prepared quality certification standards for the four hydraulic parts of construction machinery parts, even if it was late.

Therefore, in order to improve the quality of remanufactured products, research on process improvement and reliability of remanufactured parts should be promoted, and through this, it is necessary to induce a change in consumer awareness and vitalize the remanufacturing industry.

In World War II, the remanufacturing industry developed from the United States as a way to efficiently procure military supplies by saving resources and shortening the time required for parts production to solve the shortage of iron ore resources. Since the 1990s, the US, Germany, and Japan have responded to international environmental regulations and revitalized the remanufacturing industry by collecting used auto parts and electrical/electronic products to create jobs.

Remanufactured parts technology and infrastructure in the United States are the most developed, and by most consumers, remanufactured parts are recognized as having the same quality reliability as unused products and having a price advantage. Factors that can revitalize the market in this way are core suppliers for smooth supply of remanufactured parts, participation of original manufacturers in the remanufacturing industry, ease of purchase of unused products, technological advancement of professional remanufacturers, improvement of price-quality competitiveness, and It is judged that the favorable image of consumers toward remanufactured products is based on what has been formed over a long period of time [4-6].

The United States is the world's largest remanufacturing country, and the size of the remanufacturing market in 2015 is about 52 trillion won, 40 trillion won in Europe, and one-fifth of that of the United States in Korea. , 14 types of electrical and electronic components, and 4 types of construction machinery components, totaling only about 50 (Electronic Newspaper, 2019.11.07.).

Europe has an industrial structure differentiated from that of the United States, and in the case of the warranty period, 2 years for unused products and 1 year for remanufactured products are stipulated in accordance with the Consumer Protection Act [7-8].

Looking at the status of remanufacturing by major global construction equipment companies, there is Caterpillar of the United States, which ranks first in the world market as a general construction equipment manufacturer and is a leader in the field of remanufacturing. Starting in 2013, Caterpillar aims to generate 20% of its sales revenue from its remanufacturing business by 2020. It also has remanufacturing plants in the United States, Europe, India, Brazil and Singapore. 일 Komatsu Corporation of Japan produces about 30 types of excavators and loaders, and has remanufacturing facilities in Japan and Indonesia. Limited to some products, it is produced in cooperation with a professional remanufacturing company. Wealdstone, a British company, specializes in the remanufacturing of construction machinery and Caterpillar equipment produced in Europe. Volvo of Sweden produces excavators and mine construction machinery, and remanufacturing is sold at a price guideline of 65% of new products. (Reference Choi Byung-woon KIC News, Volume 20, No. 5, 2017). In Korea, major functional parts of excavators and forklifts are being remanufactured, and items subject to technology development include transmissions, axles, cylinders, hydraulic motors, and hydraulic pumps [9-10]. On the other hand, hydraulic cylinders for drilling machines use products of the same standard as those of hydraulic cylinders of excavators, but their purpose and structure are slightly different. Hydraulic cylinders for drilling machines are used for support and transverse loads, and hydraulic cylinders for excavators are used for repetitive motion loads, so the purpose of hydraulic cylinders is different. However, since the production standards of hydraulic cylinders are the same, it follows the hydraulic cylinder standards for excavators. The hydraulic cylinder is a key component that operates working devices such as lifters, leaders, and outriggers by converting the hydraulic energy of hydraulic oil supplied from the hydraulic pump powered by the engine into mechanical energy for linear reciprocating motion. The bore drilling machine has individual cylinders for operating the working tools of the boom, power head and outriggers. A drilling machine (boring, Bore Drilling Machine, Borer, Boring Machine) is a self-propelled power machine used for construction ground work or geological survey (drilling, drilling, boring). The basic structure is roughly divided into the operating device, main body, and lower body. The operating device consists of a mast, cockpit, power box, and load changer, the main body consists of a jack trigger, an engine and various tanks, and the lower body consists of a frame, roller, and hydraulic motor. In this study, a drilling machine (Daewoo Heavy Industries, DR3600) manufactured in August 1995 was purchased before disposal and research was conducted to confirm the possibility of remanufacturing. The whole was disassembled to separate parts that could be remanufactured, and the purpose of this study was to confirm the possibility of remanufacturing the hydraulic cylinder among them. Continuous quality improvement activities and production process management are essential in order for remanufactured products of construction machines to maintain equivalent performance compared to unused products. However, in domestic manufacturers, failure mode effect analysis (FMEA) required to improve the important performance of hydraulic cylinders such as compressibility, oil leakage, equivalent stress characteristics and durability is insufficient. In addition, there are no standards related to machining dimensions, so not only basic performance and durability performance are secured, but also process management is not performed. Therefore, in order to improve this, technology development and research on remanufactured cylinders should proceed [11-12].

Remanufacturing is a manufacturing method in which products or parts are systematically recovered after use and restored to the same level of performance as new products through a series of processes such as disassembly, cleaning, inspection, repair/adjustment, and reassembly.

The remanufacturing process is shown in Fig. 1, which can be divided into 6 steps. The first stage is the process of disassembling parts after collecting the external corrosion, deterioration of performance, and discarded products. The parts that are subject to remanufacturing after use are called cores, and they are collected directly by the original manufacturer or collected by the remanufacturer. After use, the hydraulic cylinder is separately inspected for A and B grades, and defective products are discarded and sorted by use. The main disassembly steps are divided into tube assembly and rod assembly, and the rod assembly includes piston, packing, O-ring, bush, backup ring separation, component disassembly and tube cover disassembly.

The second stage is a cleaning process to reuse completely disassembled components, and steam cleaning, ultrasonic cleaning, and high-pressure cleaning are typical examples. After use, high-pressure solvent cleaning is used to clean the inner diameter of the hydraulic cylinder after use, and all packings of rods and pistons are separated and discarded, and parts other than rods and pistons are cleaned with high-pressure solvent.

The third step is the inspection process to determine whether the washed units are reused or not, and the possibility of repair and adjustment is determined through the visual inspection and performance inspection process.

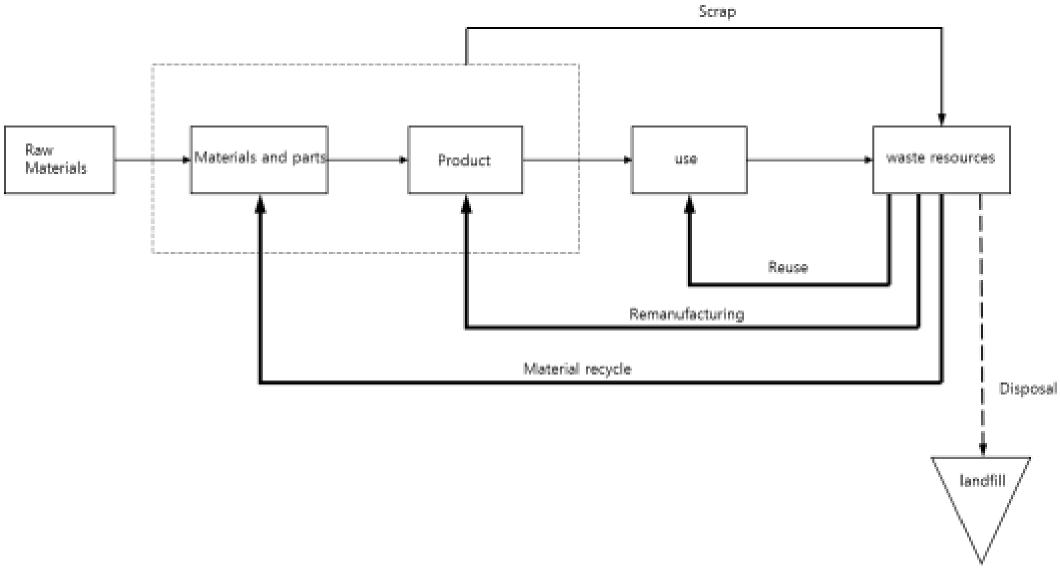

Fig. 1 Remanufacturing Process Process

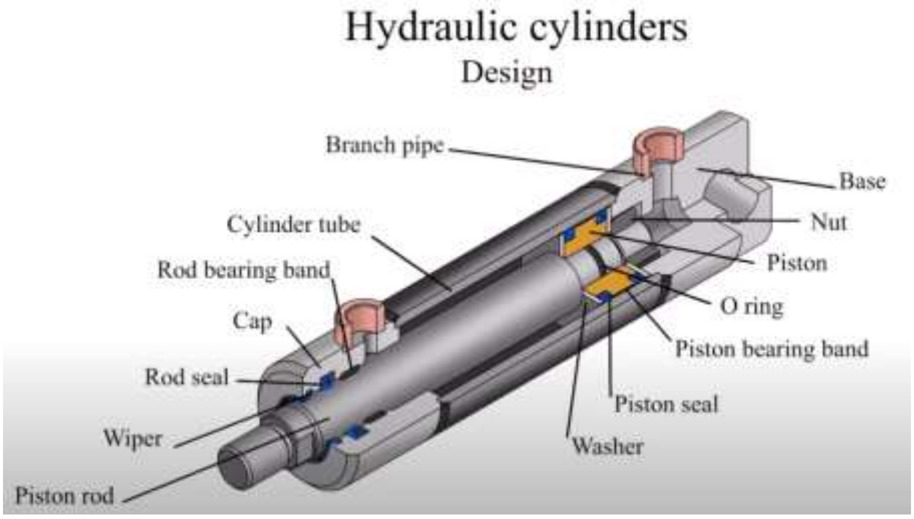

Fig. 2 Hydraulic cylinder

Table I Each part of the hydraulic cylinder

Repair or Reconditioning Parts		Substitution Parts	
Cylinder tube(Barrel)		O-ring	
Piston rod		Piston bearing band(Wear ring)	
Piston		Piston seal	
Base(End cap)		Rod bearing band(Wear ring)	

Cap(Gland)		Rod seal(Buffer seal)	
Hex nut		Wiper(dust seal)	
Washer		Branch pipe port	
Bushing		Clevis(Eye)	

Resource recycling refers to the recycling of industrial raw materials, parts, or products using process scraps obtained through the production process of various products. Resource recycling includes the comprehensive meaning of reusing products after use, remanufacturing, or material recycling. On the other hand, remanufacturing not only guarantees the same level of quality and performance as that of a new product, unlike repair that only solves the problem of defects in a specific part, but also requires a much higher level of the latest technology than repair.

Table I shows the parts related to the hydraulic cylinder. Figure 2 shows the hydraulic cylinder and Figure 3 shows the standard process for remanufacturing the hydraulic cylinder.

In this study, a technology for remanufacturing the hydraulic cylinder extracted from the drilling machine was developed by analyzing the failure. As a research method, replacement and repair parts were classified through failure analysis, and selection criteria were again presented by matching the theory and application criteria for replacement parts to the product. Repair parts were classified into discarded parts and partial repairs, and the discarded parts were determined to be non-repairable based on their appearance, and repairable parts were repaired. In addition, a hydraulic cylinder test device was developed to present a reliable remanufacturing standard, and the leakage amount of the cylinder was measured based on this test device. The cylinder reassembled by repair and replacement of parts was tested again in accordance with KS 4038 to confirm the quality as a remanufactured product. Through this study, reasonable judgment standards for industrial sites were prepared by suggesting remanufacturing standards at the level of simple recycling and minimum quality standards.

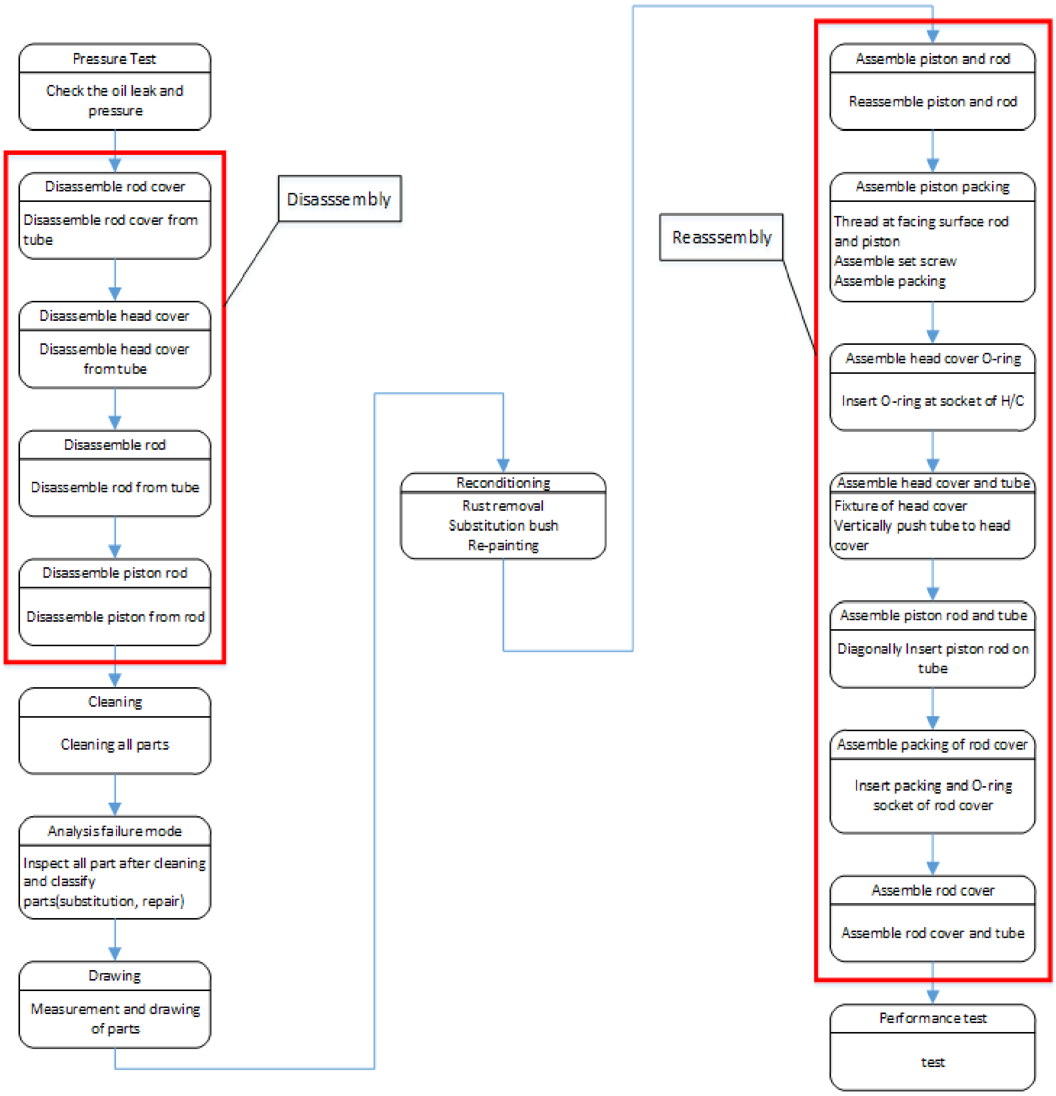

Fig. 3 Hydraulic cylinder remanufacturing process

2. EXPERIMENT

2.1 EXPERIMENTALA APPROACH

The test method for a remanufactured hydraulic cylinder for an excavator is based on the test method specified in KS I 4038:2019, with a rated speed of 1.5 m/s or less, a rated pressure of 40 MPa or less, a piston diameter of 60 mm to 300 mm or less, It was applied to remanufactured hydraulic cylinders with a stroke of 3,000 mm or less. Here, the rated pressure is the set pressure of the relief valve of the hydraulic circuit used as the allowable maximum value of the pressure generated inside the hydraulic cylinder, and the minimum operating pressure is the minimum pressure that can guarantee operation. Stick slip refers to a vibration phenomenon caused by discontinuous sliding between friction surfaces. The hydraulic cylinder force is defined as the theoretical fluid force acting on the piston face, and the hydraulic cylinder power is the mechanical power transmitted by the piston rod, and the hydraulic cylinder power Thrust efficiency is defined as the ratio of hydraulic cylinder power to hydraulic cylinder power.

As a general rule before proceeding with the test, the appearance of the hydraulic cylinder should be good, there should be no abnormalities such as breakage, bending, torsion, etc., and it should not affect other performance. The hydraulic fluid quality requirements were selected according to the KS M 2129 standard, and ISO VG 32 or ISO VG 46 was used as the hydraulic fluid.

2.2.1 MIMIMUM WORKING PRESSURE TEST

This test is conducted to evaluate the performance at the lowest operating pressure of the hydraulic cylinder. Install the hydraulic cylinder horizontally on the test equipment with no load and reciprocate 30 times at the operating speed of the hydraulic cylinder at 10mm/s and 10% of the rated pressure. During this process, check that the piston moves smoothly and there is no abnormal noise.

2.2.2 Starting pressure test

After completing the minimum operating pressure test, keep the piston at the center of the hydraulic cylinder for 24h, open the pipe on the head side, and gradually supply pressure to the rod side. Measure the pressure and record the starting pressure on the rod side. Open the pipe on the rod side and gradually supply pressure to the head side, measure the pressure when the oil leaking from the rod side port reaches

0.05mL/s or more, and record the starting pressure on the head side. At this time, if the initial test result is not satisfied, the test can be performed again after performing the no-load operation about 20 times.

2.2.3 Internal leak test

Install the hydraulic cylinder horizontally on the test equipment with no load. After stopping the hydraulic cylinder rod in reverse, open the pipe of the head port and apply the rated pressure to the rod port for 10 min. Measure the amount of leakage from the port on the head side and record the internal leakage on the rod side. After stopping the hydraulic cylinder rod forward, open the pipe on the rod side port and apply the rated pressure to the head side port for 10 min. Measure the amount of leakage from the rod side port and record it as internal leakage at the head side.

2.2.4 External leak test

Install the hydraulic cylinder horizontally on the test equipment with no load and clean the rod surface. Measure the amount of leakage in the wiper part of the rod after reciprocating the cumulative piston movement distance of 100m with more than 90% of the total stroke of the hydraulic cylinder.

2.2.5 Stick slip test

Install the hydraulic cylinder horizontally on the test equipment with no load, and apply pressure in steps of 10% of the rated pressure to the rod side and the head side. Check for stick-slip phenomenon and abnormal noise over the entire stroke.

2.2.6 Thrust Efficiency Test

Install the hydraulic cylinder horizontally on the test equipment. Install a load cell between the test hydraulic cylinder and the load hydraulic cylinder and operate at rated pressure and rated speed. Measure the pressure and load cell values when the hydraulic cylinder moves forward and backward. Thrust efficiency is calculated by the following formula.

$$\lambda = \frac{10 \times F}{P \times A}$$

λ: Hydraulic Cylinder Thrust Efficiency (%)

F: hydraulic cylinder force (kN)

F: pressure acting on the piston face (MPa)

A: Effective piston cross-sectional area (cm^2)

2.2.7 Lateral load test

Install the hydraulic cylinder horizontally on the test equipment and install a weight at the end of the rod so that a lateral load of 1% of the maximum hydraulic cylinder thrust is applied. Reciprocating operation is performed 1,000 times at 90% of the total stroke distance of the hydraulic cylinder. Perform an external leak test and record the amount of leak.

2.2.8 Pressure test

Install the hydraulic cylinder horizontally on the test equipment in a no-load state, and retract the hydraulic cylinder rod to make it stop. Apply 200% of the rated pressure to the rod and head of the hydraulic cylinder for 5 min. Check for any abnormalities such as deformation, loosening, and destruction, and record the amount of leakage by performing an external oil leak test.

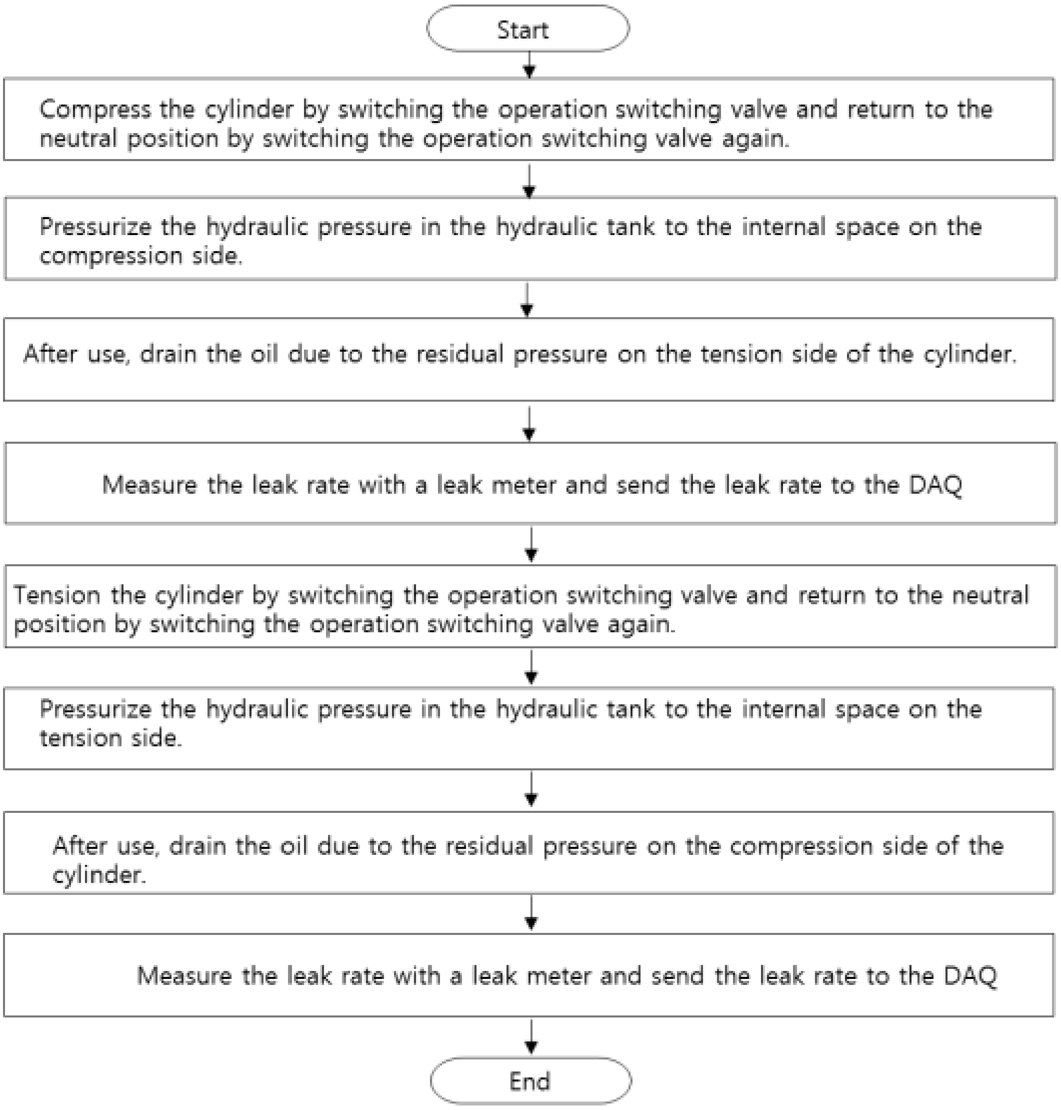

Fig. 1 Experimental Process

3. EXPERIMENTAL RESULTS

3.1 HYDRAULIC CYLINDER MEASUREMENT TEST RESULT

The internal leakage measurement method uses the pressure drop method to check the presence of internal leakage by measuring the pressure drop after shutting off the pressure of the port to be pressurized. However, in this study, the remanufactured cylinder and the waste cylinder can be distinguished from the static pressure method that measures the pressure of oil leaking from the port as opposed to the flow method that directly measures the amount of internal leakage.

First, it was decided to dispose of it through an external inspection, and the possibility of remanufacturing was determined through an internal leakage measurement test.

For the experiment, 1) a leak test using a flow meter and 2) a leak test using a static pressure were performed. All cylinders used in the experiment are used cylinders. The leak test using a flowmeter is a front outrigger sliding cylinder of cylinder number 4, and one has already been discarded due to the bending of the rod, the cylinder inner diameter is Ø100, the rod outer diameter is Ø63, and the stroke is 1080mm. The test pressure is 87 bar, the test flow rate is 7ℓ/min, and the measurement items are internal leakage and pressurization pressure.

On the other hand, the cylinder used for the leak check test under static pressure is the No. 8 Outrigger, and there are 4 cylinders, and the cylinder inner diameter is Ø125, the rod outer diameter is Ø80, and the stroke is 1560mm. The test pressure is 76 bar, the test flow rate is 7ℓ/min, and the measurement items are the leakage flow rate, pressurization pressure, and static pressure due to internal leakage. Table 2 is a table showing the allowable value of internal leakage according to the cylinder inner diameter specified in KS B 6370 5.5 of the packing standard.

Table II Allowable value of leakage according to inner diameter (KS B 6370 5.5)

Inner diameter	leakage (ml/10 min)	Inner diameter	leakage (ml/10 min)	Inner diameter	leakage (ml/10 min)

32	0.2	40	0.3	50	0.5
63	0.8	80	1.3	100	2.0
125	2.8	140	3.0	160	5.0
180	6.3	200	7.8	220(224)	10
250	11.0				

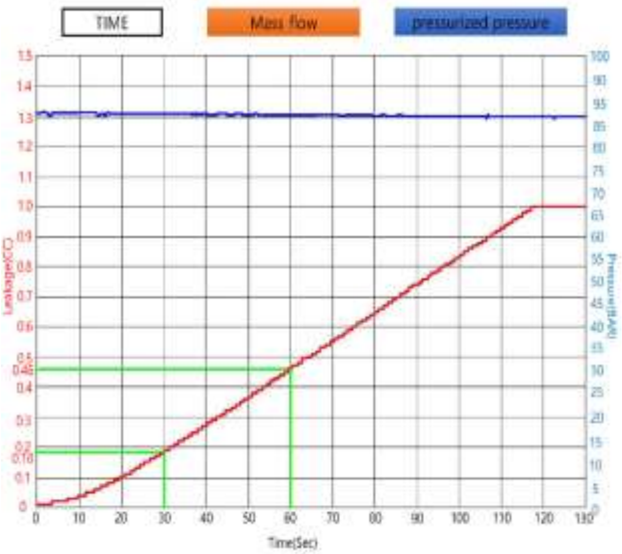

Fig. 5 Leakage test using a flowmeter

The test for checking the amount of leakage using a flow meter was conducted using a cylinder with an internal leakage of less than 1 cc/min. In Fig 1, the accumulated flow was measured after the oil leakage stabilization time, and 0.46cc was leaked for 1 minute. In this case, the cylinder was required to be remanufactured because it was out of the allowable leak rate.

In the experiment to check the amount of leakage through the static pressure, a cylinder with an internal leakage of 10cc/min or more was used. Figure 6 is a graph recorded after the oil leakage stabilization time. Since 10.41cc leaked from 20 seconds to 28.7 seconds, the total leakage flow rate was 71.79cc/min. Therefore, it is a cylinder that deviates from the standard and needs to be remanufactured. It can be seen that the static pressure of 8.7Bar is formed in 180 seconds, which is about 150 seconds after the initial oil discharge and the selected valve is switched in 28.7 seconds. In other words, it was possible to know whether or not an oil leak occurred by increasing the pressure of the opposite port due to the internal leakage.

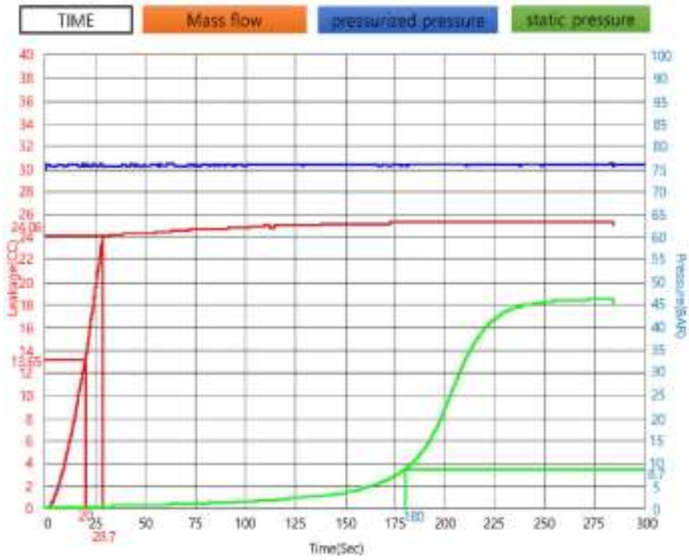

Fig. 6 Leakage test through static pressure

The next experiment is to measure cushion performance and stroke distance by the flow rate discharged from the cylinder. By measuring cushion performance, stroke distance, and flow rate, it is possible to classify cylinders that are difficult to classify remanufactured cylinders only by measuring leakage. A check valve and a pilot check valve were installed in the flow supply port and compression port for cylinder tension, respectively, and a flow meter was installed in the recovered hydraulic line to connect a monitor type data logger (Portable Data Logger).

The test cylinder is cylinder 3, Cabin Cylinder, with an inner diameter of Ø100, a rod diameter of Ø55, and a stroke length of 1500±2mm. As the experimental conditions, the test pressure was 72Bar and the test flow rate was 54ℓ/min.

After the experimental cylinder was mounted on the experimental bench, the experimental cylinder was pulled and compression stroke was performed. The value measured through the flowmeter installed in the recovery line was recorded as a graph using a data analysis program, and then the flow data was analyzed. In addition, experimental data were measured simultaneously.

The measurement items were flow rate, accumulated flow rate, and stroke, and are shown in [Fig 6]. Fig. 7 is the measurement result of the extension test and Fig. 8 is the measurement result of the compression test. The red graph is the extension and compression graph of flow measurement, and the transparent gray box on the right is the cushion section.

In other words, the buffer performance was obtained in two places when the experimental cylinder was extended and compressed, and the utilization of the flow data was determined by analyzing the values.

Therefore, 1) the buffer period is the time from the section where the deceleration starts to the section where the deceleration speed becomes "0". 2) The buffer deceleration pattern can be used to determine whether the deceleration proceeds within the range per row when testing a cylinder of the same specification after giving the upper and lower limit values to the deceleration section graph. 3) The buffer distance is the distance from the stroke where the deceleration starts to the stroke where the deceleration ends. 4) The buffer deceleration rate is calculated by obtaining the data of the constant speed section (speed between 30% and 80% of the cylinder stroke) and the shift section of the stroke data. 5) The stroke distance calculation of the cylinder can be calculated by dividing the accumulated amount of oil discharged from the cylinder by the amount of oil discharged per unit length to obtain the stroke of the laboratory cylinder, and can be selected by comparing it with the actual stroke data.

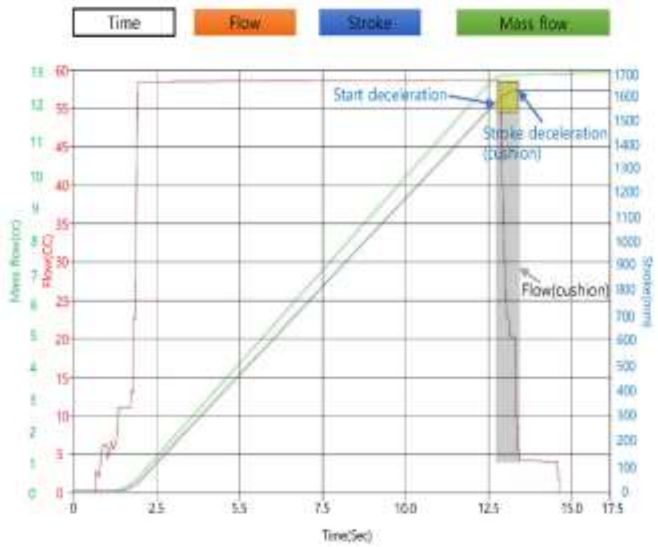

Fig.7 Accumulated leakage due to cylinder extension

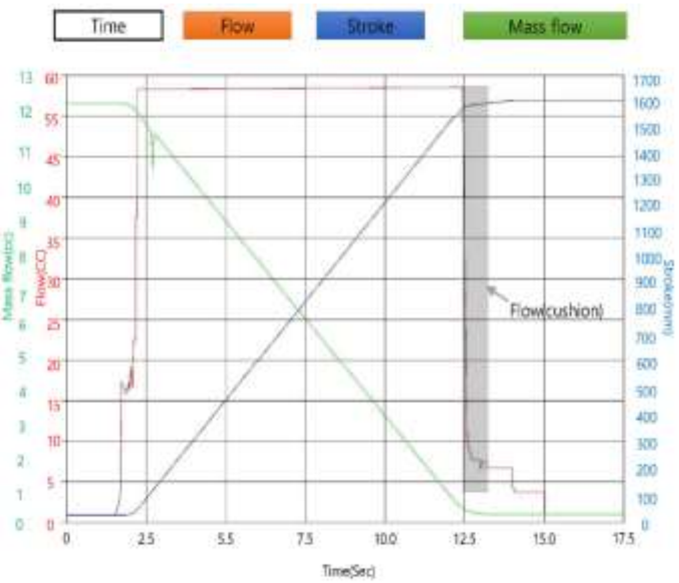

Fig.8 Accumulated leakage due to cylinder compression

Fig. 9 is a graph analyzing the flow rate curve in the buffer section when the normal cylinder is tensioned. Red is the test graph and blue is the applied error range. After testing another cylinder with the same specification, it is possible to check whether the cylinder piston and buffer ring are defective according to the flow rate curve of the same similar shape through flow analysis in the buffer section.

Fig. 10 is the result of analyzing the flow rate of the buffer section during elongation after assembling the piston end buffer ring in reverse to the cylinder of the same specification, and it can be confirmed that there is a defective assembly.

Fig. 11 shows the results of testing for tension after assembling the same length without processing the buffer ring on the cylinder of the same specification. Fig. 11 shows the results of the experiment after cutting and assembling the buffer ring in the buffer zone at the end of the piston. In Fig. 11, it can be seen that there are assembly defects, machining defects, and piston defects. Fig. 12 is a graph of the flow rate curve in the buffer section when the normal cylinder is compressed.

Therefore, when a cylinder product of the same specification is tested using the flow characteristic curve of the buffer section, it is possible to analyze the buffer performance pattern in another method by comparing it with the shape of the flow characteristic curve (deceleration pattern) set as the reference value. It is possible to select whether the product is good, assembly defect, or processing defect.

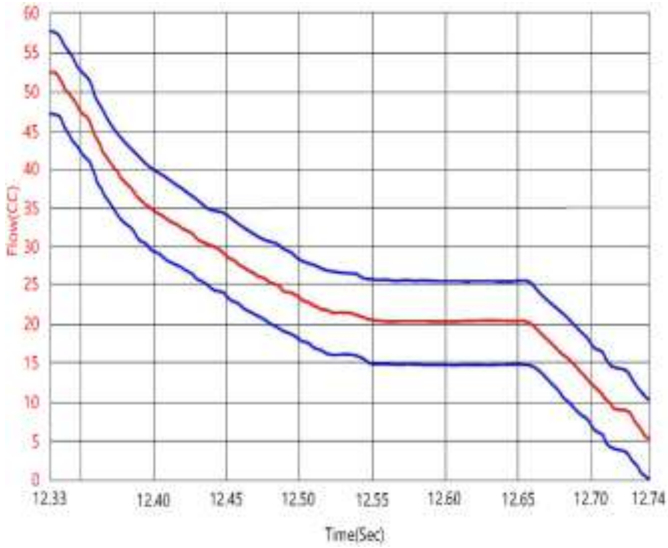

Fig.9 Analysis of flow curve in buffer section during normal cylinder tension

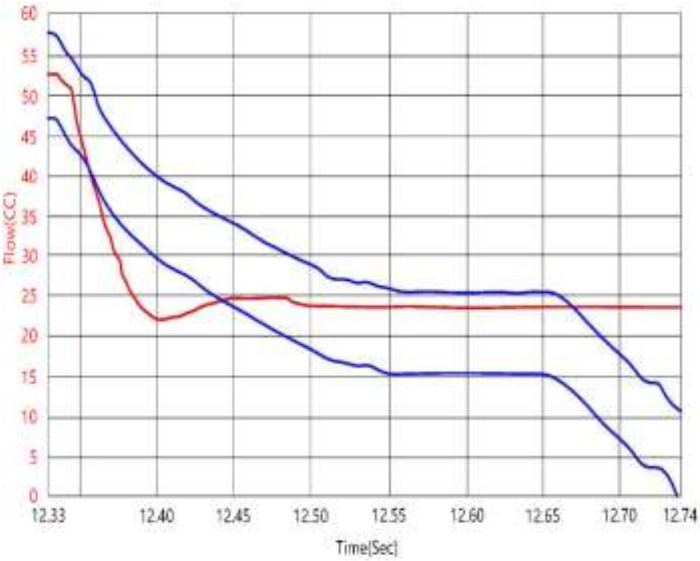

Fig.10 After assembling the buffer ring in reverse, analysis of the flow rate in the buffer section (tension)

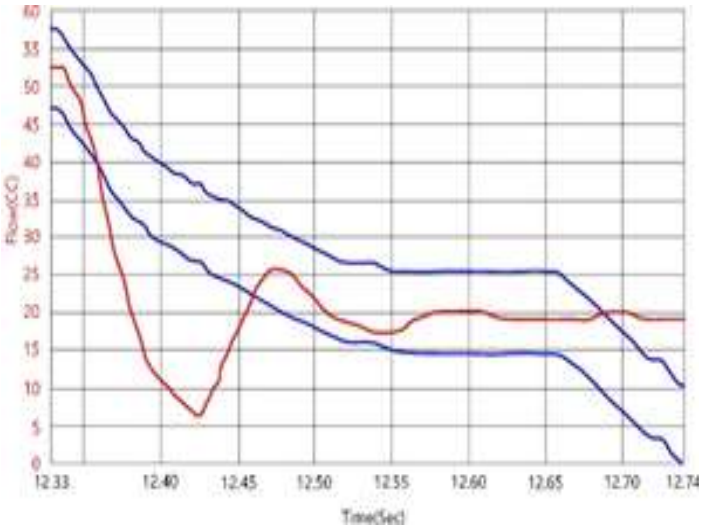

Fig.11 After assembling the defective buffer ring, flow analysis in the buffer section (tension)

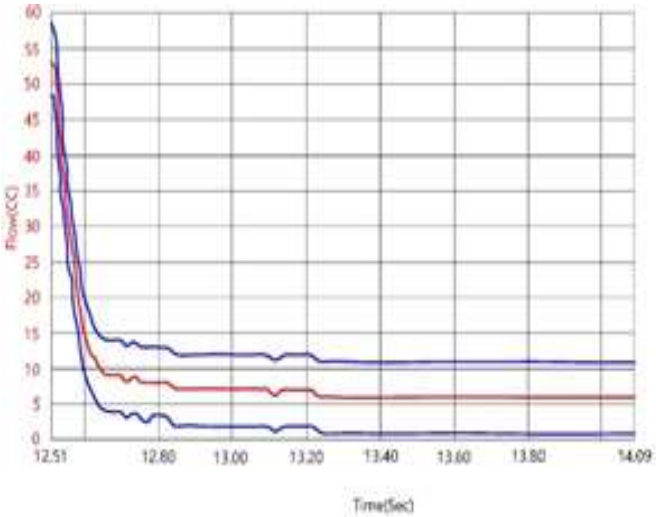

Fig.12 Flow curve for normal cylinder buffer section (compression)

4. CONCLUSION

In this study, the test apparatus of the remanufactured hydraulic cylinder for construction machinery was tested and analyzed in accordance with REMAN 304 and KS I 4038, and 95% of the performance compared to the new product was confirmed. Through this, the durability life of the remanufactured hydraulic cylinder was predicted, and the following conclusions were drawn through the study.

1) A test device was developed based on the pressure of 280kgf/cm^2 (27.45MPa) of the hydraulic pump of a 30-ton excavator, and 17 types of remanufactured hydraulic cylinders were tested and analyzed.

2) The reliability of the test equipment was increased by designing and manufacturing the oil tank, accumulator, hydraulic pump, and power unit according to the standards.

3) As a result of analyzing 17 remanufactured hydraulic cylinders using the developed test device, the performance of 95% compared to the accepted standard was confirmed.

Considering the above results, it was possible to check the quality of the remanufactured hydraulic cylinder products by packing selection and testing using a testing device, and the technical guidelines and methods to secure the reliability of the remanufactured hydraulic cylinders has been prepared.

REFERENCES

[1] Shearer, J., “Digital Simulation of a Colom-Damped Hydraulic Servosystem,” J. of Dynamic Systems, Measurement and Control, Trans. ASME, Vol. 105, pp. 251-211, 1983.

[2] Industry Standards Council, “Excavator Remanufacturing Hydraulic Cylinder Test Method KS I 4038,” The Korea agency for Technology and Standards, 2019.

[3] Industry Standards Council, “Excavator Remanufacturing Hydraulic Cylinder Quality Certification,” The Korea Agency of Technology and Standards Notice No. 2020-0075. REMAN 304, 2020.

[4] Kang, H., Kim, Y. and Lee, I., “Current Status and Promotional Measures of Domestic and Overseas Remanufacturing Industry,” J. of Korean Inst. of Resources Recycling Vol. 21, No. 4, pp. 3-15, 2012.

[5] Finney, J., Pennington, A. and Gill, G.,“A Pole Assignment controller for an Electro-hydraulic Cylinder Drivers,” J. of Dynamic Systems, Measurement and Control, Trans. ASME, Vol. 107, pp. 145-150, 1985.

[6] Yamashita, Y., “.Hydraulic and Pneumatic Components with Shock-absorbing Capacity,” J. of Japan Fluid Power System Society, Vol. 35, No. 2, pp.106-109, 2004.

[7] Saito, K., "Cylinder Cushing Mechanism," J. of Japan Fluid Power System Society, Vol. 39, No. 2, pp.97-102, 2008.
[8] Kim, D. and Zhang, Z., "Analysis of Cushion Mechanism with Relief Valve for High-speed Pneumatic Cylinder," Trans. of KSAE, Vol. 18, No. 3, pp.95-103, 2010.
[9] Kim, J., Kang, H., Han, S. and Y. Kim, Y., "Motion Characteristics of Hydraulic Actuator with Various Cushion Shapes," KSFM J. of Fluid Machinery, Vol. 18, No. 3, pp.95-103, 2010.
[10] Lee, Y. and Yoon, Y. "Modeling and Simulation of a Hydraulic Servo Actuator Cushion for Power Plants," J. of KSTLE, Vol. 29, No. 1, pp.7-11, 2013.
[11] Lee, Y., Ko, J. and Park, J. "Study of the Cushion Characteristics in accordance with Shapes of Cushion ring of Hydraulic Cylinder," J. of Drive and Control, Vol. 5, No. 2, pp.61-66, 2008.
[12] Mok, H., Jeon, C., Han, H., Song, M.., Park, B., Kwak, H. and S. Park, "A study on remanufacturing Industry for automobile parts," Trans. of KSAE, Vol.19, No. 6, pp.184-191, 2008