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DEVELOPMENT OF A DYNAMIC HIGH PRESSURE SEAL UP TO 500 MPa

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Abstract − Applications of high pressure are becoming more important in the field of heavy machinery, plant industries, novel material development and so on. The requirement of the maximum pressure limit is being constantly increased. This paper describes a sealing concept designed to increase pressure up to 500 MPa or more using bronze filled PTFE (PolyTetraFluoroEthylene) which takes advantages of both metal and PTFE. The sealing effect and the test results of the simple structure, which are similar to a re-entrant piston/cylinder, will be described in this paper.

Keywords : Dynamic Seal, Re-entrant Structure, Bronze-Filled PTFE (PolyTetraFluoroEthylene)

1. INTRODUCTION

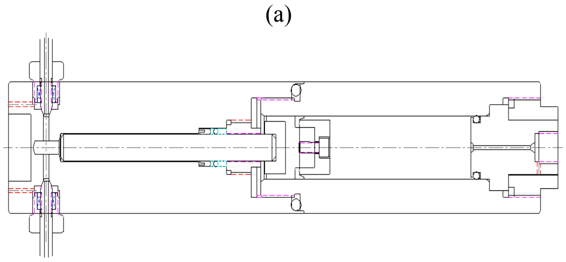
High pressure generation is required for various applications such as heavy machinery, petro-chemical industry, manufacturing, food industries and so on. Mechanical seals are devices that prevent leaks where two systems join and they can be divided into static seals and dynamic seals. There are a variety of commercial static seals, such as an O-ring, a compression seal, a diaphragm seal, and a seal using gasket. Among the above seals, an O-ring made of rubber is being used most widely in the pressure field since it has a good elastic characteristic in a wide pressure range. In order to generate high pressure up to 100 MPa, there are many kinds of available sealing techniques, including an O-ring. However, an intensifier should be used for the pressure over a few of hundred MPa, which has dynamic seals and a piston/cylinder unit inside in order to pressurize the medium. If the gap between a piston and a cylinder is manufactured with a high tolerance like PCUs (Piston Cylinder Units) used for pressure balances, the pressure control will be very effective. However, the cost might be a problem in this case. Therefore, the development of effective mechanical seals is required to reduce the cost and to prevent leaks effectively.

Generally, flexible materials, such as urethane, rubber, PTFE, soft metal, and sometimes leather, are used for the seal of an intensifier. PTFE is best known by the DuPont brand name, Teflon. Most intensifiers use an assembly with a few of the seals mentioned above.

An intensifier consists of high and low pressure parts, whose piston area ratios are generally 5:1, 10:1, and 13:1. Various seals used for the low pressure part are available, but seals for the high pressure part should be designed and manufactured elaborately in order to prevent leaks and seal ruptures. Since stress, even in the low pressure part, can be concentrated on some specific area, the material or shape of all components should be considered carefully in the design stage.

Recently, KRISS (Korea Research Institute of Standards and Science) developed a 500 MPa intensifier with a peculiar seal design. In this paper, we describe the design and the experimental results of the dynamic seals for the development of a 5:1 intensifier. Fig. 1(a) shows the bodies of commercial intensifiers and the KRISS intensifier. The dark surface resulted from an annealing treatment, but there has been no body crack or deformation in the pressure range up to 500 MPa even when it was not under any treatment. The treatment will be required in the higher pressure range. Fig. 1(b) shows the design of the KRISS intensifier.

(a)



(b)

Fig. 1. 500 MPa intensifier

2. DESIGN AND MANUFACTURING OF THE DYNAMIC SEAL

2.1. Dynamic seal

An O-ring, a single-acting seal, or a double-acting seal can be used for the dynamic seal since they have very good elastic and tough characteristics together. In general, they are used with other components, for example, backup rings, which are made of various materials. They are off the shelf devices and are relatively cheap.

In this paper, the seals were tested in order to check suitability for high pressure applications up to 500 MPa. Generally, an O-ring can be used for a pressure seal up to 200 MPa without any special design. Fig. 2 shows the test result with damaged seals at high pressure when an O-ring is used for the static seal. There was a leak through the seal, and the O-ring was ruptured at 400 MPa. The rupture pressure was dependent on the size of the O-ring. If the seal is designed and manufactured within an excellent tolerance below 0.01 mm, the pressure generation limit may be increased. However, it is difficult to apply only the O-ring to a 500 MPa intensifier due to the safety.

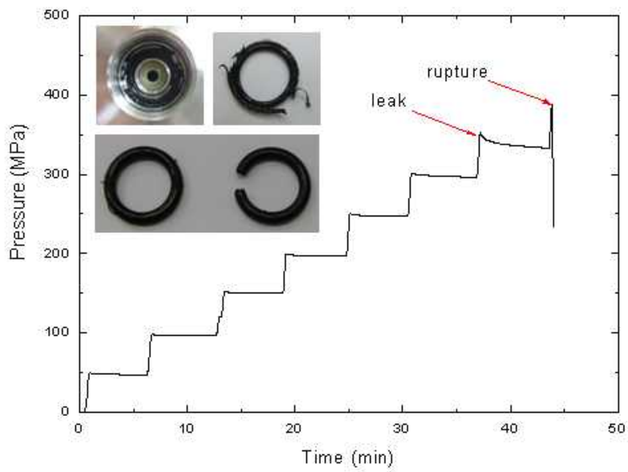
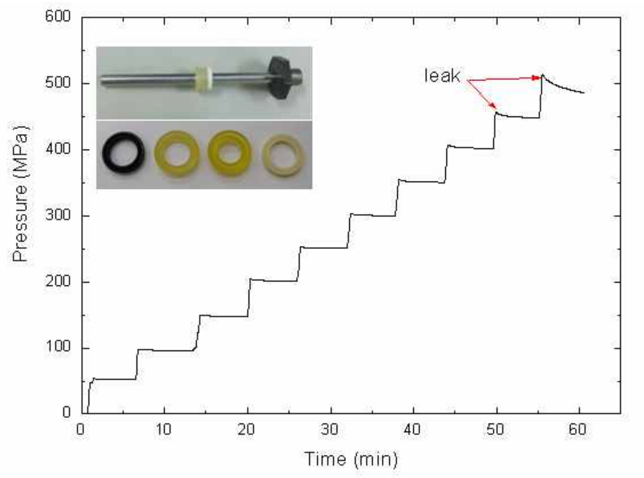


Fig. 2. O-ring test result and ruptured seal: the seal was ruptured at 400 MPa

The application of a single-acting urethane seal to the pressure instrument is very effective because it has a wide elastic region and is stronger than an O-ring. Also, it has relatively low cost, even when the seal is custom-made. Fig. 3 shows the result of the leak test when the single-acting seal (picture inside) was used for the high pressure part of an intensifier.

As shown in Fig. 3, the pressure leak begins over 450 MPa, and it is more or less serious at 500 MPa. When pressure is applied rapidly to vessel, it takes a little time to be stabilized. Therefore, the small decrease rate in the Fig. 3, even at low pressure, is normal phenomenon. When the pressure inside the vessel is released rapidly, the opposite effect can be found. However, the pressure decrease at 500 MPa is very rapid compared to the stabilization time. Even though the seal was pressurized over 600 MPa, the seal has not been damaged or ruptured due to strong elastic characteristics.

Since off-the-shelf seals are not suitable to the high pressure intensifier over 500 MPa as described above, a new design and material is required. Without elaborate manufacturing, the seal should be able to be applied to an intensifier over 500 MPa.



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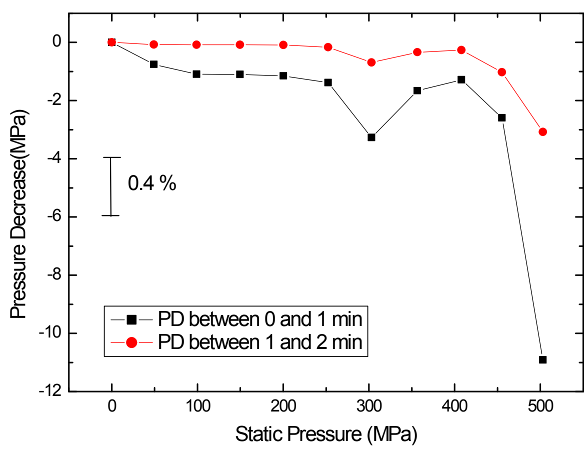


(b)

Fig. 3. Unidirectional urethane seal test result and Pressure Decrease (PD) rate with respect to pressure

2.2. Re-entrant sealing design

Common static seals are strongly pressurized when assembled. Since the pressurized seals such as a metal-to-metal seal (compression seal) have a plastic deformation, they cannot be used more than a few times. Specially, the dynamic seal should allow a piston to move freely in order to increase pressure precisely. A precise piston/cylinder assembly used for pressure balances can be an alternative to the dynamic seal. However, it is difficult to precisely manufacture the piston/cylinder with a large diameter for large volume changes of the vessel inside, and there is the problem of high cost[1]-[2].

A very effective design for the purpose of intensifier development using flexible material is shown in Fig. 4. Since the bronze-filled PTFE takes advantages of both metal and PTFE, it has a long elastic region and relatively high strength. The engagement length of the bronze-filled PTFE in the re-entrant shape is very important. The long seal is more effective than a short one, but it can cause high friction force between the piston and seal. The free movement of the piston is directly related to fine pressure control. The brass backup-ring also plays a critical role because it prevents the seal from going into the gap between the cylinder and the ring at high pressure.

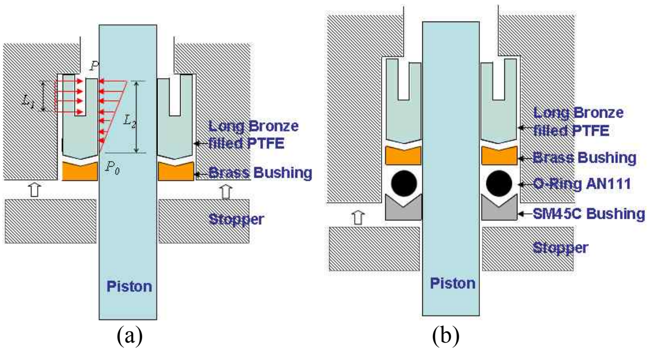
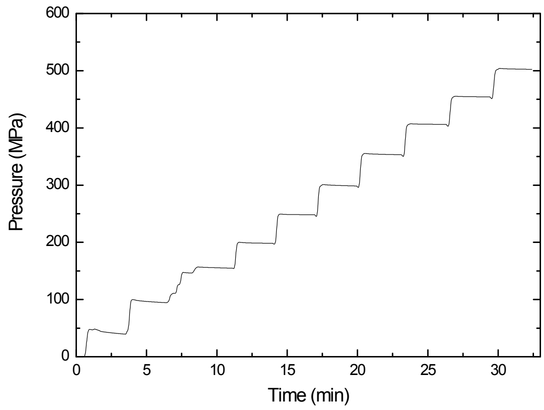


Fig. 4. Re-entrant sealing design

3. SEAL PERFORMANCE EXPERIMENT

A seal using the bronze filled PTFE with a re-entrant structure is much more effective than a single-acting seal using urethane, or an O-ring assembly, as mentioned before. Fig. 5 shows the test results when the bronze filled PTFE seal shown in Fig. 4(a) was used. Generally, a leak becomes greater according to the pressure, but the bronze filled PTFE seal has leaks less at high pressure due to self deformation as shown in Fig. 5(b). The seal is not deformed sufficiently at low pressure, since it has slightly higher strength than rubber or urethane. If the engagement length (L_1) of the seal is short, the pressure is not sealed completely.

In order to prohibit leaks at low pressure, an O-ring can be used as a double seal concept as shown in Fig. 4(b). If the initial gap between the bronze filled PTFE and the piston is not within the allowed tolerance, the O-ring can be ruptured. Fig. 6 shows excellent results when the double seal was used, even in the low pressure range. The seal was reusable even when tested over a few of hundred times and reassembled, since the bronzed filled PTFE has excellent elastic characteristics. There is a Korean patent pending for this structure[3].



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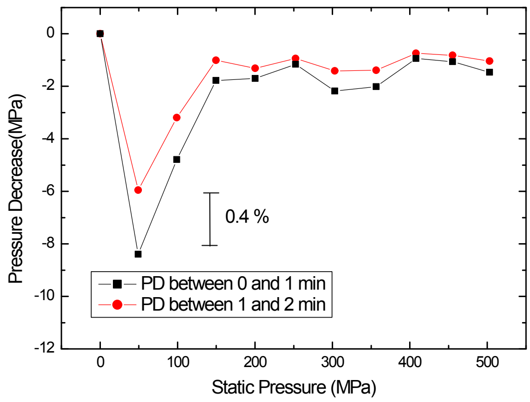

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Fig. 5. Bronze filled PTFE seal test result and Pressure Decrease (PD) according to pressure

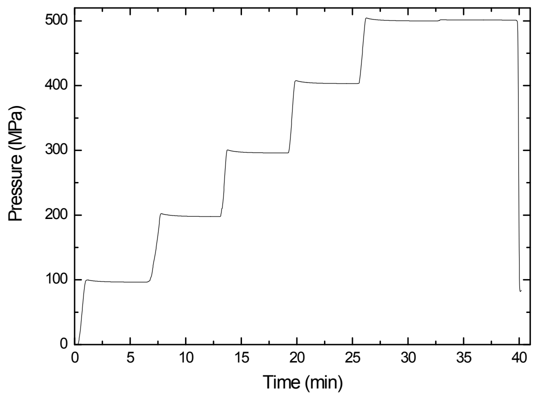
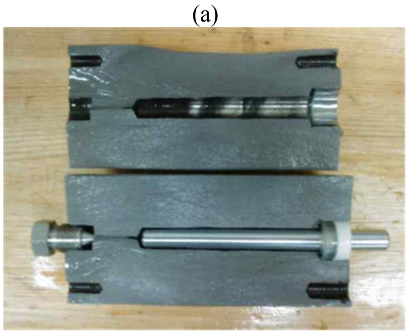


Fig. 6. Test result of the bronze filled PTFE seal with O-ring backup

(a)



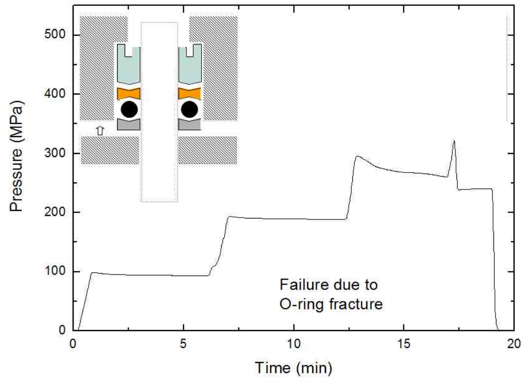
(b)

Fig. 7. Example of seals and backup rings failure

4. DISCUSSIONS

As mentioned before, the tolerance of the seal and backup ring is very important. Fig. 7 shows the ruptured components of seals used for the intensifier. The soft metal such as brass or SUS, might be under the plastic deformation range at 500 MPa. Therefore, the stress concentration should be carefully considered in the design stage. The concentrated stress over the yield strength of the material used for seals can cause the plastic deformation, and it eventually causes leaks. Furthermore, in order to prevent the plastic deformation of the metals, they should be treated or annealed. However, the annealing can have a reverse effect as shown in Fig. 7(b), if the annealing condition is not determined well. The treatment can increase the strength, but can cause susceptibility to internal cracking.

If a bronze filled PTFE with a short engagement length is used alone, pressure does not increase at all. However, if it is used with an O-ring, it becomes very effective. However, even when the seals were used together, the O-ring normally ruptured between 200 MPa and 300 MPa without appropriate backup rings as shown in Fig. 8(a). When a short bronze filled PTFE is used, the O-ring plays a critical role, and the tolerance of the backup ring becomes very important. If the backup ring was designed and manufactured carefully, there was no rupture up to 500 MPa, as shown in Fig. 8(b) despite the leak around 500 MPa.



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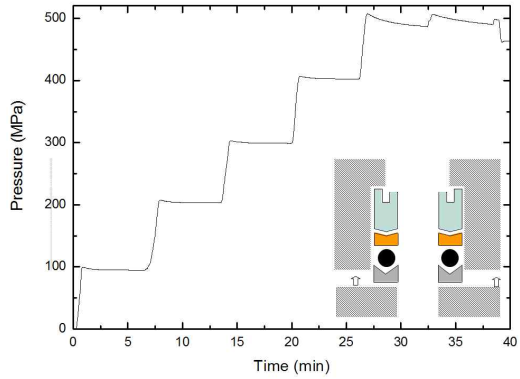

(b)

Fig. 8. The effect of backup ring design

5. CONCLUSIONS

KRISS has designed and manufactured a 5:1 intensifier with a peculiar seal of the bronze-filled PTFE. The seal showed very effective test results up to 500 MPa. In the future, the pressure range can be extended with a small gap tolerance.

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[3] Korea Patent, 10-2008-0096969 (pending)