Evaluation of Mechanical Properties and Sealing Performance of 24” Pipe Flange Connections with No.GF300 Gasket

1. Introduction

Gasketed pipe flange connections are used in many petrochemical plants, power, steel plants, etc. Asbestos gaskets are widely used because of their high heat resistance, sealing properties, high strength, easy handling properties, and economical with numerous studies having been conducted[1)-3)]. There have been numerous reports of human health hazards with asbestos gaskets published and regulations have been established in Japan since around the year 2000. However, this trend has been advancing in Europe and the United States for some time. Since 2008, asbestos gaskets cannot be used in Japan[4)].

There are two types of asbestos gaskets which are asbestos filled spiral wound gaskets and asbestos joint sheet gaskets. There were no major problems in replacing asbestos filler with expanded graphite filler of spiral wound gaskets. On the other hand, as alternatives for asbestos joint sheet gaskets, a non-asbestos joint sheet gasket containing aramid fibers, an expanded graphite sheet gaskets, and a PTFE compound sheet gaskets were developed and evaluated[5)]. Since the aramid joint sheet gasket contains a large amount of rubber, it hardens and cracks in a high temperature environment, and the bolts cannot be tightened. The expanded graphite sheet gasket is easily damaged and has poor handling properties. From this background, PTFE compound gaskets have become widely used in Japan. PTFE is excellent in heat resistance, chemical resistance, and sealing properties, and the problem of large creep has been greatly improved by improving the compounding formulation and manufacturing method. However, the PTFE compound gasket do not have a track record as asbestos gaskets do until now, and for this theoretical property study or research is required. We have been investigating the mechanical behavior of connection flange joints incorporating our PTFE compound gasket No. GF300 under normal and high temperature environments and under pipe bending[6)-8)].

It is known that gasketed connection flange connections have various nominal dimensions, and their characteristics change when the nominal diameters are different. In particular, it is said that the sealing property of the connections deteriorate as the nominal diameter increases. However, due to cost and time issues, most of the research on connection flange connections with gaskets has targeted relatively small diameter dimensions of 2 to 6 inches, and the characteristics of large diameter flange connections are yet to be clarified. Sawa et al. used a 20 inch sized pipe flange connection to characterize a spiral wound gasket connection, demonstrating that it differs from the characteristics of a small diameter pipe flange connection and that it is less sealable[9)-13)]. However, the ASME standard stipulates a 24 inch flange size with a larger nominal diameter, in addition, the mechanical properties and sealing properties of a large-diameter connection flange fastening body incorporating a widely used PTFE compounded gasket hanve not yet been investigated. Therefore, study of a pipe flange connection using such a gasket is necessary.

The purpose of this study is to evaluate the mechanical properties of the 24 inch tube flange fastener with No.GF300 by FEM analysis and experimentally. First, the basic characteristics of No.GF300 gasket are investigated in accordance with JIS B 2490[14)]. These basic data are to be used in the FEM-analysis to calculate the axial bolt force variations and gasket contact-stress distributions. In addition, the amount of leakage from the pipe flange connection is estimated using the gasket contact stress distribution calculated from the FEM analysis and the leakage gasket stress relationship obtained from the experiment. Experiments will be conducted to show the validity of the FEM analysis, and the experimental results and the FEM analysis results will be compared and examined.

In the experiment, the amount of leakage from the pipe flange connection and the fluctuation of the axial bolt force are measured. The pipe flange connections used in this study were ASME class 300 24 inch-sized connections.

Our high-performance sheet gaskets containing PTFE, such as No.GF300 used in this research, are widely used because of their excellent heat resistance, chemical resistance, sealing properties, and handling property. In addition, since it does not contain any rubber, material deterioration does not occur at temperatures below 300℃ or over time and it is considered that mechanical properties can be evaluated with high accuracy in this study.

2. Experimental method

Figure1 shows the No.GF300 gasketed pipe flange connection equipment for measuring axial bolt force fluctuations and leaks. The pipe flange connection size is ASME class 300 24 inches, and the material is SUS304[15]. It is known that the characteristics of the pipe connector change greatly depending on the presence or absence of a pipe, and this device has a long pipe like the actual pipe connection. The size of the gasket is ASME class 300 24 inches, the thickness is 3.0 mm, and the bolt nominal diameter is M39.

Strain gauges are attached to the longitudinal axis of all 24 bolts, and the axial bolt force can be measured and recorded by connecting to a strain gauge. All strain gauges are pre-calibrated. The amount of leakage from the pipe flange connection is measured by the following equation (1) using the pressure drop method.

Figure1　Experimental equipment of 24-inch pipe flange connection

$$L = \frac{MV}{tRT_1}\left(P_1 - \frac{T_2}{T_1}P_2\right) \qquad (1)$$

Here, L : leakage amount, M : molar mass, V : internal volume of the apparatus, t : measurement time, R : gas constant, T_1 : temperature at the start of measurement, T_2 : temperature at the end of measurement, P_1 : internal pressure at the start of measurement, and P_2 : internal pressure at the end of measurement.

The initial internal pressure P_1 is set to 2 MPa, and the experiment is performed in ambient temperature environment. Tightening applies as initial axial bolt forces of 34.2kN, 68.5kN, 102.7kN and 136.9kN corresponding to mean gasket stresses of 10, 20, 30, and 40MPa. After tightening, helium is introduced, and the leakage is measured.

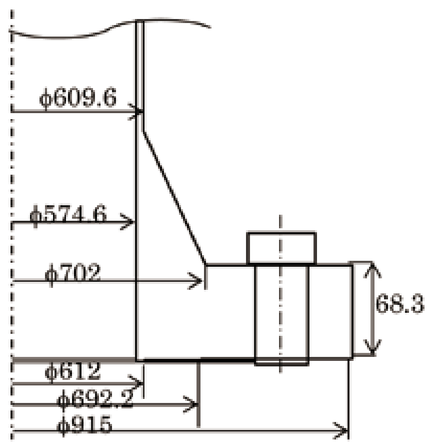

Figure2 Dimensions of 24-inch pipe flange connection

3. Gasket characteristics

The compression characteristics and leakage gasket stress relationship of No.GF300 gasket are measured in advance by experiments, and the measured values are used for FEM analysis.

3-1) Compression characteristics

First, the compression characteristics of the No.GF300 gasket at room temperature are measured using the experimental equipment shown in Figure 3. The size of the platen for compression test is JIS 10K 50A with raised face. A gasket is inserted between a pair of platens and compressed by a material-testing machine, and the amount of compression at that time is measured. Figure4 shows the stress-compression amount relationship (compression characteristics) obtained by the material test. Non-linearity and hysteresis are seen in the compression and decompression curves. These behaviors are also taken into consideration in the FEM analysis for calculation.

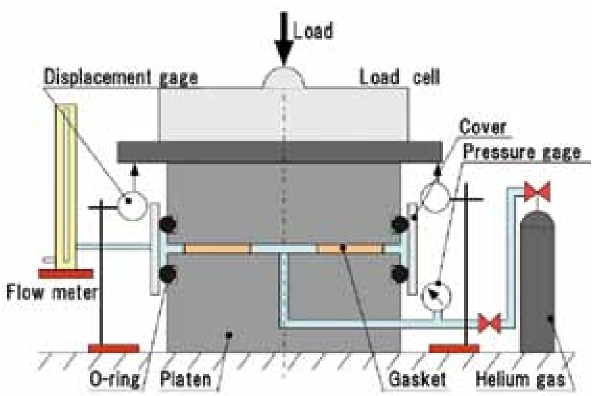

Figure3 Gasket characteristic measuring equipment

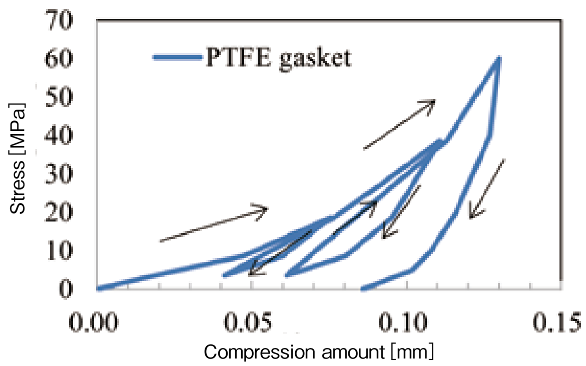

Figure4 Gasket compression characteristics

3-2) Sealing property

In the same manner as the compressive characteristics, a platen device shown in Figure 3 is used to measure the relation between gasket leakage and gasket stresses in accordance with JIS B 2490. The gasket is compressed in stages by a material-testing machine and the leak rate is measured when the material is loaded with helium at 2 MPa. The gas leaked from the gasket is collected by the rubber O-ring and sleeve, and measured using a soap membrane flow meter. Figure5 shows the measured leakage-gasket stress relationship. The vertical axis shows the logarithmic display of the amount of leakage, and the horizontal axis shows the gasket stress. It can be seen that the greater the gasket stress, the smaller the leakage. When the gasket stress was 30 MPa or more, the leakage was very small and could not be measured, so the data are not shown.

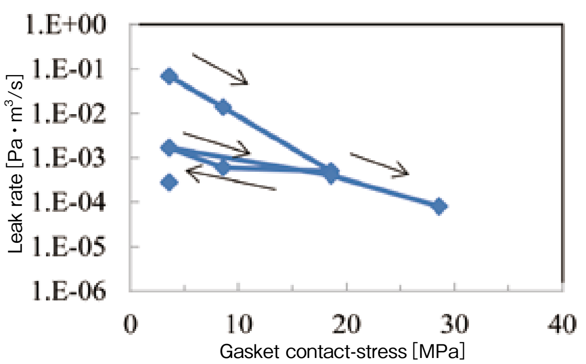

Figure5 Gasket leakage-stress relationship

4. FEM analysis

Figure6 is an FEM analysis model of a 24 inch sized gasketed pipe flange connection. A general-purpose code ABAQUS is used for the analysis and the number of elements is 2695 and the number of nodes is 4408. Considering the symmetry of the pipe flange connection, the 1/96 model (1/48 in the circumferential direction and 1/2 in the axial direction) is used. In this model, for simplification, the hexagonal nut has a circular shape with an equivalent cross-sectional area, and the screws are omitted. Figure7 shows the boundary conditions in the FEM analysis. All elements are constrained in each direction at the symmetric interface. An initial tightening force is applied to the bolt model by applying an axial load, and it is restrained when an internal pressure load is applied. The internal pressure exerts pressure on the flange and the inner surface of the pipe.

Elastic elements are used for flange and bolt models, and ABAQUS gasket elements are used for gaskets. This ABAQUS gasket element can take into account non-linearity and hysteresis characteristics. In FEM analyses, fluctuations in axial bolt force and gasket contact stress distribution are calculated.

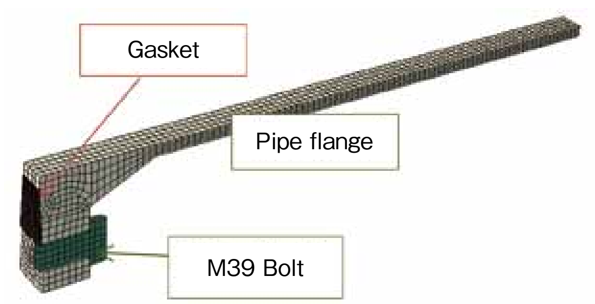

Figure6 FEM analysis model of pipe flange connection

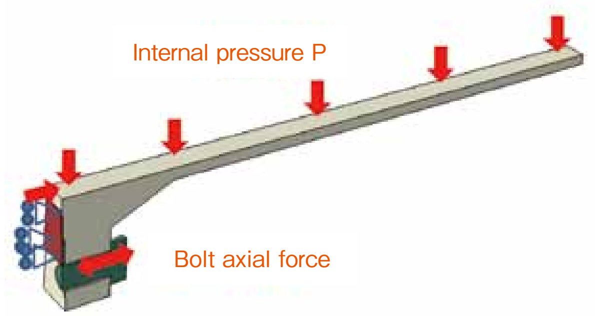

Figure7 Boundary conditions for FEM analysis

5. Experimental and FEM Analysis results

5-1) Axial bolt force

Figure8 shows the results of axial bolt force fluctuations reacting to internal pressure from experiments and FEM analysis. The horizontal axis is the internal pressure, the vertical axis is the axial bolt force, the solid line is the experimental result, and the broken line is the FEM result. The axial bolt force of the experimental results is the average value of 24 bolts. Initial tightening is applied as axial bolt forces 34.2kN, 68.5kN, 102.7kN, and 136.9 kN, which correspond to gasket contact-stresses of 10 MPa, 20 MPa, 30 MPa, and 40 MPa, respectively. Under all conditions, the axial bolt force decreased as the internal pressure increased. It is considered that this is because the flange rotation increases due to the internal pressure and the bolt axis contracts. Experimental results and FEM analysis are in fairly good agreement, indicating the validity of the FEM analysis.

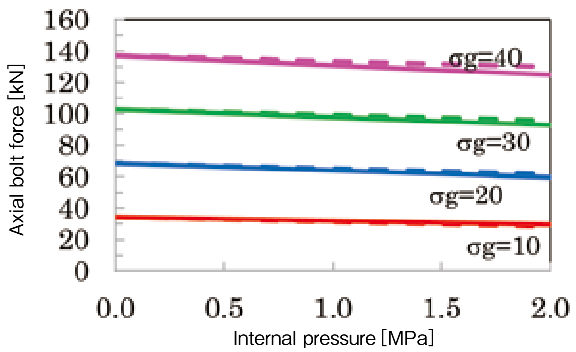

Figure8 Bolt axial force fluctuation during application of internal pressure

5-2) Gasket contact-stresses and leakage

Figure9 shows the gasket contact stress distribution at the time of tightening and at the time of applying 2 MPa internal pressure obtained from FEM analysis. The average gasket contact-stress at initial tightening is 10 MPa, 20 MPa, 30 MPa and 40 MPa. In all the contour diagrams obtained, it can be seen that the gasket outer diameter is disengaged from the flange flat seat and is not in contact with the flange and that the contact stresses are zero. Looking at the data at the time of initial tightening, the contact stress becomes larger toward the outer diameter side due to the flange rotation. It can also be seen that the gasket contact-stress on the inner diameter is zero even when the mean gasket contact-stress is large. This is because the inner diameter of the gasket is separated from the flange by the flange rotation and is not in contact with the flange In addition, it was found that the change in the circumferential distribution of gasket contact stress was very small. When internal pressure applied, the sum of the gasket contact stresses decreases due to the thrust force in the axial direction.

Here, the leakage from the flange connections is estimated from the gasket contact-stress distribution obtained from the FEM analysis and the leakage gasket

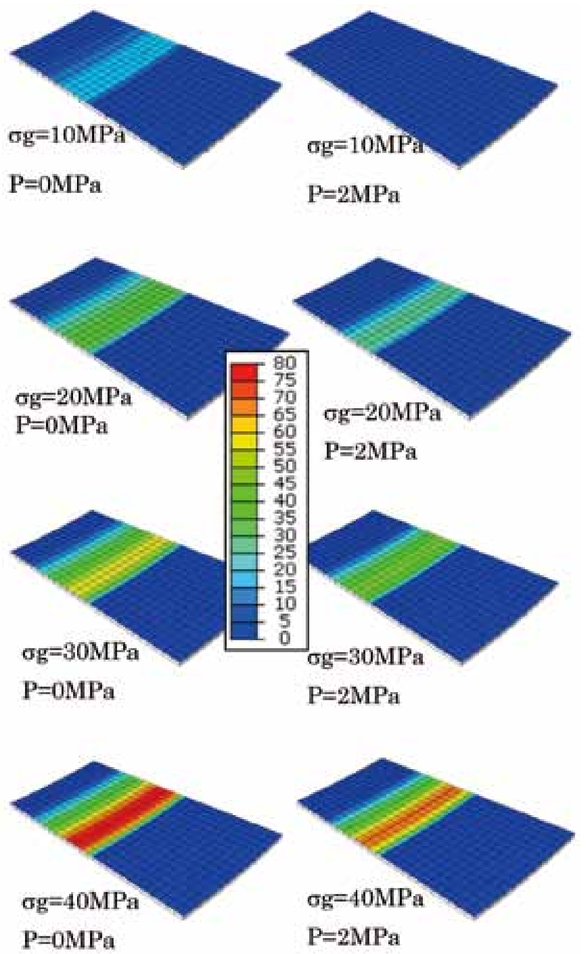

Figure9　Gasket contact-stress distribution obtained from FEM analysis

stress relationship also shown in Figure4 obtained by experiment[11),12)]. Figure10 shows a comparison of the leak measured experimentally and the estimated leak. The vertical axis is the leakage per unit length by dividing the total leakage by the contact of the gasket at the outer circumference. It can be seen that the larger the gasket contact-stress, the smaller the leakage. In addition, the estimated leakage and the experimental results are in good agreement, demonstrating the validity of the leakage estimation method and FEM analysis.

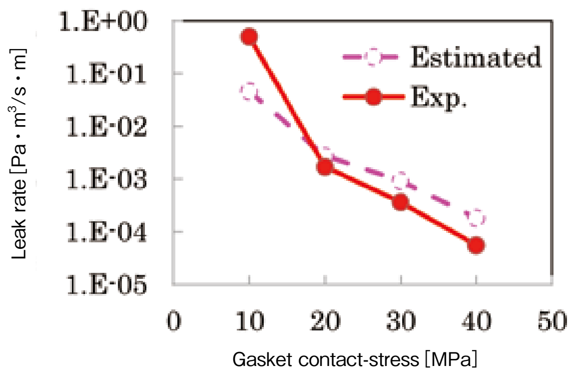

Figure10　Comparison of measured and estimated leaks from gaskets

6. Discussion

6-1) Effect of nominal diameter of pipe flange connection on axial bolt force fluctuation

Figure11 shows the values of the load factor when internal pressure is applied to the 2 inch, 4 inch, 8 inch, 12 inch, 16 inch, 20 inch, and 24 inch pipe flange connections incorporating the No.GF300 gasket calculated from FEM analysis. The average target gasket contact-stress is 20 MPa, and the internal pressure is set to 2 MPa. The load factor shown on the vertical axis is the increment rate of the axial bolt force when an external force (in this case, internal pressure) is applied. A positive value means that the axial bolt force increases, and a negative value indicates that the axial force decreases. It was found that the load factor tends to decrease as the nominal diameter of the pipe flange increases. This is because the larger the nominal diameter of the pipe flange, the smaller the bending rigidity of the flange ring, and flange rotation is likely to be promoted when internal pressure is applied, and as a result, the bolt is easily contracted. Figure12 shows the gasket contact stress distribution for each nominal diameter pipe flange. The horizontal axis is the ratio of the gasket width and is dimensionless. Under all dimensional conditions, the gasket contact-stress decreased when internal pressure was applied, but this became more apparent as the nominal diameter increased. It is considered that the larger the nominal diameter, the larger the area for receiving the internal pressure, the larger the thrust force, and the larger the value of the load factor, so that the ratio of the loss of gasket contact-stress increases.

Figure13 shows the leakage estimated by the same method as the result in Figure10 for a 2 inch to 24 inch pipe flange connections. The average value of the target gasket contact stress is 30 MPa, and the leakage is the leak per unit length obtained by dividing the total leak by the gasket outer contact circumference. As the nominal diameter of the pipe flange increases, the leakage per unit length increases, but the vertical axis is not a logarithmic scale but a linear scale, and the difference is not so large in reality.

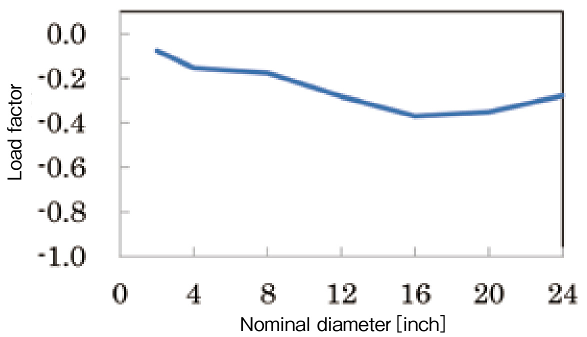

Figure11 Effects of nominal diameter on load factor in pipe flange connections

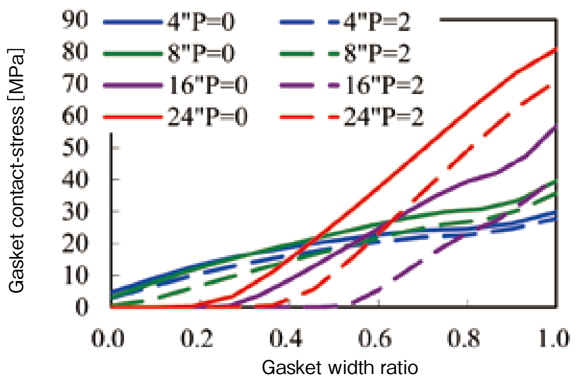

Figure12 Radial gasket contact stress distribution in the connection of each pipe flange nominal diameter

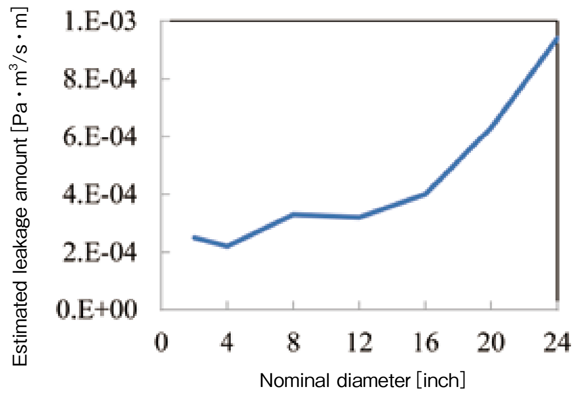

Figure13 Effect of pipe flange nominal diameter on leakage amount per unit length

6-2) Comparison of sealing properties of pipe-flange connections using No. GF300 and No. 6596V expanded graphite filled gasket

Figure14 shows the relationship between the leakage per unit length and the gasket contact-stress of the pipe flange connections using No. GF300 and No. 6596V expanded graphite filled gasket. As before, the pipe flange connection size is ASME class 300 24 inches and the internal pressure is 2 MPa. The validity of the FEM analysis method has been confirmed by comparing the FEM analysis and the experiment for the pipe flange fastener using No. 6596V. It was

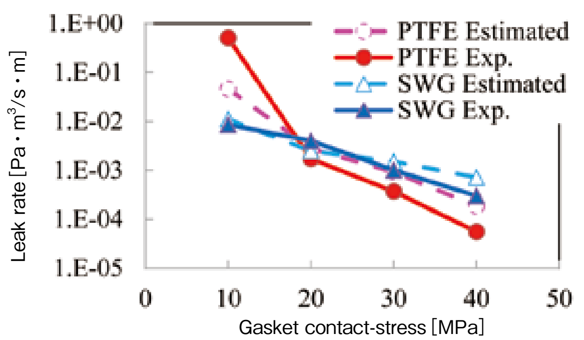

Figure14 Comparison of seal performance of each pipe flange connection using No. GF300 and No. 6596V

observed that when the gasket contact stress is smaller, the leakage rate is relatively large, but when the gasket contact stress is larger, the sealing property of the pipe flange connection using the No. GF300 is better than that of the pipe flange connection using the No. 6596V. The pipe flange connection using expanded graphite, which has the filler material of No. 6596V, exhibits good sealing performance even with relatively small stress. On the other hand, it is considered that the No. GF300 could not conform to the flange surface with a smaller stress, but was able to when the gasket contact-stress became larger, and exhibited a higher sealing property by compression of the material. From the strength calculations, some pipe flange connections are not applicable for spiral wound gaskets. However, it was found that in these locations, the sealing property of No.GF300 is same or better than that obtained from the spiral-wound gasket.

7. Conclusions

In this study, the mechanical properties of ASME class 3000 24 inch pipe flange connection with No. GF300 were investigated by experiment and FEM analysis, and the following conclusions were obtained.

(1) In accordance with JIS B 2490, the compression characteristics and leakage gasket contact-stress relationship of No. GF300 were measured.

(2) The leakage from the pipe flange connection was estimated from the above gasket characteristics and the gasket contact stress distribution results were obtained from the FEM analysis. In addition, both results were in good agreement with the experiment demonstrating the validity of the estimation method.

(3) Through FEM analysis and experiments, it was clarified that the axial bolt force decreases due to flange rotation when internal pressure is applied to the 24 inch pipe flange connection with No. GF300. It was also shown that the FEM analysis results are in good agreement with the experimental results.

(4) Using FEM analysis and basic gasket data, it was clarified that the larger the nominal diameter of the pipe flange, the smaller the load factor and the larger the leakage amount.

(5) It was clarified that No. GF300 exhibits higher sealing performance than a pipe flange connection using an expanded graphite filled spiral wound gasket when a recommended surface pressure of 35 MPa is applied. From the strength calculation, it was found that even in the pipe flange connection to which the spiral wound gasket cannot be applied, the sealing performance of GF300 is equal to or better than that when the spiral wound gasket is used.

8. References

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