## *"Fastener Troubles, Causes & Solutions" Series*

# Fluid Leakage of Pipe Flange: Sealing Performance Governed by Gaskets

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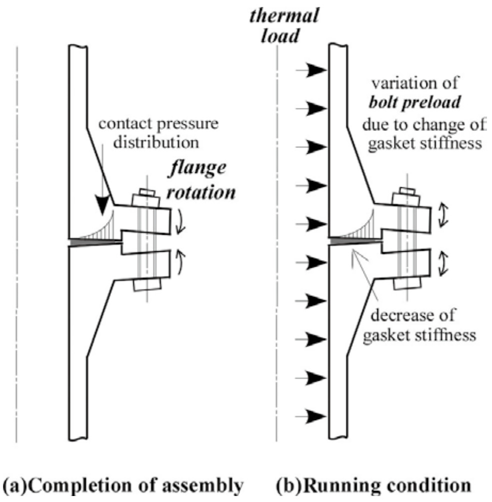
## Introduction

Our life is supported by various infrastructures, among which pipelines that transfer fluids are the most fundamental ones. The structure of a pipeline basically consists of pipes and pipe flanges. Problems like the leakage of internal fluids most likely occur from the joint that connects pipe flanges. The sealing performance is largely influenced by the axial bolt force which fastens a pair of pipe flanges. In order to prevent the leakage of internal fluids, a thin sheet called a gasket is usually inserted between the two pipe flanges. The stiffness of gaskets is very low, so the mechanical properties of gaskets significantly affect the fastening characteristics of pipe flanges and the behavior when the flanges are subjected to internal pressure and thermal load from the internal fluids. Therefore, this article deals with the situation where high-temperature fluids flow inside the pipe flanges with a gasket being inserted, and explains the change of axial bolt forces which determines the sealing performance.

## Structure of Pipe Flange and Compression Characteristics of Gasket

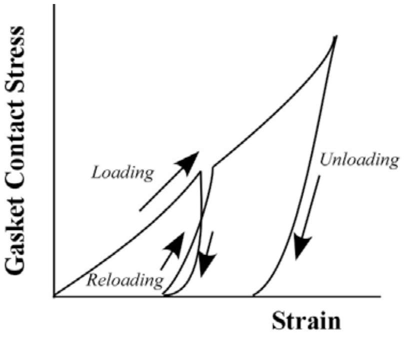
Figure 1(a) shows the state in which the fastening of pipe flanges is completed. Figure 1(b) shows the state of the pipe flanges under high thermal load in running condition. Widely-used sheet gaskets have a low stiffness. Therefore, the contact pressure due to the axial bolt force drastically increases from the inside to the outside, as shown in Figure 1(a). This distinctive distribution pattern prevents the leakage of internal fluids. In that case, the two pipe flanges are deformed so as to make their outer ends get closer. Such deformation pattern is called flange rotation. When the plant is operating and the temperatures around the pipe flanges increase, the gasket stiffness decreases and the flange rotation becomes more evident. The resulting decreased axial bolt force may cause the reduction of gasket contact pressure and lead to the leakage of the internal fluids.

Fig. 1. Pipe flange ▶

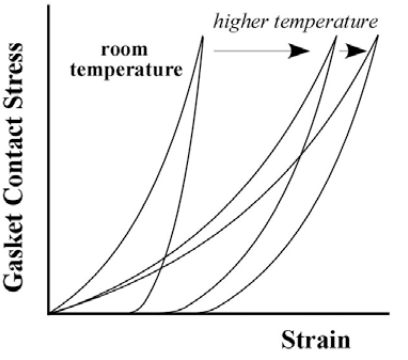


(a)Completion of assembly (b)Running condition

Figure 2 (a) shows the compression characteristics of a sheet gasket containing lots of fibers. The vertical axis is the gasket contact pressure, and the horizontal axis is the gasket strain. With the axial bolt force being increased, the gasket contact pressure nonlinearly increases against the strain. Then, when unloaded at some level of contact pressure, the contact pressure sharply drops comparing to the loading process and it exhibits a characteristic of hysteresis. In this way, the compression characteristics of gaskets show a complicated behavior involving nonlinearity and hysteresis. On the other hand, it is fairly difficult to conduct a systematic evaluation because the compression characteristics vary depending on the materials and composition of gaskets. Furthermore, the gasket stiffness decreases as the temperature rises. Figure 2 (b) schematically shows the temperature dependency of the sheet gasket's compression characteristics. The gasket stiffness is found to decrease as the temperature rises. Consequently, in order to evaluate the thermal and mechanical properties of pipe flanges in which high temperature fluids flow, it is necessary to collect the data of compression characteristics of the objective gaskets with their temperature dependency.



(a) Nonlinear behavior of sheet gasket



(b) Effect of temperature on gasket stiffness

▶ Fig. 2. Compression characteristics and its temperature dependency on a sheet gasket

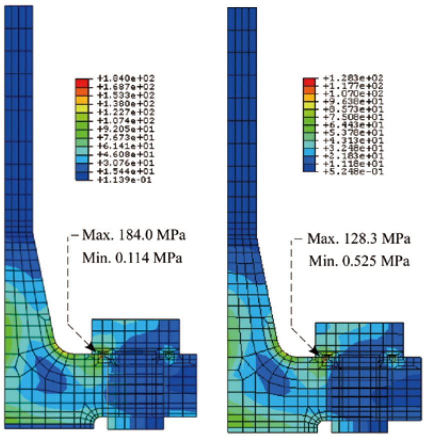
Related academic institutions have published the results of the research on a device to measure the compression characteristics of gaskets together with their temperature dependency. Finite element analyses introduced in the following paragraphs use the compression characteristics of gaskets measured by the device.

## Axial Force Variation of Pipe Flange Bolt Subject to High-temperature Thermal Load

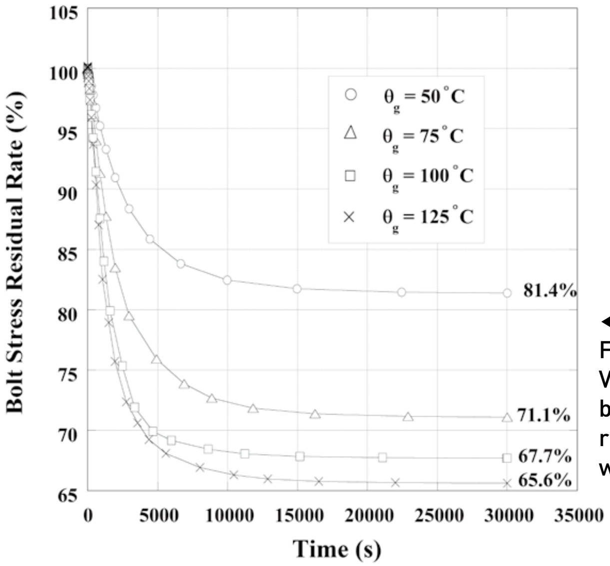
Using the compression characteristics of gaskets obtained by experiments, thermal and mechanical behaviors of pipe flanges subjected to heat from high-temperature fluids are analyzed by means of finite element analysis. Because the characteristics of gaskets govern the overall mechanical behavior of pipe flanges and various types of pipe flanges and gaskets can be analyzed comparatively easier, axi-symmetric models are used instead of 3-dimensional models. Please refer to the references for the details of the method to convert pipe flanges with 3-dimensional geometry into axi-symmetric models.

The target pipe flanges are fastened by 8 bolts, and the axial bolt stress upon completing fastening is 100MPa. The average gasket contact pressure generated by this axial stress is about 22MPa. The gaskets are 3mm in width and are composed of aramid fibers. Figure 3 shows an example of the analytical results of stress distributions. The stress is represented by Tresca stress. Figure 3(a) shows the result upon completing fastening. Figure 3(b) gives the result when the average temperature of the gasket under thermal load rises to 100℃ after reaching a steady state. Note that the maximum stress is decreased to about 70% of the initial state. This value is roughly proportional to the axial bolt force, and therefore it can be considered that the axial bolt force is also decreased to approximately 70%. Figure 4 shows the variations of bolt stress residual rate with time. Bolt stress residual rate is defined by dividing the axial bolt force after a certain period of heating by the initial axial bolt force. The parameter appearing in the figure is the average gasket temperature θg. The axial bolt force significantly decreases as the average gasket temperature θg increases from 50℃ to around 75℃. However, as θg reaches 100℃ and further to 125℃, the decreasing rate of axial bolt force gets smaller. This phenomenon is consistent with the decrease of gasket stiffness under high temperature obtained by experiments.

**Fig. 3**



(a) At completion of tightening (b) In steady state for θg = 100 °C



◀ **Fig. 4. Variations of bolt stress residual rate with time**

## Heating Experiment of Pipe Flanges

Finite element analysis is an effective approach to obtain the mechanical behavior of various shapes of pipe flanges. However, in order to analyze the behavior of pipe flanges under high temperatures, it is necessary to properly formulate the compression characteristics of gaskets and verify the validity of axi-symmetric models via experiments. Figure 5 shows an overview of the device used in the heating experiment of pipe flanges. The size and shape of the target pipe flanges and gaskets are the same as the model constructed in the finite element analysis. The temperature on the bolt shank is measured by a thermocouple. The axial bolt force is measured by a strain gage for high temperature use. Thermal load is applied using a magnet-type heater attached to the inner surface of pipe flanges. The output of the heater per unit area is around 4897W/m$^2$. According to the experimental result, about 75% of the output flows into the pipe flanges. The initial axial bolt stress is varied in 3 levels, i.e., 50MPa, 100MPa, and 150MPa.

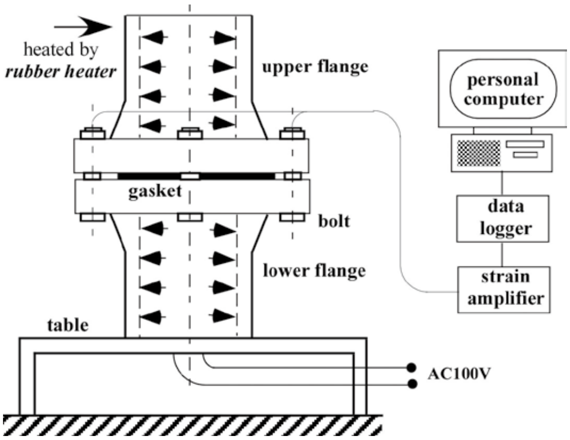


**Fig. 5. Device used to heat up pipe flanges**

Figure 6 is an example of the experimental results. The vertical axis represents bolt stress residual rate and the bolt shank temperature; the horizontal axis is the elapsed time after the start of heating. The temperature and strain are measured on the bolts marked with odd numbers out of the total 8 bolts. After 15,000 seconds of heating, the bolt temperature rises to 115℃, and the axial bolt force decreases to around 75%. In Figure 7, the bolt stress residual rates after 15,000 seconds of heating are compared between the analytical and experimental results. The horizontal axis is the axial bolt stress. The bolt stress residual rate slightly increases with increasing axial bolt stress; however, its effect is insignificant. Although there is a minor difference between the analytical and experimental results, considering the assumptions set for the analysis, the analytical method introduced in this article is considered practically effective.

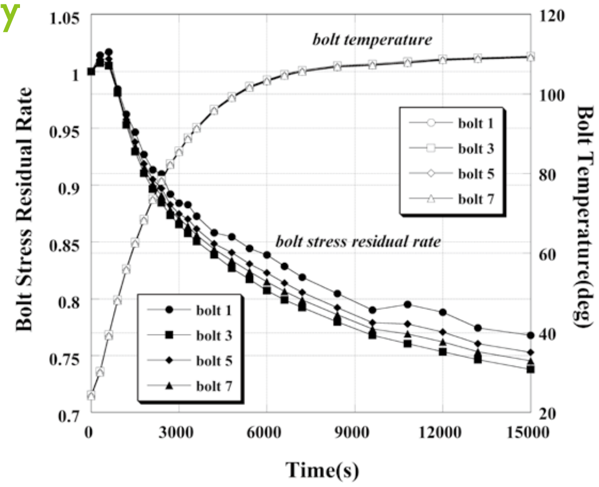


Fig. 6. Experiment result

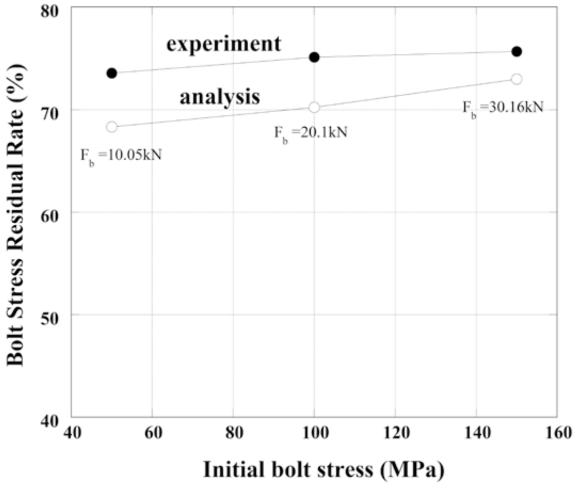


Fig. 7. Bolt stress residual rates after 15,000 seconds of heating

## Conclusion

It can be said that the number of pipe flanges used in pipelines for high-temperature fluids is actually unlimited. A considerable number of pipe flanges among them face the problem of leakage. Specifically, the complicated thermal and mechanical characteristics of gaskets used for the bolted joints of pipe flanges make it difficult to solve the leakage problem. Then, the magnitude of axial bolt force, which fastens the pipe flanges, can be the guideline to determine the sealing performance. On the other hand, unlike the bolts involving the problems of mechanical external forces, the bolts used for pipe flanges are expected to generate a gasket contact pressure that does not incur leakage. Based on the above, it is also considered that there is no problem if the axial bolt force varies as much as 30% of the design value. The next article will explain the sealing performance of pipe flanges in pipelines for low-temperature fluids. ■

## Reference

1. *Toshimichi Fukuoka, "Threaded Fasteners for Engineers and Design – Solid Mechanics and Numerical Analysis –", pp. -256-262, Corona Publishing Co., Ltd. (2015)*
2. *Fukuoka, T., Nomura, M. and Nishikawa T., Analysis of Thermal and Mechanical Behavior of Pipe Flange Connections by Taking Account of Gasket Compression Characteristics at Elevated Temperature, ASME Journal of Pressure Technology, Vol.134, Paper No.021202 (2012)*