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Verification of factors affecting compressive load of a metal gasket

Kimihiko Kinugawa
NICHIAS Corporation,
Tsurumi Technical Center

Katsutoyo Itoi
NICHIAS Corporation,
Tsurumi Technical Center

Kanji Hanashima
NICHIAS Corporation,
Tsurumi Technical Center

Abstract

Dual purpose casks for transport and long-term storage have a flat and groove flanges construction such that a groove is provided on the lid of a cask. The metal gasket is closed in the groove to achieve high leak-tightness. The metal gasket used at the seal boundary of a cask consists of three components: a coil spring, an inner lining, and an outer jacket. This report verifies factors affecting the compressive load of the metal gasket by the Finite Element Analysis (FEA). First, the compressive load of the metal gasket was sought by the FEA, and the value was compared with the test result. The result of the FEA corresponded reasonably well with the test result, and the analytical approach by the FEA has been established. Next, the relationship between the wire diameter used for coil spring and the compressive load of the metal gasket at tightening was verified by using the FEA. As a result, it was confirmed that the compressive load at tightening increases with the increase of the wire diameter used for coil spring and the wire diameter used for coil spring is one of the important factors significantly affecting the compressive load of the metal gasket at tightening.

Introduction

A metal cask has four functions to safely transport and store spent fuel: 1) to contain radioactive materials in spent fuel within the cask; 2) to block radiation from spent fuel; 3) to prevent unburned uranium and plutonium from reaching critical mass; and 4) to remove heat from spent fuel. Particularly for the function of containing radioactive materials within the cask, the metal cask consists of a thick, cylindrical steel body and two steel lids, primary and secondary (Fig. 1 [1]).

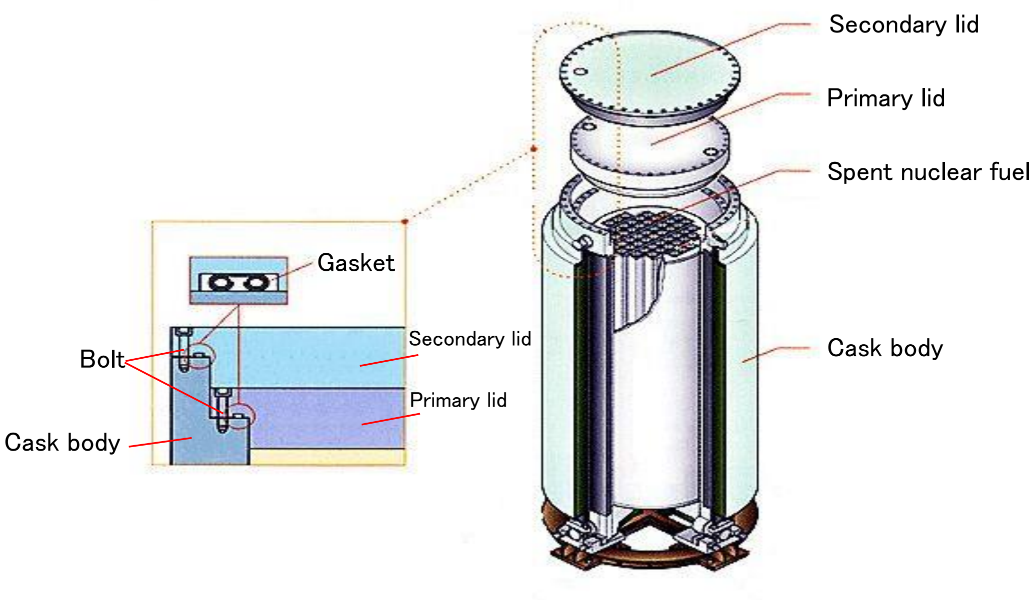


Figure 1 Metal cask

The junction between the lid and the body forms a seal boundary, and a metal gasket (Hereinafter, "metal gasket" is called "gasket") is used to seal the junction. Since the seal boundary must be able to securely contain radioactive materials, high leak-tightness is required of the gasket. The gasket is made of metal to ensure use and long-term safety under severe conditions. To provide high leak-tightness, it consists of three layers as shown in Fig. 2 below: an outer jacket as the outermost layer, an inner lining as the middle layer, and a coil spring as the innermost layer.

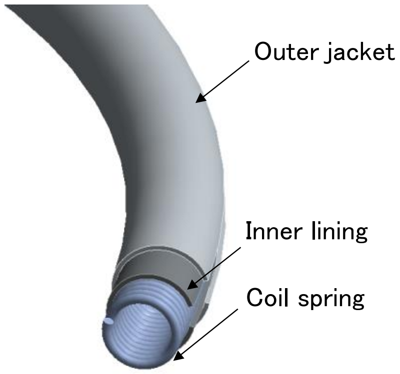
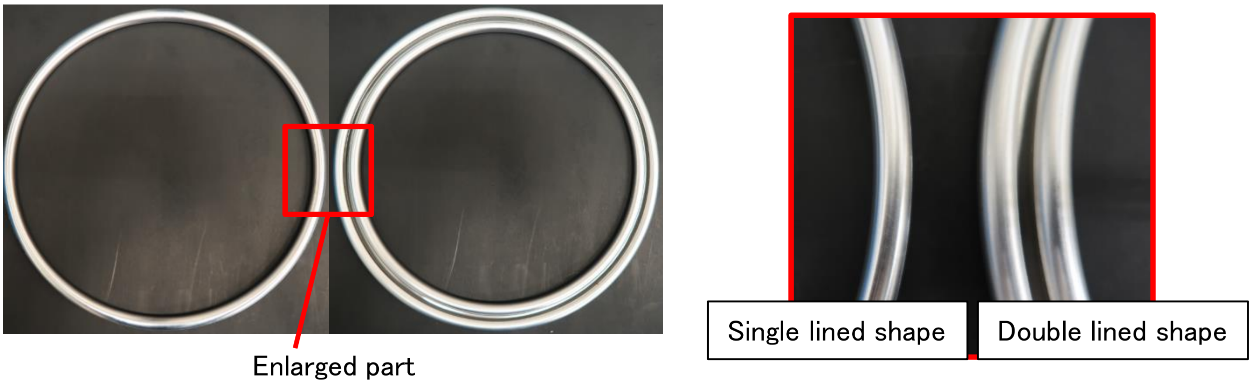


Figure 2 Structure of gasket

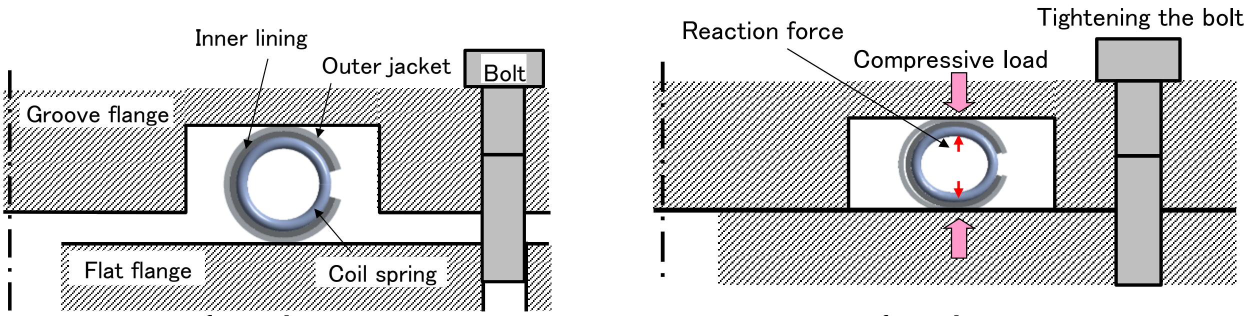
In addition to single lined shape, there are double lined shape with two sealing rings, which are made of two single lined shape (Fig. 3).



(Single lined shape) (Double lined shape) (Enlarged part)

Figure 3 Shape of NAFSIL™

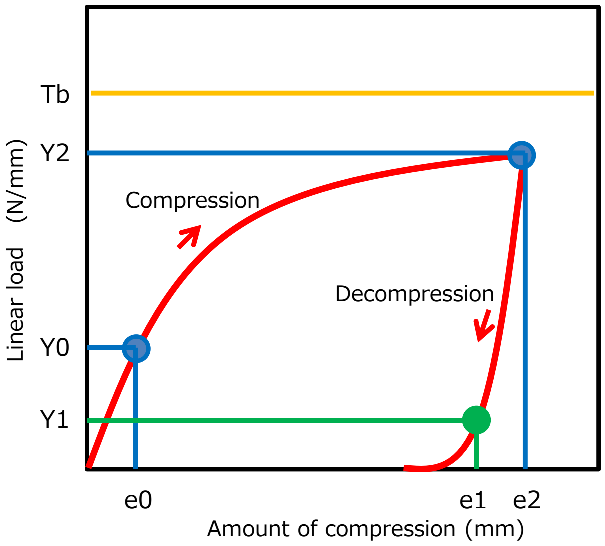
The seal boundary of the cask is of a so-called flat and groove flanged construction. A gasket is placed in the groove and the flanges are tightened with bolts. Flat and groove flanges are tightened with bolts until the flange faces come into contact with each other. Therefore, a uniform compressive load can be applied to the gasket, ensuring leak-tightness (Fig. 4).



Before tightening After tightening

Figure 4 Gasket and flange of flat and groove

As the gasket is compressed, the amount of compression and the magnitude of the compressive load increase. Generally, gasket properties are represented by a compression curve with the amount of compression as the horizontal axis and the linear load as the vertical axis, which is obtained by dividing the compressive load by the circumference of the gasket (Fig. 5).



Tb: Total bolts tightening linear load
Y2: Linear load of a gasket at maximum compression
Y0: Linear load of a gasket reached the start point of sealing
Y1: Linear load of a gasket reached the end point of sealing upon decompression of a gasket
e2: Maximum compression of a gasket

Figure 5　Compression curve of gasket

When compressed, the gasket is deformed and brought into close contact with the flange face and obtains leak-tightness. The minimum compressive load at which leak-tightness is obtained is defined as Y0 (Linear load of a gasket reached the start point of sealing).
As previously described, the gasket is used as compressed to the groove depth, and the amount of compression at that time is called e2 (Maximum compression of a gasket). And the linear load applied to the gasket at the compression amount e2 is called Y2 (Linear load of a gasket at maximum compression). The gasket used for the cask needs to have a linear load Y2 exceeding Y0 or more in order to obtain leak-tightness.

$$Y2 > Y0$$

Further, a flat & groove flange can provide stable leak-tightness. However, if the gasket is firm and the total bolts tightening linear load Tb is less than the compressive load on the gasket, the flange faces do not come into contact with each other and stable leak-tightness is not obtained. The following condition must be met so that the gasket is fully tightened.

$$Tb > Y2$$

In order for the gasket to obtain stable leak-tightness, the compressive load on the gasket must meet the following condition when the gasket is compressed to the groove depth.

$$Tb > Y2 > Y0$$

For general gaskets for non-cask applications, an appropriate amount of compression is specified and recommended for different gasket sizes (cross-sectional diameters) based on Y0 at which leak-tightness is provided. On the other hand, gaskets for casks are required to ensure stable leak-tightness over a long period of time. Even if the gasket relieves stress over a long period of time, it is not sufficient that the initial linear pressure exceeds Y0 in order to maintain air tightness, so Y2 is often required.. Different values of Y2 are required for different types and components of casks. In terms of corrosion resistance and long-term stability, it is difficult to change the type of material of gasket components. Therefore, Y2 needs to be adjusted without changing the material of gasket components and the gasket size (cross-sectional diameter) and the amount of compression e2. We examined adjusting Y2 by changing the material size of gasket components. The results are described below.

Factors affecting the Linear load of a gasket at maximum compression (Y2)

Table 1 shows the factors that affect Y2 in terms of 5M.In a test to measure Y2, these factors interact with each other. To ensure the validity of measurement data, the test needs to be repeated a large number of times. FEA can evaluate the effect of the target material and size on Y2 by excluding these factors. To use FEA, it is essential that the analysis results are comparable with the test results.

Evaluation was conducted in the following two steps:

Step1. Examine the validity of FEA

Step2. Evaluate the effect of adjusting the dimensions on Y2

Table 1 Factors affecting Y2 considering 5M

<table>
<tr><th>5M</th><th colspan="2">Factor</th></tr>
<tr><td rowspan="7">Material</td><td rowspan="2">Outer jacket</td><td>Material</td></tr>
<tr><td>Thickness</td></tr>
<tr><td rowspan="2">Inner lining</td><td>Material</td></tr>
<tr><td>Thickness</td></tr>
<tr><td rowspan="3">Coil spring</td><td>Material</td></tr>
<tr><td>Wire diameter</td></tr>
<tr><td>Cross sectional diameter</td></tr>
<tr><td>Machine</td><td colspan="2">Condition</td></tr>
<tr><td>Man</td><td colspan="2">Condition</td></tr>
<tr><td>Method</td><td colspan="2">Several process condition</td></tr>
<tr><td>Measurement</td><td colspan="2">Measurement error</td></tr>
</table>

Step1. Examine the validity of FEA

The validity of FEA was examined by comparing the compression curve obtained from the gasket compression test with the compression curve obtained from the FEA.

(1) Compression testing using a press machine

Test sample

The single lined shape NAFSIL™ was used as a test sample.

Table 2 Test sample (Single lined shape NAFSIL™)

Part	Material	Dimension (Single lined shape)	mm
Gasket	-	Cm: Cross sectional diameter	10.0
		Di: Inner diameter	250
Outer jacket	Al 1050	To: Thickness	0.5
Inner lining	Alloy 600	Ci: Cross sectional diameter	9.0
		Ti: Thickness	0.5
Coil spring	Alloy 90	Cc: Cross sectional diameter	8.0
		Dw: Wire diameter	1.00

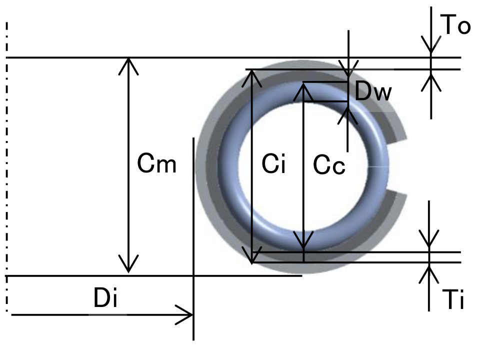


Figure 6 Dimension of gasket

Test condition

The compression testing machine shown below was used in the test. The gasket in Table 2 was placed on the lower platen. A compression curve was obtained by compressing the gasket to e2 (1.1 mm).

Table 3 Test condition

Equipment type	Test press
Material of platen	SUS304
Height of spacer ring	8.9 mm
Maximum compression of a gasket e2	1.1 mm

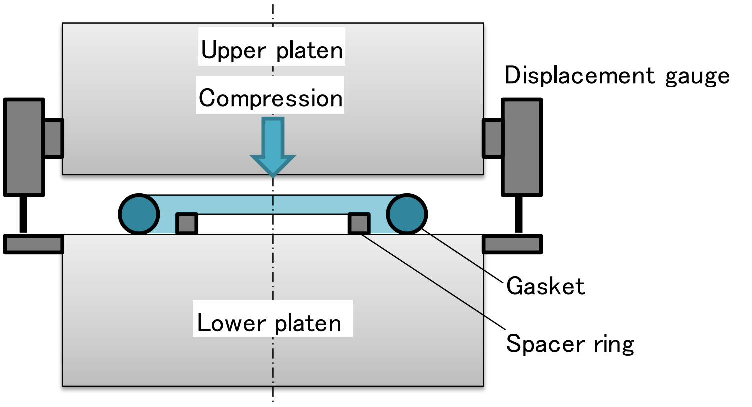


Figure 7 Compressive test equipment

(2) FEA

As with the test, FEA was performed on the gasket shown in Table 2. In the analysis, ANSYS 19.2 and a three-dimensional, cyclic symmetry model of the test sample were used. The actual spiral structure of the coil spring was modeled. The upper and lower platens were positioned as shown in Fig. 8. With the lower platen fixed, a compressive displacement equal to e2 (1.1 mm), was applied to the upper platen in the Z-axis direction (Fig. 9).

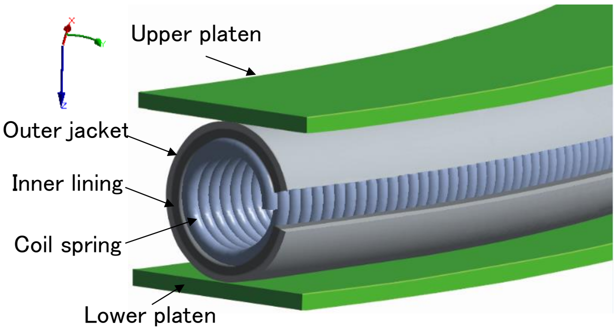


Figure 8 FEA model

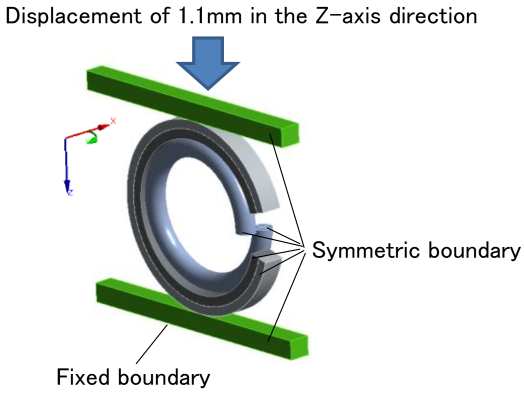
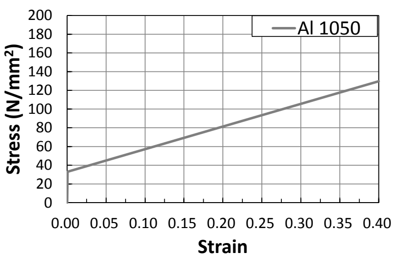
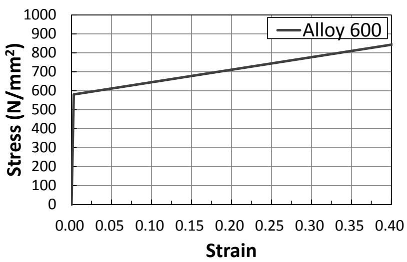


Figure 9 Boundary condition

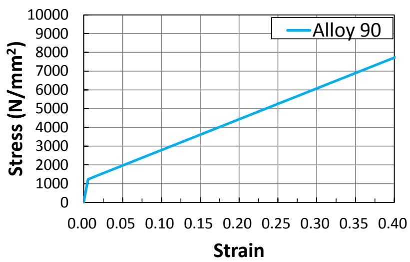
The flange was modeled as a rigid body. A bilinear plasticity model was used to represent the material properties, except for the rigid body (Fig. 10). The coefficient of friction was set for the contact surfaces.



(Outer jacket)



(Inner lining)



(Coil spring)

Figure 10 Material properties of the gasket

Result

Fig. 11 shows the compression curves and Y2 obtained from the test and the FEA result.

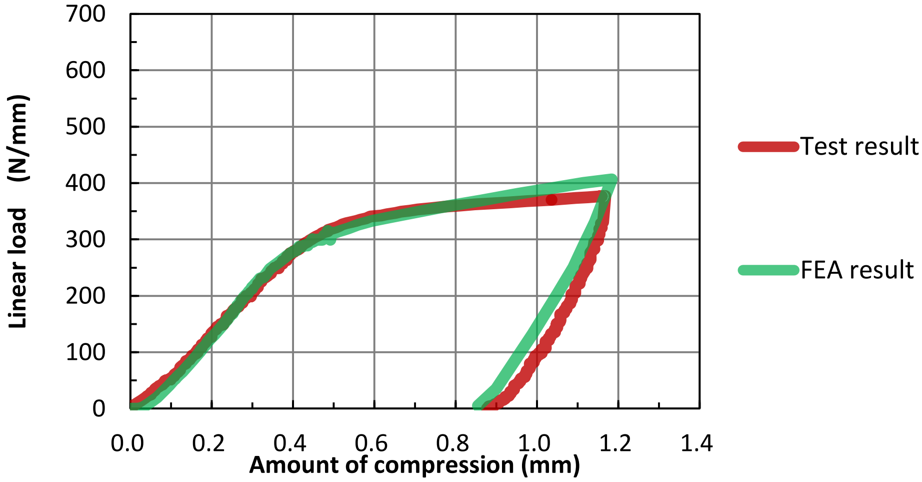


Figure 11 Compression curves of gasket

The compression curve and Y2 from the FEA are in good agreement with those from the test. Thus, the FEA estimation of the compression curve and Y2 for the gasket NAFSIL™ is valid, indicating that the effect of adjusting the dimensions on Y2 can be evaluated by FEA.

Step2. Evaluate the effect of adjusting the dimensions on Y2

The dimensions that can be adjusted are the thickness of the outer jacket, the thickness of the inner lining, and the wire diameter and cross sectional diameter of the coil spring. Particularly, the potential effect of the wire diameter on Y2 was evaluated (Table 4). The analysis model in Fig. 8 was used in the evaluation.

Table 4 Dimension of gasket

Part	Dimension	FEA 1	FEA 2	FEA 3	FEA 4	FEA 5
		[mm]				
Gasket	Cm: Cross sectional diameter	10.0	←	←	←	←
	Di: Inner diameter	250	←	←	←	←
Outer jacket	To: Thickness	0.5	←	←	←	←
Inner lining	Ci: Cross sectional diameter	9.0	←	←	←	←
	Ti: Thickness	0.5	←	←	←	←
Coil spring	Cc: Cross sectional diameter	8.0	←	←	←	←
	Dw: Wire diameter	0.96	0.98	1.00	1.02	1.04

Fig. 12 shows the compression curves and Y2 estimated by FEA. Y2 for the gasket increases with the wire diameter of the coil spring.

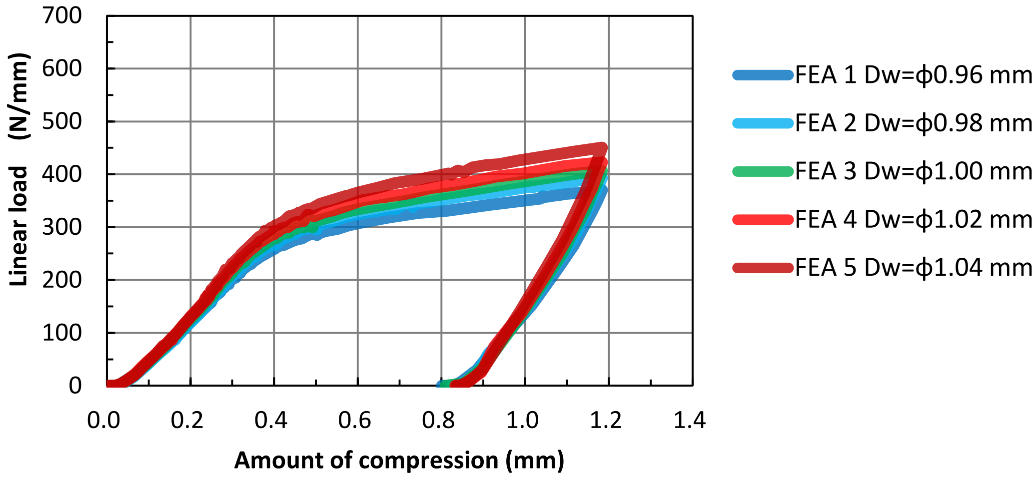


Figure 12 Compression curves of Gasket

Fig. 13 shows the relationship between Y2 and the wire diameter of the coil spring, which is obtained from Fig. 12. Y2 for the gasket increases linearly with the increase of the wire diameter of the coil spring.

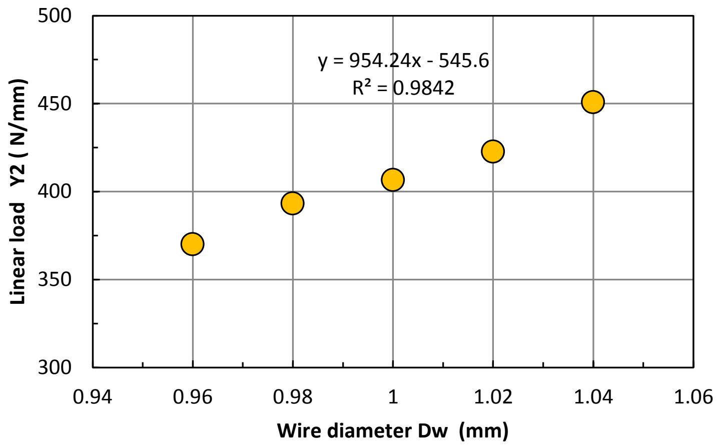


Figure 13 Relationship of wire diameter and Y2

This indicates that Y2 can be designed by adjusting the wire diameter of the coil spring without changing the gasket size (cross-sectional diameter), e2.

Conclusions

The following findings were obtained from this study.

- The compression curve and Y2 from the FEA are in good agreement with those from the test. Thus, the FEA estimation of the compression curve and Y2 for the gasket NAFSIL™ is valid.
- Y2 can be designed by adjusting the wire diameter of the coil spring without changing the gasket size (cross-sectional diameter), e2.
- FEA can be used to design a metal gasket that meets the requirements for metal gaskets for cask applications.

Reference

[1] The Japan Atomic Power Company, "Power Station Management-Dry Cask Overview".
http://www.japc.co.jp/project/cycle/drycask03.html, (Access date 2019-4-10)