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Analysis of Cooling Ball Stress to Prevent Spontaneous Ignition of Coal Stockpiles

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Abstract

Damage caused by spontaneous ignition in coal stockpile is proportional to the increase in coal thermal power plant. The problem of spontaneous ignition is not only severe economic damage but also a typical plant damage caused by harmful gases generated during the fire. Because coal is porous, it causes oxygen to be absorbed in the amount of oxygen per unit weight of oxygen, resulting in low humidity and low thermal conductivity. The cause and effect of spontaneous ignition are very complex, so it is difficult to prevent it beforehand and once it is difficult to digest it, it is difficult to digest it. This study examines structural stability by conducting a structural analysis of the cooling ball system to prevent spontaneous combustion of coal stockpile plants and external pressures.

Keywords: *Pressure Vessel, Spontaneous Ignition, Coal Stockpile, Cooling Ball, Nitrogen, Pressures Stress*

1. Introduction

The damage caused by spontaneous ignition of coal stockpile often occurs in proportion to the increase in the amount of low carbon used in coal-fired power plants. It is not only a serious economic damage but also a typical example of causing environmental pollution caused by harmful gas Power plant damage.

In the related industry, physical or chemical solutions are proposed to solve the problem of low self-ignition spontaneous ignition, but the cost and effect of expensive facility construction and operation are not ensured and the field is suffering from difficulties. A coal-fired 500-MW thermal power plant will have approximately six 500-ton capacity coal reservoirs, five of which will be supplied with normal coal, and the other will have a reserve coal reserve and is operated with low-profile. When the coal is loaded in the outdoors, the powder dust is blown, polluting the environment of the workplace, and a part of the raw material is lost due to the wind. Recently, the problem of spontaneous ignition is getting bigger because it is stored mainly in a closed reservoir. In addition, the gas generated in the spontaneous ignition process may cause gas explosion if not released to the outside, and spontaneous ignition in the storage facility may induce dust explosion. In this way, safety management for prevention of spontaneous ignition is very important in the space where coal is stored and measures against fire occurrence are needed. One method of this countermeasure is an automatic cooling ball device which emits a digestive liquid and lowers the temperature when the temperature of the low - leaning is above a certain temperature by a cooling ball extinguishing method.

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This study is a study on the structural safety of the cooling ball device, and it performs structural analysis on the pressure of the inner tank against the gas pressure and the structural analysis of the cooling ball shape against the external pressure and evaluates the structural safety [1].

2. Design Theory

When a cooling ball is buried in a coal stockpile with coal, the cooling ball is likely to be damaged due to the weight of the coal. The cooling ball is in the form of a pressure vessel. The inner tank is subjected to internal pressure by the digestive fluid. The external shape is buried in the coal stockpile and receives the external pressure of the coal.

The stress acting on the thin cylindrical container can be divided into x direction stress and y direction stress, and y direction stress is calculated as follows. The load p acting on the wall can be expressed as the product of the pressure p acting on the inside and the area [2].

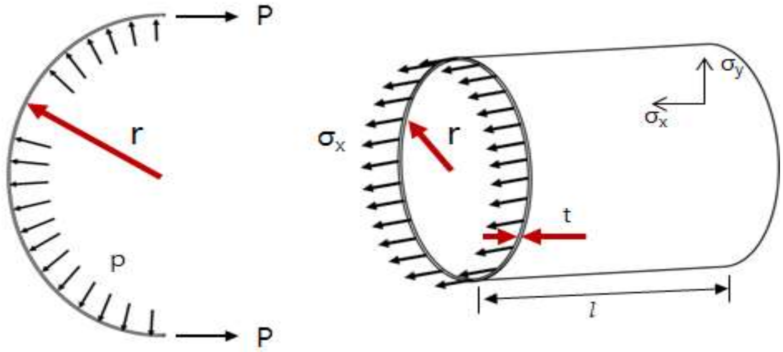

Figure 1. Cylindrical Pressure Vessel

The stress acting on the thin cylindrical container as shown in Figure 1 can be divided into the x direction stress and the y a direction stress, and the y direction stress is calculated as follows. The load (P) acting on the wall can be expressed as the product of the pressure (p) acting on the inside and the area [3].

$$P = pd_i l \tag{1}$$

t = Thickness
l = Length in x direction
d_i = Inner diameter

$$\sigma_y = \frac{pd_i l}{2tl} = \frac{pd_i}{2t} \tag{2}$$

The stress as in Equation 2 is called circumferential stress or hoop stress. In addition, if the stress acting on the cylindrical cross section in the x direction is plotted, the area of the cross section in the x direction is π, d_i, t, and the load P is the equation $\frac{p\pi d_i^2}{4}$, so the x direction stress is as follows.

$$\sigma_x = \frac{p\frac{\pi}{4}d_i^2}{\pi dt} = \frac{pd_i}{4t} \tag{3}$$

The direction stress of Equation 3 is called longitudinal stress and axial stress. Eq. 2 and Eq. 3, the stress is twice as large and the direction stress is large at the same condition [4, 5].

Then, the theoretical expression of a spherical pressure vessel having a diameter d, which is a cooling ball shape, can be described as follows. The load $P = \frac{1}{4} p \pi d_i^2$ acting on the thin wall surface and the area of the cross section is π, d_i, t. The stress in the x direction is expressed by the following equation.

$$\sigma_{sphere} = \frac{\frac{1}{4} p \pi d_i^2}{\pi d_i t} = \frac{p d_i}{4t} \tag{4}$$

Equation 4 is equivalent to Equation 3 in the x direction. Therefore, the cooling balls are Eq. 4 is applied. In the case of external pressure, the equation is as follows d_o is the outer diameter [5] [6].

$$\sigma_o = \frac{p d_o}{2t} \tag{5}$$

3. Structural Analysis Result

3.1. Structural Analysis of Internal Gas Tank

The cooling ball is composed of an internal tank in which liquid nitrogen is contained, a control unit, a fire extinguishing liquid injection nozzle, an external case, and a solenoid valve. Figure 2 shows the assembled state of the cooling ball and shows the cutting plane.

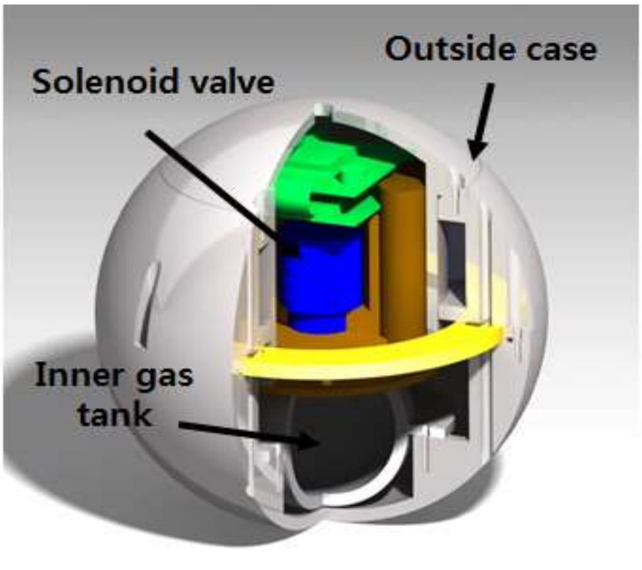

Figure 2. Cutaway of Cooling Ball

Figure 3 shows the shape of the inner gas tank, which is fixed by an external flange. The inside pressure is 3.0MPa with liquefied nitrogen [7].

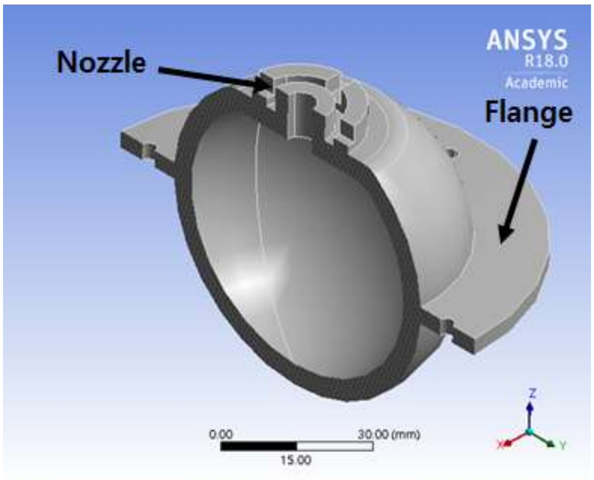

Figure 3. Inner Gas Tank Real Shape

As mentioned in the theory, when the pressure vessel is a thin cell structure when the thickness t is smaller than 10 times the diameter d, the inner tank of the cooling ball has a ratio of the diameter d and the thickness t to 0.0833 It is a thin cell structure.

Table 1. The Thin Shell Classification of Pressure Vessel for Inner Tank

Division	t(mm)	d_i(mm)	t/d	Standard
Inner Tank	5	60	0.0833	t/d ≤1/10 to shell

Structural analysis first analyzes the shape of a simple internal tank without a flange and compares and verifies the output value with the theoretical value. And the actual shape with the flange. Theoretical calculations are based on Eq. 4 was used.

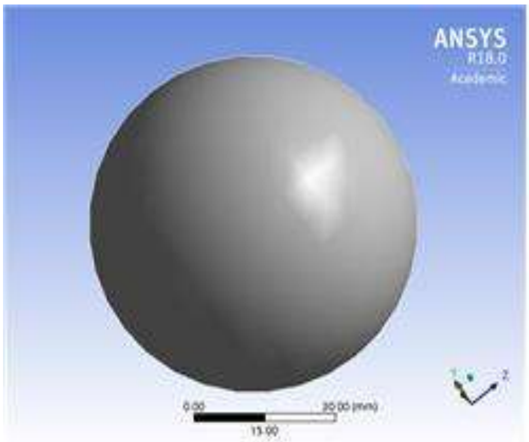

Figure 4. Inner Gas Tank Modeling Simplified

Here, the inner diameter di was 60 mm, the thickness t was 5 mm, and the pressure P was 3.0MPa as the inner pressure. As a result, the theoretical calculation value was calculated to be 9.0MPa. Figure 4 shows a simple shape without a flange. CATIA program was used for shape design.

Structural analysis was performed using ANSYS R18.0 under the condition that the internal pressure of 3.0MPa was applied to the entire interior. Figure 5 represents the mesh (mesh), which is divided into 1,152 [8, 9].

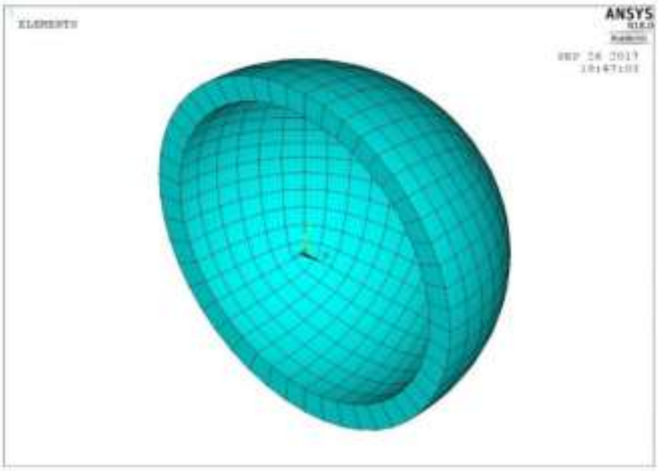

Figure 5. Mesh of Inner Gas Tank Simplified (ISO view)

Figures 6 and 7 show the result of Principal Stress analysis. The unit is (MPa). As shown, the inner surface is stressed up to 9.11MPa and the outer surface is subjected to stress of 7.59MPa.

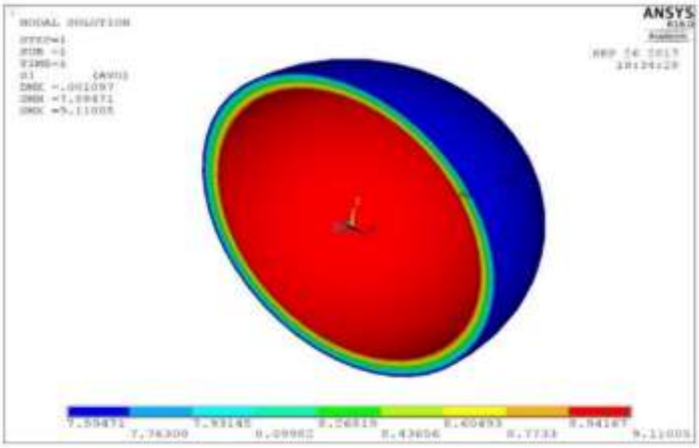

Figure 6. Principal Stress Distribution of Cooling Ball (ISO view)

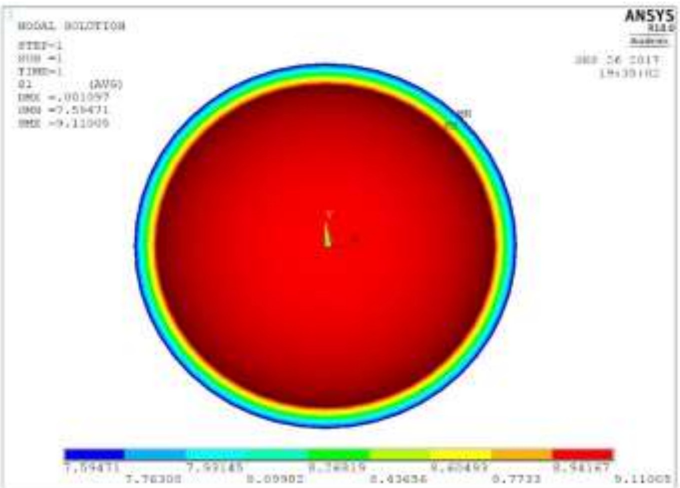

Figure 7. Principal Stress Distribution of Cooling Ball (Inside View)

Table 2 compares the results of ANSYS with those calculated by theoretical equations. In general, if the error is within 5%, the result is excellent, and the error is 1.2% based on the theoretical formula.

Table 2. The Comparison of Calculated Stress and Analyzed Stress (Simplified)

Division	Stress
Theoretical Value	9.00Mpa
Interpreted Value	9.11Mpa
Error	1.22%

Based on the above analysis conditions, structural analysis of the actual shape of the cooling ball with the flange and the primary nozzle was performed to evaluate the structural safety of the inner tank.

The restraint condition of the structural analysis is defined as the same condition as the simple shape, and the internal pressure is interpreted as 3.0MPa. Figure 8 shows Principal stress because of structural analysis on actual shape. As shown in the figure, the maximum stress was 11.17MPa at the bottom of the tank, and the stress in the tank was 7 ~ 8MPa. Compared with the result of simplified form, the difference of 1 ~ 2MPa is shown by the shape of flange and control part.

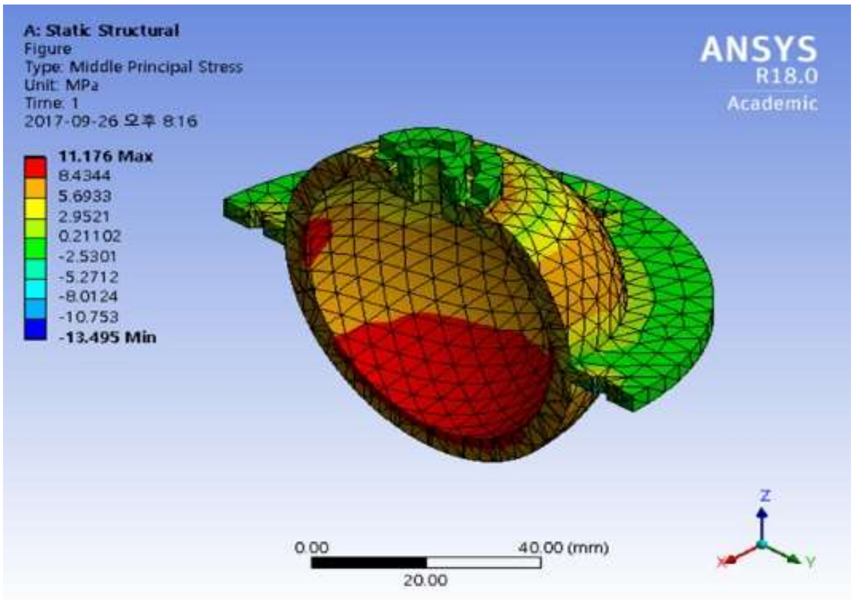

Figure 8. Analysis Result of Cooling Ball for Real Inner Shape (Principal Stress)

Figure 9 shows the deformation of the internal gas tank, with a deformation of 0.0024 mm in the downward direction. This indicates that even if 3.0MPa pressure is applied to the inner tank, the deformation occurs finely and it is considered that it has structural safety for the pressure.

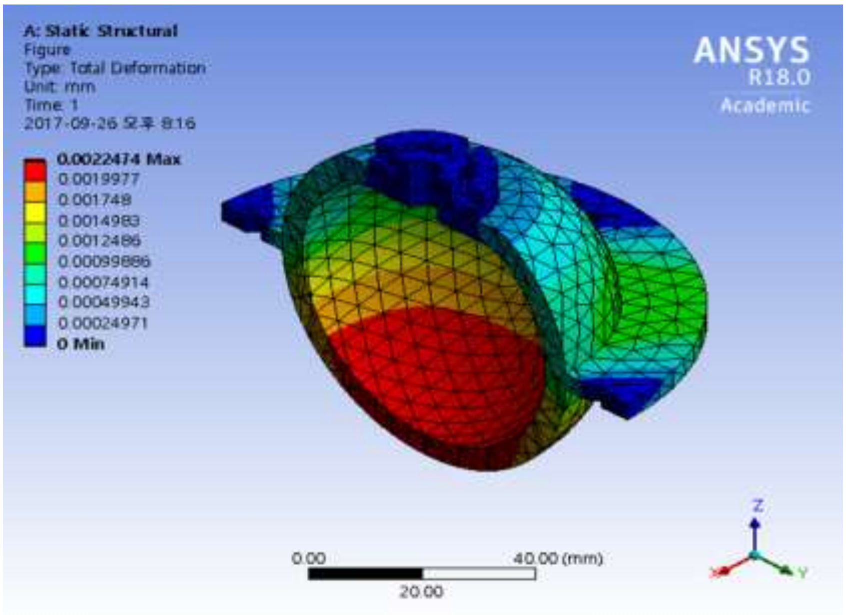

Figure 9. Analysis Result of Cooling Ball for Real Inner Shape(Deformation)

3.2. Structural Analysis of External Features

The outer casing of the cooling ball is immersed in the low-carbohydrate, protecting the internal gas tank and other internal devices. While low-carbohydrate power plants have different heights, and amounts of low-carbohydrate power plants, the structural analysis of the exterior casing of the cooling ball was carried out considering the maximum load. Since the stress analysis of the external carbon back is performed under the minimum conditions, it is not possible to ensure structural safety at the point of maximum 30 m of the carbon since it is not possible to secure structural stability due to the Buckling phenomena caused by the high carbonate height.

Coal density was 1,506, and its height was 30 m, making it possible to select 0.443MPa of external pressure on the cooling ball. As stated in the theory, the outer casing is considered a shell structure if the outer casing is 10 times smaller than the diameter (t), so that the outer casing of the cooling ball is of diameter (d) and thickness (d). The structural analysis used the same ANSYS R 18.0 as the internal tank and provided the condition for external pressure to be applied at 0.443MPa [10].

Table 3. The Thin Shell Classification of Pressure Vessel for Cooling Ball Outer Shape

Division	t(mm)	d_i(mm)	t/d	Standard
Outer Shape	5	160	0.0313	t/d $\leq$1/10 to shell

Figure 10 shows the mesh of the outer case, divided into 17,000 pieces.

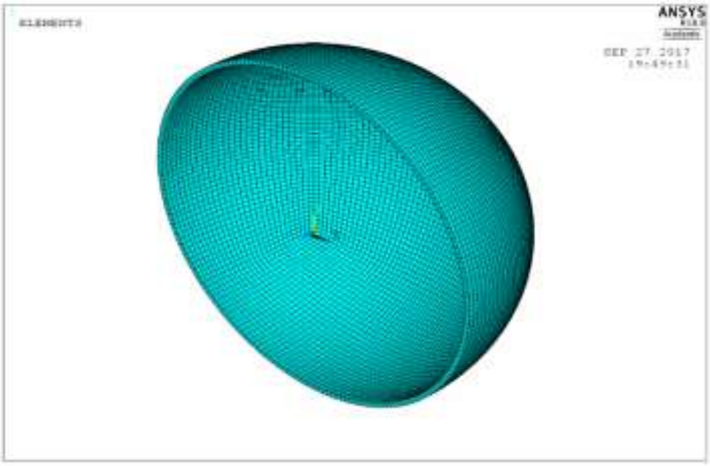

Figure 10. Mesh of Outside Case Simplified (ISO view)

Figures 11 and 12 show the result of Principal Stress analysis. The unit is MPa. As shown in the figure, the inner surface has a maximum stress of 7.7MPa and the outer surface has a stress of 7.48MPa.

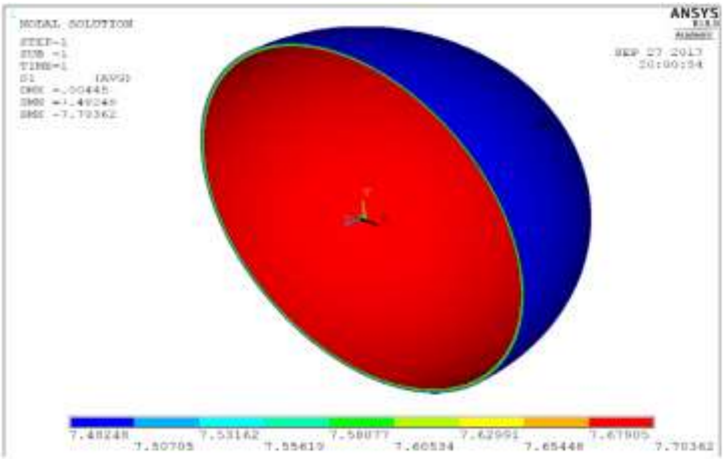

Figure 11. Analysis Result of Cooling Ball (ISO View)

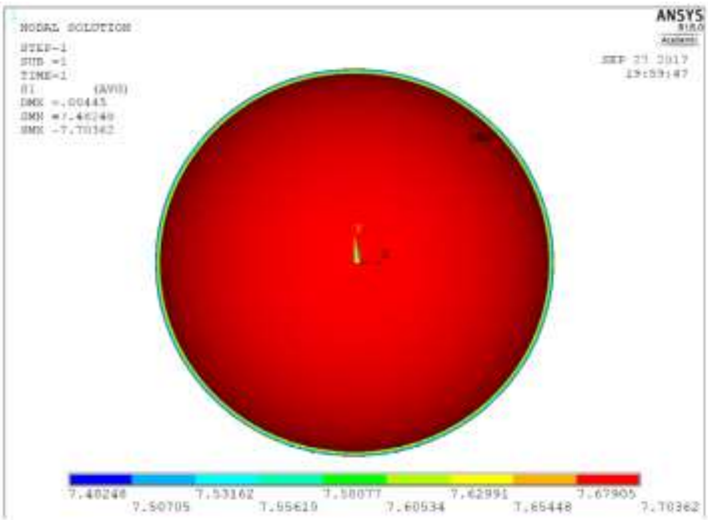

Figure 12. Analysis Result of Cooling Ball (Inside View)

Table 4 compares the theoretical calculation with the ANSYS result. In theory, the error in the results was 2.67 percent, a good result.

Table 4. The Comparison of Calculated Stress and Analyzed Stress

Division	Stress
Theoretical Value	7.50Mpa
Interpreted Value	7.70Mpa
Error	2.67 %

Structural analysis was performed for the actual features based on the above analysis conditions. The outer casing is equipped with internal fittings, solenoid valves, and controls, so it has a complicated structure.

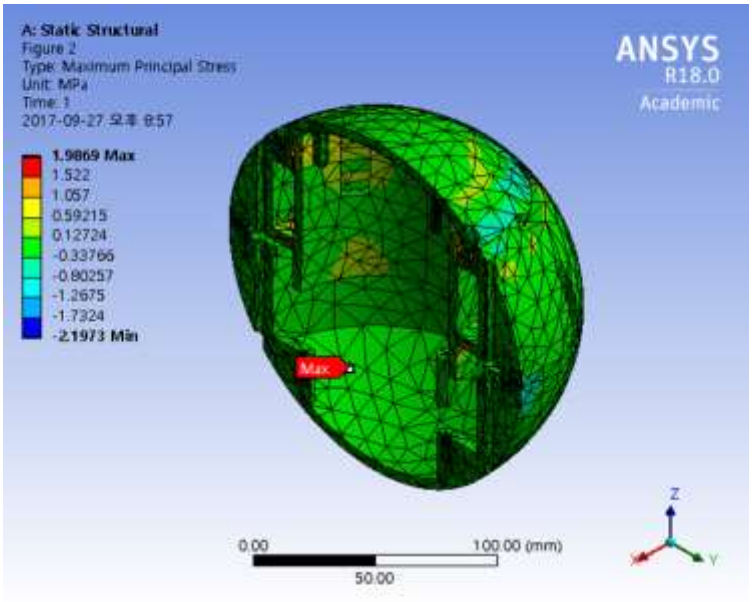

Figure 13. Analysis Result of Cooling Ball for Real Outside Shape (Principal Stress)

As shown in Figure 13, the maximum stress is 1.9MPa, and the stress is concentrated in the joint of the outer case. The reason why the stress is low is judged as the influence of the mounting of various internal devices inside. Figure 14 shows the deformation of the outer case and the deformation of the outer case of the pressure by 0.00025 mm occurred at the part where the control device is mounted. Therefore, it is considered that it has the structural safety against external pressure.

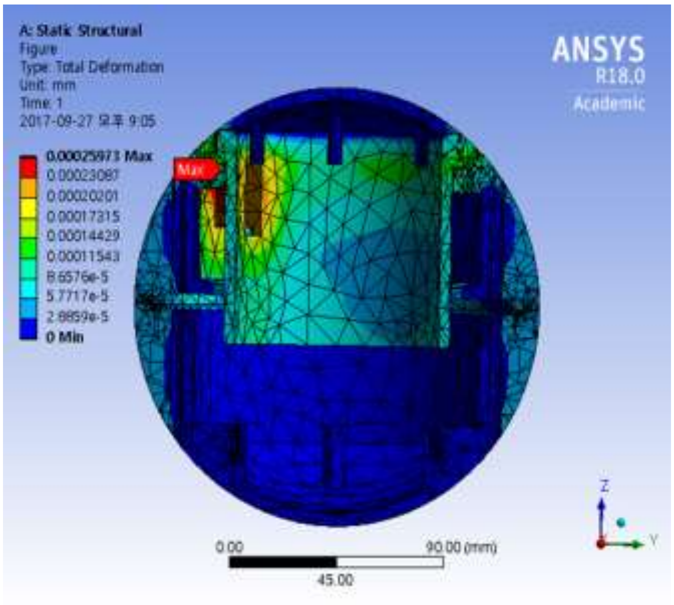

Figure 14. Analysis Result of Cooling Ball for Real Outside Shape (Deformation)

As a result of structural analysis of the actual internal pressure and structural analysis of the external casing, the internal tank with the maximum variation of 0.0024MPa is the maximum stress 11.17MPa and the maximum displacement is the maximum.

Table 5. Analysis Result of Real Shape

Division	Actual Internal Tank	Actual External Tank
Maximum Stress	11.17Mpa	1.9Mpa
Maximum Deformation	0.0024mm	0.00025mm
Structural Safety	structural stability	structural stability

4. Conclusion

In this study, the ANSYS results of theoretical equations and simple types of pressure vessels were compared for safety analysis on internal tank and external casing under pressure. Based on this validation, structural safety is assessed by analyzing the stress analysis and the variation rate for the actual features. The analysis results show that the internal tank has safety for internal pressure, and the external casing of the cooling ball also holds safety for the external pressure. In the future, this study plans to carry out structural analyses considering materials and temperature considerations.

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