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Solution to technical issue for practical use of concrete cask in Japan.

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Abstract

Hitachi Zosen provides design and fabrication of transportable storage metal cask, and is developing concrete cask system for future demand in Japanese market. During the long-term operation of austenitic stainless steel canister, the possibility of chloride induced SCC (Stress Corrosion Cracking) shall be considered. In order to introduce the concrete cask system to Japanese market, the important technical issue is to prevent the occurrence of SCC and to secure containment function of transportable storage canister made of austenitic stainless steel during long storage period.

One of the measures to prevent the SCC is to convert surface tensile stress to compressive one. It is confirmed that both zirconia peening and ball burnishing are effective methods to prevent SCC.

Although those methods can be expected to prevent SCC for long storage period, it is not established how to apply to the surface of canister. Furthermore, a method to ensure that SCC does not occur is not identified clearly during the storage period.

To solve above issues, Hitachi Zosen proposes as follows:

- For the prevention of SCC occurrence, residual stress improvement (tensile to compressive) would be applied during shop fabrication and after lid welding of the canister during operating floor.
- In consideration of additional safety, it is proposed that helium leak detection is carried out by measuring surface temperature during the storage.
- Also it is necessary for us to investigate an appropriate manufacturing sequence to reduce residual tensile stress due to welding.

Introduction

A metal cask storage system is used for spent fuel dry storage in Japan. In the near future, a concrete cask storage system is expected from the viewpoints of its economic efficiency, reduction of waste and short delivery period. In addition, it can be used as an alternative way when the metal cask face to some issue, such as undersupply of metal casks. In respect to application of concrete cask in Japan, some studies have been started by Central Research Institute of Electric Power Industry (CRIEPI) [1]. SCC, the most important issue for concrete cask application in Japan, occurs when three factors exist simultaneously; i.e. tensile stress, sea salt environment and austenitic stainless steel.

Since Japan is surrounded by the ocean, the interim storage facility would be built at coastal area. The saline air contacts directly to the canister surface due to the cooling air from seashore. Saline particles in the cooling air adhered to the surface of the canister might induce the SCC and lose its containment function in the worst case.
Removal of one of the factor mentioned above is needed to prevent SCC. The factor of residual tensile stress can be improved by zirconia shot peening, burnishing or WJP (Water Jet Peening), etc. and converted to the compressive stress. In addition, crack inspection method shall be established to detect appearance of SCC in service condition for preparing such the emergency condition.

Scenario of countermeasure against SCC by Hitachi Zosen

Three factors, stress, environment and material are necessary to induce SCC that is shown in Figure.1. We have to understand that if one of the factors is able to eliminate, SCC will not occur.
Figure.2 shows SCC countermeasure scenario by Hitachi Zosen. We propose a scenario of countermeasures against SCC on the basis of residual welding stress. At first, for the prevention of SCC occurrence, residual stress improvement (tensile to compressive) would be applied during at shop after welding of the canister shell and bottom plate. At this time, we are considering the Zr shot peening. Large amount of compressive stress is provided by Zr shot peening at the surface of the shell.

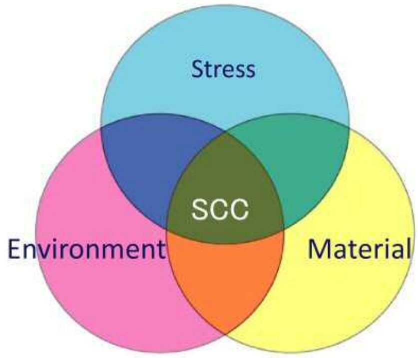


Figure 1 Three factors for SCC

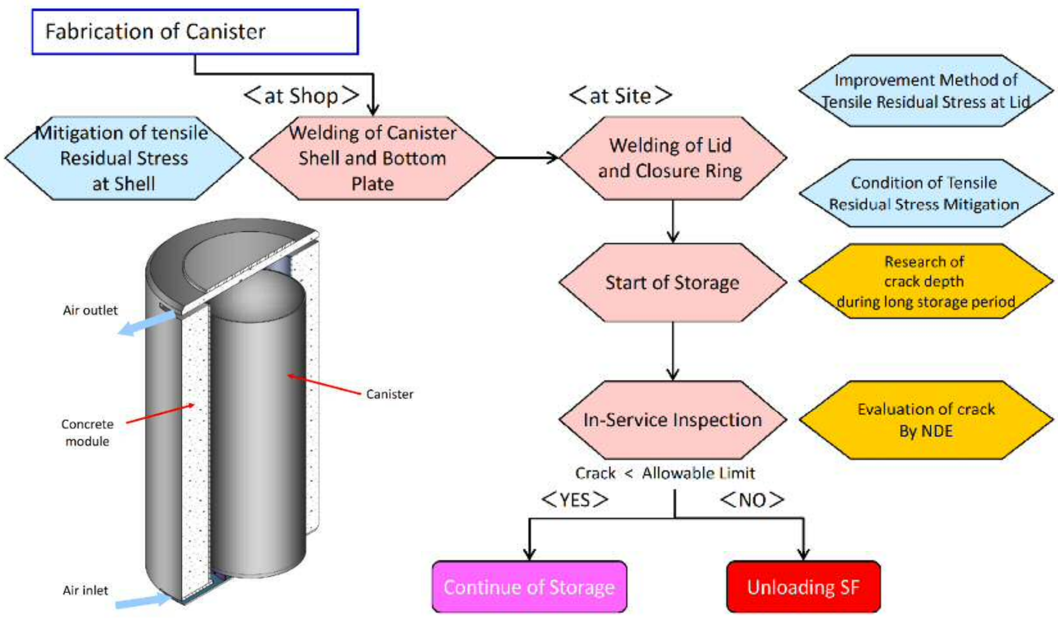


Figure 2 SCC Countermeasure Scenario by Hitachi Zosen

Next, after welding of primary lid and closure ring at site, we consider to perform the stress mitigation methods (Burnishing, WJP or USP (Ultrasonic Shot Peening)).

In consideration of additional safety, it is proposed that crack inspection using over-pack is carried out by visual inspection, eddy current, ultrasonic inspection or acoustic emission.

Welding condition for reducing tensile residual stress

The purpose of this study is to reduce residual stress in surface of shell and lid.

Figure.3 shows the image of surface processing to improve a residual stress. By this equipment, compressive stress will be added to shell and lid surfaces. We understand the area of tensile stress should be processed properly. If its area of tensile stress is small, the process can be shorten, so we have to select proper welding condition to reduce the area of tensile stress. By numerical analysis, we study which condition is better to reduce the tensile stress due to the welding.

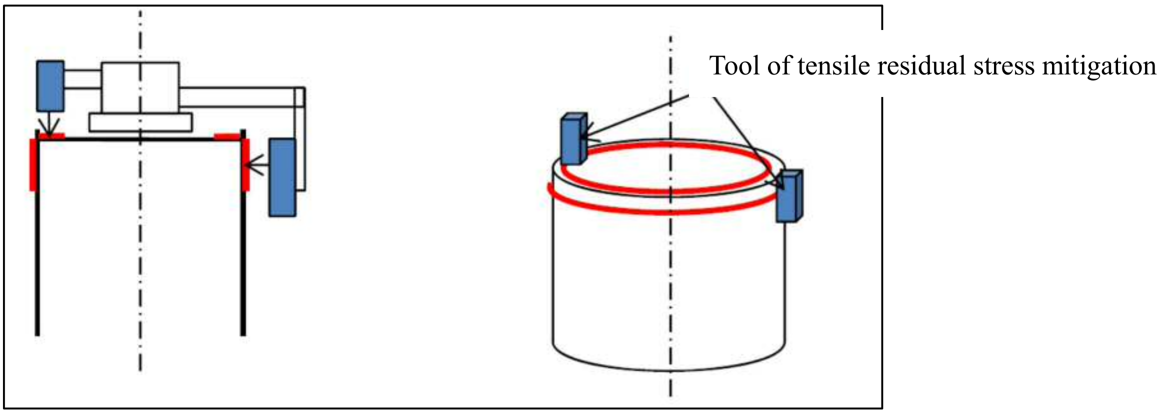


Figure 3 Surface Processing to prevent SCC

Figure.4 shows 2D Axial Symmetry model, having top part of the canister with full-scale diameter (1828.8mm) and wall thickness (12.7mm) was made of austenitic stainless steel and manufactured by using the TIG (Tungsten Inert Gas) welding technique.

Figure.5 shows the analysis cases which consider the differences of the followings. For the purpose of reducing tensile residual stress area, analysis was carried out using the similar welding condition at shop by using 2D axial symmetry model.

Part A shows difference in of groove depth (16mm～30mm) and gap (0～5.7mm) between shell and primary lid. Part B shows difference in welding pass in primary lid. Part C shows difference in weld sequence in closure lid.

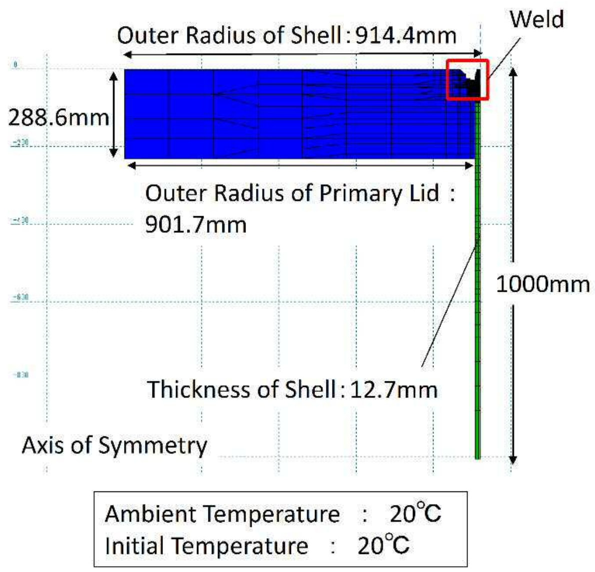


Figure 4 2D Axial Symmetry Model

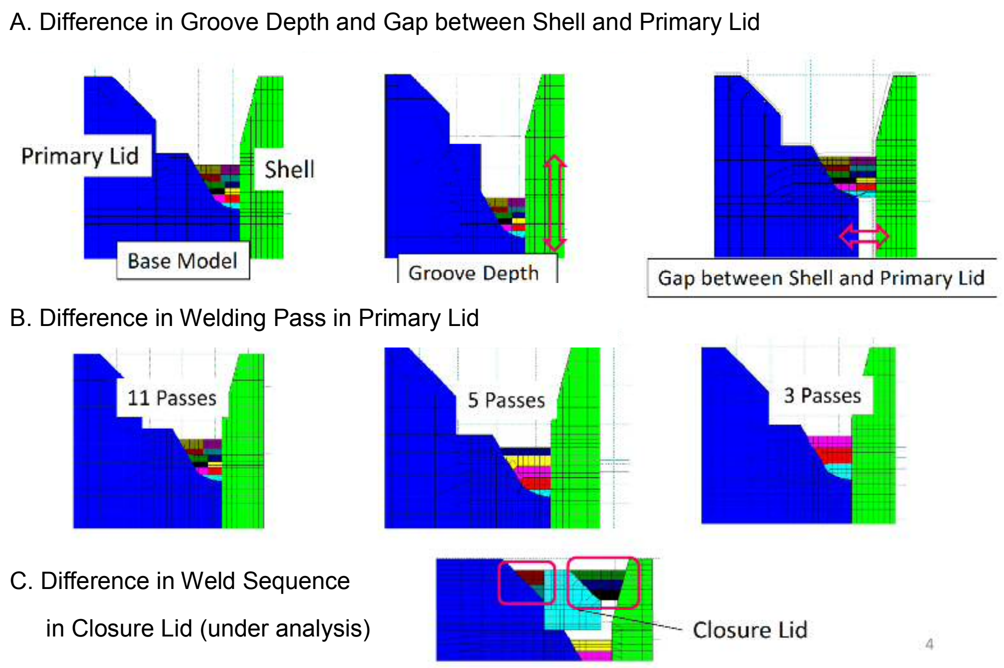
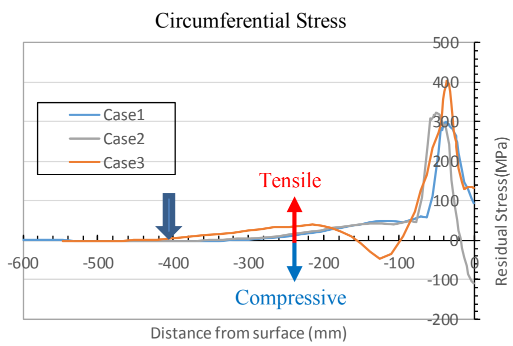


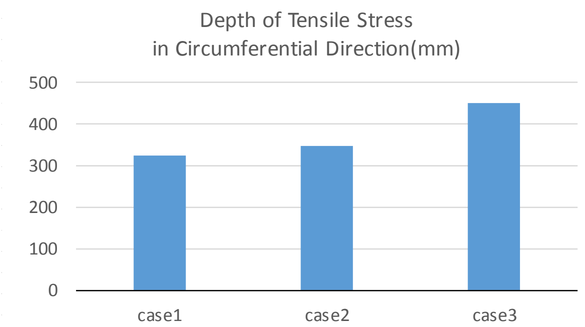
Figure 5 Analysis case

Figure.6 shows the result of Part A. It was carried out an analysis in three cases. It is thought that the influence of groove depth and gap on the residual stress is small. But, in order to reduce depth of tensile stress, groove depth and gap should be made as shallow as possible.

Figure.7 shows the result of Part B. It was carried out an analysis in four cases. Case 1 was the conventional TIG welding of the 11 passes. In cases 2～4, hot wire TIG welding is applied.

Depth of tensile residual stress generated by conventional TIG is smaller than hot wire TIG. In the case of using hot wire TIG, reducing welding pass is effective in order to reduce depth of tensile stress and welding distortion.





Distribution of residual stress

	Groove Depth (mm)	Gap (mm)
Case1	16	0
Case2	30	0
Case3	16	5.7

Figure 6 Effect of groove depth and gap between shell and primary lid (Part A)

Part C is influence of weld sequence in closure lid. In order to evaluate the difference of the welding sequence, we performed in the analysis of the four cases shown in Figure.8. It shows that welding sequence does not affect the residual stress in these cases (Figure.9).

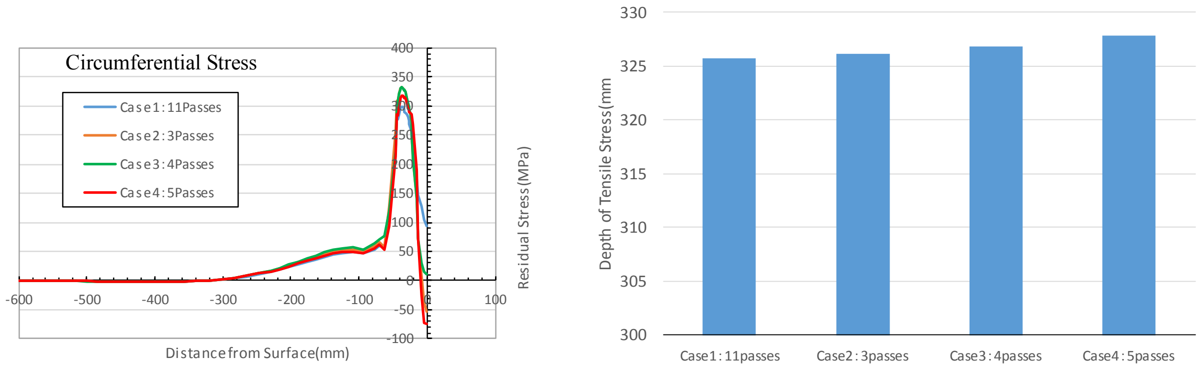


Figure 7 Effect of Welding Pass in Primary Lid (Part B)

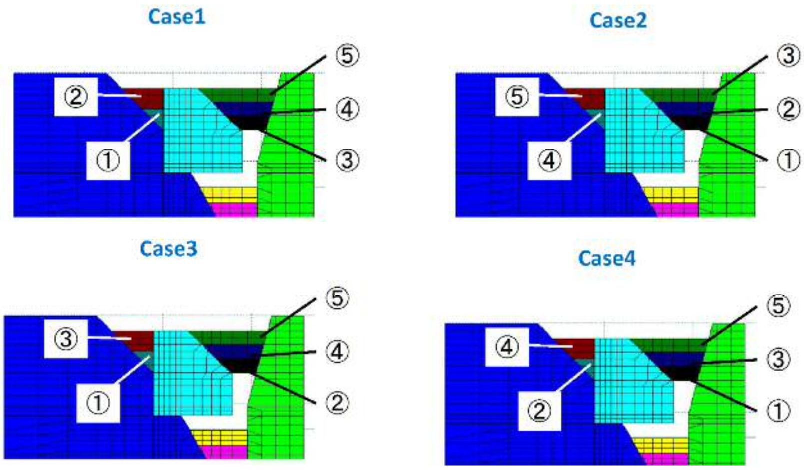


Figure 8 Welding Sequence (Part C)

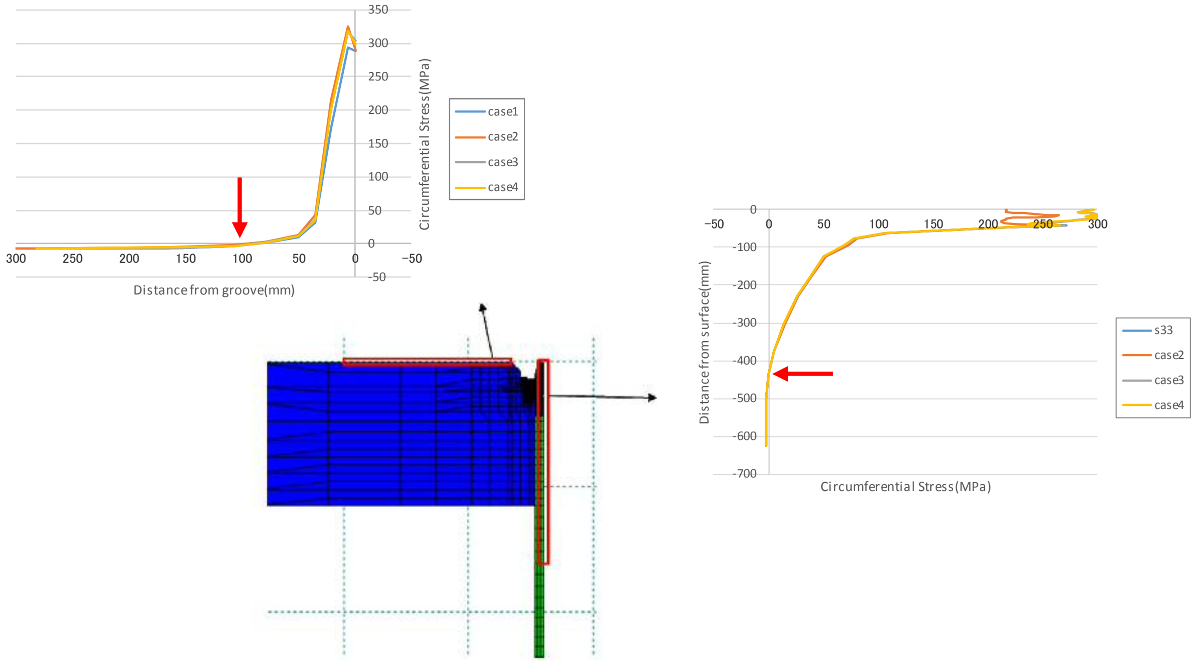


Figure 9 Effect of weld sequence in closure lid (Part C)

Inspection Method during Storage

Periodic in-service-inspection may be required in Japan because the regulatory agency in Japan may concern about SCC and it is necessary to find SCC during storage. In the US, the utilities have many storage experience but they didn’t concern about SCC. They perform surface inspection by visual observation, but it is not easy to detect SCC occasion visually. So NDE (Non Distractive Examination) may be required to find SCC.
When NDE is performed at storage pad, we have some issues as follows.

(1) Space for instruments is very narrow between canister and concrete cask.
(2) It is difficult to access cables of instruments in concrete cask. Some access routes are necessary for concrete cask.
(3) Some parts of canister surface are hidden behind canister supports allocated at concrete cask annulus.

Instead of NDE, the other approach we propose is detecting method of helium gas leak explained in the next column [2]. In case that perpetrated cracks through canister are produced, thermal condition inside cask is changed because helium inside is leaked and internal pressure is reduced. So we suggest the method using temperature variation of canister surface temperature.

Detecting method of helium gas leak from canister

In the concrete cask storage system, spent fuel is installed and weld-sealed in a canister. The canister is filled with helium gas and its containment shall be maintained and inspected during the storage. The helium gas enhances heat removal from spent fuel. When helium gas leaks, the effect of helium gas convection is weakened in the canister. Then, the temperature on the canister surface changes. By using this principle, the detecting method using information of temperature changes on the canister side surface has been proposed. However, there are the following problems in the proposed method.
Helium gas of atmosphere pressure (0 kPa) level was filled into the canister before heating. Then, the inner pressure reached 56 kPa in the steady state with the condition of a heating rate of 22.6kW. The test started when a valve was opened to leak the helium gas. Figure10 shows temperature measurement points.
The temperature difference (=T_B-T_T) was defined as ΔT_{BT}, and a detecting method of the helium leak using ΔT_{BT} was examined.
Figure11 shows the relationship between the change of ΔT_{BT} and that of the inner pressure of the canister. Fig13 shows the relationship between the change of ΔT_{BT} and that of the inlet air temperature.

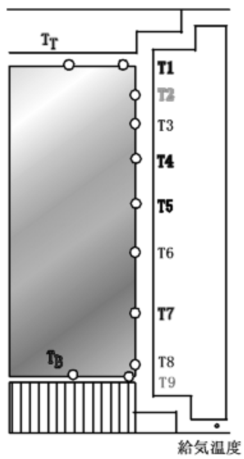


Figure 10 Temperature measurement points

It was found that ΔT_{BT} increases significantly due to the helium leak.

Figure.12 shows the relationship between the change of ΔT_{BT} and that of the inlet air temperature. It was found that ΔT_{BT} increases during the helium leak although the inlet air temperature decreases.

The phenomenon that the canister surface temperature changes due to the helium leak from the canister was verified. Especially, the temperatures of the bottom and the top of the canister change significantly. It was found that ΔT_{BT} increases remarkably during the helium leak. Thus, the helium leak can be detected based on the change of ΔT_{BT}. The ΔT_{BT} increases monotonously to a fixed value during the helium leak, even if the inlet air temperature decreases. The helium leak can be detected at the early stage of the leak by observing both ΔT_{BT} and the inlet air temperature.

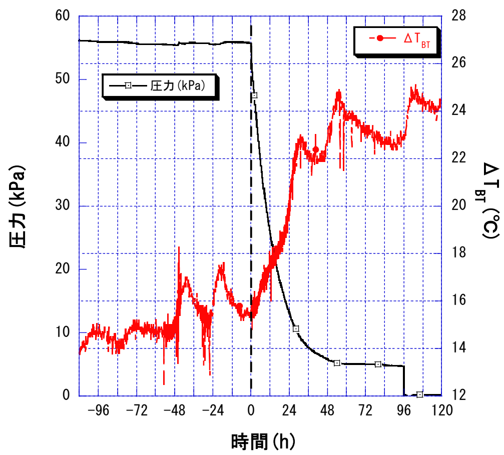


Figure 11 Change of ΔTBT and pressure

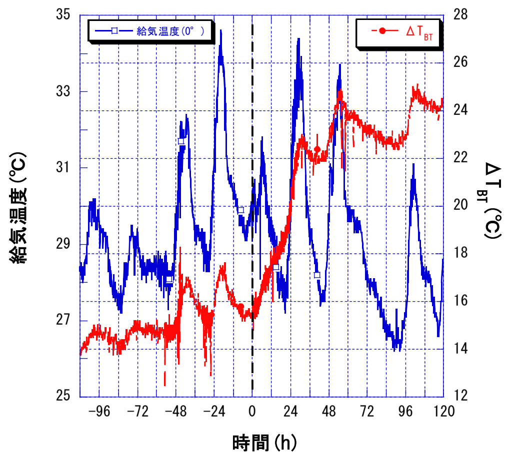


Figure 12 Change of ΔTBT and Tin

Conclusions

The main conclusions are as follows

A. Effect of Groove depth and gap between shell and primary lid

- In order to reduce depth of tensile stress and welding distortion, groove depth and gap should be made as shallow as possible.

B. Effect of welding pass in primary lid

- Depth of residual stress and welding distortion generated by conventional TIG is smaller than hot wire TIG.
- In the case of using hot wire TIG, reducing welding pass is effective in order to reduce depth of tensile stress and welding distortion.

C. Effect of weld sequence in closure lid.

- Welding sequence does not affect the influence to residual stress

D. Detecting method of helium gas leak from canister

・The phenomenon that the canister surface temperature changes due to the helium leak from the canister was verified. The helium leak can be detected based on the temperature change.

Acknowledgments

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References

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