Proceedings of the 18th International Symposium on the
Packaging and Transportation of Radioactive Materials
PATRAM 2016
September 18-23, 2016, Kobe, Japan

Paper No.5027

Selecting Material for Transportable Storage Canister Shell for Concrete Cask

Ryoji Asano
Hitachi Zosen Corporation

Masanori Goto
Hitachi Zosen Corporation

Yoshikazu Miyaji
Hitachi Zosen Corporation

Abstract

A canister loaded spent fuels stored in a concrete over-pack is planned to be taken out from the concrete over-pack, and to be shipped to a reprocess plant and /or a final disposal repository facility by a metal transport over-pack (a transport cask) after the scheduled storing period of several decades. For the safe transport, it is necessary to confirm that the canister shall satisfy the technical requirements specified in the transport regulations for radioactive materials. The canister shell will be containment boundary. As the canister is usually filled with inert gas such as helium gas, corrosion from the outside surface of the canister during the storage period is one of the technical issue to be solved for the safe transport after the storage. As a spent fuel storage facilities is possibly to be installed near sea shore in Japan, stress corrosion cracking induced by chloride ion in saline air becomes an issue to be considered in addition to other corrosion. Using high anti-corrosion material such as super austenitic stainless steel and/or duplex stainless steel might be one of the solutions to solve the issue. However, we selected ordinary austenitic stainless steel for the canister material. In this paper, we explain the reasons why ordinary austenitic stainless steel is selected for the shell and lid material, taking into consideration of corrosion, workability and weldability, availability of material, and economy.

Introduction

A concrete cask or a concrete module is a spent fuel storing system developed in the United States. As the system is more economical than the other storage systems, the storing facilities of 80% or more adopt this system in the United States. Although the system has not been introduced in Japan, it is expected that the introduction of the concrete cask system will be considered in near future for its economical domination.

The canister that is one of the components of a concrete cask is a containment system. It is necessary to maintain the containment function not only during storage period of several decades but at the transportation after the storing period. It is necessary to prevent the loss of containment function due to corrosion during the storing period. Stainless steels that are an excellent corrosion resistance materials are used for the material of the canister.

In the case that a spent fuel storage facility is built at sea coastal location, measures to prevent the stress corrosion cracking induced by the chlorine ion in saline air should be considered.
Ordinary austenitic stainless steel type 304 is the most prevalent material used in the U.S. for the canister considering corrosion resistance. In addition to the material, it is possible to consider the usage of super austenitic stainless steels and/or duplex stainless steel which have higher corrosion resistance. In this paper, super austenitic stainless steels and duplex stainless steel were added to the ordinary austenitic stainless steel, and comparative study was conducted on the corrosion especially on stress corrosion cracking, workability and weldability, availability of the materials and economy.

Concrete Cask

The structure of a typical concrete cask is shown in Figure 1. The concrete cask consists of a metallic canister and a concrete over pack. The canister is the confinement system that contains spent fuels in it. The concrete over pack is the radiation shielding and also provides the ventilation duct for air that cools the surface of the canister directly.
The cooling air is taken from the inlets installed in the bottom part of the concrete over pack, and the warmed air is exhausted from the outlets installed at the top part of the over pack as shown in Figure 1. If the cooling air contains the corrosive material, the corrosion effect should be considered that may affect its containment function during the storage period. When the cooling air contain sault particle from sea water, it is necessary to be care of the stress corrosion cracking (SCC) induced by the chlorine ion in the saline air.

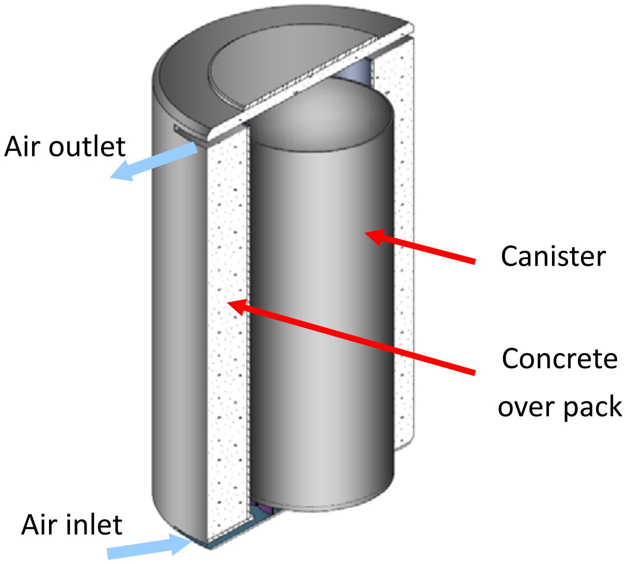

Figure 1 Concrete Cask

Candidate Materials for Canister

As a storage facility may be built at coastal location in Japan, the corrosion resistant material is requested to use for canister material. Although Type 304 stainless steel is the most prevalent material used in the U.S. for the canister, type 304L(1) and/or 316L(1) austenitic stainless steel was selected as an candidate material of ordinary austenitic stainless steel (Ordinary S.S.) that exhibits modestly more resistance to SCC than Type 304. In addition to the Ordinary S.S., SA240-S31254(1) is selected as a candidate of super-austenitic stainless steels (Super S.S.) and G4303 SUS329J4L(2) is selected as a candidate of duplex stainless steel (Duplex S.S.) that have better corrosion resistance characteristic than Ordinary S.S.

Chemical Composition and mechanical properties of the materials

Table 1 shows the chemical composition of the candidate materials. Comparing to Ordinary S.S., Super S.S. has higher content of nickel, and Duplex S.S. has higher content of chrome. Moreover, the nitrogen is added to both materials that is not added to Ordinary S.S.

Table 2 shows mechanical properties of the materials. Comparing to Ordinary S.S., the mechanical strength of both material is higher. Duplex S.S. has the maximum strength among three materials. On the contrary, the elongation of Ordinary S.S. is the highest, and Duplex S.S. is lowest. The hardness is the opposite order of the elongation.

From the mechanical properties, it is understood that Duplex S.S. is a harder material than the other two.

Table 1 Chemical composition

	Ordinary S.S (Type 316 L)	Duplex S.S. (SUS 329 J4L)	Super S.S (SA 240-S31254)
C (%)	0.03	<0.03	0.020
Mn (%)	<2.00	<1.50	1.00
P (%)	<0.045	<0.04	0.030
S (%)	<0.030	<0.03	0.010
Ni (%)	12.00-15.00	5.50-7.50	17.50-18.50
Cr (%)	16.00-18.00	24.00-26.00	19.50-20.50
Mo (%)	2.00-3.00	2.50-3.50	6.00-6.50
N (%)	-	0.08-0.30	0.18-0.22

Table 2 Mechanical properties

Property	Ordinary S.S (Type 316 L)	Duplex S.S. (SUS 329 J4L)	Super S.S (SA 240-S31254)
σ_u (N/mm^2)	480	690	650
0.2% proof stress (N/mm^2)	175	485	300
E (%)	40	20	35
Hardness (HBW)	187	290	223

Corrosion resistance

It is necessary to consider the overall corrosion, the pitting corrosion, the crevice corrosion, and SCC as the corrosion induced on the canister surface. For evaluating corrosion resistance of each material, the pitting resistance equivalent number (PRE) is used that is widely used to evaluate the corrosion resistance in the seawater environment. PRE is calculated by the following formula.

Ordinary and Super S.S.: Cr (%) +3.3xMo (%) +30xN (%)

Duplex S.S.: Cr (%) +3.3xMo (%) +16xN (%)

PRE of each material is calculated as follows. Mean values of the table 1 is used for the calculation of PRE.

Ordinary S.S.: 25.3
Duplex S.S.: 37.9
Super S.S.: 46.6

As PRE of Super S.S. is best, and that of Duplex S.S. follows, the super S.S. is the most corrosion resistant material among the three. However, it is reported that under the certain combined condition, even the super S.S. is susceptible to SCC. Therefore, the comparison on materials focuses to saline air induced SCC, taking into consideration of the conditions mentioned above.

Condition that SCC is induced

It is well known that SCC is induced under the combined condition of environment, material and stress. Oppositely, SCC is not induced if one of the conditions is disappeared. This is shown in Figure 2, and each condition is discussed as follows

Environmental condition

As the environmental condition is determined automatically by the location where a spent fuel storage facility is installed. It may be possible to control it by setting up a filter at the air inlets of a concrete cask to remove salt particles in the saline air, but it is not so practical method. The environment condition is assumed here not to able to be controlled to mitigate SCC.

Material condition

It is so difficult and not so practical to completely mitigate SCC by the selection of the material as described in the previous section.

Figure 2 Schematic diagram of SCC induced conditions

Although the resistance of SCC become smaller in the order of S.S Super, Duplex S.S. and Ordinary S.S, there still exists the probability.

Stress condition

The surface residual stress should be tensile stress to induce SCC. It is never induced oppositely under the compressive stress condition.

The tensile stress condition results from the fabrication process of canister such as cold work and welding. Moreover, in the operation process, the lid is welded to the canister body after loading the spent fuels at nuclear reactor site. The high tensile residual stress in weld area and heat affect zone results from these welding process.

The distribution of residual stress measured in the longitudinal weld of the canister shell in the depth direction is shown in Figure 3 in blue line. It shows that high tensile stress is generated by welding.
It should be noted that the stress condition in the Figure 2 will disappear if the residual tensile stress is changed into compressive one.
The zirconia peening (Zr peening) and low plasticity burning method (LPB) are such practical method for changing the residual tensile stress to compressive one. Figure 3 also shows the result of the Zr peening effect in the longitudinal weld in green line. The method changed the high tensile stress to compressive one up to 800 micro-meter depth from the outer surface of a canister.
The effect of surface stress improvement was confirmed by SCC test of $MgCl_2$ solution at 143℃. Figure 4 shows the result of the SCC test. There were many indications of crack on the test piece of as weld condition, but no indication was observed on the test piece applied the Zr peening. It should be noted that the method can be applied to any kind of metal.

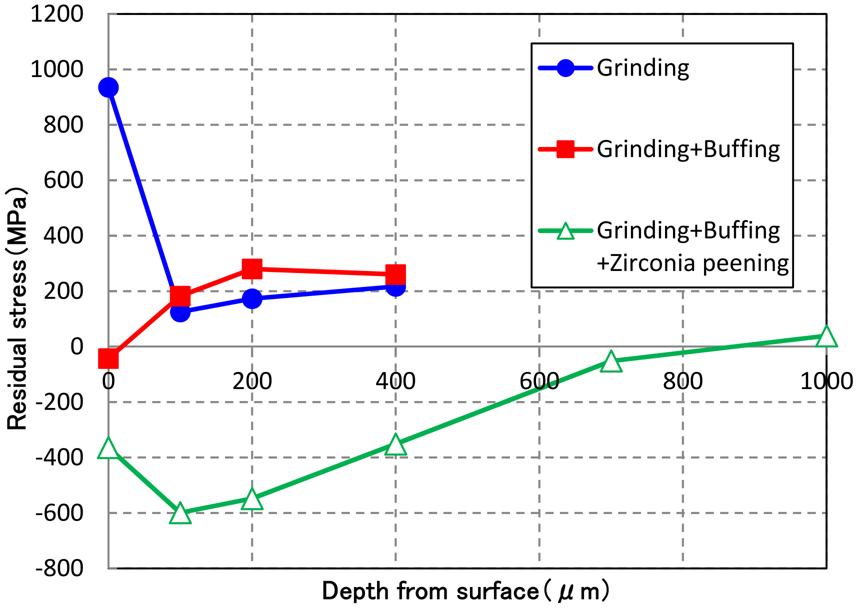

Figure 3 Residual stress distribution in direction of thickness at weld part

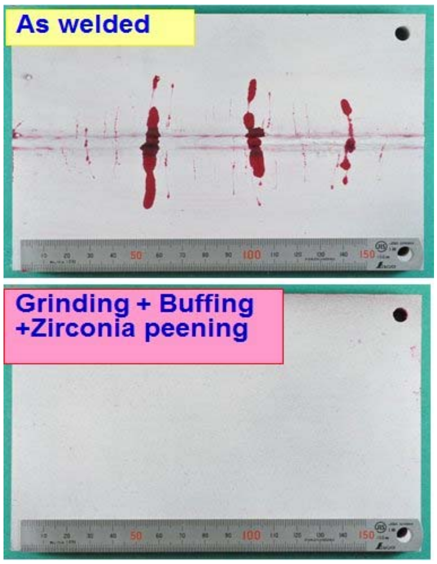

Figure 4 Effect of changing tensile stress to compressive stress

Workability and Weldability

Duplex S.S and Super S.S are harder than Ordinary S.S. but there is no significant difference among the three materials on the workability.
Regarding weldability, Ordinary S.S. including Type 304L and 316L is a material that has steady weldability. There are a lot of experiences to use welding in the equipment for the nuclear power plant. Super S.S. also has steady weldability, but the experience is not so much especially in nuclear equipment.
On the other hand, the possibility of the delay cracking caused by hydrogen embrittlement is concerned for Duplex S.S. The extension of the crack that starts from the route will be stopped in the layer, and the crack will not come out the weld surface. This means that the crack will not be detected by multi-

PT which is weld inspection method admitted by U.S. competent authority. UT should be applied in addition to multi-PT. As the welding and inspection are curried out at the spent fuel storage pool area of nuclear reactor, such works should be avoided if possible.

Material Availability

Ordinary S.S. is very popular and easy to obtain, and its supply capacity is larger enough to meet large amount of demand. On the other hand, the supply capacity of Duplex S.S. and Super S.S. is limited. It may become issue when large number of concrete casks are needed to fabricate at one time.

Economy

Table 4 shows the unit price of Ordinary S.S. (Type316L), Duplex S.S. (SUS329J4L) and Super S.S. (S31254). As the unit price is varied at the time, it is rough idea to compare the economy of the materials. From the table 3, it can be say that the cost of Duplex S.S. is 1.5 times higher than that of Ordinary S.S., and Super stainless cost is 2.3 times higher.

Table 3 Material cost

	Ordinary S.S (Type 316 L)	Duplex S.S. (SUS 329 J4L)	Super S.S (SA 240-S31254)
Unit price of plate (JPY/kg)	420	610	970

Conclusions

For a concrete cask canister material, three kinds of material with good corrosion resistance characteristic were compared on corrosion resistance especially saline air induced SCC, workability and weldability, availability, and economy..

Corrosion resistance

The material condition of SCC cannot be completely eliminated by selecting material. The method to improve the surface residual stress to compressive is most reliable method to mitigate SCC. Both Zr peening and LPB are such method which can be applied to all materials.

Workability and weldability

There is no dominant difference in the workability. Regarding weldability, the stability and experience of the Ordinary S.S. are very good. Because of the delay cracking caused by hydrogen embrittlement for Duplex S.S., it is necessary to apply UT in addition to multi-PT for the lid weld inspection.

Availability

The availability of the Ordinary S.S. is the best. Both Super S.S. and Duplex S.S. have the limitation in the supply capacity, and it may not be possible to meet a large amount of demand at one time.

Economy

The Ordinary S.S. is the most economical. The cost of the Super S.S. is twice or more expensive than that of the Ordinary S.S.

The result was scored as shown in Table 4. The Ordinary S.S. which obtained the highest score was selected for the canister material, which surface residual stress would be improved to compressive stress by the surface improvement method such as Zr peening method to mitigate SCC.

Table 4 Score of comparison result

Element	Ordinary S.S (Type 316 L)	Duplex S.S. (SUS 329 J4L)	Super S.S (SA 240-S31254)
Corrosion	2	2	2
Workability and Weldability	2.5	1	2.5
Availability	3	1.5	1.5
Economy	3	2	1
Total	10.5	6.5	7

(score) high :3, average :2 low: 1

References

(1) JIS 4304 Hot rolled stainless steel plate and strip
(2) ASME Code Sec. II SA 240 Specification for heat-resisting chromium and chromium-nickel stainless steel plate, sheet, and strip for pressure vessel, ,