DEVELOPMENT OF METAL CASK FOR NUCLEAR SPENT FUEL

T. MATSUOKA, S. KURI, K. OHSONO, S. HODE

Mitsubishi Heavy Industries, Ltd., Kobe Shipyard &Machinery Works, Hyogo-ku, Kobe 652-8585, Japan - E-mail: toshihiro.matsuoka@kind.kobe.mhi.co.jp

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Introduction

It is one of the realistic solutions against increasing demand on interim storage of spent fuel assemblies arising from nuclear power plants in Japan to apply dual purpose (transport and storage) metal casks. Since 1980's Mitsubishi Heavy Industries, Ltd. (MHI) has been contributing to develop metal cask technologies for utilities, etc. in Japan, and have established transport and storage cask design "MSF series" which realizes higher payload and reliability for long term storage.

MSF series transport and storage casks use various new design concepts and materials to improve thermal performance of the cask, structural integrity of the basket, durability of the neutron shielding material and so on. This paper summarizes an outline of the cask design that can accommodate BWR spent fuel assemblies as well as the new technologies applied to the design and fabrication.

Outline of the Cask Design

The MSF series casks that use the new technologies are designed to meet IAEA transport regulations. Overall external view of the MSF transport and storage cask is illustrated in Figure 1, and its specification as a sample is shown in Table 1. Cylindrical part and base part of main body that function as a primary gamma shield are made of forged carbon steel. Primary lid and secondary lid also made of forged carbon steel are screwed to the top of main body in order to allow continuo us monitoring of pressure variation of the inter-space between the two lids during storage.

Specially developed neutron shielding material is installed in the concentric space between the main body and the outer shell. Heat conductor plates made of copper are longitudinally welded along with the main body and outer shell through the neutron shielding layer. Inside the cask cavity, basket assembly consisting of 69 separated square pipes made of boronated aluminum is installed to space spent fuel assemblies, and has the functions of accommodating them and of sub-criticality control. A pair of shock absorber made of wooden material covered with stainless steel plate is installed at both ends of the cask to absorb impact energy and alleviate the impact force imposed on the cask and its content in a drop accident.

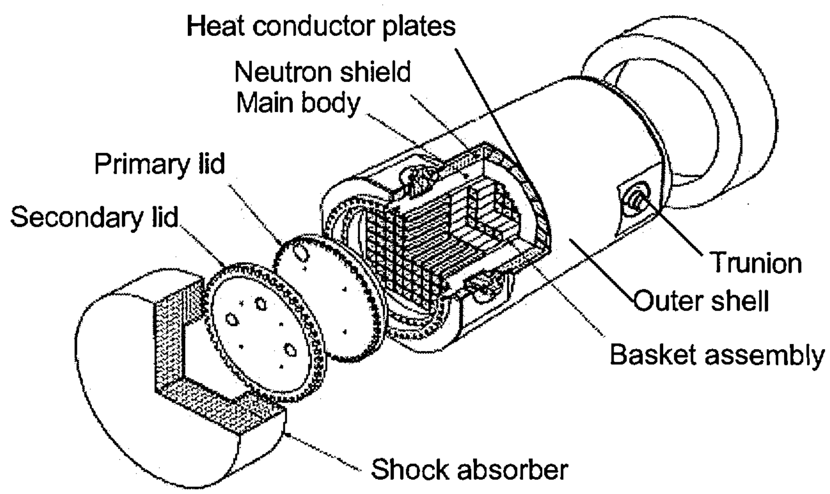

Figure 1 Cask external shape

Item	Specifications
Specification of Fuel	
Type of fuel assembly	BWR 8x8
Initial enrichment	3.2 %
Burn-up (max.)	40 GWd/t
Cooling time	10 years
A sample of designed cask	
Number of fuel assemblies	69 sets of fuel assembly with channel box
Design heating power	19kW
Weight of cask	119ton (Including lids, basket and fuel assemblies)
Size of cask	
Including shock absorber	3.6m(W) x 6.6m(L)
Excluding shock absorber	2.6m(W) x 5.5m(L)
Materials	
Body	Carbon steel forging
Neutron shielding	Epoxy resin
Basket	Boronated aluminum by powder metallurgy
Containment device	Metallic gasket

Table 1. MSF cask specification (a sample)

Key Technologies

The following key technologies for design and manufacturing are applied to the MSF series. Purposes of technologies used in cask design are shown in Table 2.

Item	Purpose		
	Improve reliability	Increase payload	Simplify fabrication
New-developed manufacturing method - monolithic forging			O
New structure - polygon shaped body - Basket assembly		O	O
New material - New-developed boronated aluminum alloy - New-developed neutron shielding material - Metallic gasket	O O	O	O

Table 2 Purposes of used technologies

- Monolithic forging

With regard to the manufacturing method, main body forging of the cask is using "monolithic forging method", which means that heated steel is shaped into vessel by only forging technique.

Circumferential welding between cylindrical part and base part is required to fabricate main body in the ordinary process of cask manufacturing. And heat treatment and inspection on the welded seam are also required after welding. This radical new method eliminates any welding work.

This also eliminates in service inspection on the welded seam during long-term storage. Accordingly MSF cask has gained improved reliability by the elimination of welding.

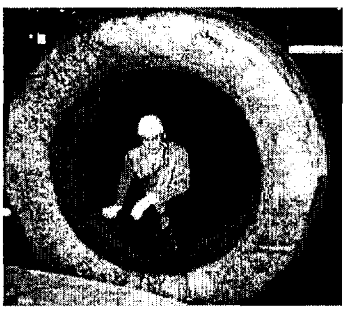

Figure 2 Monolithic forging for MSF cask

-Basket assembly

The simplified basket assembly consists of individual not jointed square pipes that are inserted into the body and directly supported by the internal face of the body.

Assembling to structure form plates is required to fabricate basket in the conventional process but the new structure eliminates this process. The validity of this structure is verified by the 9-meter drop demonstration test.

- Shape of main body

Monolithic forging is shaped into polygonal configuration by machining. The body forging after machining is illustrated in Figure 3.

Temperature of the basket should be kept low when aluminum is used for the basket structural material. For meeting the mentioned above object, internal face of the body forging is machined to make "steps" in its cross section in order to fit the external shape of basket assembly which consists of individual square pipes. This provides close contact between external surface of the basket assembly and internal face of the body forging, thus heat dissipation performance is greatly improved by enabling to enlarge heat transfer area. As a result of the design, it is possible to get lower temperature of basket than conventional configuration of the cylindrical body that gives a larger gap between the basket and the body internal surface.

External face of the body forging is also machined in a polygonal shape to provide optimized configuration for gamma shielding with minimum weight. Inside and outside machining of body forging make the body compact to maximize the number of fuel assembly to be housed within weight and dimensional limits imposed on the cask design.

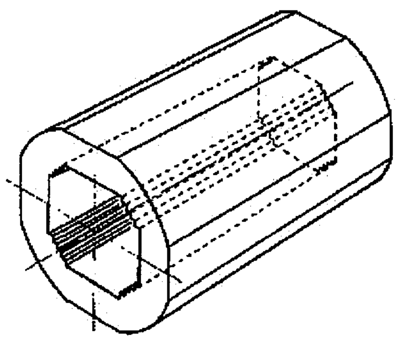

Fig. 3 Shape of body forging of MSF series cask after machining

-Basket material

MSF series cask uses boronated aluminum without aging treatment. Powder metallurgy is adopted for its manufacture process.

Several types of aluminum alloys usually reinforced by aging treatment are used for many types of basket in order to increase accommodation of fuel assemblies. The usual manufacturing process of boronated aluminum alloy (shielding plate) is to dissolve boron in molten aluminum alloy to pour the ingot case, then form the ingot into plate by rolling.

However, the strength of aluminum reinforced by aging treatment is lowered during use in high temperature condition because of over-aging and it is difficult to predict over-aging effect because experimental data are scarce. And because there is a tendency for segregation of boron to grow in the ingot while the molten aluminum is being solidified it is difficultto obtain homogeneous boron distribution. As large deposit give boronated aluminum to more brittleness, it is difficult to ensure stiffness toughness.

The solution of the over-aging problem is that boronated aluminum without aging treatment is used for material of basket of casks. Design yield point and tensile strength have been verified to envelop the result of long term heating tests. (Shown in Figure 3) Powder metallurgy solves the homogeneity problem of boron distribution and brittleness problem. Manufacturing method oþ owder metallurgy excludes coagulating process of molten aluminum and provides boronated aluminum with small precipitation and good homogeneity of boron distribution.

Detailed characteristics of the boronated aluminum used for the cask are reported in "DEVELOPMENT OF BORONATED ALUMINUM ALLOY FOR BASKET OF CASK FOR NUCLEAR SPENT FUEL" also presented at ICONE9.

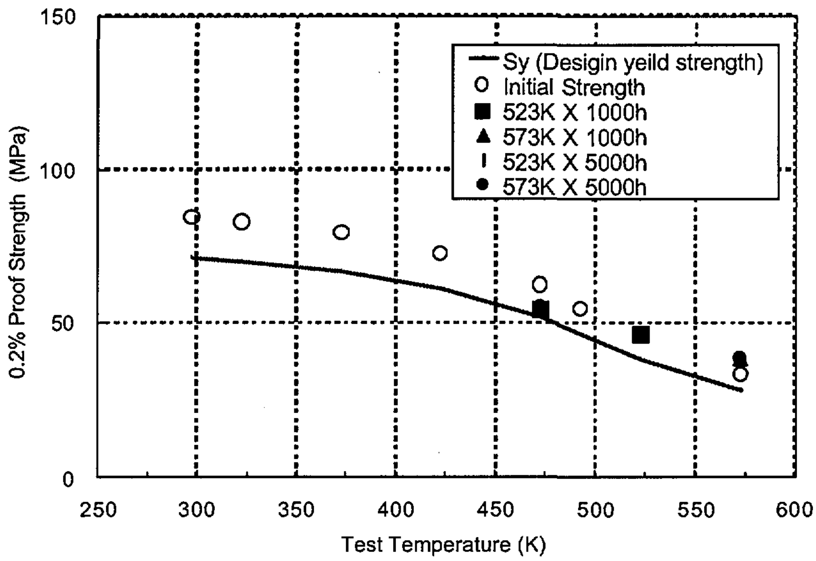

Figure 3 Design yield point of boronated aluminum

- Shielding material

MSF series cask uses high durability neutron shielding material.

In order to maintain shielding performance of the cask for long-term storage, it is extremely important to maintain the integrity of neutron shielding material at its service temperature. However, the usual neutron shielding material deteriorates and its hydrogen content is reduced when the material stays in high temperature condition for a long time.

For MSF series casks, components of the refractory material which are added for providing neutron shielding material with fire-extinction-property were investigated. And a better neutron shielding material with improved refractory material so as to minimize hydrogen loss even during service has been used.

Detailed characteristics of the neutron shielding material used for the cask are reported in "DEVELOPMENT OF NEUTRON SHIELDING MATERIAL FOR CASK" also presented at ICONE9.

-Metallic gasket

MSF series casks adopt metallic gasket for dual purpose of transportation and storage as containment device. With regard to transportation situation, it is delicate to maintain containment integrity after a drop accident with a metallic gasket because too much displacement of lid breaks containment integrity. MSF series cask have been designed so that movement of lid is limited by mechanical structure of lids and flange. Validity of cask design and integrity of containment are confirmed by the 9-meter drop demonstration test.

Verification of technologies

It has been confirmed by analysis and demonstration tests that MSF series casks that use new structures satisfy IAEA transport regulations. Outline of demonstration test is the following:

- Heat dispersion test
Heat transfer analysis method and heat dispersion performance of inside structure of cask has been confirmed by demonstration. Figure 4 shows that the temperature of basket parts analyzed by ABAQUS code is on the conservative side.

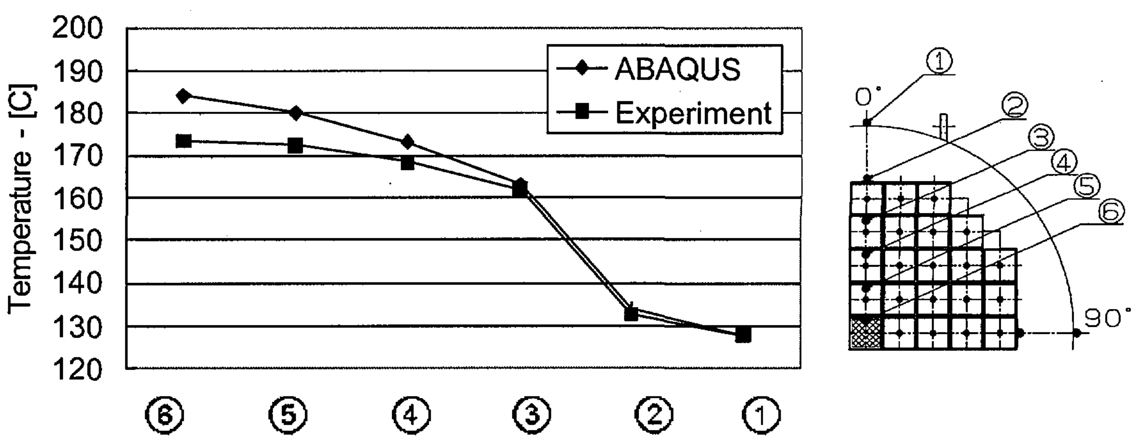

Fig. 4 Comparison between heat transfer test and experiment for the slice model

- Structural integrity
Using 1/2 scale model, drop test has been performed as shown in Figure 5 in order to verify the containment integrity, validity of the cask and compliance with the regulation requirements.

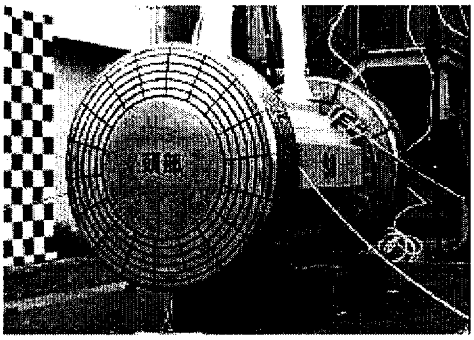

Fig.5 1/2 Scale model for drop test

Confirming the basket structure
It has been confirmed that there was no permanent deformation of the basket.

Confirming the containment integrity
It has been confirmed that the containment integrity has not been broken and cask design for keeping containment has been appropriate.

Conclusions

This cask features new technologies for:

a) Structure (main body, basket, and shock absorber); and,

b) Materials (boronated aluminum, neutron shield, and body forging); thus, the storage capacity has been improved by nearly 10% as compared to the conventional design. And these new technologies have been confirmed by demonstration tests.

This cask is planed to be proposed for transportation and interim storage of spent fuel.