DEVELOPMENT OF BASKET WITH ENRICHED BORATED ALUMINUM ALLOY

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ABSTRACT

Kobe Steel, Ltd. has been producing enriched boron-10 from the spring of 2001, and the unique manufacturing process of borated aluminum alloy was developed. In this process, aluminum alloy is melted and agitated using a vacuum induction furnace with higher temperature than that of common aluminum alloy fabrication method, and is cast into mold in vacuum atmosphere. Accordingly, it is possible to manufacture the high quality aluminum alloy which has the uniform distribution of boron and do not include impurity such as oxidizing slag etc.

There are two types of basket designs using borated aluminum alloy, one is using plates, which is already applied to our storage packages, and the other is using extruded rectangular pipes. The production technique of the latter type of basket was established this time. The good thermal conductivity at the assembly of each pipe is confirmed by performing the thermal test and the analysis of it. The basket using extruded rectangular pipes is easy to assemble staggeringly and bound around them by supporting parts, therefore, fewer machining is necessary for it compared with the basket using plates. Accordingly, it can reduce the production cost of a basket.

1. INTRODUCTION

Borated aluminum alloy is one of the most important materials and widely used for the basket of dry spent fuel packages because of its excellent thermal conductivity and lighter weight etc. The maximum boron content in aluminum alloy is limited up to a few weight % at most, however it is possible to have enough quantity of boron-10 for maintaining the sub-criticality of fuel assemblies loaded in the package by using enriched boron-10.

The unique manufacturing process of borated aluminum alloy was developed. In this process, aluminum alloy is melted and agitated using a vacuum induction furnace with higher temperature than that of common aluminum alloy fabrication method, and is cast into mold in vacuum atmosphere. Using of this material, the production technique of the basket of the extruded rectangular pipes was established, and the good thermal conductivity at the assembly of each pipe is confirmed by performing the thermal test and analysis. This paper reports this new developed aluminum alloy and basket.

2. DEVELOPMENT OF BORATED ALUMINUM ALLOY

2.1 MELTING AND CASTING METHOD

Vacuum induction melting equipment is shown in figure 1. The materials of mother alloys compounded as the specific kind of aluminum alloy are melted using vacuum induction melting equipment, then they are cast into mold by way of handling container. The casting molds are designed for the optimum shape to have the enough cooling speed, therefore borated aluminum compounds can be distributed uniformly in the ingot. The flat shape ingot for rolling plates and column shape for extruding are used.

2.2 CHARACTERISTICS

The merit of this fabrication method is that aluminum alloy are melted with higher temperature (about 1000 degrees Celsius) than that of common aluminum to melt borated aluminum compounds, of which melting point is very high, therefore their particle size can be fine. Accordingly, it is possible to manufacture the high quality aluminum alloy which has the uniform distribution of borated compounds and do not include impurity such as oxidizing slag etc. Various kinds of aluminum alloys can be designed such as 1000, 3000, 5000 and 6000 series suited to customers' specifications. In this process, it is possible to reuse the scrap materials which are made as by-products through the fabrication.

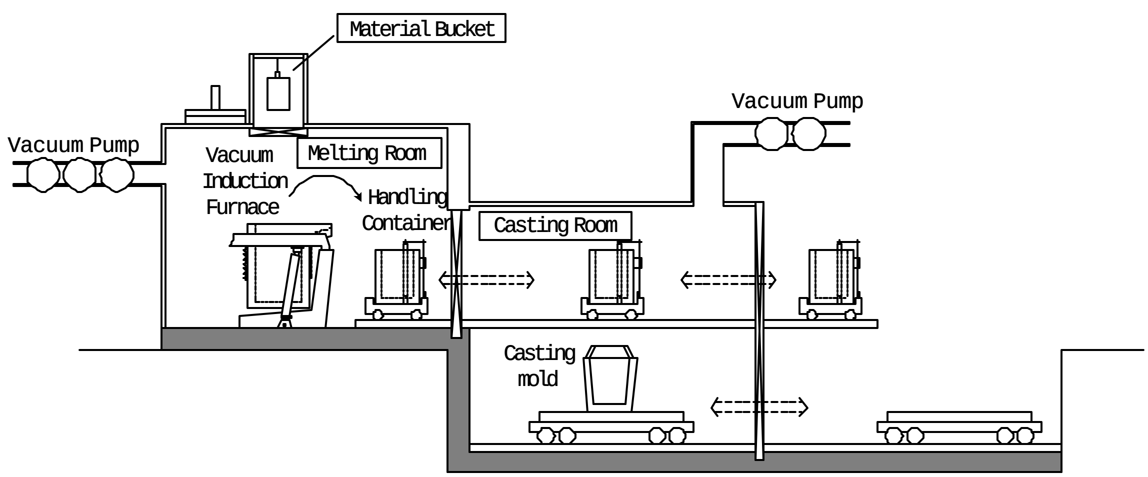


Figure 1, Vacuum Induction Melting Equipment

3. DEVELOPMENT OF EXTRUDED BASKET

3.1 MATERIAL SPECIFICATION

The borated aluminum alloy developed is based 3004 aluminum alloy taking account of extruding resistance, corroding resistance and mechanical properties. The chemical composition of this material is shown in table 1, and the measured mechanical properties are shown in table 2. It is shown that the borated 3004 aluminum alloy has almost the same mechanical properties as those of 3004 aluminum alloy. The diminishing of mechanical strength under elevated temperature condition is not remarkable because this material is not a heat treated aluminum alloy. The boron content of this material is approximately 1 wt% when used for structural members, however, it is possible to be increased up to 4 wt% in case that it is not used for structural members.

Table 1, Chemical Composition of Borated 3004 Aluminum Alloy

Material	B	Si	Fe	Cu	Mn	Mg	Zn
Borated 3004 Aluminum Alloy	0.6–1.3	<0.30	<0.7	<0.25	1.0–1.5	0.8–1.3	<0.25

Table 2, Mechanical Properties

Material	Tensile Strength (N/mm^2)	Proof Stress (N/mm^2)	Elongation (%)
Borated 3004 Aluminum Alloy	187	85	23
3004 Aluminum Alloy *	min. 159	min. 62	min. 7

Note* : These data are quoted from the Aluminum Standards and data

3.2 STRACTURE OF BASKET

The developed basket is used for transportation and storage packaging of the BWR spent fuels. The cross section of the extruded rectangular pipe of this basket and the geometry of corner contacts of each pipe when they are fabricated are shown in figure 2. Each rectangular pipe is easily assembled staggeringly and bound around them by supporting parts so as to be the same load transferring area at the corner. Therefore, it is possible to reduce the fabrication parts remarkably and fewer machining is necessary for it compared with the basket using plates. Accordingly, it can reduce the cost of production. Each rectangular pipe is manufactured by extruding method using borated aluminum alloy mentioned in chapter 2. The photograph of the extruded pipe is shown in picture 1.

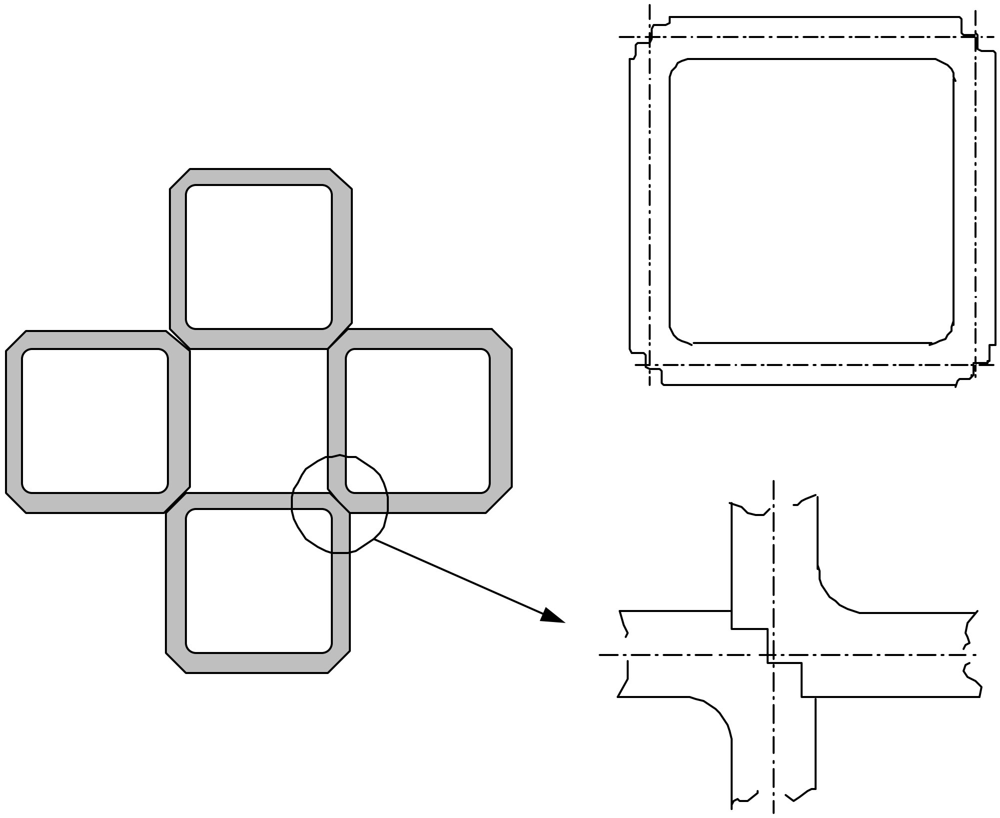
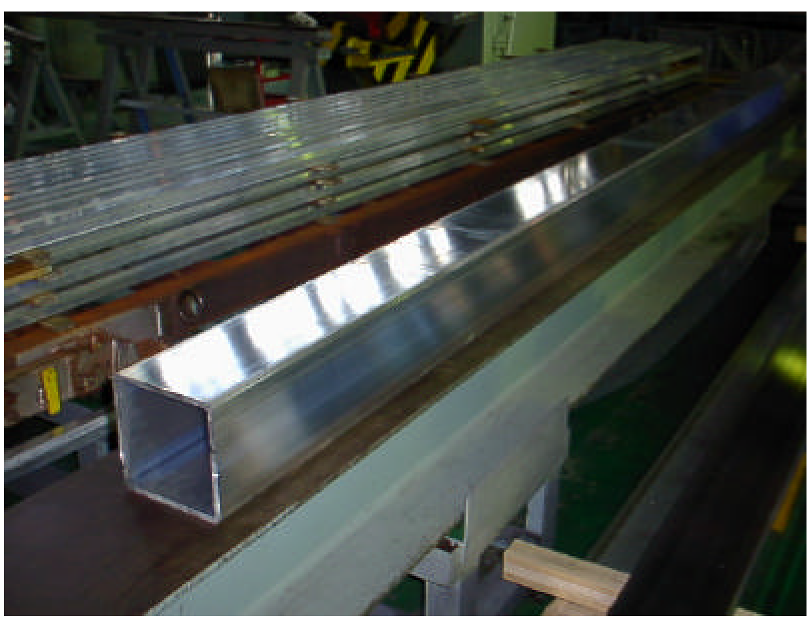


Figure 2, Cross Section of Extruded Rectangular Pipe



Picture 1, Extruded Rectangular Pipe

3.3 THERMAL TEST

This basket is assembled from each rectangular pipe therefore it may be possible that each corner contact is thermal conductivity resistance and the heat transferring function is not enough. That is ununiformity of heat transfer because of the differences of thermal conductivity resistance of each corner contact. Then thermal test using assembled model from actual extruded rectangular pipes was performed.

(1) TEST MODEL

The thermal test model is shown in figure 3 and explained as followed.

(a) The test model of 57 cells basket is assembled from 32 rectangular pipes of 500mm length and bound around by steel band.

(b) The both longitudinal ends of the model are insulated by the insulated boards and mats, then heat transfer direction is only radius direction.

(c) A heater is set only at the center of the model and temperature of each point is measured with thermo couples.

(d) Thermo couples are set shown in figure 3 and at the middle point of height.

(e) Thermal power of heater can be controlled by the controlling board and thermo couples are connected to P.C. by way of a data logger.

(2) TEST PROCESURE

(a) Thermal power is controlled so as to be about 200* degrees Celsius at the center pipe of basket.

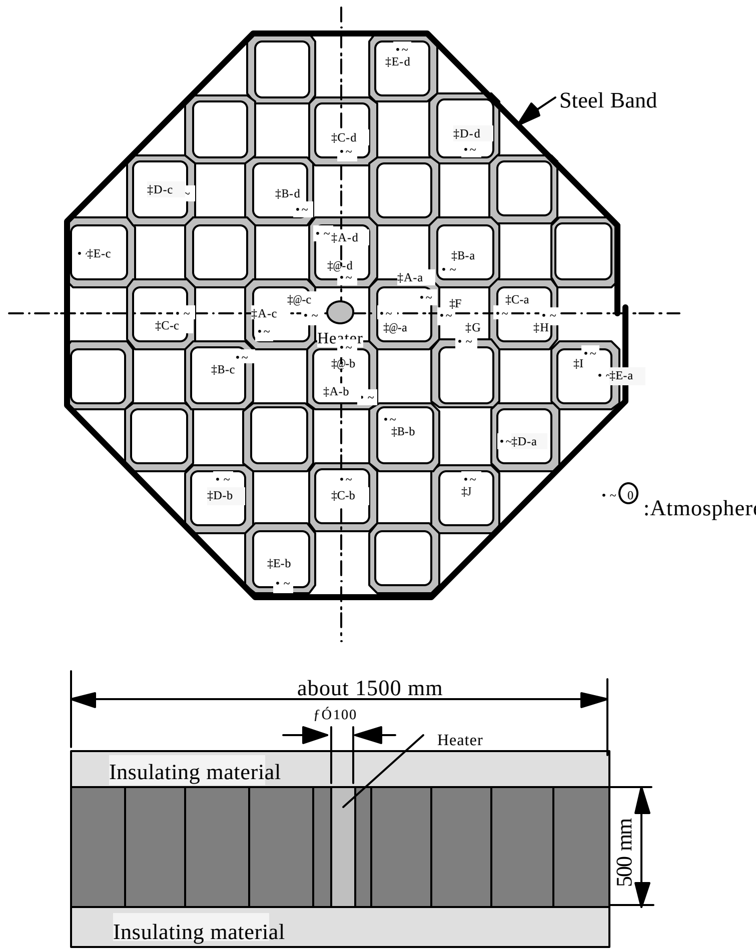
(b) Thermal power is kept to be the steady condition.

(c) Temperatures of each point are measured on the steady condition.

Note* : This is almost the actual temperature of basket and the thermal power is 1.5 kW.

(3) TEST RESULTS

Temperatures of each point of basket on the steady condition are shown in table 3. It is obvious from the results that differences of temperatures of symmetric points are within a few % and confirmed that ununiformity caused by thermal conductivity resista nce of each corner contact is negligible small.



Note1:Thermo couples are set on the middle of height of basket cell.
Note2:X means point of thermo couple.

Figure 3, Thermal Test Model

Table 3, Results of Thermal Test

Data No.	1		2		3		4		5		6	
	Temp*1	Ratio*2	Temp.	Ratio	Temp.	Ratio	Temp.	Ratio	Temp.	Ratio	Temp.	Ratio
a	178.1	0.99	133.8	0.98	123.3	1.02	89.3	1.00	81.5	1.02	63.4	1.02
b	178.9	1.00	134.6	0.98	120.3	0.99	89.7	1.01	78.5	0.98	60.6	0.97
c	180.7	1.01	139.1	1.02	117.4	0.97	88.4	0.99	79.9	1.00	63.5	1.02
d	179.8	1.00	139.2	1.02	124.9	1.03	88.6	1.00	79.8	1.00	62.1	1.00
Ave.	179.4	-	136.7	-	121.5	-	89.0	-	79.9	-	62.4	-

Note*1:Temp = (Measured temperature) – (Atmosphere temperature)
Note*2:Ratio = (Temp)/(Ave.)

3.4 THERMAL ANALYSIS

(1) PRELIMINARY ANALYSIS

Before the thermal analysis of basket model is performed, the preliminary calculation of thermal test model is performed to confirm the modeling of corner contacts. In this case, the slight gaps between each pipes equivalent to corner contact thermal resistance so as to reproduce the same temperature distribution as that of thermal test.

(2) ANALYSIS OF BASKET MODEL

Thermal analysis of cross sectional model of packaging in which 57 spent fuels can be loaded is performed with the corner contacts model derived by the preliminary analysis. Total thermal power loaded in packaging is 20 kW. Insides of each basket cell are insulated conservatively therefore it is only basket pipes that can transfer the heat. Inside of packaging is purged by helium gas. The analysis model and conditions are shown in figure 4 and table 4 respectively. As the results are shown in table 5, the maximum temperature of the basket center is 206 degrees Celsius therefore it is confirmed that the basket assembled from extruded rectangular pipes has the enough heat transfer ability. It can be said that this results are conservative because insides of basket cells are insulated.

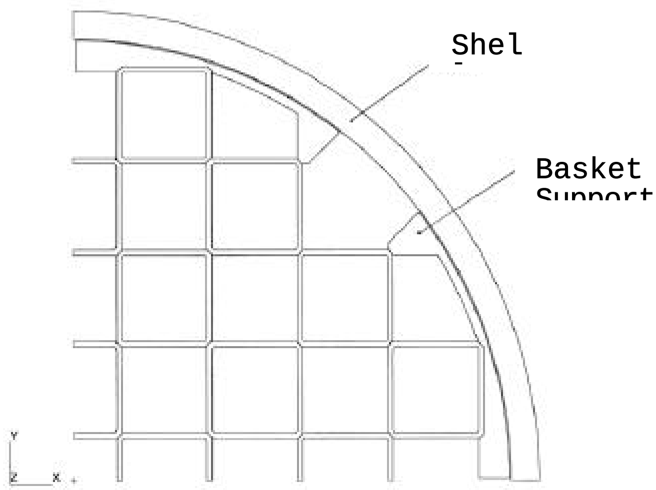


Figure 4, Thermal Analysis Model of Basket

Table 4, Analysis Conditions of Basket Model

	Analysis Conditions	Remarks
Thermal Power	20kW/packaging 0.351kW/fuel	Uniformly distributed inside basket cell
Thermal Heat Transfer inside Basket Cell	Not considered	
Temperature inside Wall of Shell	140 degrees Celsius	Given as boundary condition
Purged Gas	Helium Gas	

Table 3.5, Results of Analysis of Basket Model

Evaluated Points	Temperature (Unit: degrees Celsius)
Center of Basket	206
Outside of Basket	157

4. CONCLUSION

The unique manufacturing process of borated aluminum alloy was developed using a vacuum induction melting equipment. In this process, it is possible to manufacture the high quality aluminum alloy which has the fine borated aluminum compounds and the uniform distribution of boron, and do not include impurity such as oxidizing slag etc. The production technique of the basket was also established using the extruded rectangular pipes of this new developed borated aluminum alloy, and the good thermal conductivity at the assembly of each pipe was confirmed by performing the thermal test and the analysis of it.