Experimental Study of Heat Removal Ability and Lead Slump of Lead-type Multi-wall Cask

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Introduction

- Numbers of the lead-type multi-wall casks have been produced. However, conservative designs are adopted for the lead-type cask, because the experimental data about heat removal ability and lead slump is insufficient.

- A lead layer is formed by casting. The melted lead is poured into the clearance between two carbon steel cylinders.
- Thermal expansion coefficient of lead is larger than that of carbon steel. So, without certain treatment, a narrow gap between lead layer and carbon steel wall formed during solidification and cooling of lead.
- We call this treatment for sticking lead layer to carbon steel shells (or stainless steels) “lead-soldering treatment”. By this treatment, the heat removal ability of the lead-type cask satisfies design specification, and the lead slump is prevented.

- In this study, experiments were carried out to obtain these data for appropriate design.

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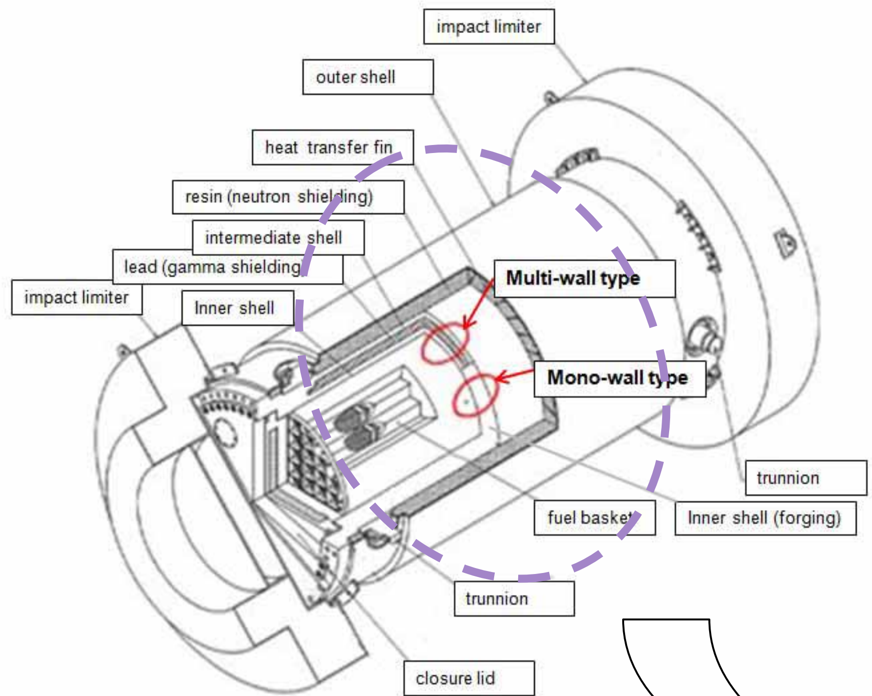
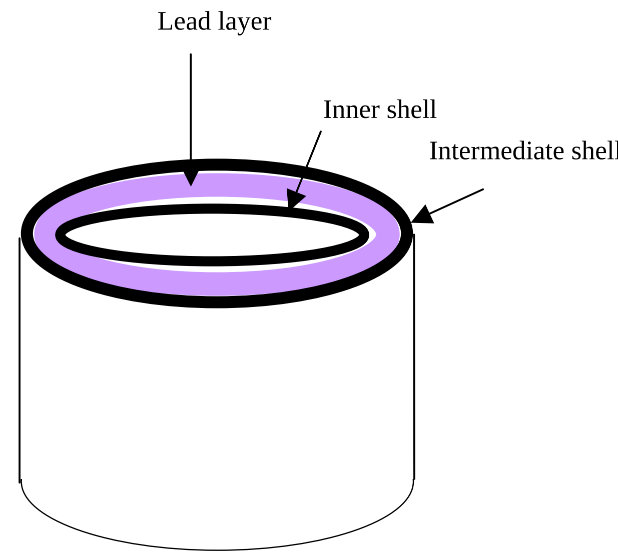
Test Models



Hitz-B54



Test Model

Lead layer is sandwitched between innner steel shell and inntermediate steel shell.
Models consist of inner shell, lead layer and inntermediate shell.
Outer shell and resin layer were eliminated.

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Models

L-Model

with Lead-soldering treatment

S-Model

without Lead-soldering treatment

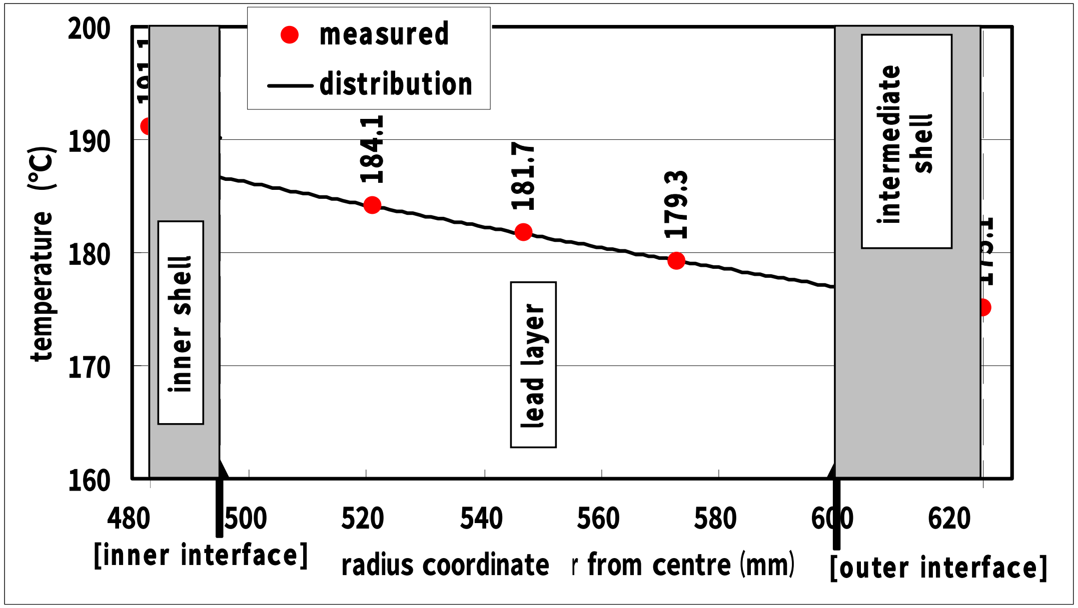
Heat Transfer Test

- To find out the heat transfer characteristics of the lead-type multi-wall cask
- Those characteristics of the models with and without "Lead-soldering treatment" were compared..

- Inner surface of inner shell heated by electrical heater at four levels (100,150,200,250 ° C).
- The temperature were kept over 6hours to make steady states.

Results for L-Model

(with Lead-soldering treatment)



Temperature distribution of L-Model
(heater temperature kept 200 ° C)

- Temperature distribution(black line) was estimated from radial heat flow, calculated using three temperature data in the lead layer.
- At the outer interface, the temperature gap is negligible.
- At the inner interface, a small temperature gap is find, but considering the accuracy of thermocouples, it can be said almost negligible.

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Heat resistance at the interface

(L-Model, with “Lead-soldering treatment”)

Temperture of inner surface of inner shell (°C)	Temperture of outer surface of intermediate shell (°C)	Temperture of circumference (°C)	Heat flow* per unit hight (W/m)	Heat resistance at interface** (m^2K/W)
95.0	90.7	27.1	3539	3.68E-04
143.4	133.9	29.3	6807	8.56E-04
191.1	175.1	29.8	10321	1.23E-03
239.7	215.7	30.3	15639	1.11E-03

*Computed with the heat transfer equation of pipe based on 3 data in lead layer

**Sum of heat resistance at inner and outer interface

- **Heat resistance at two interfaces are rather small.**
- **This heat resistace seems to increase with heat flow.**

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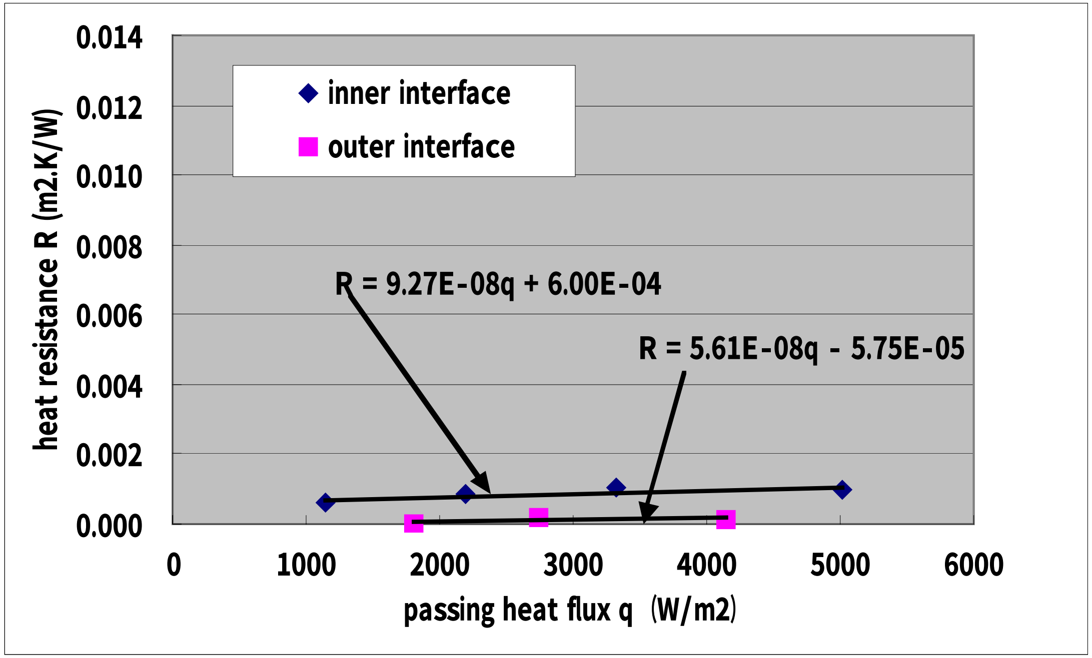
Heat resistance vs heat flux

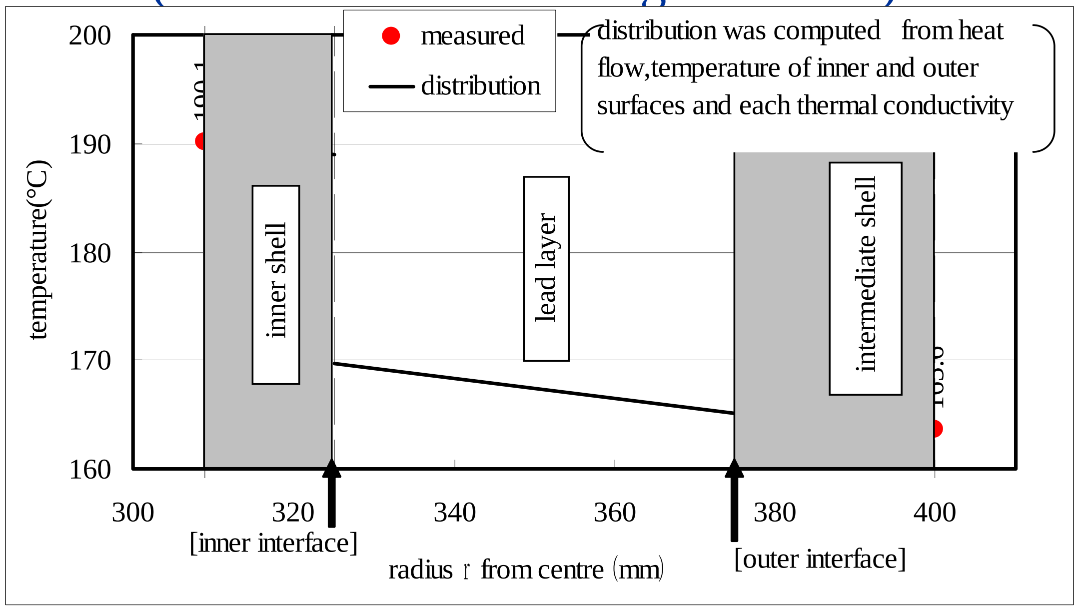
(L-Model, with “Lead-soldering treatment”)



- **The values of heat resistans are very small, but propotional to the heat flux.**

Results for S-Model

(without Lead-soldering treatment)



Temperature distribution of S-Model
(heater temperature kept 200 ° C)

- **Temperature distribution(black line) was estimated from radial heat flow, calculated at the outer surface of the intermediate steel shell, using the heat transfer coefficient estimated by the results of measurement of L-Model.**
- **The temperature gap at interface is far larger than that of L-Model.**
- **The effect of the lead-soldering treatment for the heat resistances is evident.**

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Heat resistance at the interface

(S-Model, without "Lead-soldering treatment")

Temperture of inner surface of inner shell (°C)	Temperture of outer surface of intermediate shell (°C)	Temperture of circumference (°C)	Heat flow* per unit hight (W/m)	Heat resistance at interface** (m^2K/W)
93.0	78.0	18.2	1974	1.546E-02
141.6	119.2	19.3	3929	1.088E-02
190.1	163.6	21.8	6553	6.910E-03
237.9	210.7	19.5	9931	3.688E-03

*Computed with the heat transfer coefficient of outer surface of L-Model

**Sum of heat resistance at inner and outer interface

- Heat resistance at two interfaces are lager than those of L-Model at one or two digit..
- This heat resistace seems to decrease with heat flow.

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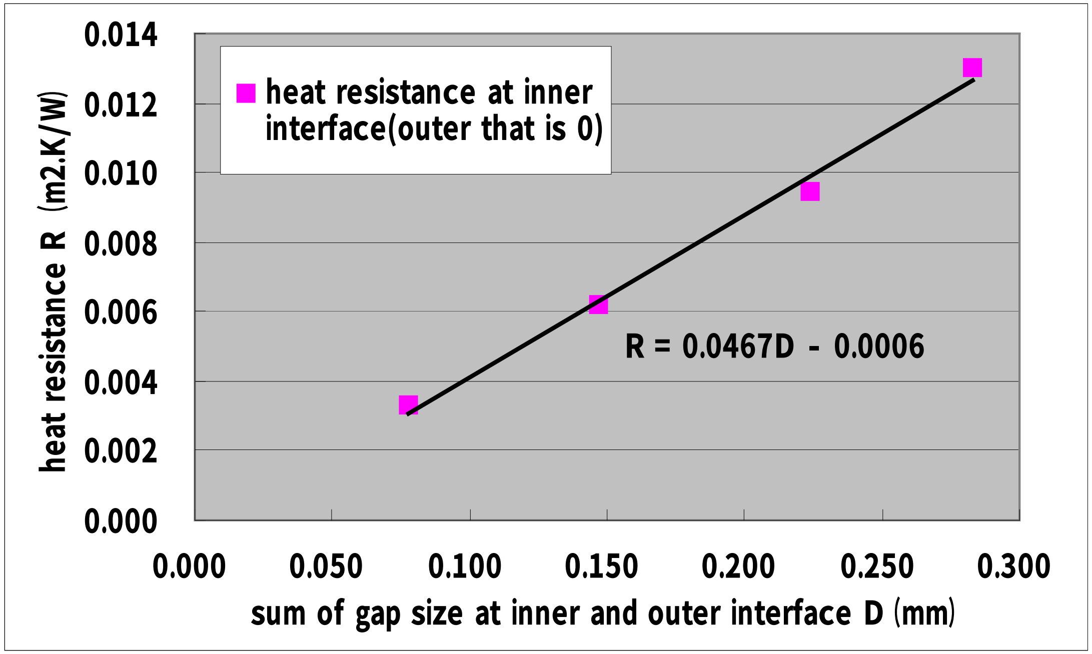
Heat resistance vs gap size

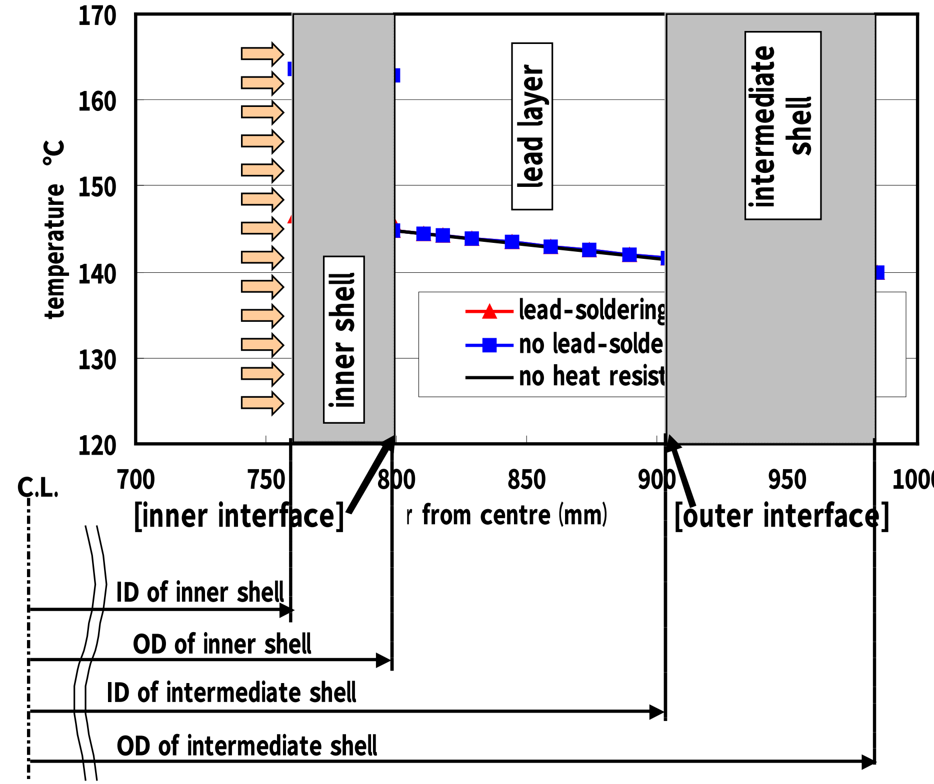
(S-Model, without “Lead-soldering treatment”)



- **Total size of the gaps were estimated by FEM analysis reproducing the test.**
- **The values of heat resistans are evidently propotional to the gap size.**

Trial calculation for actual cask

- The calculating formulas for the heat resistance of the interface were obtained by the test results mentioned above.
- Using these formulas, the temperature distribution for actual cask was calculated by FEM analysis.
- The temperature distribution without the lead-soldering treatment(blue) are far above from that in case of the heat resistance of the interface equal to zero(black).
- The temperature distribution with the lead-soldering treatment (red) are little differ from black solid lines.
- The effect of the lead-soldering treatment is evident on actual cask, as expected.



Thermal boundary conditions
#Heat flux at inner surface of inner shell : 1178W/m2
#Temperature at the outer surface of intermediate shell :140 ° C

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Lead Slump Test

- “lead slump” : The deformation of lead layer under a drop impact.
- When the deformation forms small gap on the top end of lead layer, the gap may allow some passage of γ-ray.
- How the “Lead-soldering treatment” effect against the lead slump

- Same two models above dropt and the top end deformation were measured.

Conditions

Before the drop

Target

After the drop

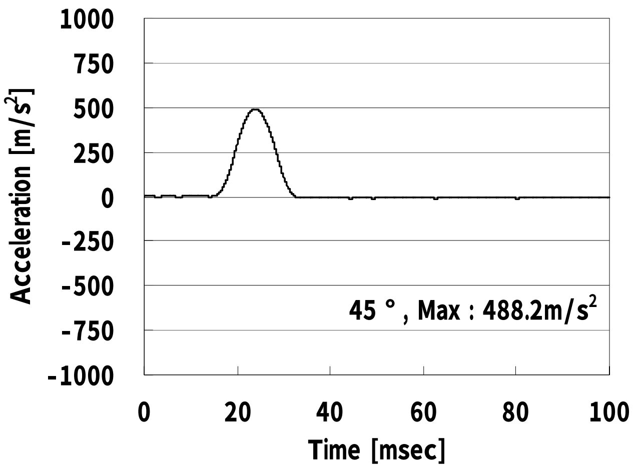
Model	Drop height (m)	Target depth (mm)	Target density (ton/m^3)
L-Model	0.3	200	0.2
S-Model	1.0	200	0.15

Conditions, the drop height and the shock absorbing characteristics of the collision target; depth and the density, were settled to achieve the same impact acceleration as that assumed for the actual casks.
(Hitz-B54 cask, end drop test in 0.3m height and impact limiters were equipped, 451m/s2).

Results
L-Model, acceleration

Monitoring position		Maximum acceleration (m/s^2)
Circumferential direction at outer surface of intermediate shell	Height from base plate	
0°	60mm	478.5
45°		488.2
90°		499.2
135°		476.1
180°		469.3
225°		452.6
270°		449.1
315°		462.5

Measured data were processed with the low path filter of 250Hz



- **The accelerations were almost equal to that assumed for the actual casks. So, the drop test was performed as intended.**
- **Impact acceleration wave is smooth and shows that the collision was as expected.**

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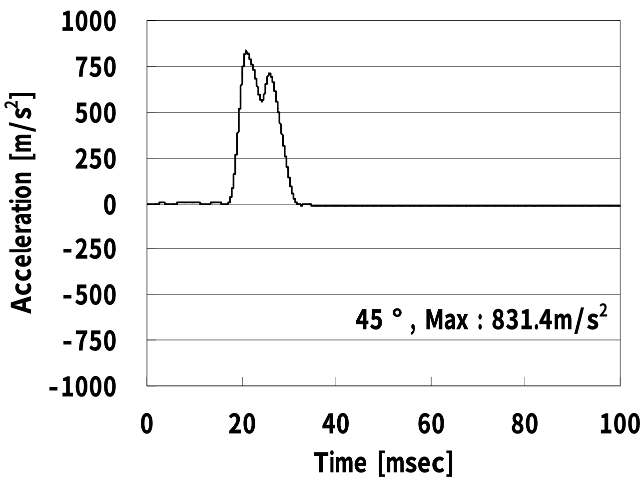
S-Model, acceleration

Monitoring position		Maximum acceleration (m/s²)
Circumferential direction at outer surface of intermediate shell	Height from base plate	
0°	60mm	826.7
45°		831.4
90°		821.4
135°		748.1
180°		725.9
225°		739.2
270°		767.2
315°		806.7

Measured data were processed with the low path filter of 350Hz



- **The impact accelerations were far large than that assumed for the actual casks.**
- **Sample shape of impact acceleration wave has two peeks.**
- **S-Model is without lead-soldering treatment, and the lead layer does not stuck to the steel shells. The cause of the acceleration behavior is presumed that the lead layer and the steel shells move separately.**

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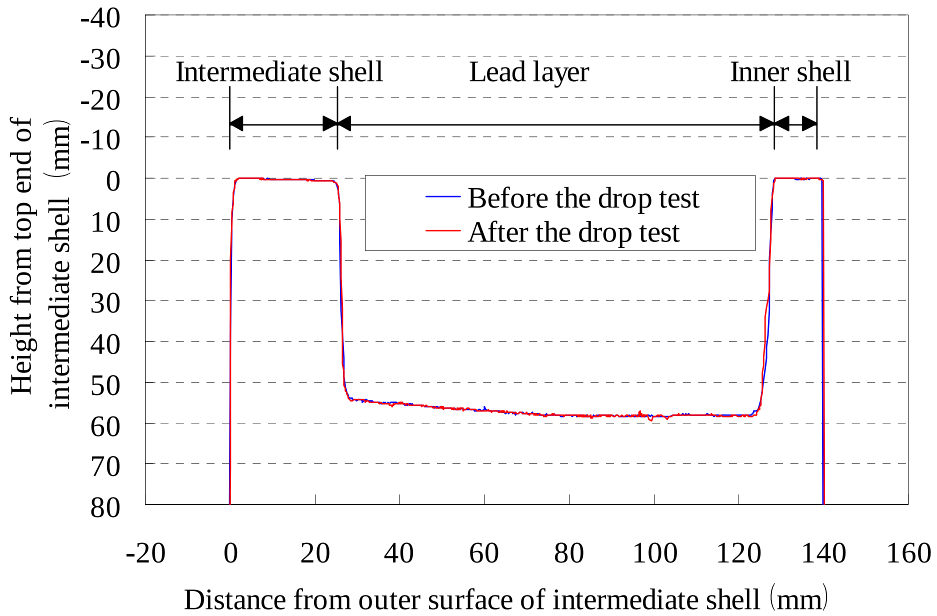
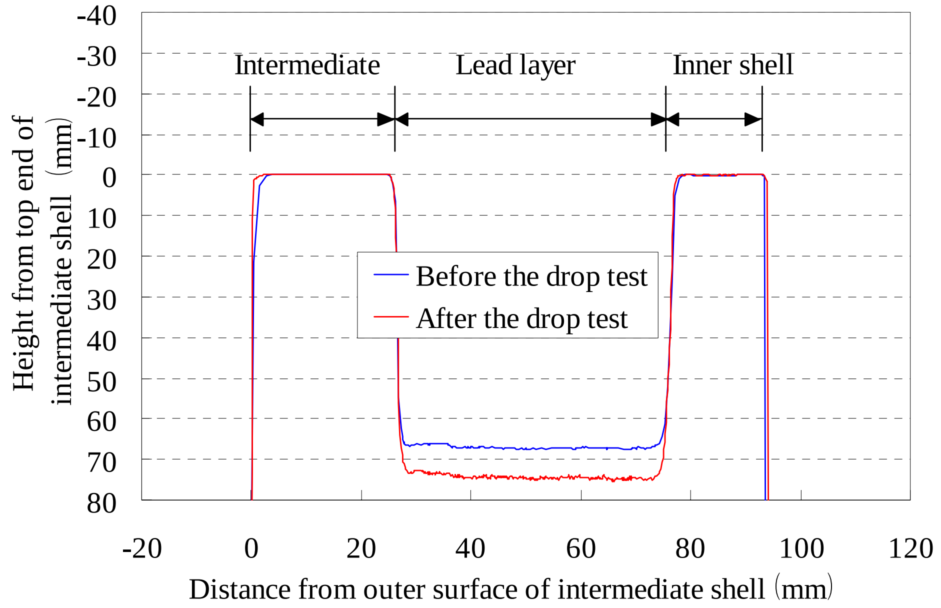
Deformations at the top end of lead layer



L-Model

with Lead-soldering treatment

- **There is almost no difference between two shapes(before the drop and after the drop). No lead slump occurred.**



S-Model

without Lead-soldering treatment

- **In case of S-Model, without lead-soldering treatment, the top end of the lead layer sank down so much.**
- **lead-soldering treatment works to avoid the lead slump.**

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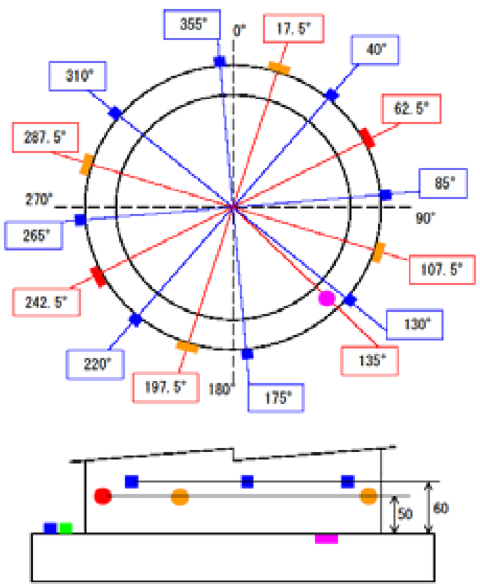
Amount of lead slump

Circumferential direction at top end surface of lead layer	L-model: Average of lead layer height from top end of intermediate shell — Before the drop test (mm)	L-model: Average of lead layer height from top end of intermediate shell — After the drop test (mm)	L-model: Amount of lead slump (mm)	S-model: Average of lead layer height from top end of intermediate shell — Before the drop test (mm)	S-model: Average of lead layer height from top end of intermediate shell — After the drop test (mm)	S-model: Amount of lead slump (mm)
0°	57.51	57.53	0.02	66.68	73.59	6.91
45°	57.34	57.56	0.22	66.58	72.97	6.39
90°	57.17	57.07	-0.09	66.72	72.64	5.93
135°	58.30	58.28	-0.02	66.62	73.38	6.76
180°	58.53	58.45	-0.08	66.31	73.21	6.90
225°	58.43	58.42	-0.02	67.07	74.27	7.21
270°	58.12	58.22	0.10	66.77	73.87	7.10
315°	57.69	57.85	0.16	66.52	73.49	6.96

CONCLUSIONS

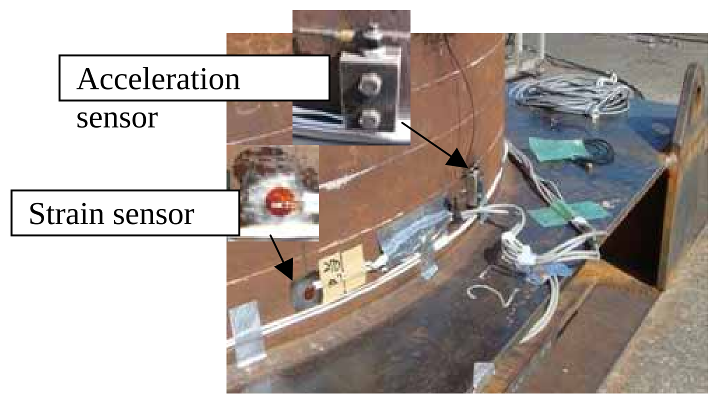
- The heat transfer ability and the lead slump of the lead-type multi-wall cask were confirmed experimentally using scale model.
- The heat resistance between the lead layer and the steel shells are almost negligible with lead-soldering treatment.
- The heat transfer ability of actual cask with the lead-soldering treatment, which was calculated with the formula defined after the experimental result, was almost the same as the one where the heat resistance between the lead layer and the steel shells equal to zero.
- No lead slump occurred on the model with the lead-soldering treatment. The test conditions were settled to achieve the same impact acceleration as the assumed one for the actual casks. So, it is thought that no lead slump will occur for actual casks.

Thank you for your attention.



Acceleration sensor

Strain sensor



Non-contact displacement sensors

Guide rail

Reflective paint (white color)

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