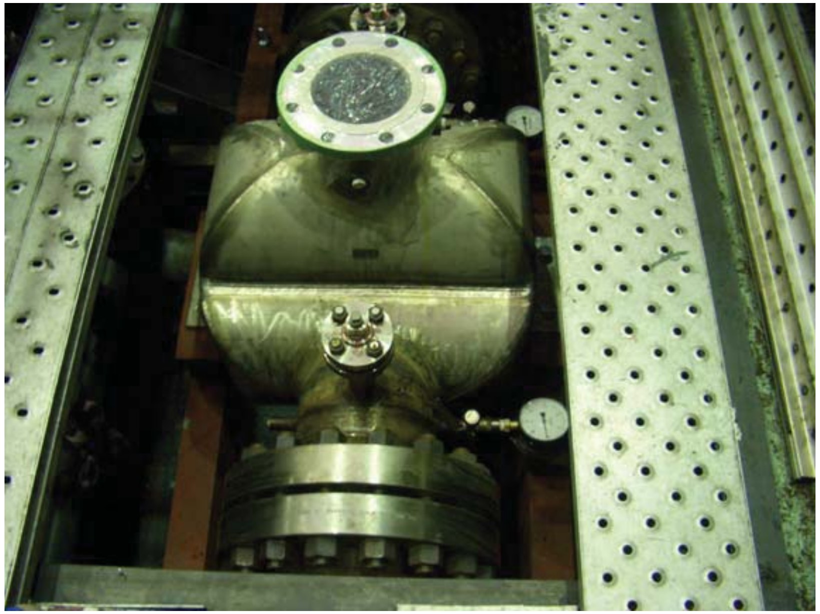
Modeling of Kobe's High Performance heat exchangers and Microchannel reactors



19 June, 2012
K. Noishiki, Development group
KOBE STEEL, LTD

KOBELCO

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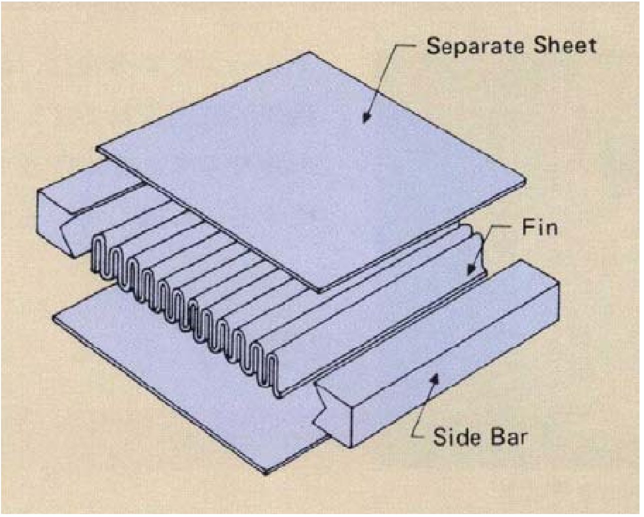
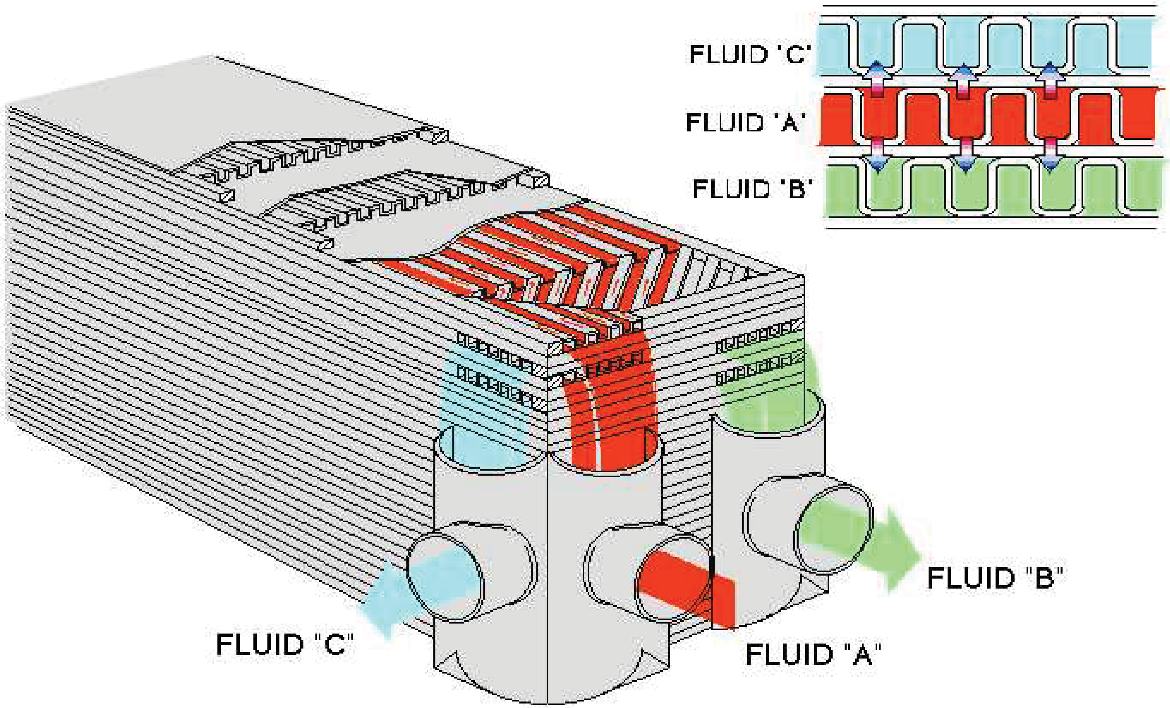
(SMCR: Stacked Multi-Channel Reactor)

Kobe Steel, Ltd Background to technology





Over 40 years experience as major manufacturer of compact heat exchanger (ALEX=Brazed Aluminum Plate-fin type).

Extensive range of technologies to design and fabricate heat exchangers of this type.

Has now developed the micro or milli channel heat exchanger (like PCHE (Printed Circuit Heat Exchanger) and MCR (Microchannel Reactor) based on this technology.

Printed Circuit Heat Exchanger (PCHE)

Micro channel Heat Exchanger
(PCHE: Printed Circuit Heat Exchanger)

＜Application＞

a) Gas cooler for offshore use

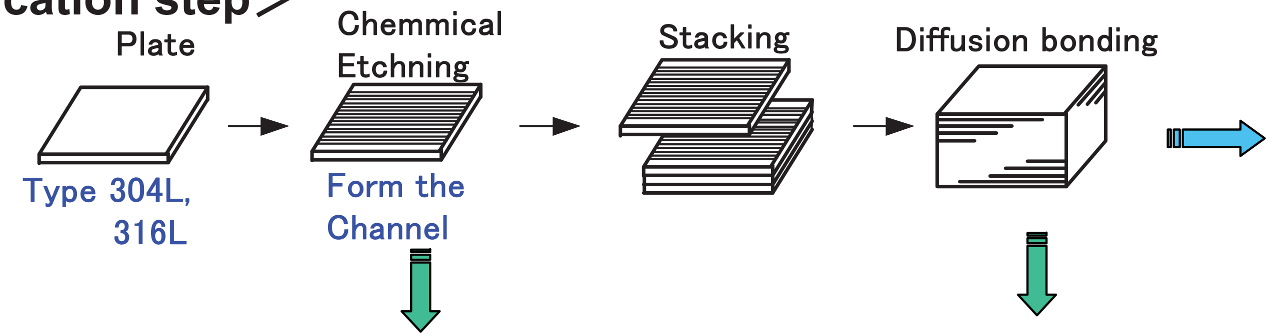
b) Special use for high pressure, high temperature or large temperature difference

＜Features＞

a) can withstand high pressure (over 50MPaG)

b) High thermal performance (approximately 1/10th of Shell &Tube type)

＜Fabrication step＞



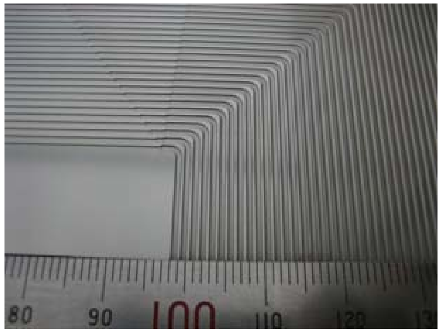
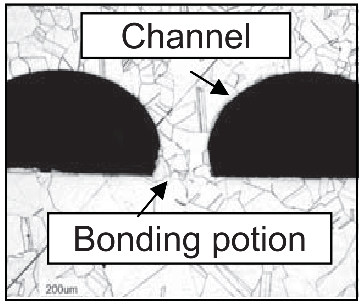
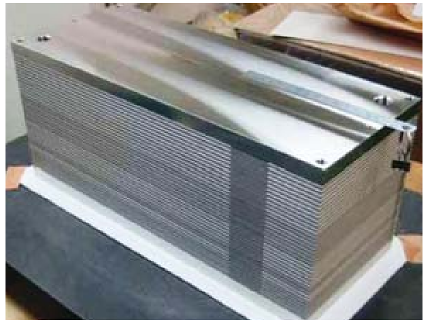


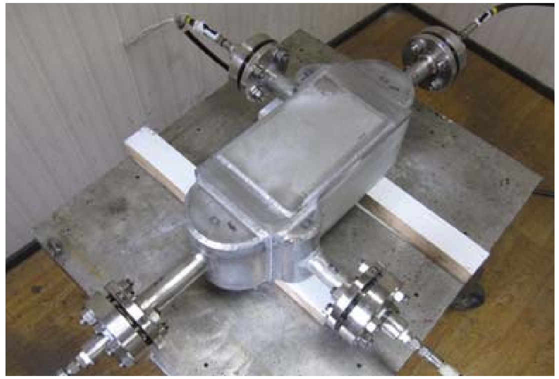
Image of channel



Cross sectional view of diffusion bonding



Outside view of core block with header & nozzle



Note: **KSL can fabricate this equipment based on ASME code with stamp (2010E+2011a).**

Design and rating software for heat exchanger

<Design Software>

KSL's own software and technique

<Rating software(Aspen PlateFin)>:

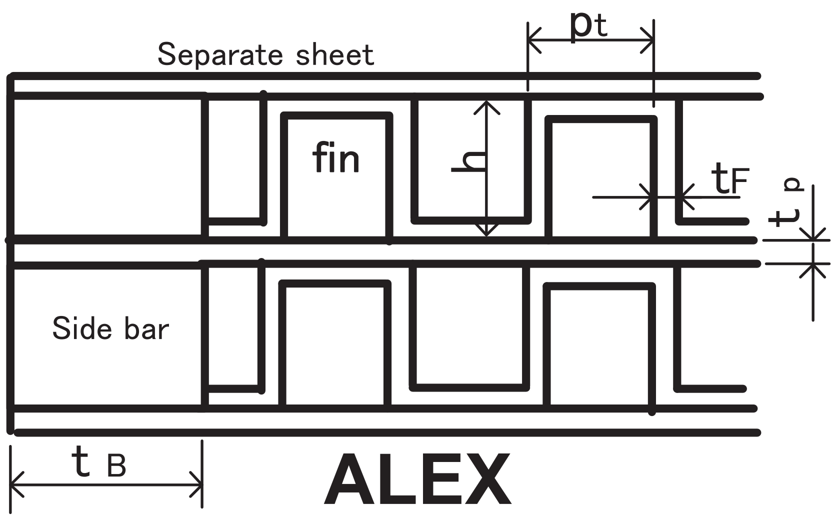
- Stream by stream simulation and thermosyphon
- Detailed layer by layer simulation
  (including stacking arrangement)
- Crossflow exchanger simulation (single or multi-pass)

Note- Fin performance or channel data were measured by KSL.
and the data are linked to Aspen PlateFin.

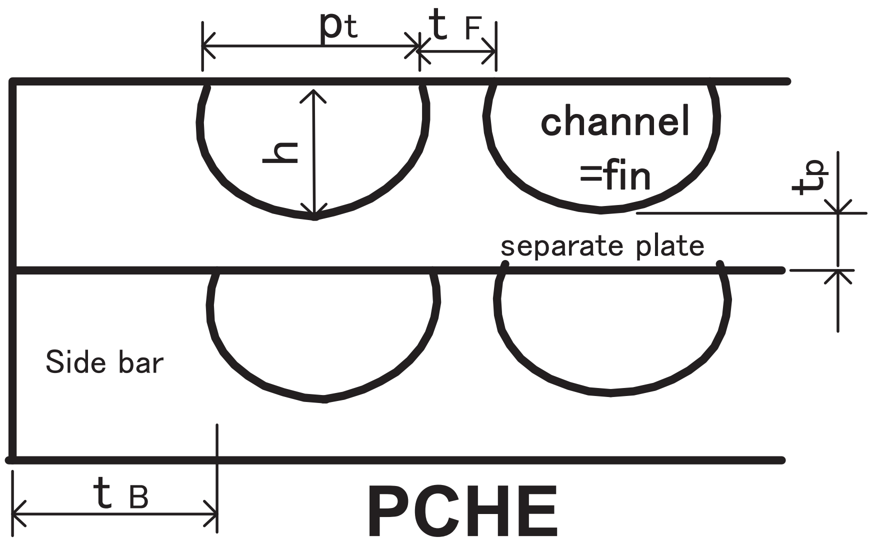
Comparison between ALEX and PCHE for PlateFin

All design parameters for ALEX and PCHE are basically the same.

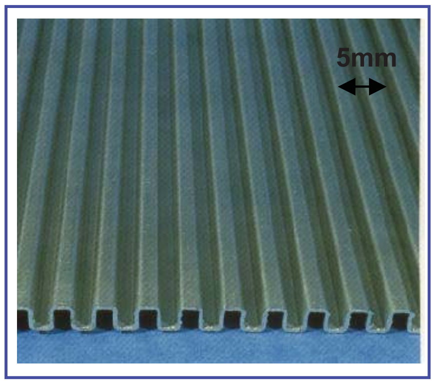
Hence heat transfer and pressure drop performance will be calculated using the same design tool as for ALEX.



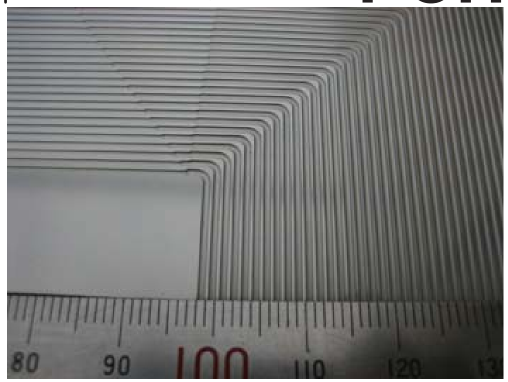
ALEX



PCHE



Fin = Channel,
pt: pitch of fin
h: height of fin,
tF: thickness of fin
tB: thickness of side bar



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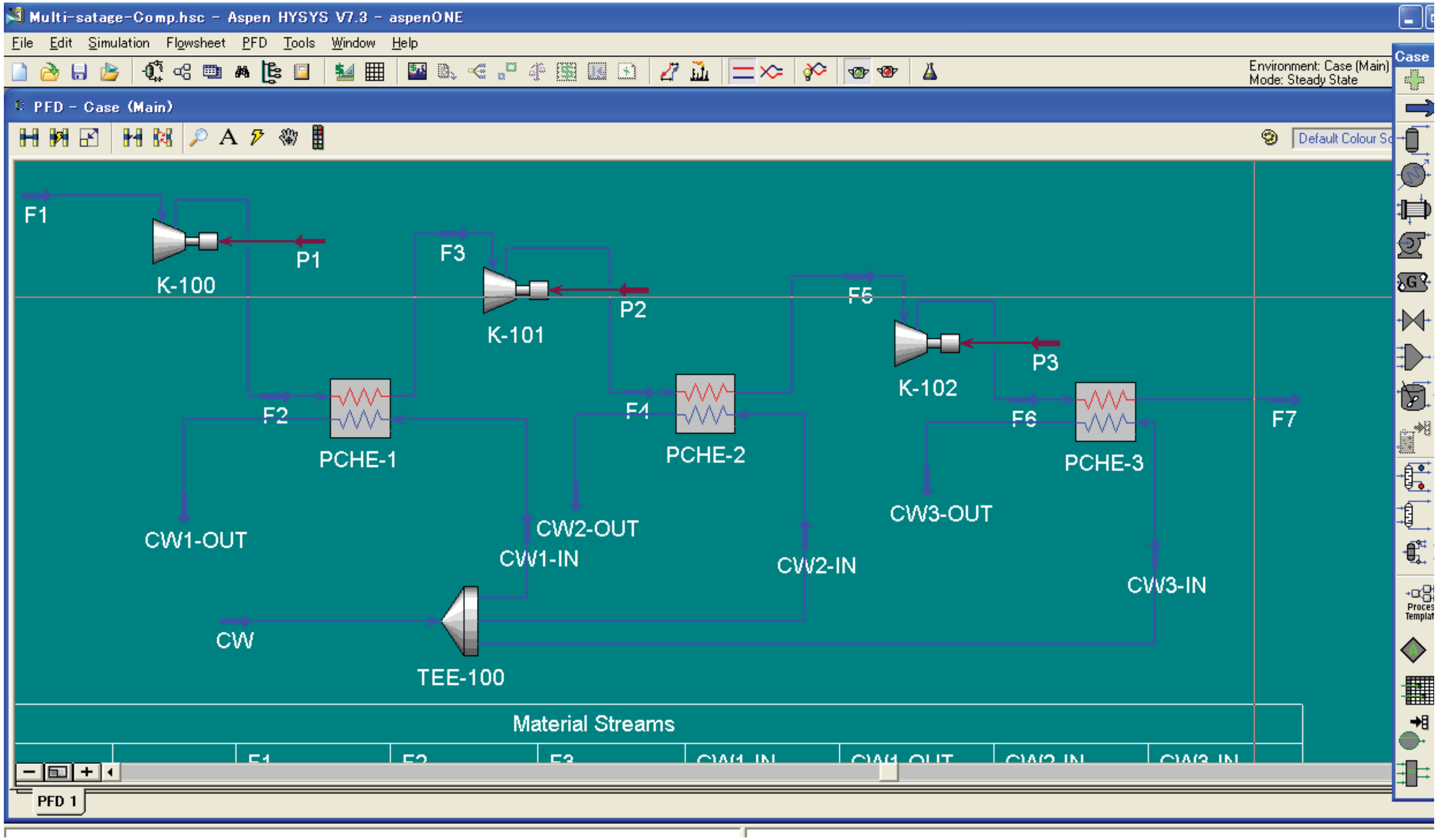
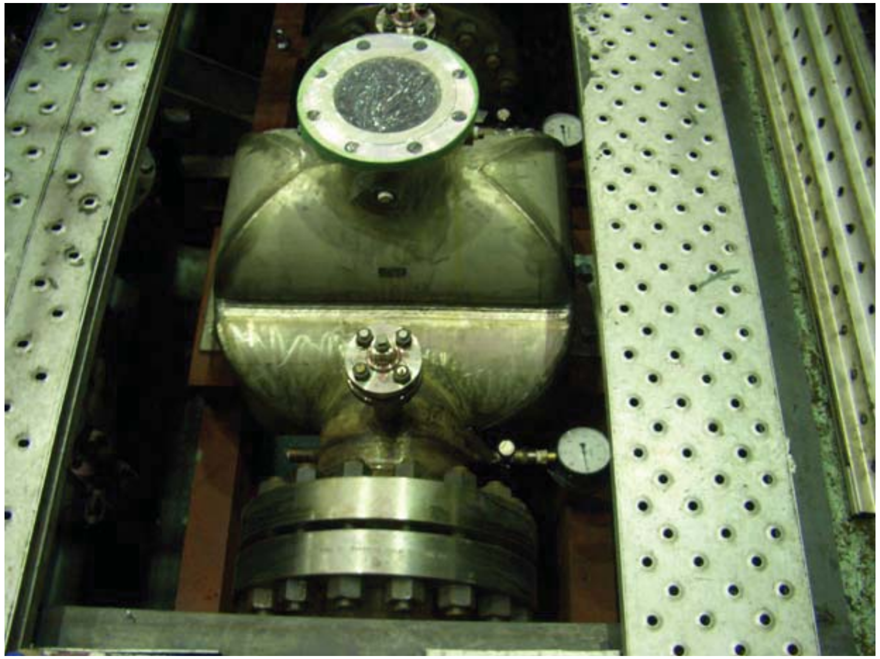
Link between Aspen Hysys and PlateFin



Operation condition for Multi-Stage Compressor is simulated by HYSYS. The some operation condition are checked by the link between HYSYS and Aspen PlateFin.

Performance check of PCHE
(After cooler for Compressor)

Shell&Tube
Φ650×4200TL-TL (5500kg)



PCHE
330X350X650 (700kg)

Design Pressure: 8MPaG (Hydrostatic test: 12MPaG)
Code: Japanese High Pressure Gas Safety Law (with stamp)

KSL tests confirm the mechanical and thermal performance of this PCHE to be superior to S&T.
***Performance calculation & Rating : KSL's own software and technique**
(PCHE:S&T) Volume: 1:10, Weight: 1:8

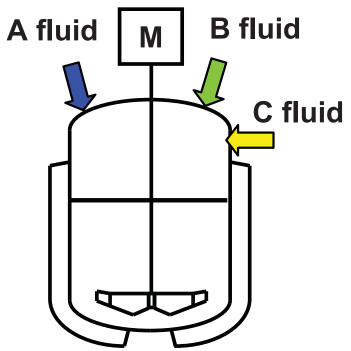
Microchannel reactor
(Stacked Multi-channel reactor)

Microchannel Reactor
(SMCR: Stacked Multi-Channel Reactor)

SMCR is the stacked multi-channel reactor for the large capacity use, it is very easy to built the numbering-up（multi-channel of one unit) by using the channel arrangement of third dimension .

→ ***Improve batch operation to continuous operation for large capacity***

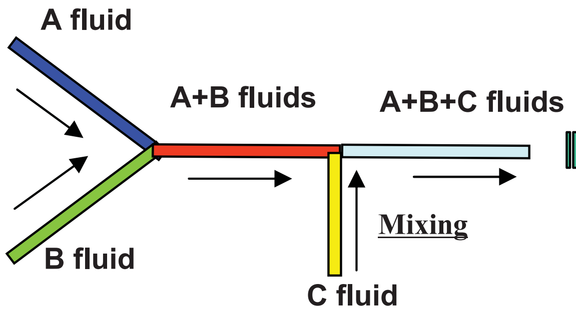
Mixer type（batch operation)



Continuous

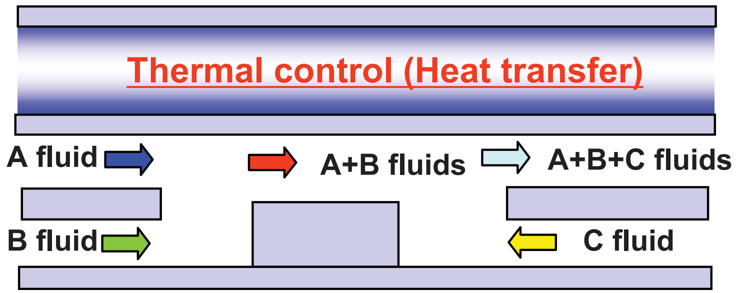
<2 dimensional>

Y shape tube (Existing MCR)



<3 dimensional>

Plate type (SMCR)



Cross sectional view of channel

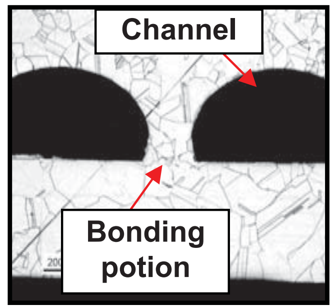


Photo of bonding area

<Application>

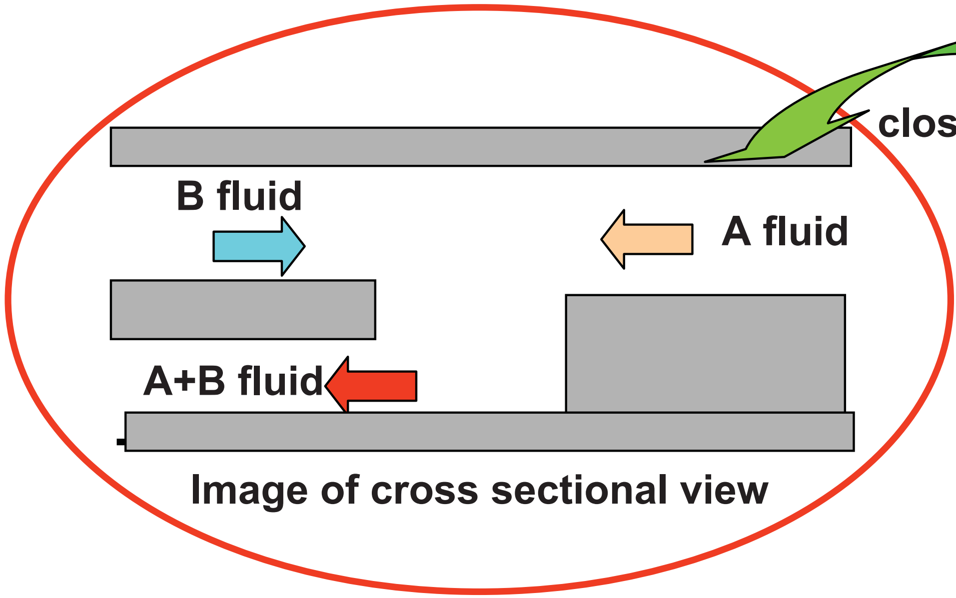
a) Extraction

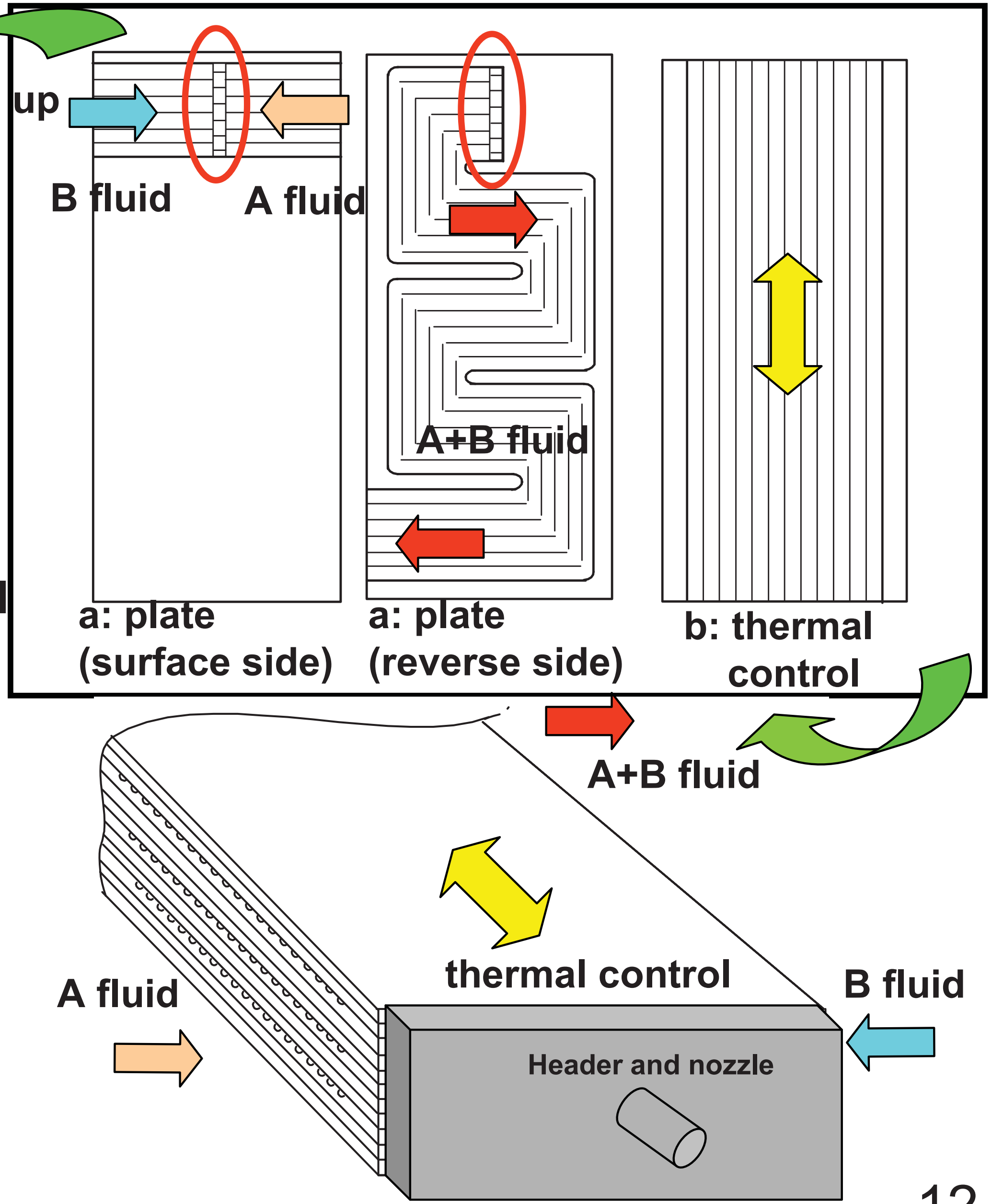
b) Polymerization (Highly exothermic reaction)

c) Reaction (liquid & liquid, liquid & gas and others)

⇒ **It will be very important to estimate thermal performance of each reaction.**

Conceptual design - Large capacity Microchannel Reactor





Stacked plate (b+a+b+a+b: plate and thermal control) will be bonded to one block.

Chanel number

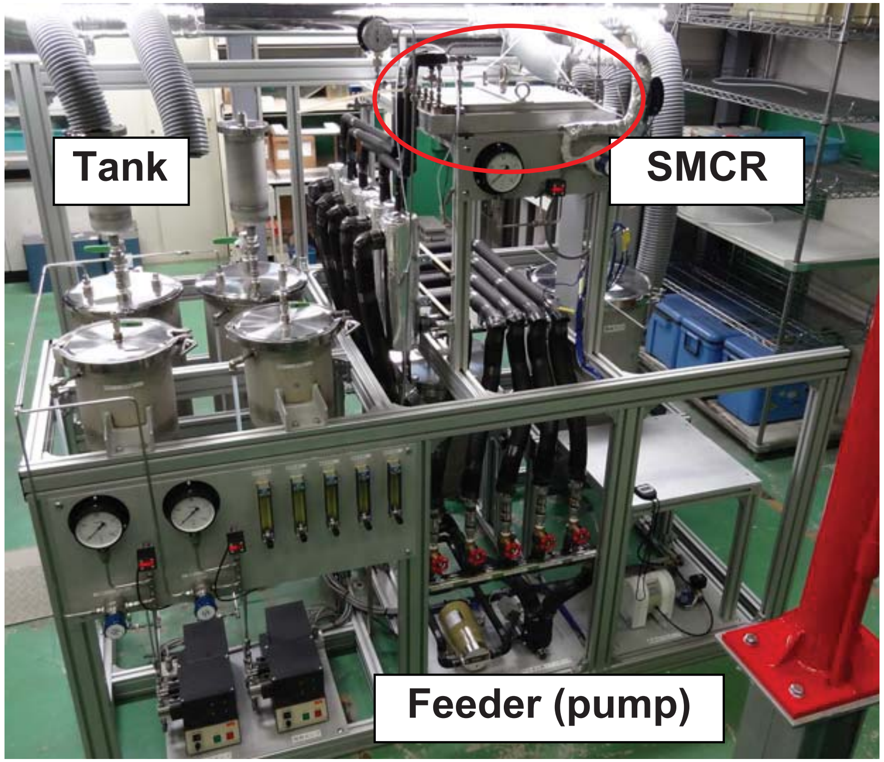
＝channel／plate ×stacked number

（Feature）

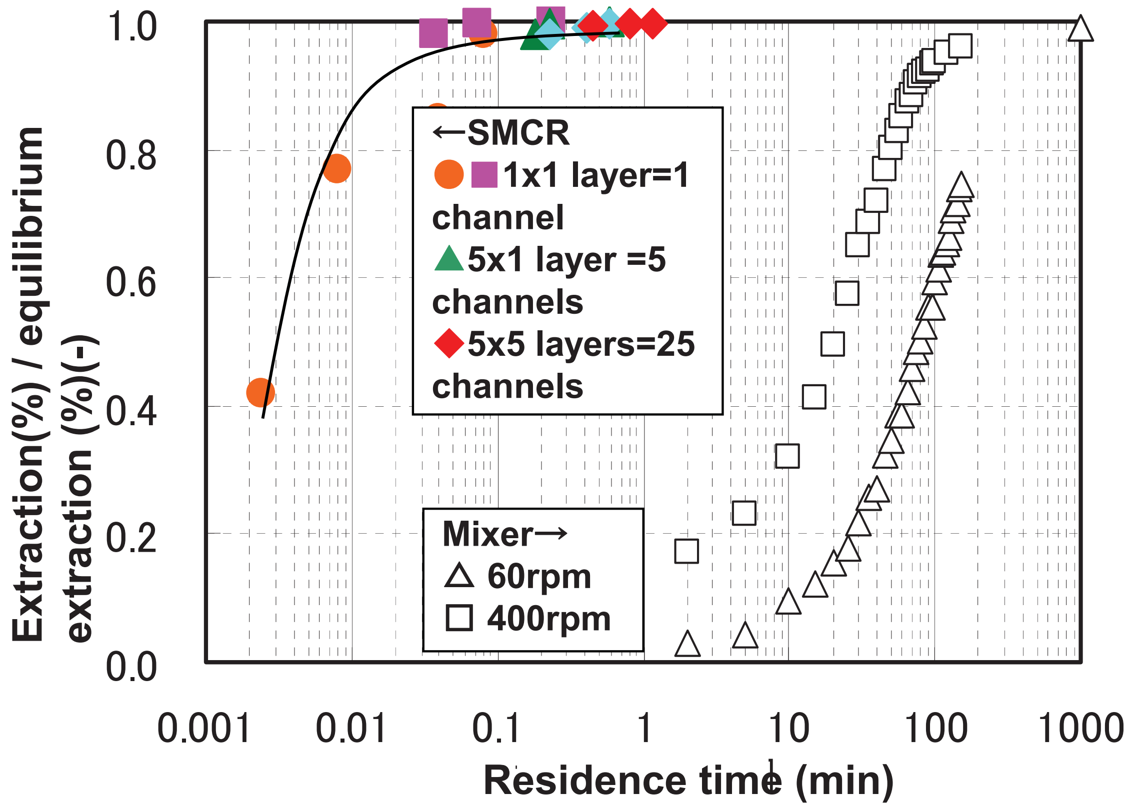
Each stream has uniform pressure drop, so maldistribution is minimized.

Due to this, a large capacity Micro channel reactor can be designed and fabricated.

Testing results for extraction use of SMCR



Testing device



Test results (extraction from phenol 0.1wt%/dodecane to water)

a) No deterioration of extraction ratio by using SMCR
b) Residence time of SMCR can reduce 1/100 of Mixer type

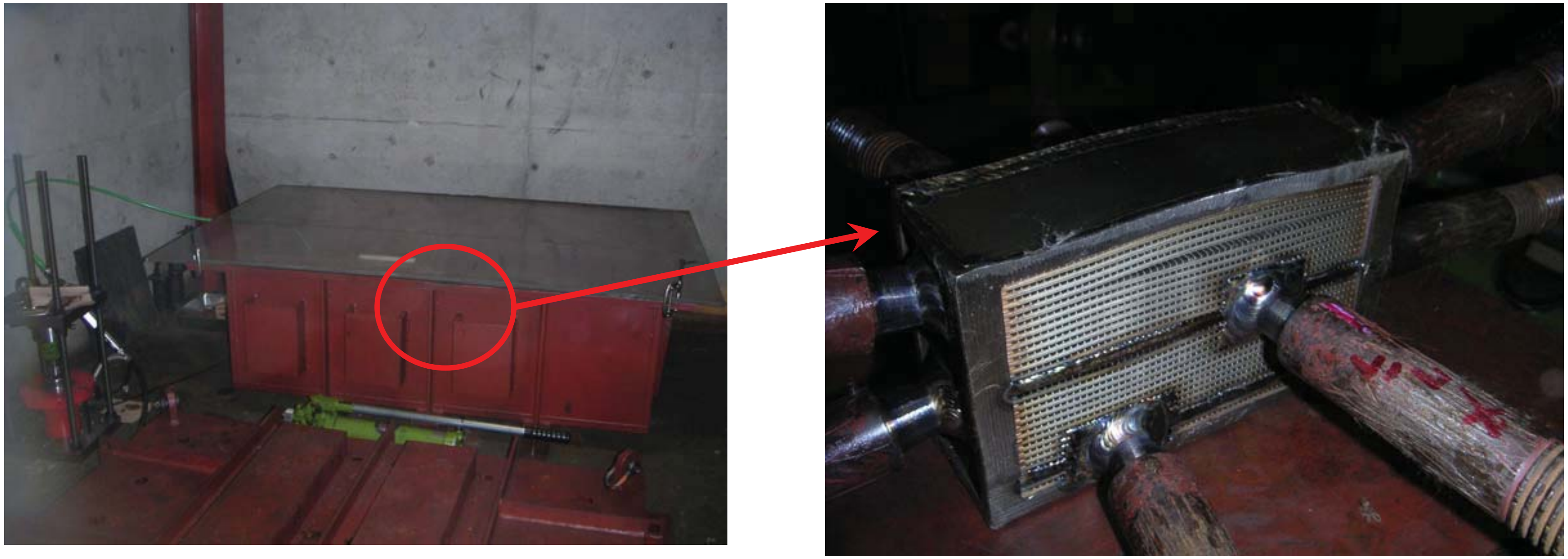
⇒ KSL will use HYSYS and Aspen PlateFin to simulate the thermal performance and mass-transfer of SMCR by same concept of PCHE.

Conclusion

- Based on BAHX technologies, Kobe steel is now developing Microchannel heat exchangers and reactors for some applications such as cooler for compressor, extraction and reaction use.
- The heat transfer is most important issue for design of these equipment.
- The channel shape information of PCHE can be changed to the fin shape by using same hydraulic diameter and free flow area.
- Kobe steel presented the design method for the Microchannel equipment by using PlateFin.
- The process data such as some stage compressor or extraction process from HYSYS are linked to Aspen PlateFin.
- We reported the design result by PlateFin and the operation test results of this compressor cooler.
- And also, we introduced Large capacity Microchannel reactor and the importance of HYSYS and Aspen PlateFin to simulate the thermal and mass-transfer performance.

For reference

Bonding strength check



Bursting test of sample core by diffusion bonding

Bonding quality was confirmed by bursting test .

→ **Bursting pressure was over 100MPaG.**
(Channel size: 2mmx1mm, pitch 2.3mm,
material: stainless steel)

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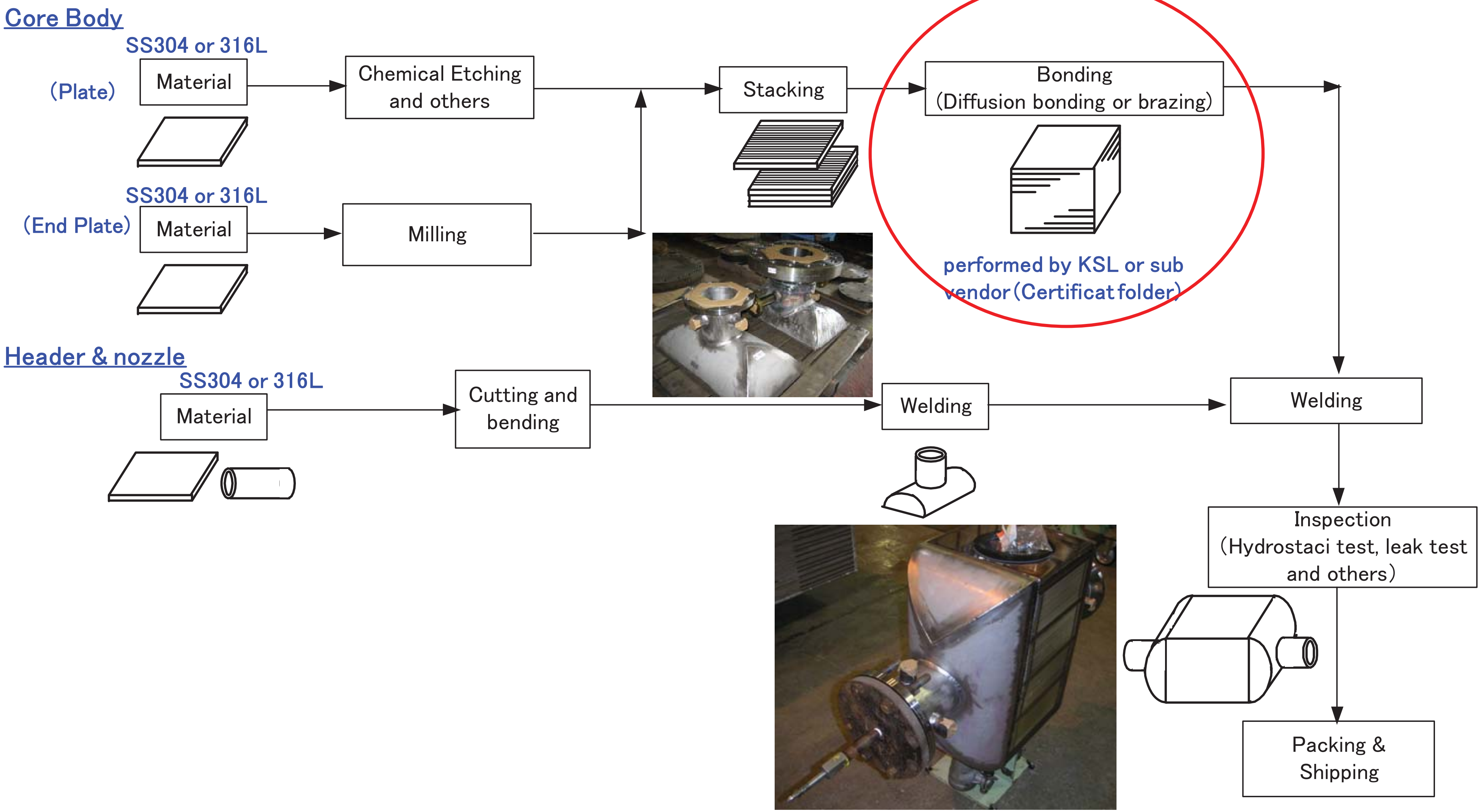
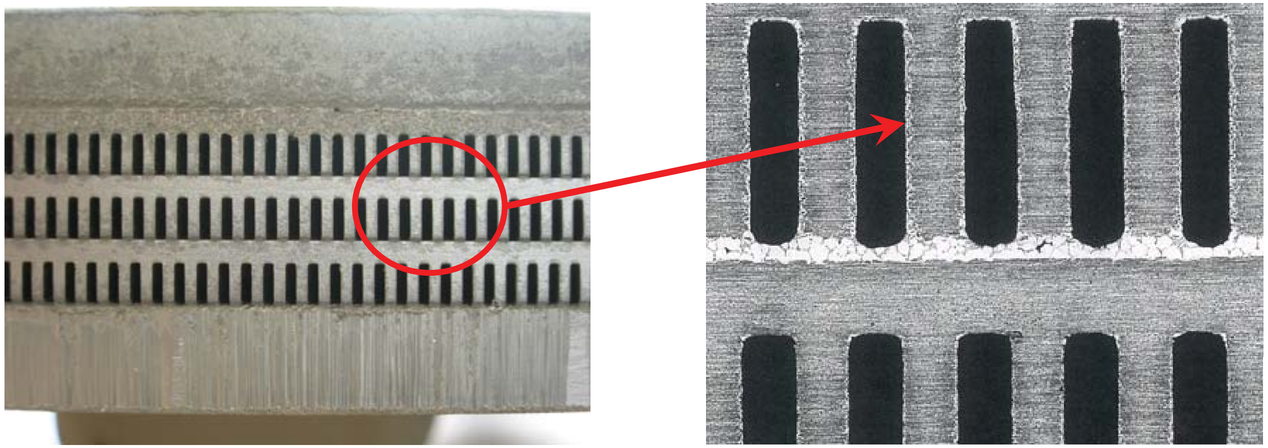
Fabrication flow of PCHE (Printed circuit Heat Exchanger)

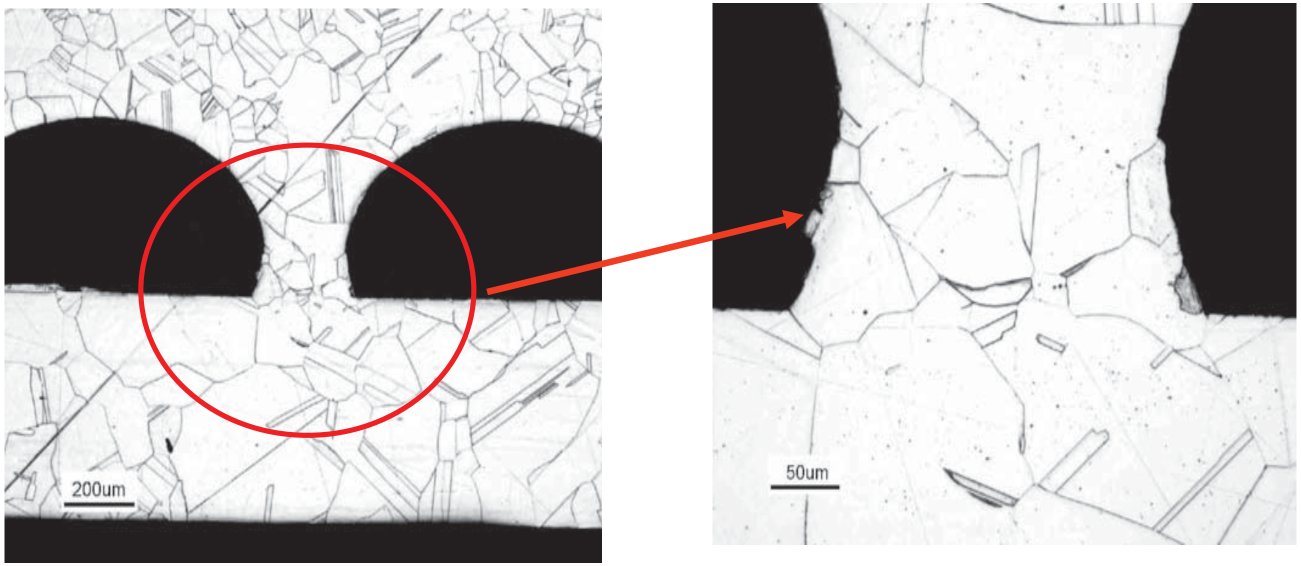


Bonding method

Brazing
(Aluminum and
others)



Diffusion bonding
(Stainless Steel)



Bonding method and material is selected based on the channel size, corrosion resistance, required strength and other relevant factors.

New Requirements in ASME for diffusion bonding

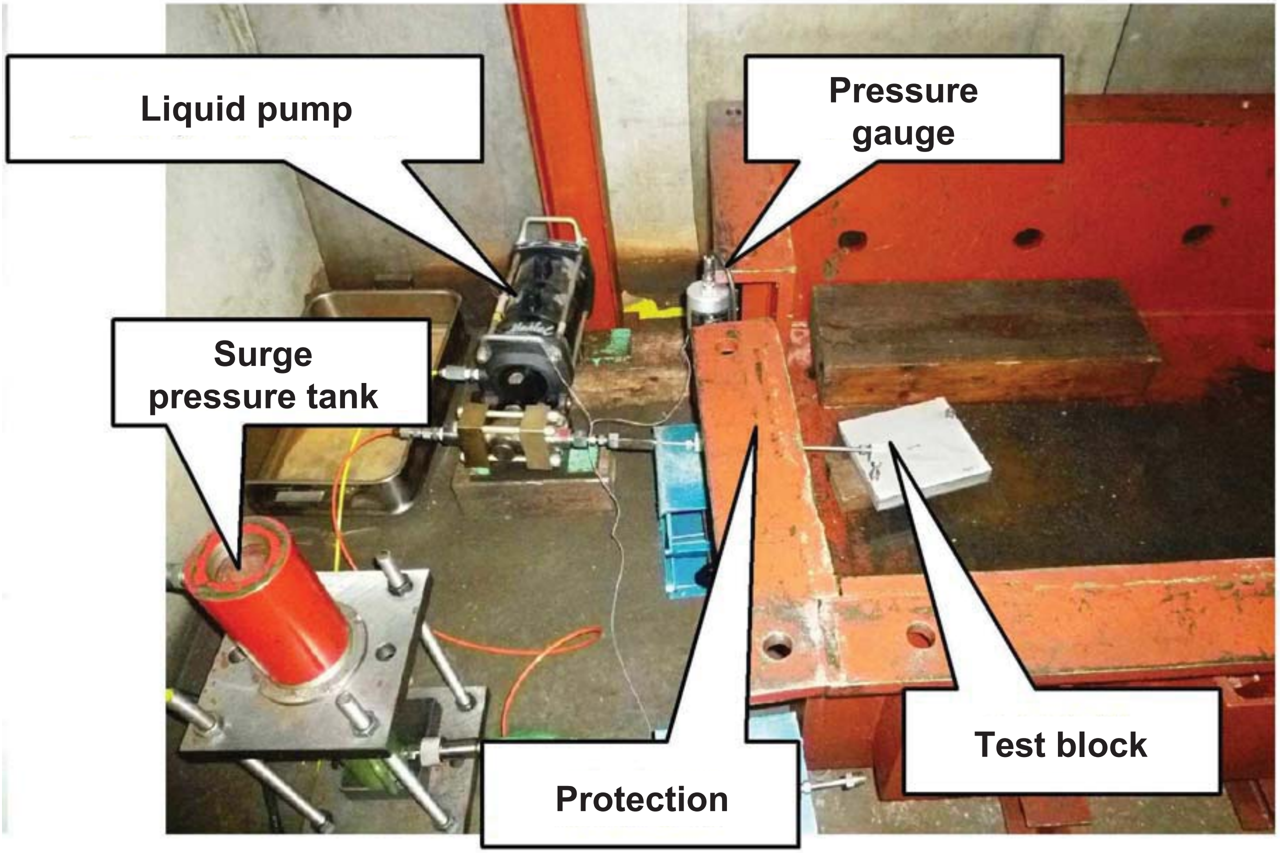
There were the special requirement for Diffusion bonding in Code Case(2437-1, 2621-1). But these requirements are limited to the special application.

Based on the customers requests,
the general requirements are specified in ASME 2011a as follows,
ASME Sec. VIII Div.1 "Diffusion bonding" at Mandatory Appendix-42
Sec. IX "Diffusion Welding" in QW-185

Requirement for production tests (only key issues):
aa) Test block shall be a minimum of a 200mm x200mmx 50 interface planes
bb) free from cracks and shall show no incomplete bond or porosity on or adjacent to the bond lines
cc) After the bonding, mechanical properties (TS,YS Hardness) shall match the ASME requirements (same as base metal).

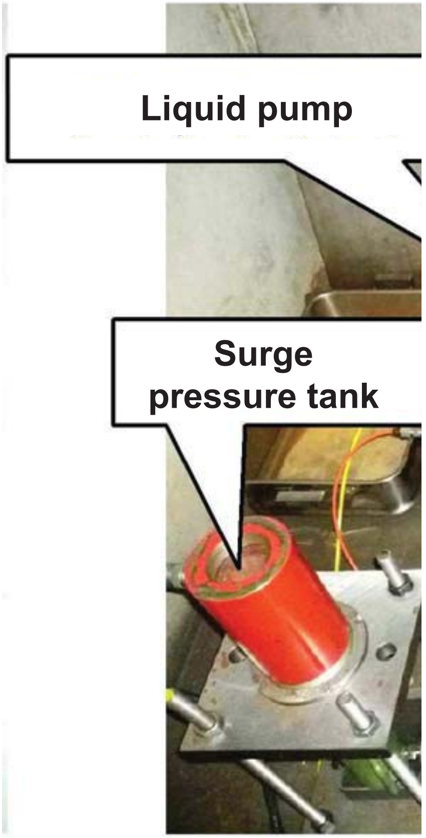
Further more, M.A.W.P. (Maximum Allowable Working Pressure) for the device will be decided by the results of the bursting test in UG-101.

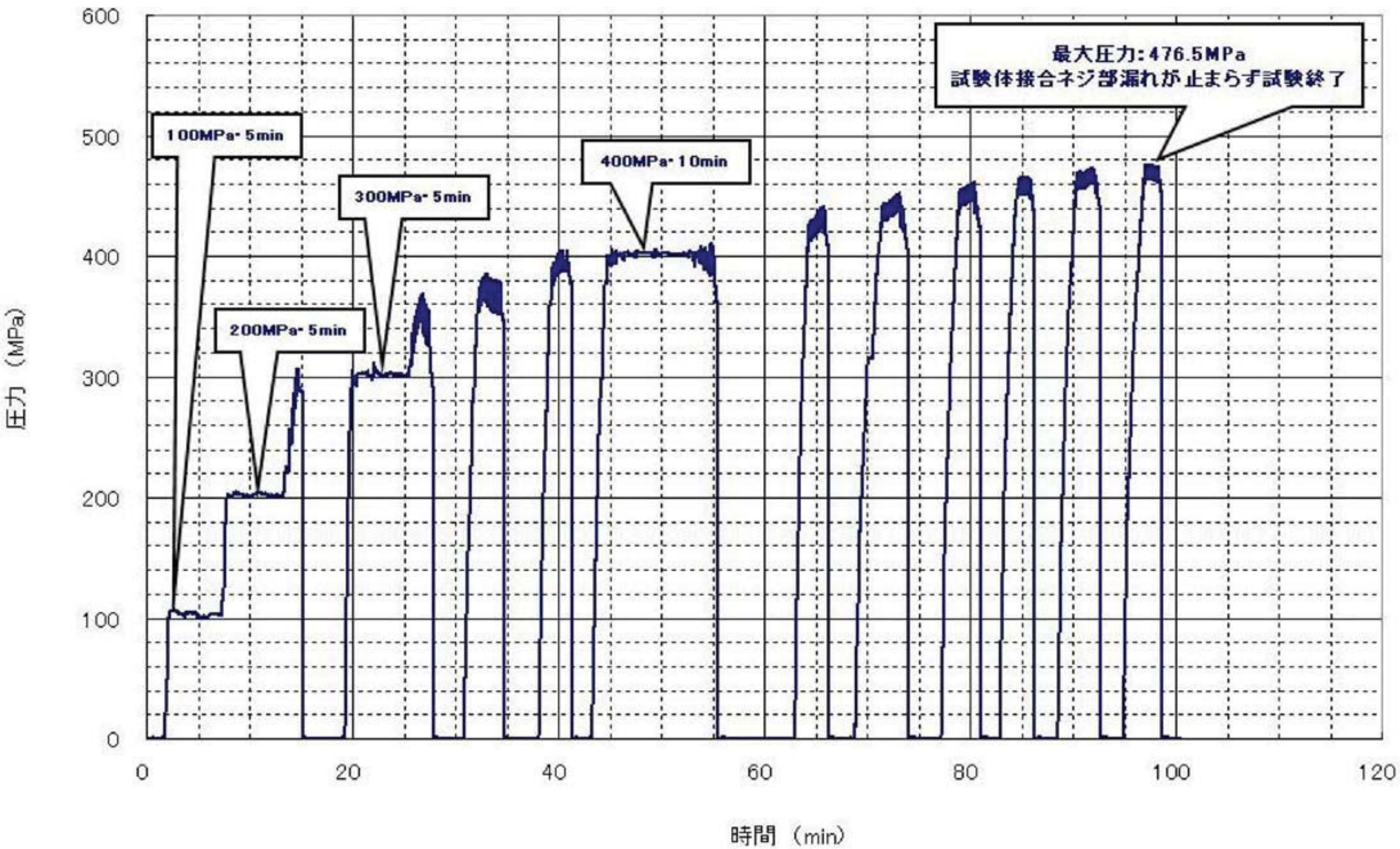
Busting test Results (sample)



MAWP (Maximum Working Pressure) will be decided based on bursting test (ASME UG-101).

Busting test Results (sample)





MAWP (Maximum Working Pressure) will be decided based on bursting test (ASME UG-101).

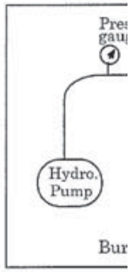
Bursting test results based on ASME

MANUFACTURER'S REPORT OF PROOF TEST TO ESTABLISH MAXIMUM ALLOWABLE WORKING PRESSURE OF DIFFUSION BONDING CORE

Report No. DBHE01

Reference DWG No. Y2025 Date December 26, 2011

D.B. Proces



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Test Specimen No.	Bu Hy at wa
BT-2	

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BURSTING TEST

Test Specimen No.	Bursting test pressure or Hydrostatic test pressure at which the test was stopped	Tensile Strength		Character of Failure & Location	Pressure gauge & Recorder used to the test
		Specified minimum	Average actual		
BT-2	99.76 MPa	485 MPa	536.5 MPa	Ridge	NKIS1015 NKIS1034 NKIH18

Therefore the maximum allowable working pressure of the diffusion bonding core 12ST24040 shall be computed as follow in accordance with ASME CODE SECT. VIII UG101.

$$P = \frac{B}{4} \times \frac{S_\mu E}{S_\mu \mathrm{avg}}$$

where B = bursting test pressure, or hydrostatic test pressure at which the test was stopped, MPa

E = efficiency of welded joint, if used.

S_μ = specified minimum tensile strength at room temperature, MPa

S_μ avg = average actual tensile strength of test specimens at room temperature, MPa.

$$P = \frac{B}{4} \times \frac{S_\mu E}{S_\mu \mathrm{avg}} = \frac{99.76}{4} \times \frac{485}{536.5} = 22.5 \quad \mathrm{MPa}$$

We certify th
were prepare
2010 edition

Witnessed

AI

Manager Quality Assurance
Takasago Equipment Plant
Kobe Steel,Ltd

PQR for diffusion bonding based on ASME

After the bonding, we confirmed that mechanical properties (TS,YS Hardness) matched the ASME requirements (same as base metal).

Tensile Tests (QW-153 / App.42 6.2 (a))

Specimen	Width/ Diameter (mm)	Thickness (mm)	Area (mm ^{2})	Ultimate Load (N)	UTS (MPa)	Elongation (%)	Failure Location
PTPT-6 No.1 (V)	Φ6.38	N/A	31.97	15734	492	69.7	A
PTPT-6 No.2 (V)	Φ6.38	N/A	31.97	15742	492	74.0	A
PTPT-6 No.3 (V)	Φ6.39	N/A	32.07	15776	492	72.8	A
PTPT-6 No.1 (H)	Φ6.38	N/A	31.97	17224	539	68.1	A
PTPT-6 No.2 (H)	Φ6.37	N/A	31.87	17248	541	68.1	A
PTPT-6 No.3 (H)	Φ6.38	N/A	31.97	17196	538	67.3	A

Hardness Tests (App.42 6.2 (a))

Type	Results	Type	Results
Rockwell B PTPT-6 No.1 (V)	64.0	Rockwell B PTPT-6 No.1 (H)	62.0
Rockwell B PTPT-6 No.2 (V)	64.2	Rockwell B PTPT-6 No.2 (H)	63.4
Rockwell B PTPT-6 No.3 (V)	64.9	Rockwell B PTPT-6 No.3 (H)	63.3

Bend Tests (App.42 6.2 (a))

Laboratory Test Number PTPT-6 Rev.2 (PTP-4 Rev.2)

We hereby certify that the statements in this record are correct and that the test coupons were prepared, diffusion bonded, and tested in accordance with the requirements of Section IX and Sec. VIII Div.1 App.42 of the ASME BOILER AND PRESSURE VESSEL CODE.

ASME

Manufacturer Metal Technology Co. Ltd. Himeji Plant

Prepared by technical section engineer T. Komiya Date 10/15/11

Certified by technical section manager Y. Yamamoto Date 10/15/11

Reviewed by Quality Control section manager F. Kimura Date 10/15/11

corrected by T.K. (T.S.E) 10/21/11 Certified by Y.Y (T.S.M) 10/21/11 Reviewed by F.K 10/21/11 (QCM) 10/17/11

Laboratory Test Number PTPT-6 Rev.2 (PTP-4 Rev.2)

We hereby certify that the statements in this record are correct and that the test coupons were prepared, diffusion bonded, and tested in accordance with the requirements of Section IX and Sec. VIII Div.1 App.42 of the ASME BOILER AND PRESSURE VESSEL CODE.

ASME

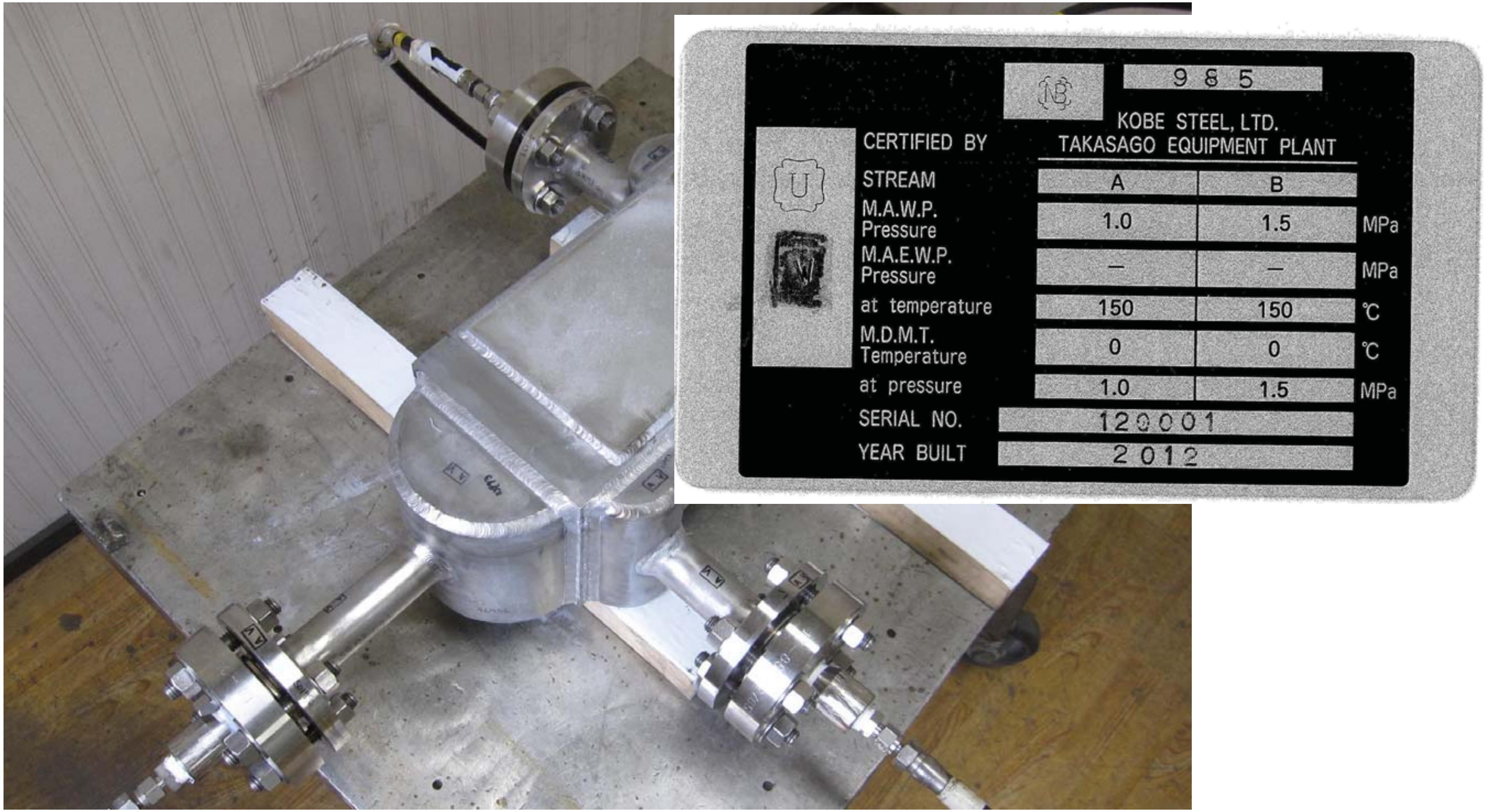
Manufacturer Metal Technology Co. Ltd. Himeji Plant

Prepared by technical section engineer T. Komiya Date 10/15/11

Certified by technical section manager Y. Yamamoto Date 10/15/11

Reviewed by Quality Control section manager F. Kimura Date 10/15/11

Demo heat exchanger based on ASME code



Demo heat exchanger (size 150Wx150Hx300mm)