MECHANICAL PROPERTIES OF ALUMINIUM ALLOYS FOR TRANSPORT AND STORAGE CASK AFTER LONG TERM STORAGE

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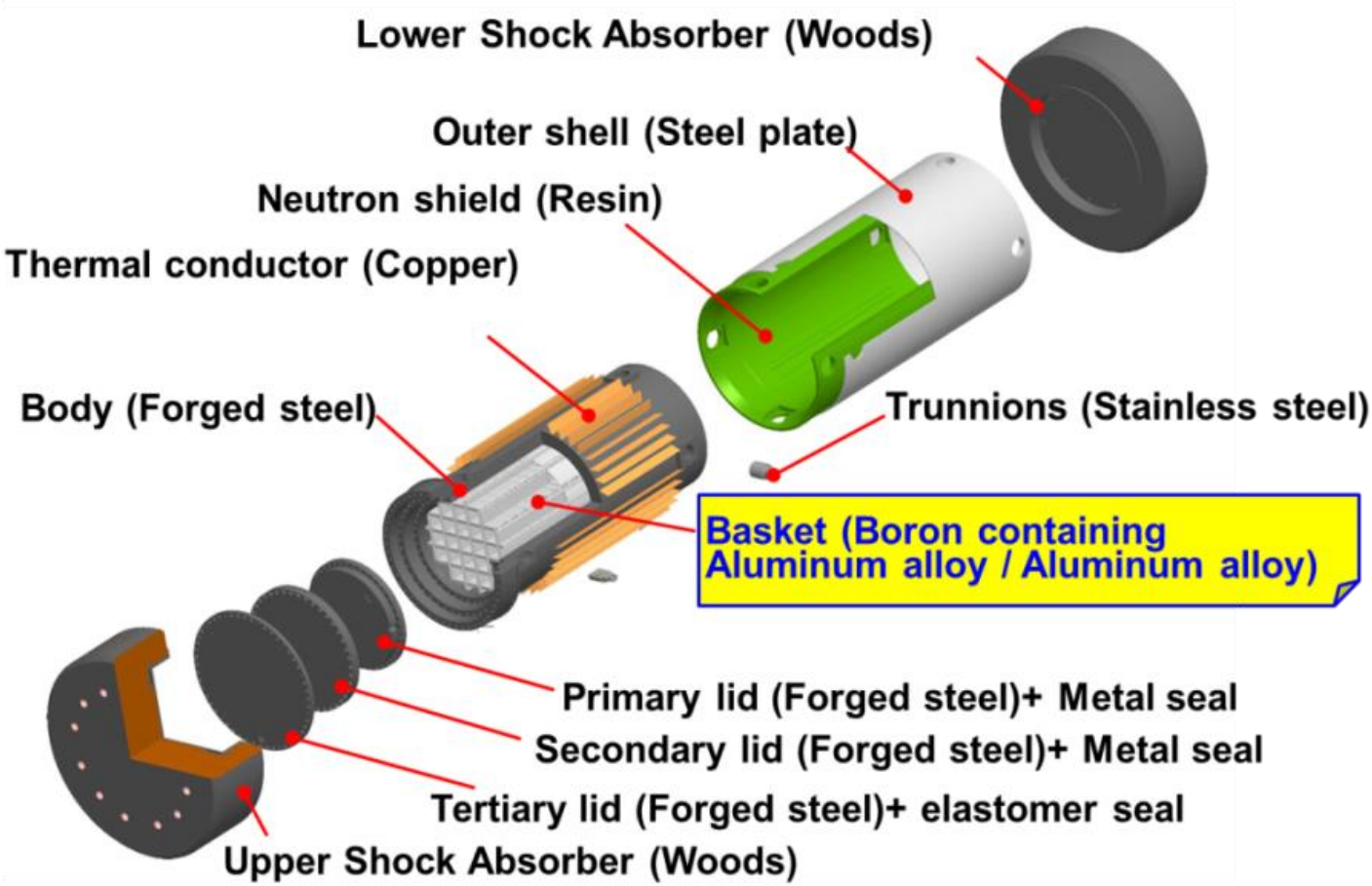
1. INTRODUCTION

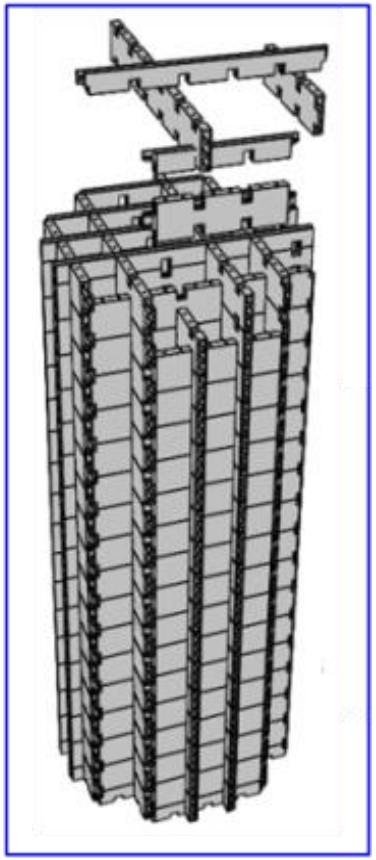
- Aluminium alloys are widely used for BASKET MATERIAL of transport and storage casks as structural members.
  - ✓ Aluminium alloys have a good heat-transfer performance and a material workability as well as a good specific strength.
  - ✓ Mechanical properties of aluminium alloys may change during storage since cask service temperature may affect micro structure of aluminium alloys over the long time period.
- It is essential to identify degradation of mechanical strength for normal storage and transport accident after long term storage (up to 60 years in Japan).

  - ☐ Micro structural strengthening mechanism
  - ☐ Effects of thermal deterioration on mechanical properties

Structure of basket for MSF-type dual-purpose cask

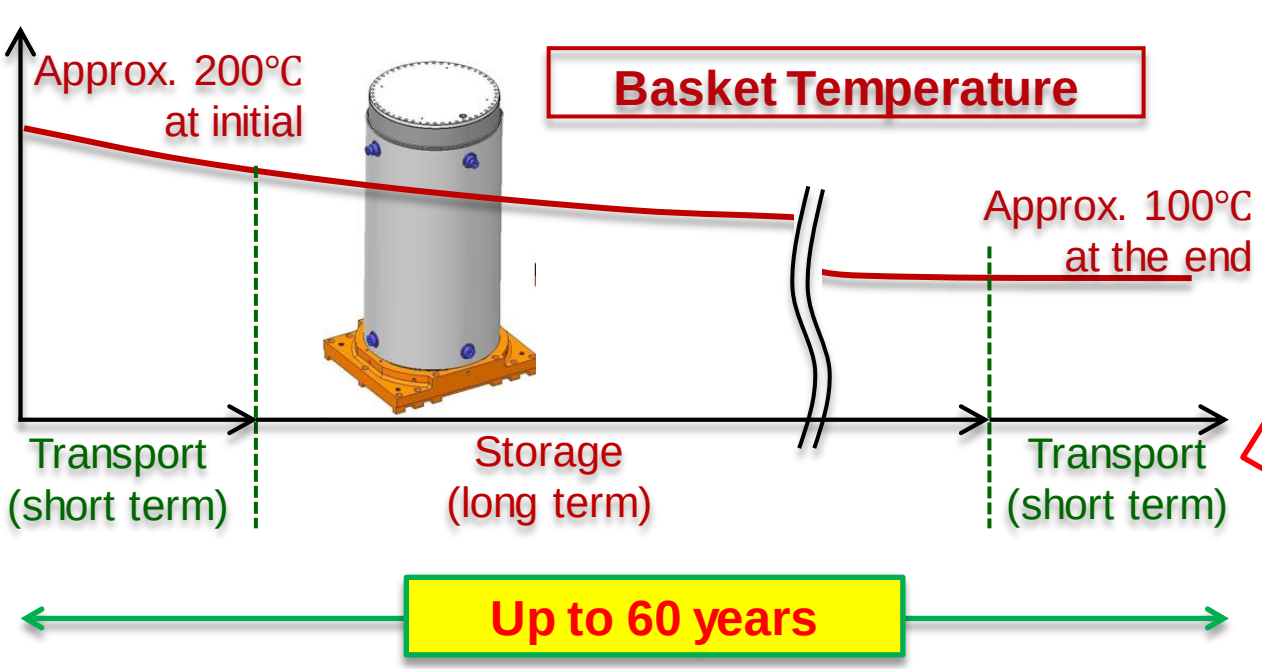
- Basket is an assembly of hollow tubes made of aluminium alloys.





Thermal and mechanical loads on cask

- Casks are used for transport, long term storage and transport after storage of spent nuclear fuels.

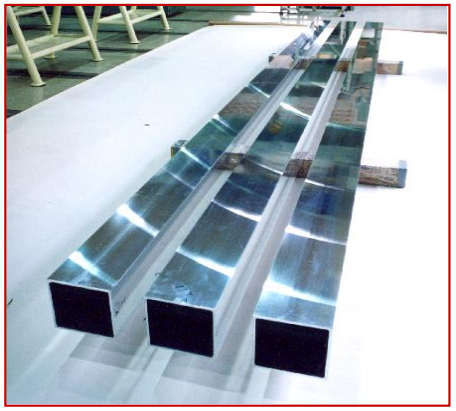


Transport Accident
(9m Drop)

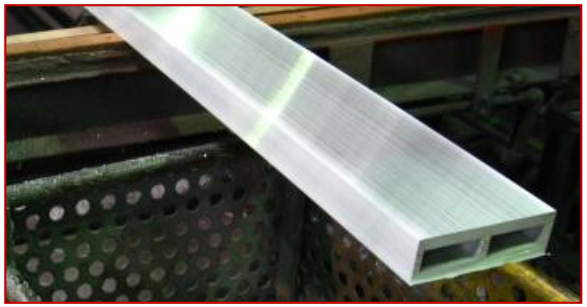
Basket is required to have mechanical strength enough for keeping structural integrity against transport accident after storage.

Aluminium alloys used for basket of MSF-type cask

- BC-A6N01
  - Al-Mg-Si alloy with particles of B_4C
  - Hot extrusion
  - No special heat treatment



- A3004
  - Commercial Al-Mn alloy (JIS)
  - Hot extrusion
  - No special heat treatment



Chemical compositions of sample materials (mass%)

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al	B_4C
BC-A6N01	**0.7**	0.16	0.02	0.03	**0.5**	<0.01	<0.01	<0.01	Bal.	5.0
A3004	**0.20**	0.5	0.19	1.1	**1.0**	0.01	0.05	0.02	Bal.	-

Strengthening mechanisms

- Four major factors contribute to mechanical strength of metallic alloy.

Solid Solution Strengthening	Precipitation Strengthening	Strain Hardening	Strengthening from Grain Boundaries

- Difference between aluminium alloys and ferrous materials essentially comes from the difference in thermal stability of the matrices.

Melting Points
- 1811K for iron
- 933K for aluminium

Aluminium alloy

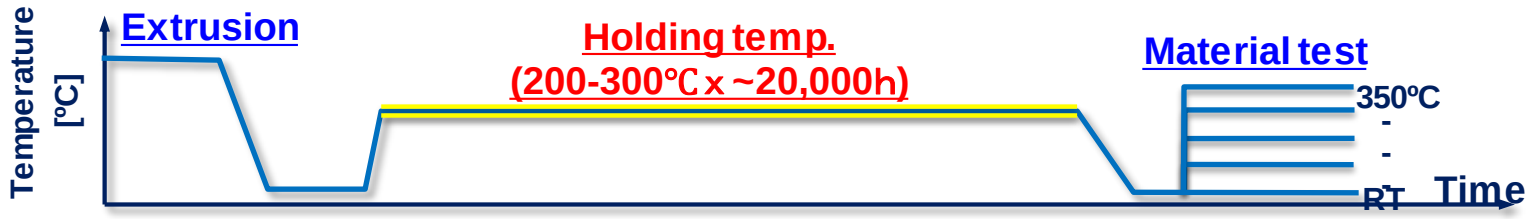
Time-dependent changes in the strengthening mechanisms have to be taken into account even at operation temperature (Approx. 200℃).

THERMAL DETRIORATION: changes in mechanical properties

Heat treatment process for evaluation of thermal deterioration

(1) Long-term overaging heat treatment

- Long-term aging conditions determined by using Larson-Miller Parameter (LMP) to be equivalent to thermal exposure far above 60 years at 200 ºC.



(2) Slow cooling from high-temperature annealing

- Precipitation strengthening and unequilibrium excess solid solution strengthening are fully removed by holding at high temperature and following cooling with cooling rate small enough to cause any supersaturated solution.

Test conditions

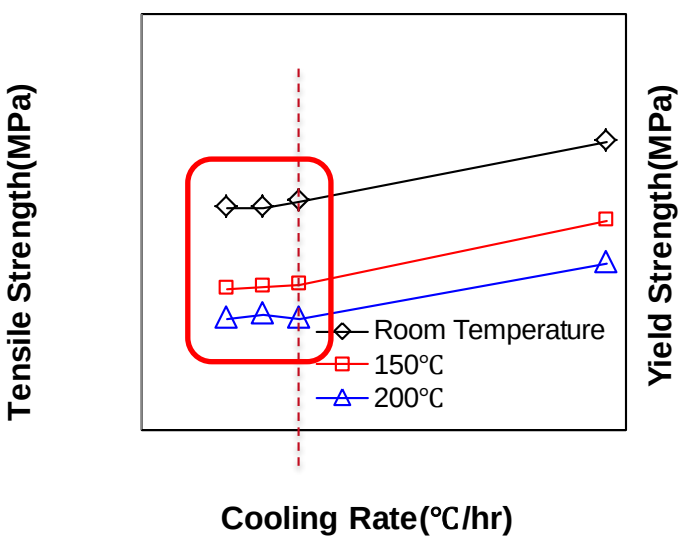
(*) Air cooling

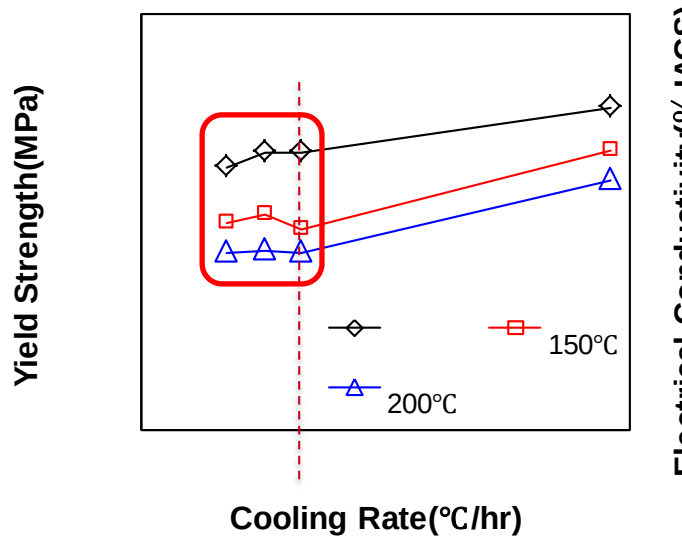
Material		BC-A6N01			A3004		
Parameters		Temp. (ºC)	Hold time (hr)	Cooling rate (ºC/hr)	Temp. (ºC)	Hold time (hr)	Cooling rate (ºC/hr)
Long-term overaging	LA1	200	20,000	Furnace cooling	--	--	Furnace cooling
	LA2	--	--		250	10,000	
	LA3	300	20,000		300	10,000	
Slow cooling	SC1	520	10	>600 (*)	520	10	>600 (*)
	SC2			--			10
	SC3			--			5
	SC4			2			2
	SC5			1			1
	SC6			0.5			0.5
	SC7			--			0.3

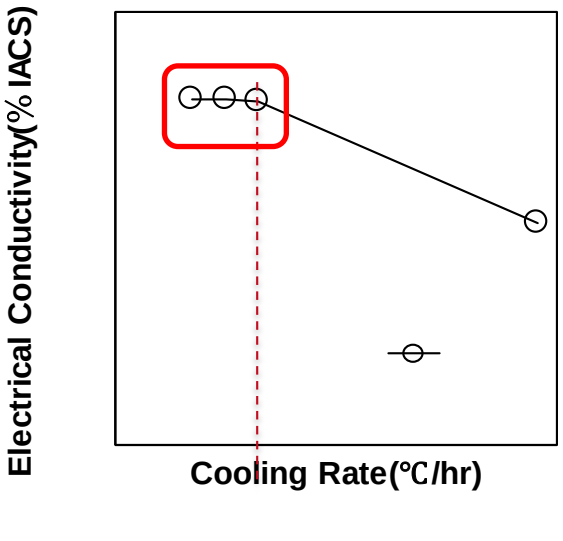
- Tensile test (tensile and yield strength)
- Electrical conductivity measurement (index of solute atom concentration)

Test results

- BC-A6N01 (Slow cooling)







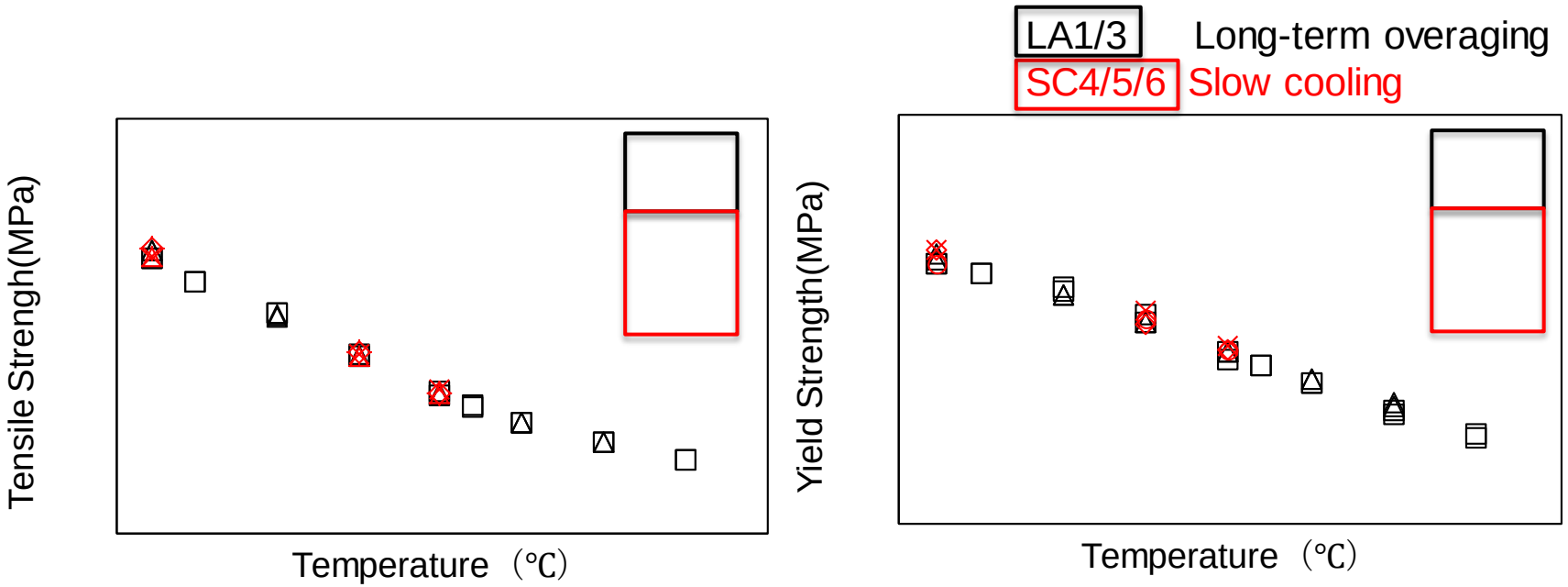
Under the cooling rate of 2 ºC/hr or less,

- Tensile strength and yield strength are almost stable.
- Electrical conductivity is also stable.

Solid solution and precipitation states reached stable.

Test results

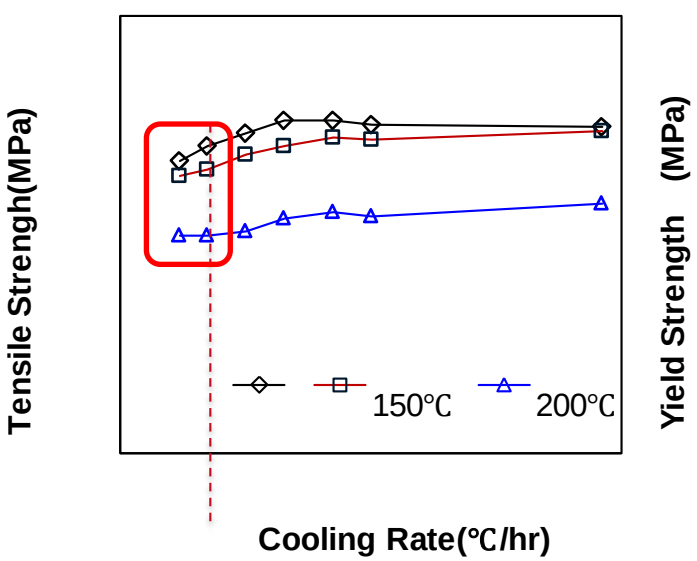
- BC-A6N01 (Overageing and Slow cooling)

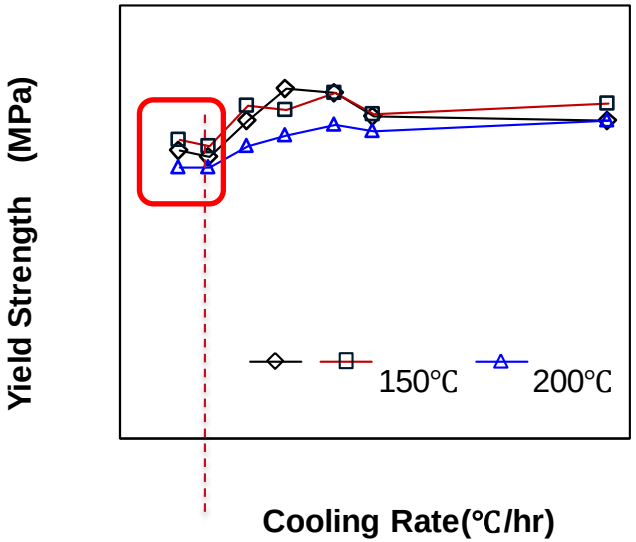


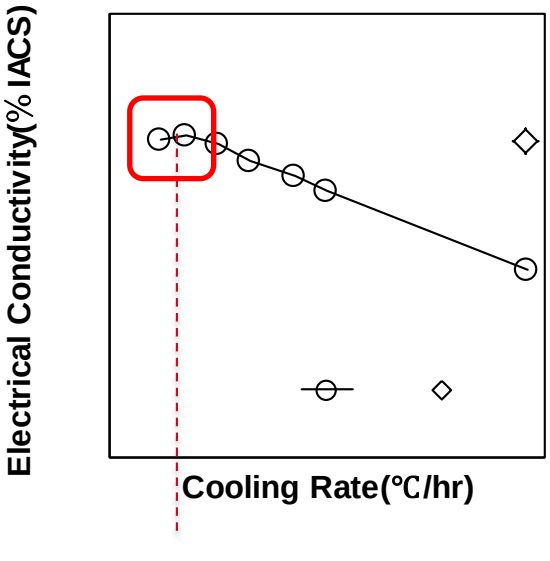
Strengths of “Long-term overaging(20,000H@200/300ºC)”
and strengths of “Slow cooling (< 2ºC/h） ”
are equivalent at each temperature.

Test results

- A3004 (Slow cooling)







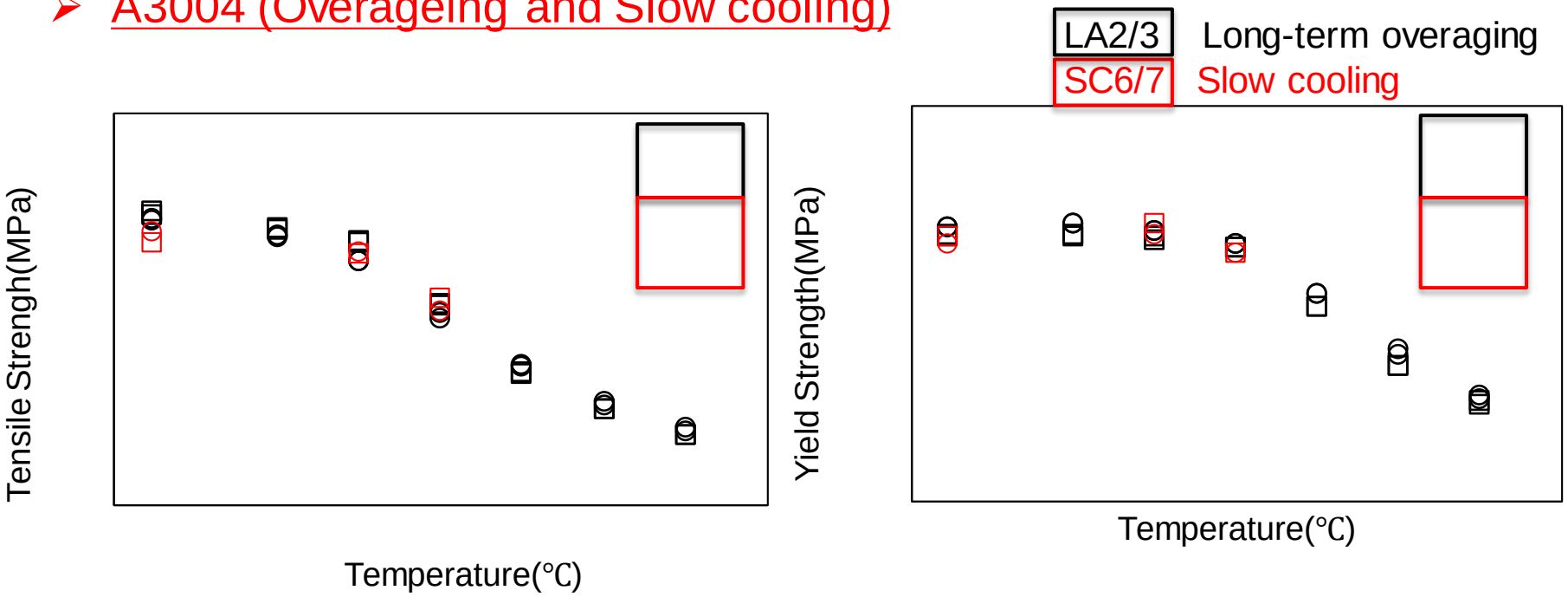
Under the cooling rate of 0.5 ºC/hr or less,

- Tensile strength and yield strength are almost stable.
- Electrical conductivity is also stable.

Solid solution and precipitation states reached stable.

Test results

- A3004 (Overageing and Slow cooling)



Strengths of "Long-term overaging(10,000H@250/300ºC)"
and strength of "Slow cooling (< 0.5ºC/h) "
are equivalent at each temperature.

4. CONCLUSION

- Mechanical properties of aluminium alloys may change during storage (even at operation temperature of approx. 200ºC).
- To assess thermally deteriorated mechanical properties of basket materials after long-term storage (60 years), two kinds of approaches were proposed.
  - ✓ the long-term overageing heat treatment
  - ✓ the slow cooling from high temperature annealing
- Solid solution and precipitation states reached stable by slow cooling method under the cooling rate of 2ºC/hr or less for BC-A6N01 and under the cooling rate of 0.5ºC/hr or less for A3004.
- Both heat treatment methods can make the aluminium alloys stable state of thermal deterioration.
- These results suggest that it is possible to estimate thermally deteriorated mechanical properties of the aluminium alloys.

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Thank you for your attention!