



Effects of Alloying Elements on Thermal Conductivity

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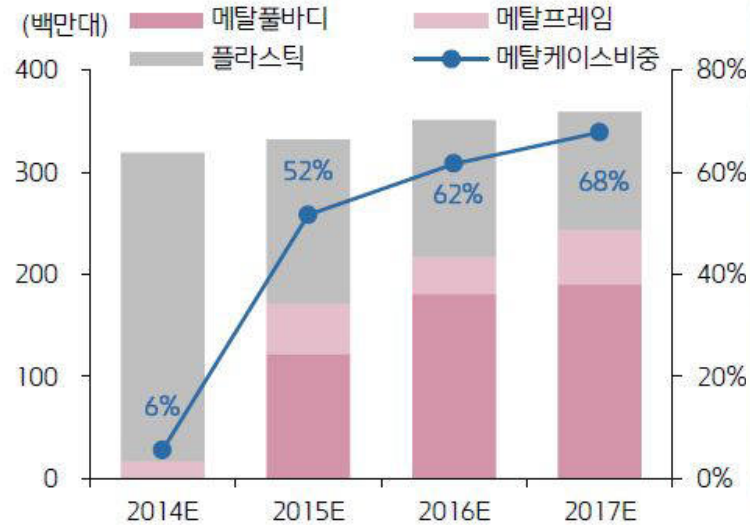
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Introduction

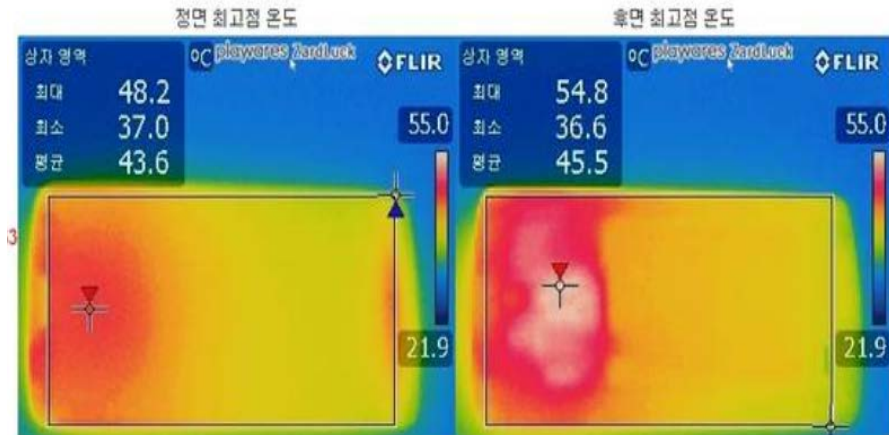
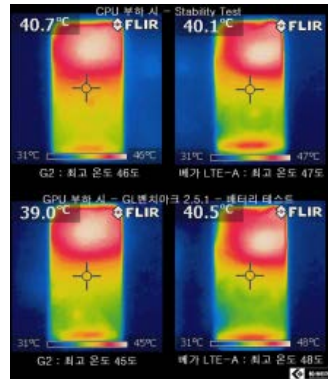
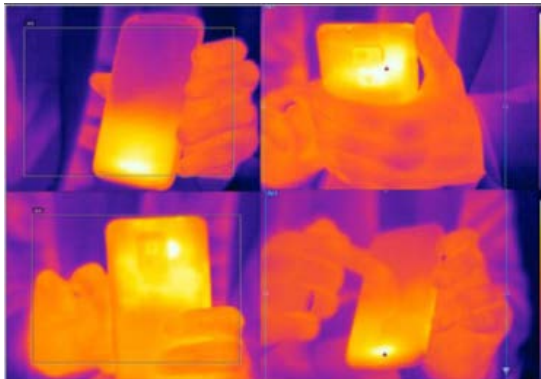
Industrial Needs for High T.C Products

삼성전자 스마트폰 메탈케이스 채용비중



아이폰6 및 아이폰6S의 유니바디(압착형) 메탈 케이스의 구조 [사진=9TO5Mac]

자료: 키움증권



Introduction

Smarter **Electric Applications**

Rotor alloys

High electrical conductivity

High Conductivity and Creep Resistance alloys

Aluminium conductor cable



Electrical applications alloys are found in: wires, motors, and connectors.

Cooler **Heat Transfer Applications**

Long Life™ alloys

Heat exchanger applications

6360 High Performance alloy

High-dissipation heat sink for semiconductors



Heat transfer applications alloys are found in: condensers, A/C pipes, and heat sinks.

Lighter **Lightweight Applications**

Cylinder Head alloy

High thermo-mechanical cylinder head

High Formability and High Strength alloys

Body-in-white and closure panels



Lightweight applications alloys are found in: cylinder heads, wheels, and body panels.

Stronger **Structural Applications**

Aural™ alloys

High Pressure Vacuum Die Casting (HPVDC)

High Strength and High Performance alloys

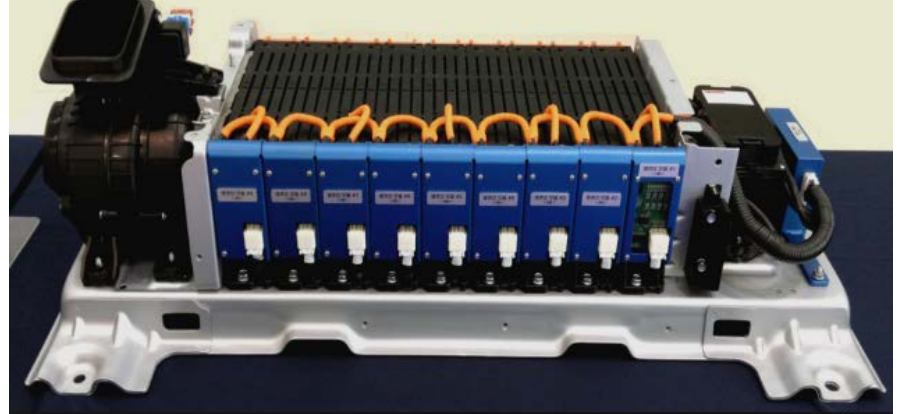
High yield strength applications and crash management



Structural applications alloys are found in: shock towers, crash systems, and space frames.

Introduction

■ Industrial Needs for High T.C Products



STRUCTURE

G8 X621 H7 LED HEADLIGHT

Luxeon ZES LED chips 10W/PCS,
6000LM, >50000 hours

Aluminum spiral heat,
large cooling area,
better thermal performance

Orange color cap
Full of enthusiasm

Smooth Aluminum
Substrate,
good heat dissipation

REMOVABLE CARD SLOTS,
EASY TO INSTALL

Waterproof plug



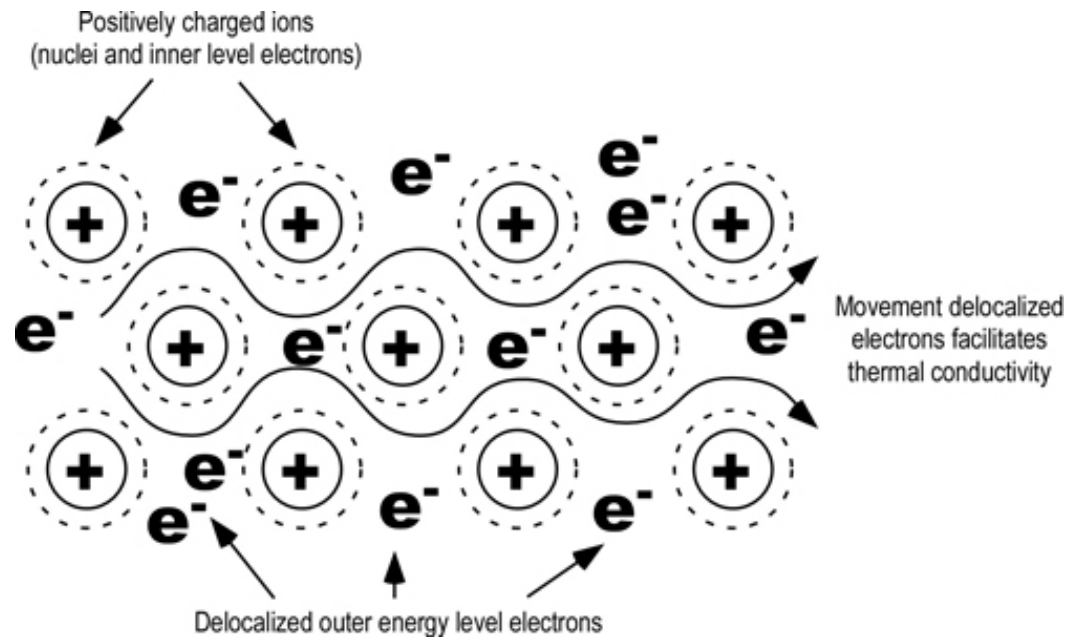
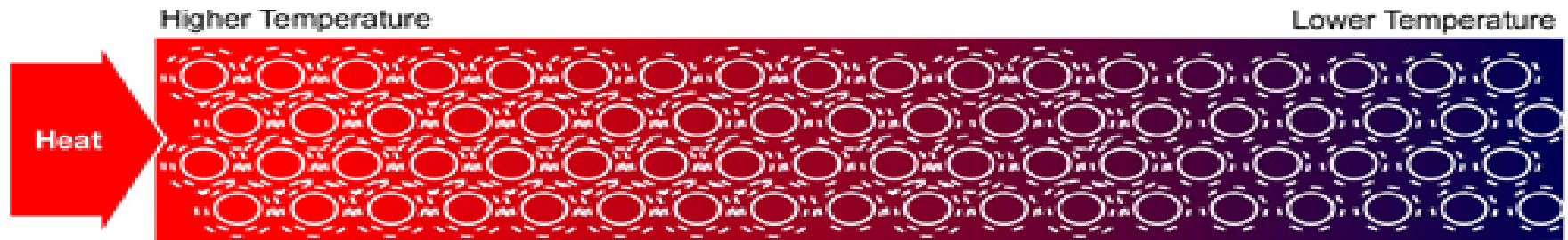
JEEP WRANGLER JK
7 INCH LED HEADLIGHT



JEEP WRANGLER JK
7 INCH LED HEADLIGHT

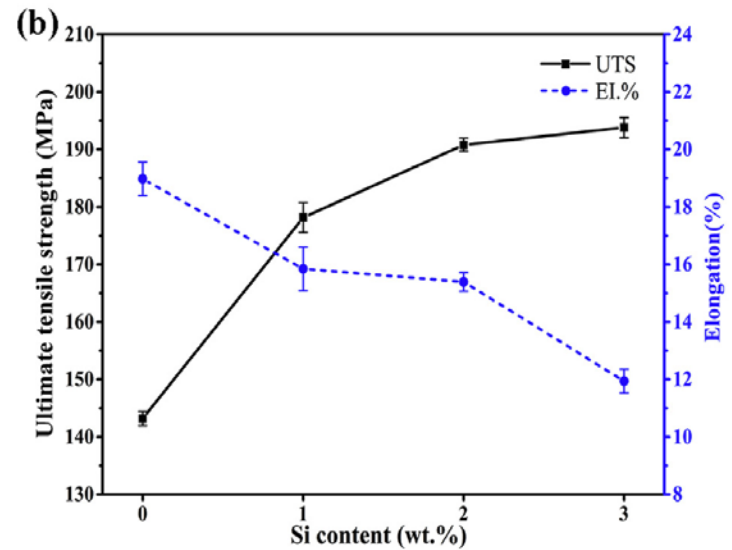
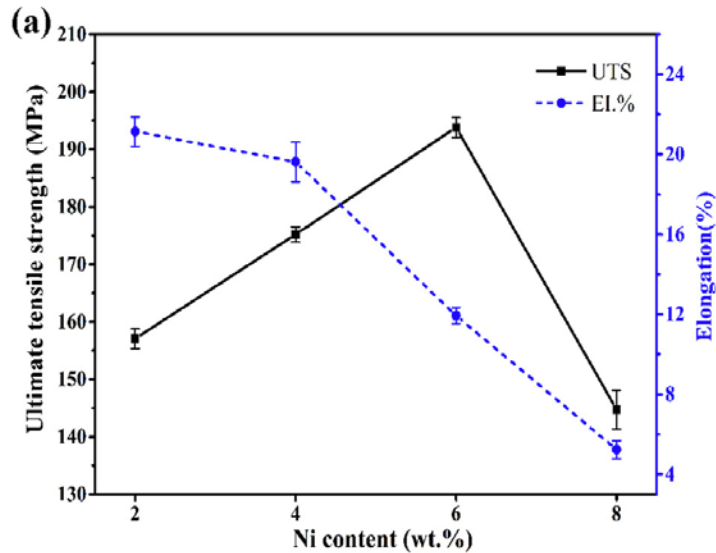
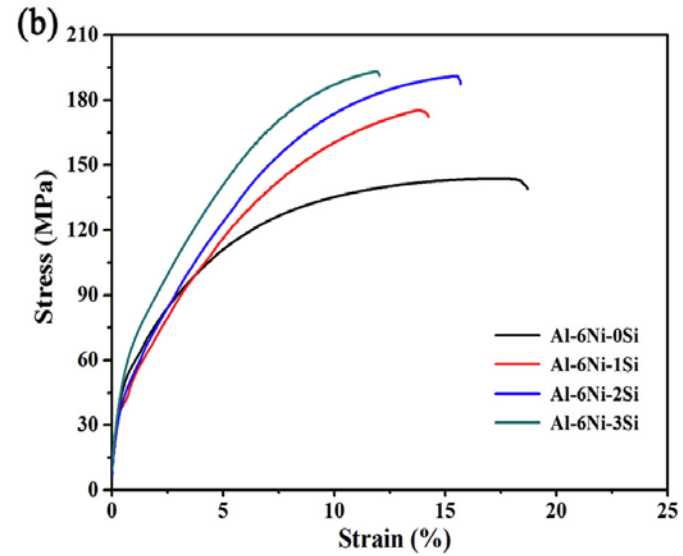
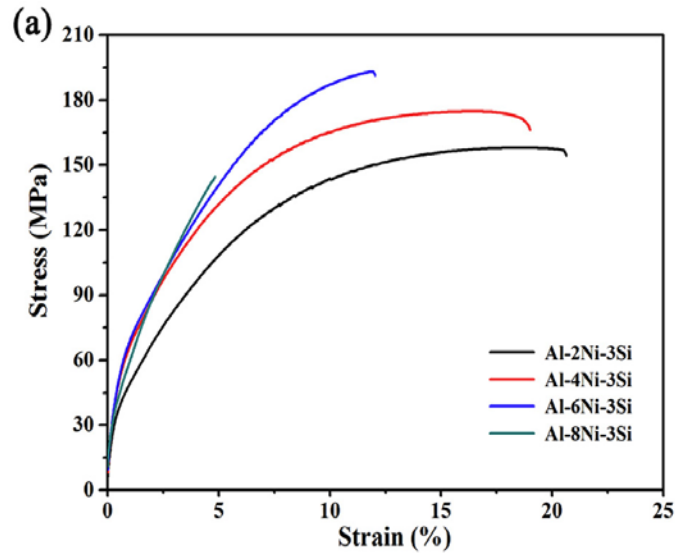
Introduction

■ Conduction



➤ Thermal conductivity is strongly related with free electron density and ..?

Introduction

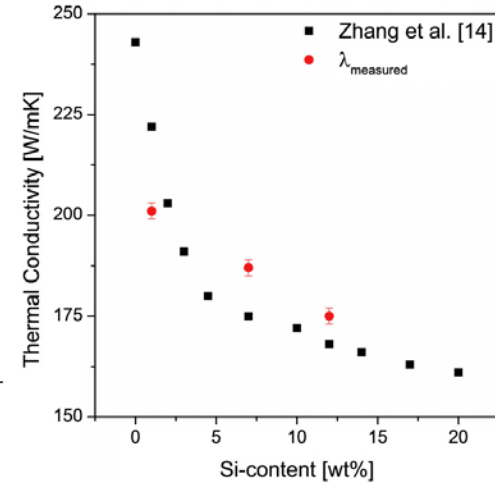
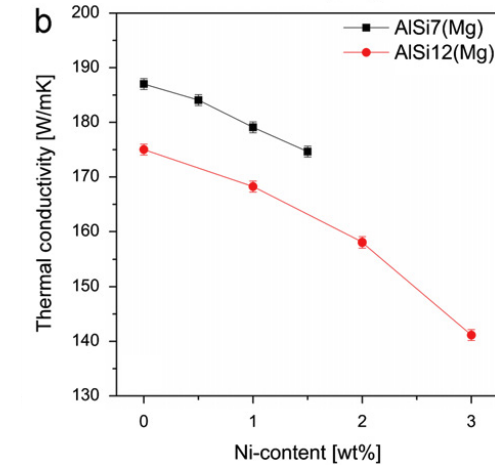
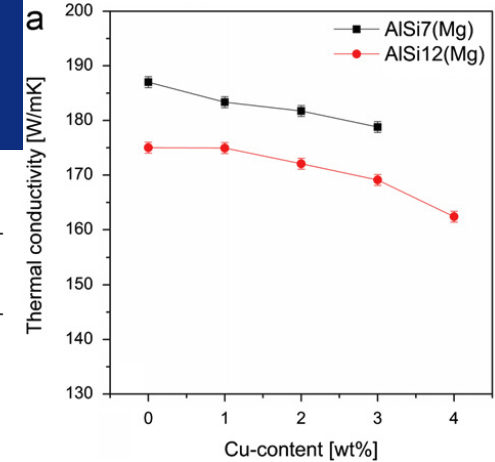


Introduction

Table 2

Volume fractions of the different phases at 250 °C (predicted by simulation) as well as TC and CTE of the investigated alloys.

Alloy	Si	Mg ₂ Si	Al ₁₅ (Fe,Mn) ₃ Si ₂	Al ₂ Cu	Al ₅ FeNi	Al ₃ Ni	Al ₃ Ni ₂ (Al ₃ CuNi)	Al ₇ Cu ₄ Ni	Al ₅ Cu ₂ Mg ₆ Si ₆	TC [W/mK] 20–60 °C	CTE [$\times 10^{-6}$ K ⁻¹] 250 °C
1	7.75	0.79	1.90	-	-	-	-	-	-	187.0	22.89
2	7.90	0.80	1.63	-	1.60	-	-	-	-	184.1	23.25
3	8.04	0.82	1.52	-	2.90	-	-	-	-	179.1	22.67
4	8.14	0.83	1.54	-	2.94	1.03	-	-	-	174.6	22.78
5	7.75	-	1.97	0.71	-	-	-	-	1.18	183.4	23.23
6	7.84	-	1.90	-	0.31	-	1.09	-	1.19	175.8	23.27
7	7.98	-	1.68	-	1.72	-	1.20	-	1.21	175.4	23.01
8	8.13	-	1.58	-	2.97	0.09	1.28	-	1.24	171.5	22.80
9	7.90	-	2.01	2.01	-	-	-	-	1.21	181.8	23.30
10	7.94	-	2.01	-	-	-	0.57	1.42	1.21	177.1	23.19
11	8.02	-	2.03	-	-	-	2.72	0.06	1.23	174.1	23.25
12	8.18	-	1.82	-	1.16	-	3.03	-	1.25	167.8	22.86
13	8.08	-	2.05	3.34	-	-	-	-	1.23	178.8	23.38
14	8.08	-	2.06	0.52	-	-	-	2.41	1.24	177.3	23.34
15	8.16	-	2.07	-	-	-	1.77	1.84	1.25	171.1	23.23
16	8.24	-	2.09	-	-	-	3.94	0.45	1.26	163.9	22.94
17	13.70	0.82	2.16	-	-	-	-	-	-	175.0	21.98
18	14.27	0.87	1.74	-	3.43	-	-	-	-	157.5	21.74
19	14.82	0.90	1.73	-	3.80	1.97	-	-	-	158.1	21.47
20	14.91	0.91	1.66	-	4.01	4.01	-	-	-	141.2	21.56
21	13.68	-	2.02	0.70	-	-	-	-	1.22	175.0	21.99
22	14.07	-	1.71	-	2.13	-	1.29	-	1.26	164.6	21.92
23	14.47	-	1.65	-	3.36	1.11	1.39	-	1.30	157.3	21.74
24	14.71	-	1.64	-	4.19	2.63	1.46	-	1.34	150.8	21.32
25	13.95	-	2.16	2.11	-	-	-	-	1.24	172.1	21.78
26	14.16	-	2.18	-	-	-	2.85	0.06	1.27	160.9	21.71
27	14.53	-	1.80	-	2.80	-	3.41	-	1.35	152.0	21.28
28	14.97	-	1.67	-	4.26	1.01	3.69	-	1.40	150.4	21.28
29	14.47	-	2.18	3.60	-	-	-	-	1.21	169.1	21.67
30	14.31	-	2.20	-	-	-	1.98	1.92	1.33	159.9	21.65
31	14.75	-	2.00	-	1.01	-	5.29	-	1.37	148.6	21.49
32	15.10	-	1.73	-	3.30	-	5.76	-	1.41	148.4	21.22
33	14.44	-	2.31	4.72	-	-	-	-	1.23	162.4	21.75
34	14.60	-	2.25	-	0.33	-	0.61	3.77	1.23	159.2	21.49
35	14.96	-	2.22	-	0.75	-	4.78	1.32	1.26	148.1	21.08
36	15.25	-	2.00	-	2.08	-	7.12	-	1.35	142.7	20.52



Experimental Procedures

■ Alloy Design

⊗ Thermodynamic Calculation

- Thermocalc, PanDat

⊗ Solidification Behavior

- JMatPro

⊗ Casting Simulation

- Anycasting

■ Mechanical Property Evaluation

⊗ Tensile Property

■ Thermal Property

⊗ Thermal diffusivity

Experimental Procedures

■ Materials (XRF Results)

[at.%(wt.%)]								
No.	Alloys	Si	Ni	Ca	Mg	Zn	Fe	Al
1	N30	-	2.47 (5.22)	-	-	-	0.04 (0.08)	97.49 (94.69)
2	NX405	-	3.98 (8.23)	0.84 (1.19)	-	-	0.04 (0.08)	95.14 (90.50)
3	NX410	-	4.15 (8.56)	1.20 (1.69)			0.05 (0.09)	94.90 (89.66)
4	NX430		3.93 (8.06)	2.96 (4.14)	-	-	0.04 (0.08)	93.07 (87.71)
5	NX410MZM	-	4.26 (8.86)	1.20 (1.70)	0.95 (0.82)	0.09 (0.22)	0.06 (0.12)	92.43 (88.28)
6	NX430MZM	-	4.15 (8.46)	3.32 (4.62)	0.82 (0.70)	0.09 (0.21)	0.05 (0.11)	91.57 (85.91)
7	SX4030	4.55 (4.66)	-	2.68 (3.92)	-	-	0.05 (0.10)	92.71 (91.29)

Experimental Procedures

■ Melting Condition

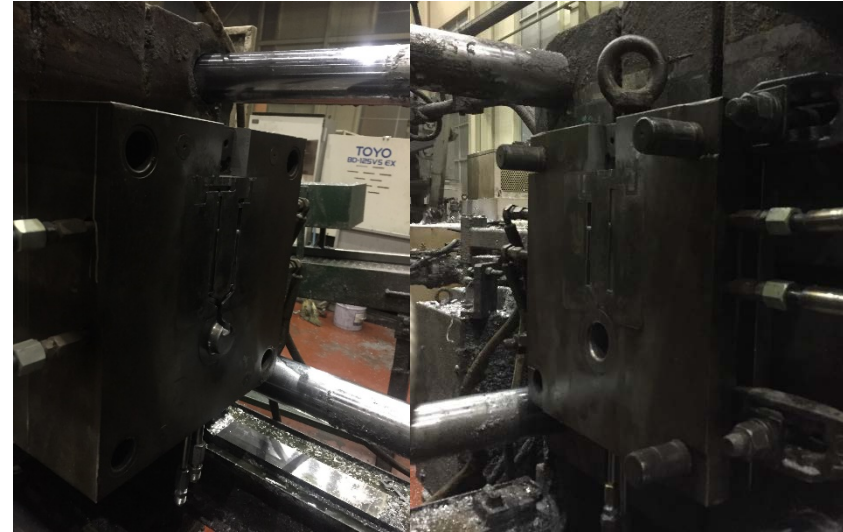


<Fig. Furnace with 30kg Crucible>

- ⊕ **Crucible Capacity: 30kg in Al**
- ⊕ **Weight of Molten Metal for 1 Batch: 18~20kg**
- ⊕ **Melting Temp.: 720°C(Al-Si Alloy), 750~765°C(Al-Ni Alloy)**

Experimental Procedures

■ Casting Condition

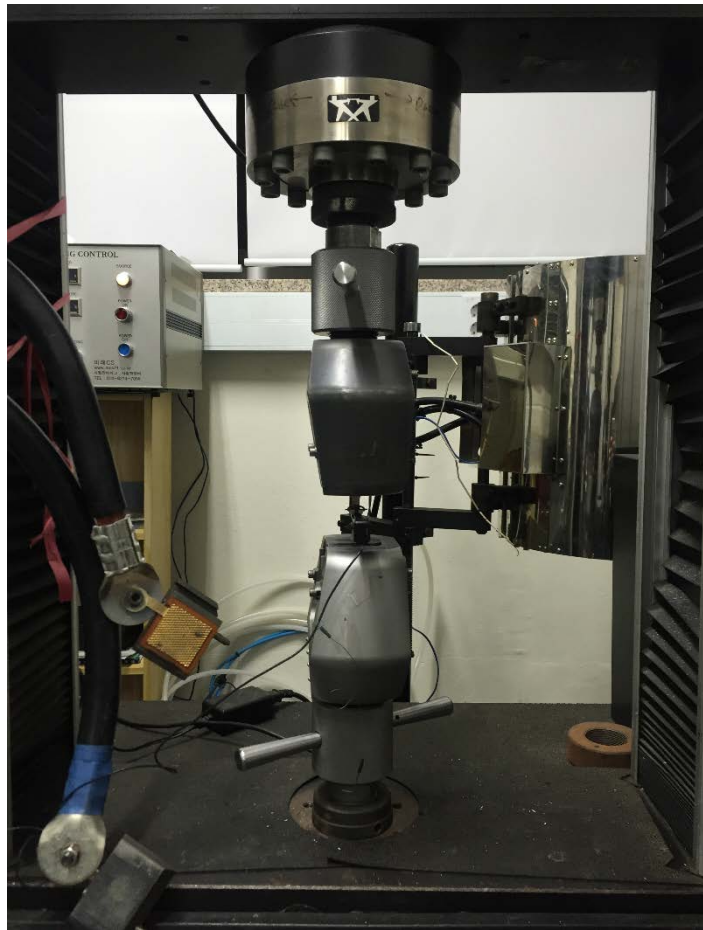


<Fig. High Pressure Die-Casting Machine-125 Ton (Left), Mold Cavity (Right)>

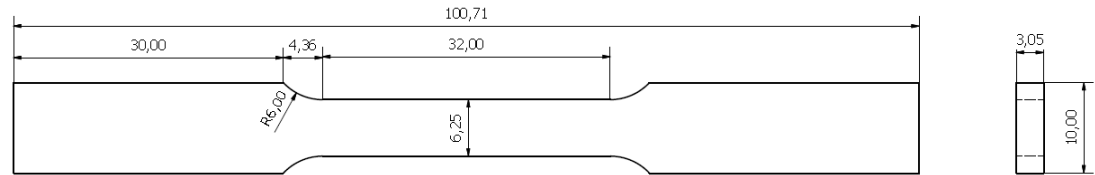
- ⊗ **Mold Preheating Temp.: 180°C**
- ⊗ **Plunger Speed: 0.1~0.3m/s (Low Speed Stage), 2.0m/s (High Speed Stage)**
- ⊗ **Plunger Diameter: 40mm**
- ⊗ **Thickness of Biscuit: 4~7mm**
- ⊗ **Injecting Melt for 1 Shot: About 60g**
- ⊗ **Number of Shots: 40 Shots for Each Alloy Composition**

Experimental Procedures

■ Tensile Test



<Universal Testing Machine
(Instron 5584)>

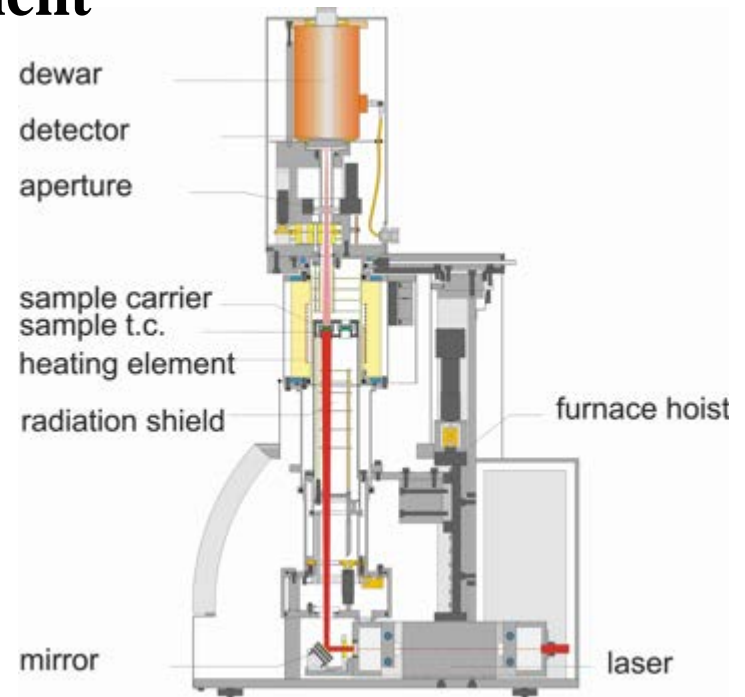
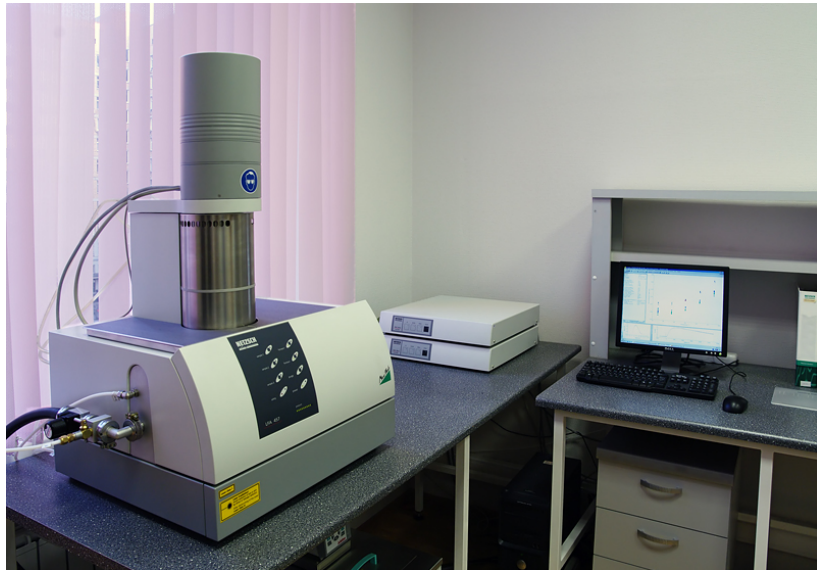


Test Condition

Test Condition	
Specimen	ASTM E-8 Subsize (Plate)
Strain Rate (/s)	2×10^{-4} /s
Gauge Length (mm)	25.0
Gauge Width (mm)	6.25
Gauge Thickness (mm)	3.05

Experimental Procedures

■ Thermal Conductivity Measurement



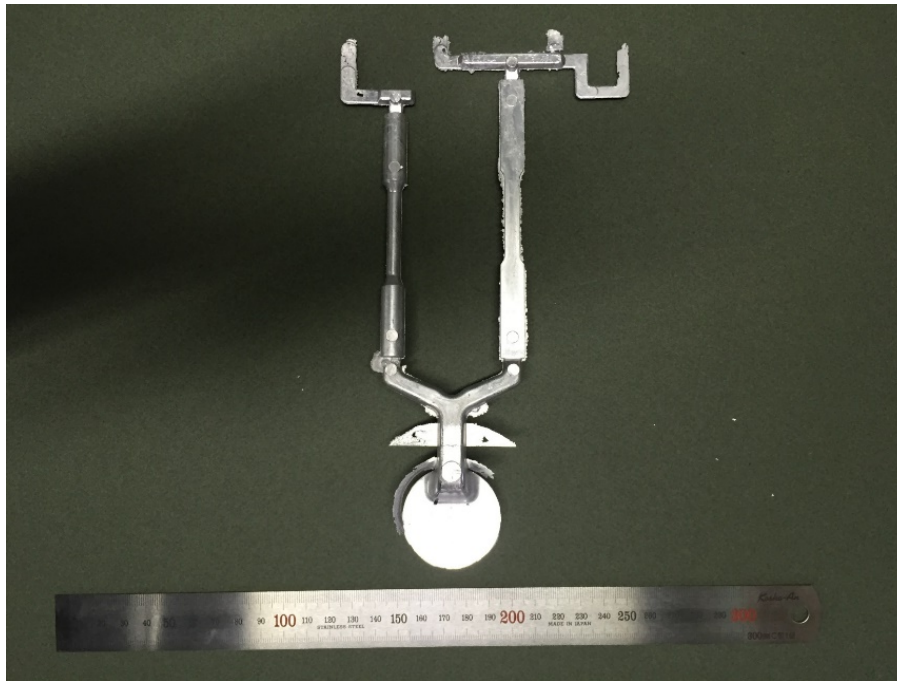
<Fig. Thermal Diffusivity Measuring Machine, LFA 457 (Left),
Schematic Diagram of Measuring Machine (Right)>

⊗ Temperature: 25°C

⊗ Number of Shots: 5 Shots for Each Sample

Results

■ Specimen

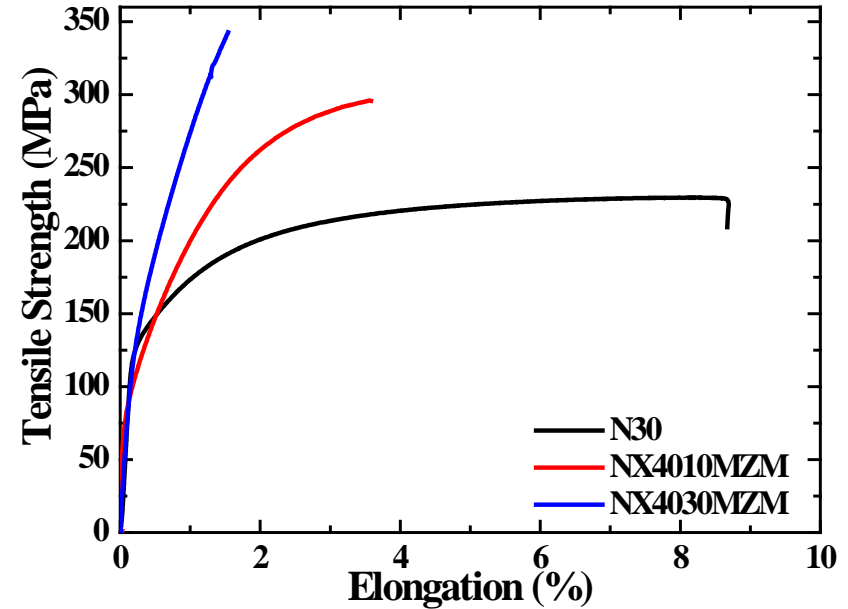
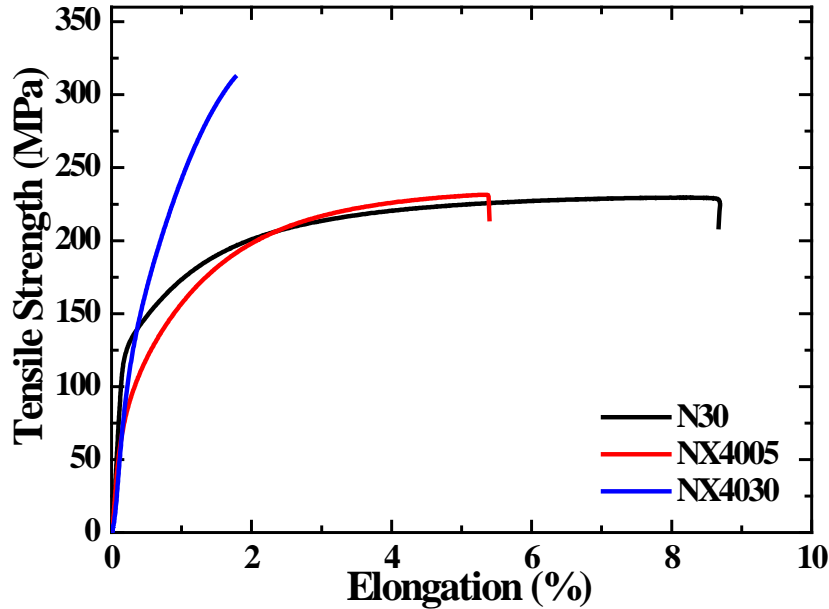


<Fig. As-cast Specimen>

Results

■ Tensile Property

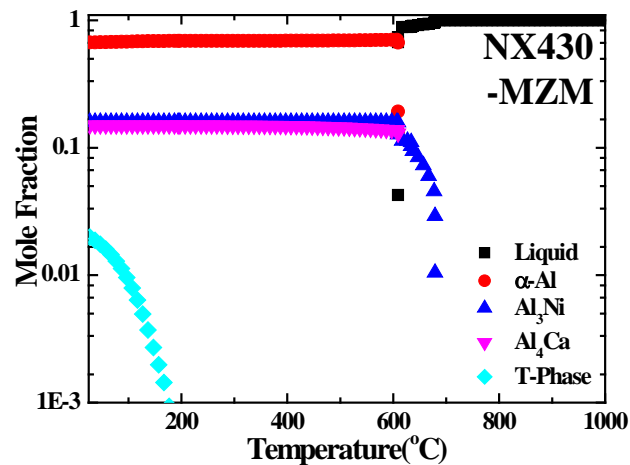
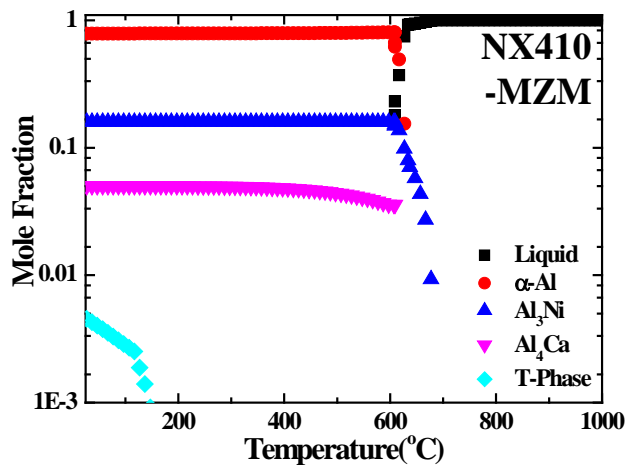
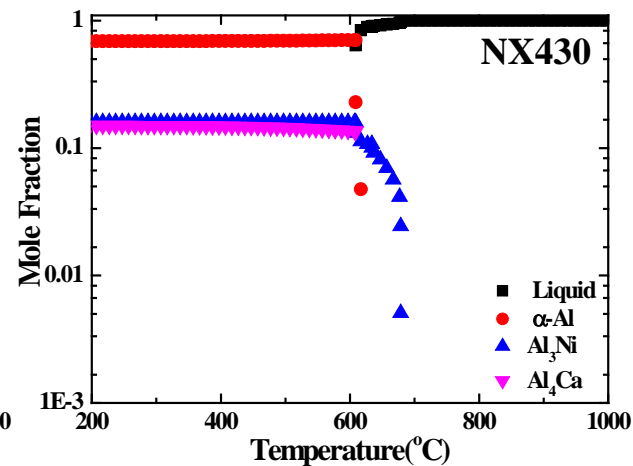
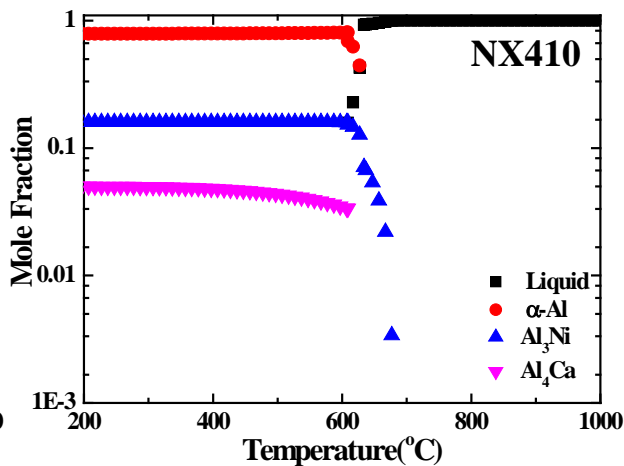
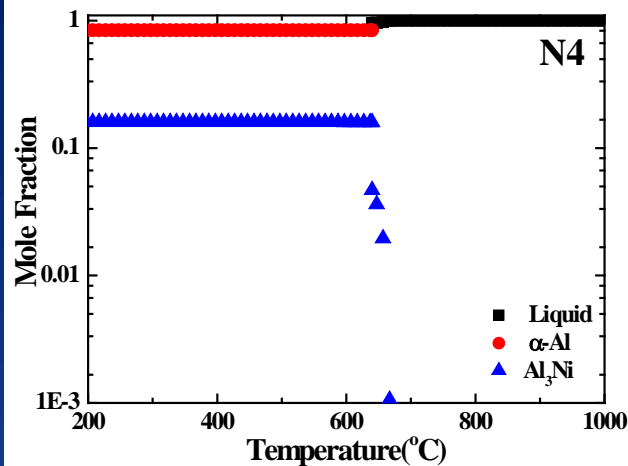
ADC 12 (Commercial Alloy): UTS=295MPa, $K^*=92\text{W/m}^2\text{K}$



	Y. S. (MPa)	U.T.S. (MPa)	El. (%)	Unif. El. (%)	S.H.E., n
N30	142.2	229.5	8.3	7.9	0.179
NX4005	146.5	233.8	4.7	4.6	0.284
NX4030	194.5	310.5	1.1	1.0	0.513
NX4010MZM	168.6	295.8	2.7	2.5	0.419
NX4030MZM	197.7	341.2	1.0	0.9	0.556

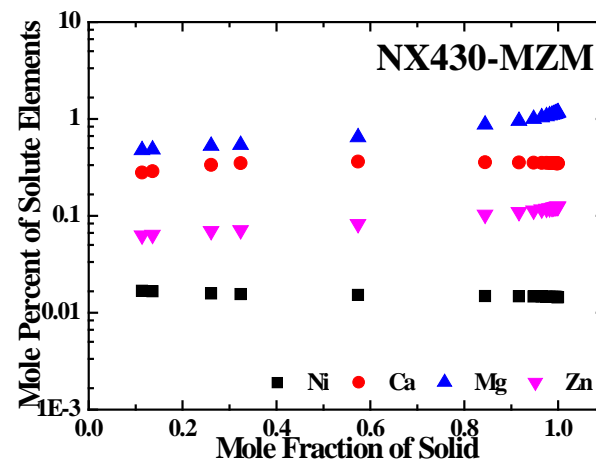
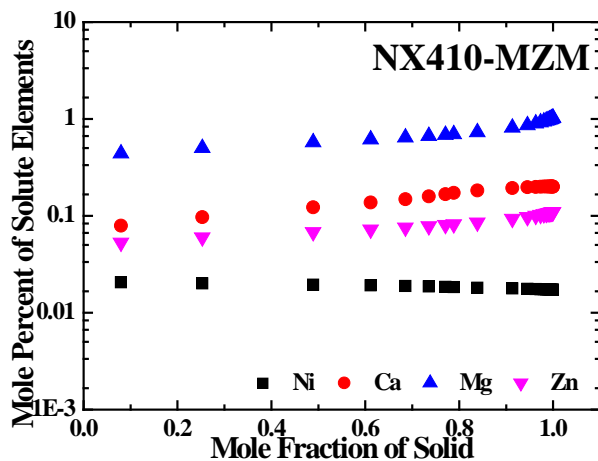
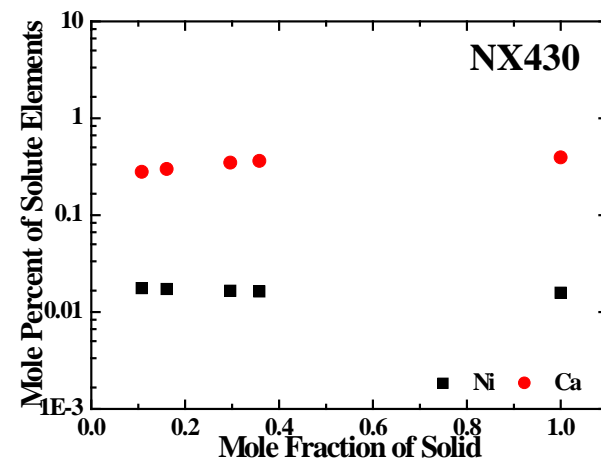
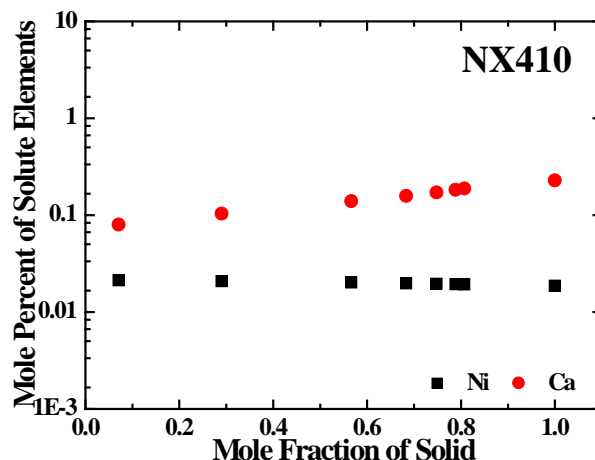
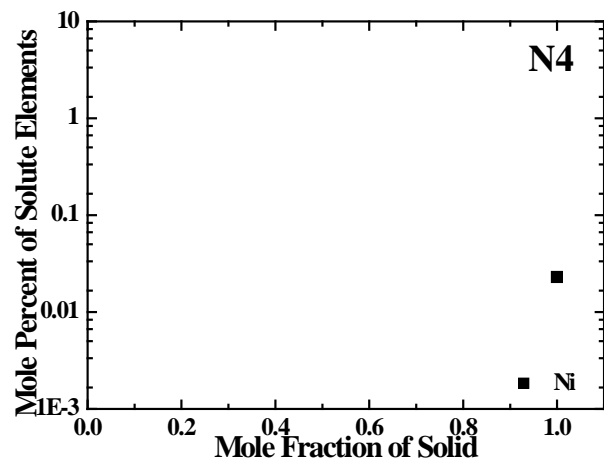
Results

■ Solidification Behavior



Results

■ Solute Elements in α -Al Phase During Solidification



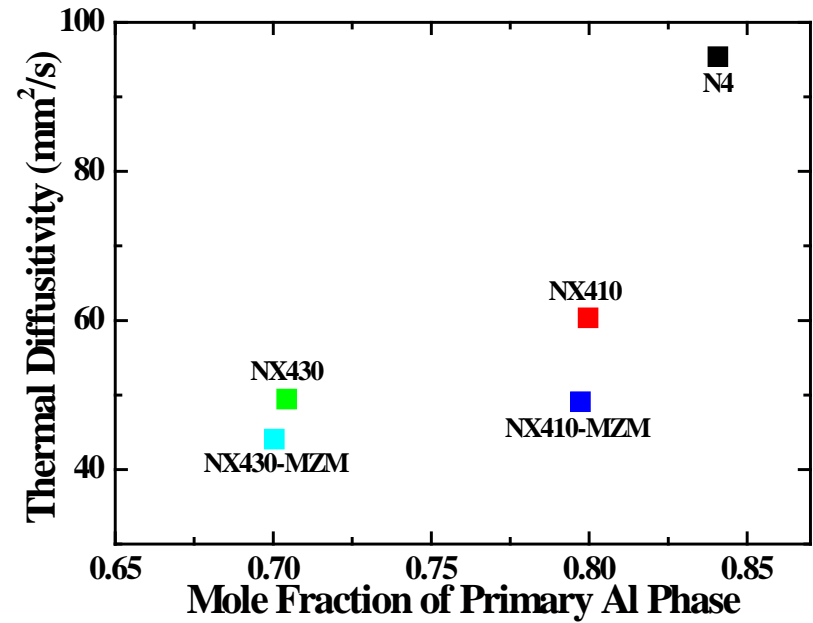
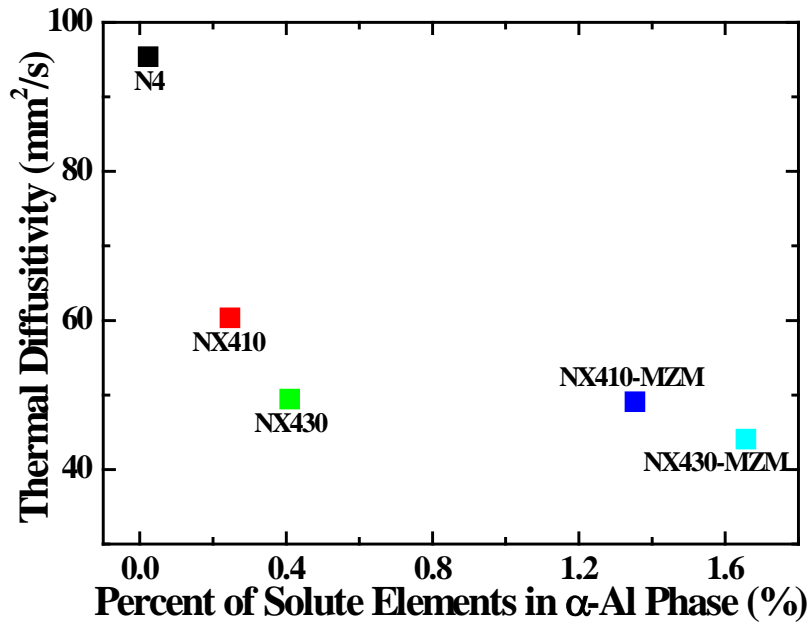
Results

■ Atomic Percent of Solute Elements in α -Al Phase

	N4	NX410	NX430	NX410- MZM	NX430- MZM
Ni	0.0229	0.0186	0.0158	0.0172	0.0145
Ca	-	0.2280	0.3940	0.2001	0.3478
Mg	-	-	-	1.0269	1.1695
Zn	-	-	-	0.1096	0.1253
Total	0.0229	0.2466	0.4098	1.3538	1.6571

Results

■ Thermal Property vs (Impurity in α -Al) and (α -Al Fraction)



	N4	NX410	NX430	NX410-MZM	NX430-MZM
α -Al	0.8408	0.7997	0.7043	0.7973	0.7004
Solute Elements in α -Al (at.%)	0.0229	0.2466	0.4098	1.3538	1.6571
Thermal Diffusivity (mm ² /s)	95.385	60.326	49.439	49.094	44.064

Conclusion

■ Alloy Design

⊕ Al-Ni-X alloys were designed based upon thermodynamic consideration.

■ Mechanical Property Evaluation

⊕ YS and UTS was improved by adding Ca, Mg, Zn, but elongation was decreased because IMC was formed in Ca-rich alloys.

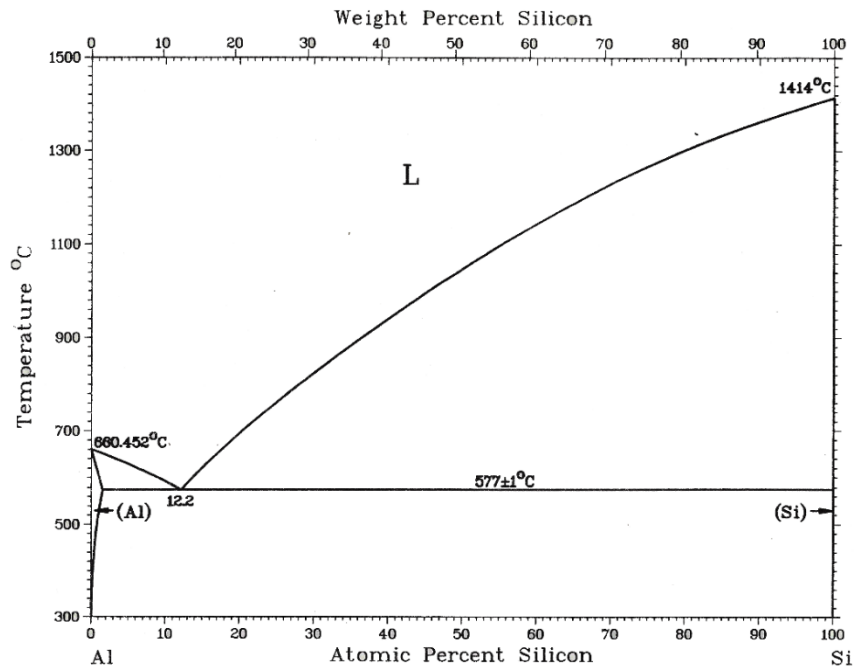
■ Thermal Conductivity

⊕ Actual thermal diffusivity value was well matched with the trend of the impurity in primary aluminum phase and the fraction of primary aluminum phase calculated by thermodynamic calculation.

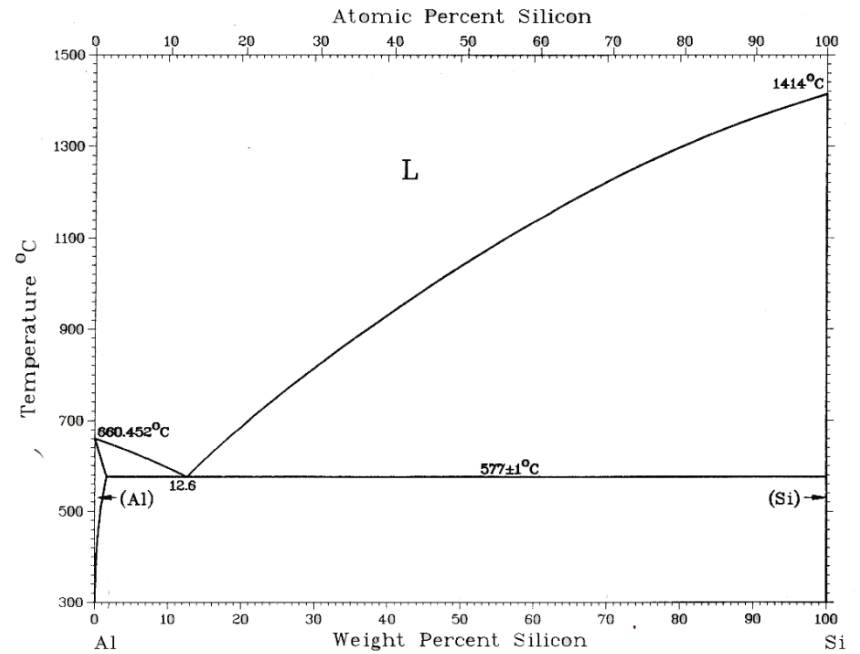
Appendix

Al-Si

■ Al – Ca, Cr, Cu, Fe, Li, Mg, Ni, Si, Sn, Sr, Zn



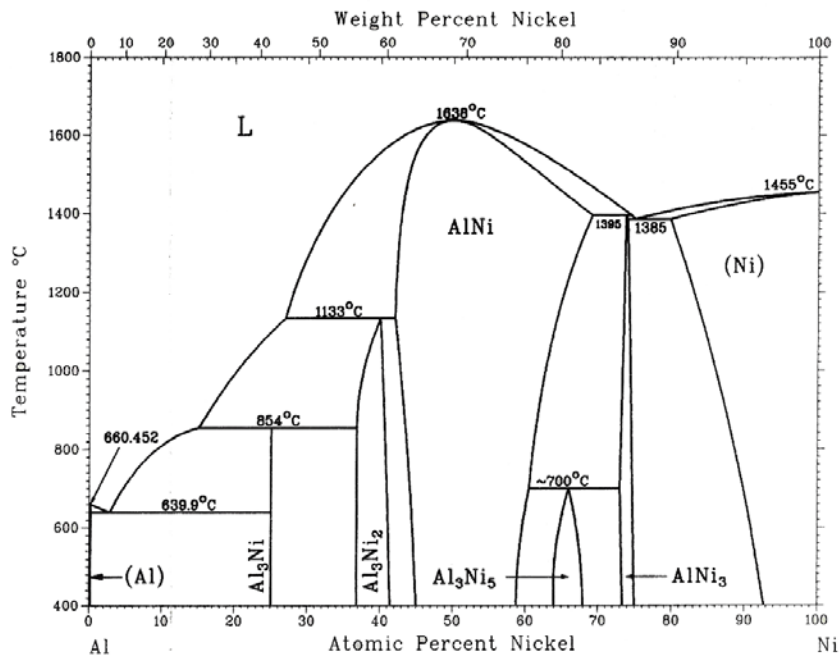
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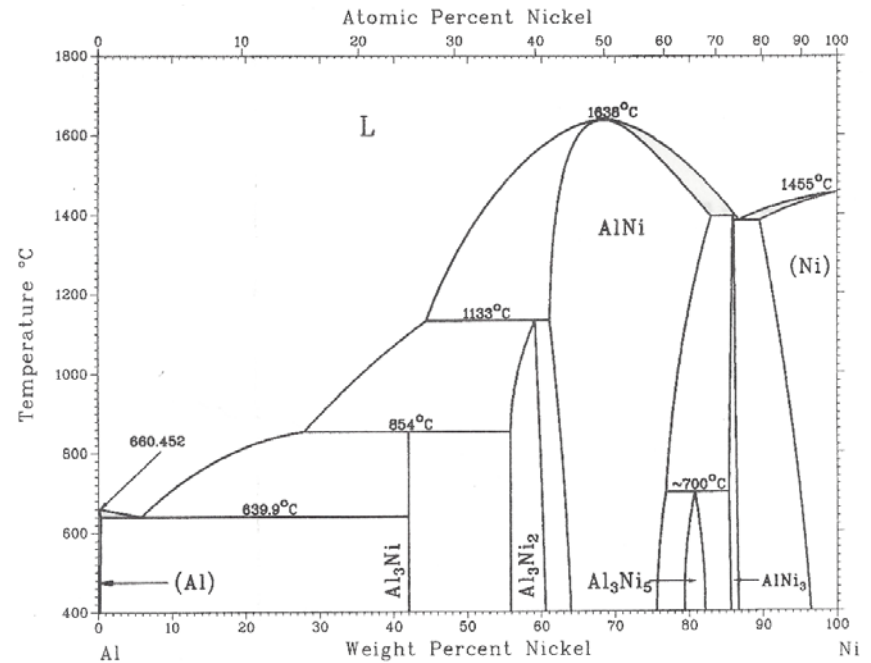
[wt.%]

Al-Ni

■ Al – Ca, Cr, Cu, Fe, Li, Mg, Ni, Si, Sn, Sr, Zn



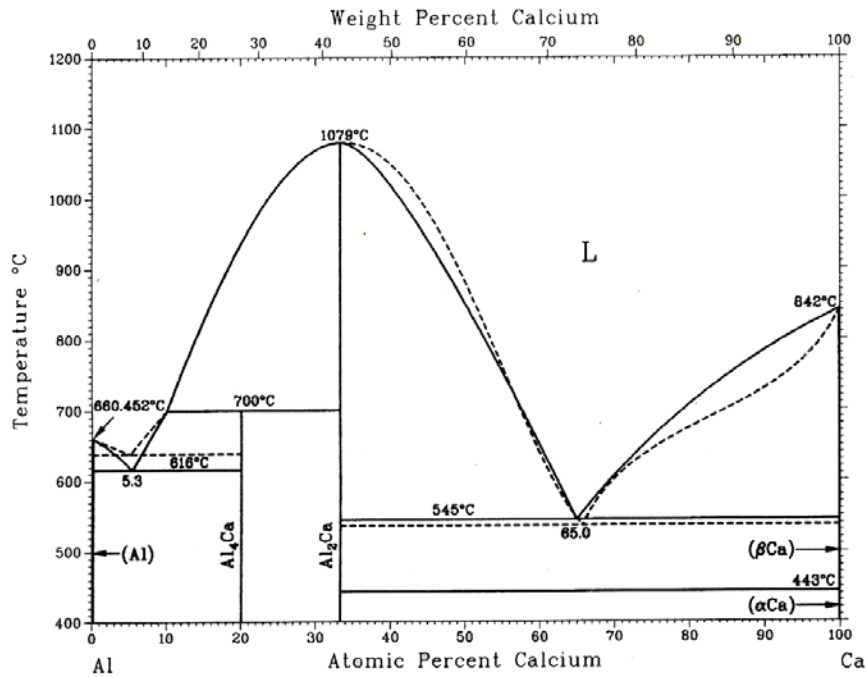
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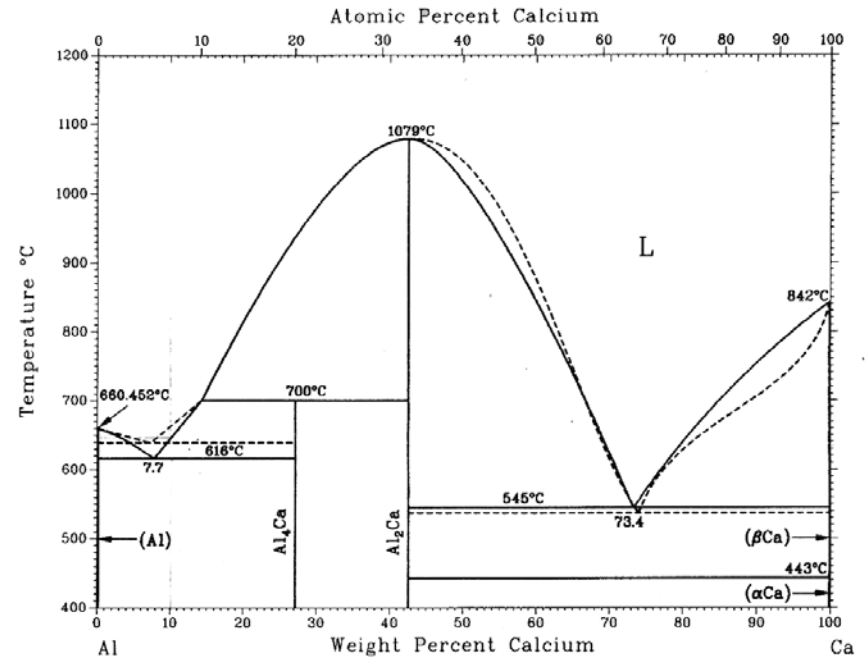
[wt.%]

Al-Ca

■ Al – Ca, Cr, Cu, Fe, Li, Mg, Ni, Si, Sn, Sr, Zn



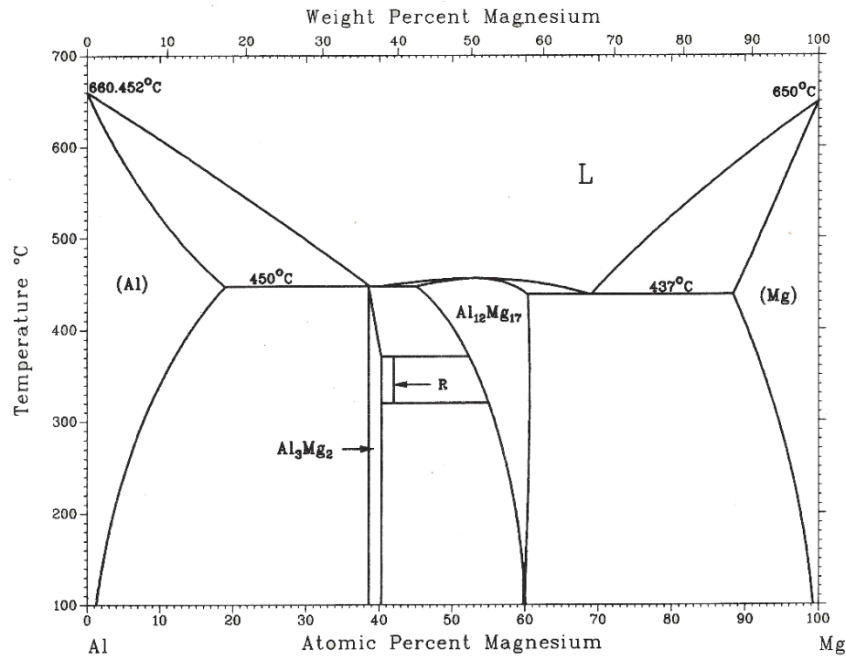
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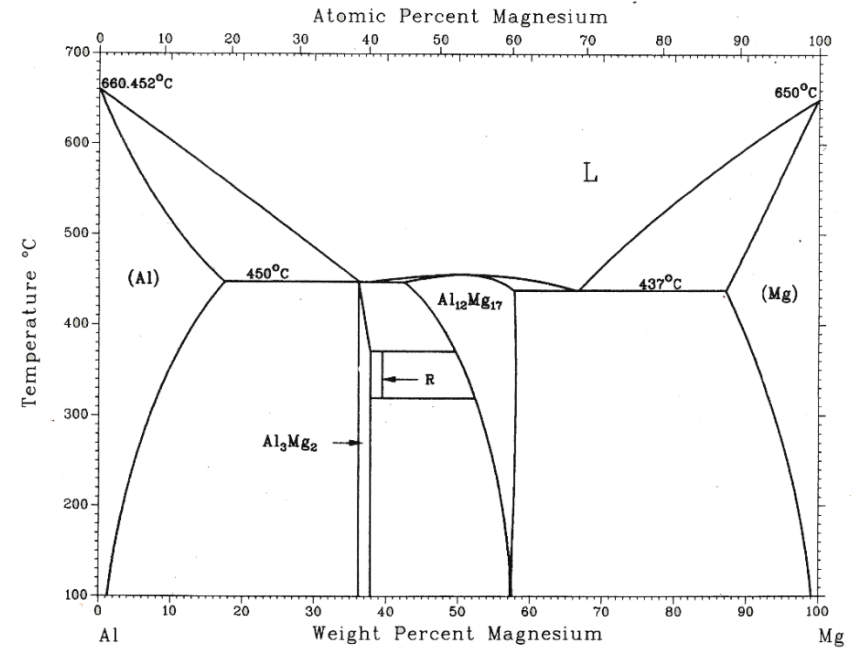
[wt.%]

Al-Mg

■ Al – Ca, Cr, Cu, Fe, Li, Mg, Ni, Si, Sn, Sr, Zn



[at.%]



[wt.%]