01: Introduction to aluminum alloy

Internal Training เทคโนโลยีและปัจจัยที่ส่งผลต่อคุณภาพของอะลูมิเนียมผสมที่ผลิตจากกระบวนการ High Pressure Die Casting

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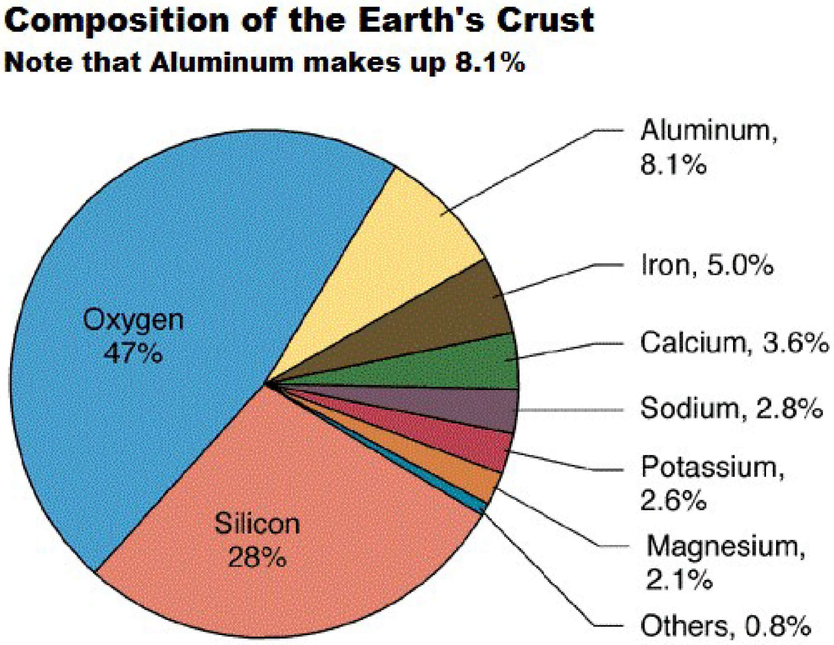
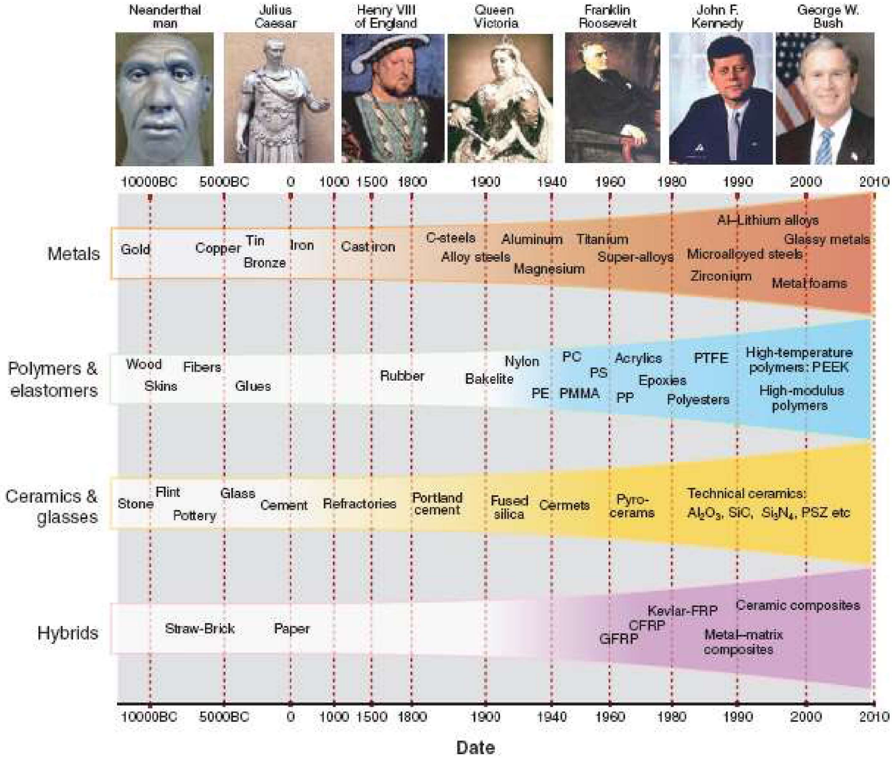




- **1807 -** The English chemist Sir Humphrey Davy underlined the existence of the element arguing that "alum" was the salt of an unknown metal which he said should be called ‘alumium’. The name was respelt as the more pleasant sounding ‘aluminium’ by later scientists. Davy tried unsuccessfully to produce aluminium by electrolysing a fused mixture of aluminium oxide and potash.

STAGE 1

BAUXITE MINING

The primary source of aluminum is a rock called bauxite.

STAGE 2

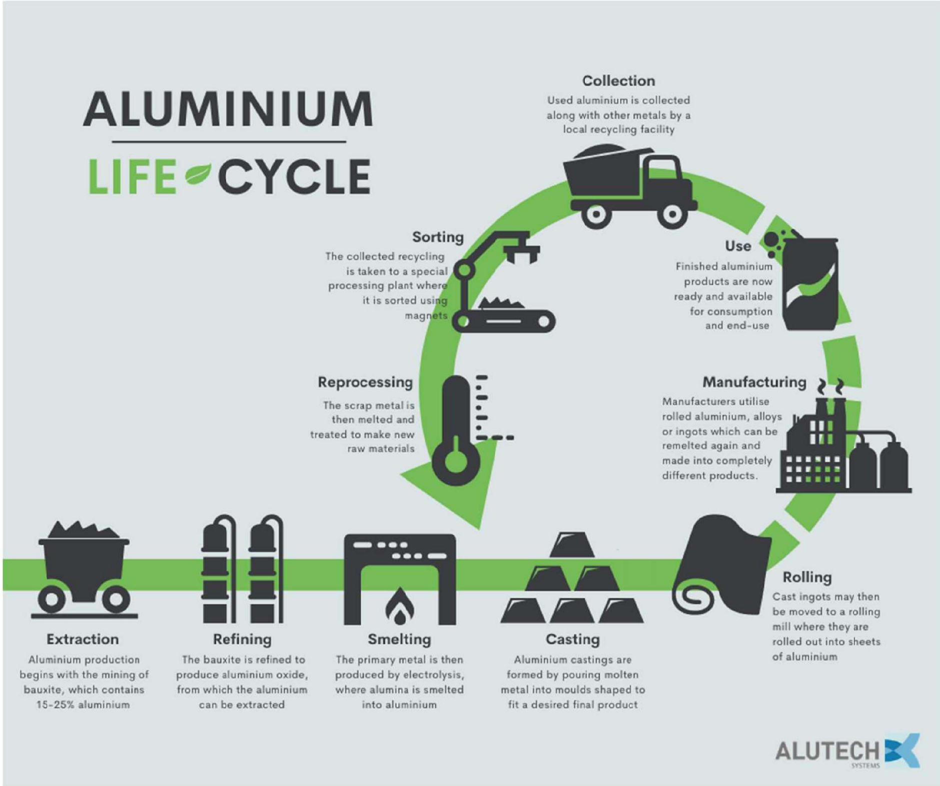
ALUMINA PRODUCTION

Bauxite is then processed into alumina.

STAGE 3

ALUMINUM PRODUCTION

Then through the process of electrolysis, alumina is turned into aluminum.



Recycling 1 ton of aluminum saves 6 tons of bauxite and 9 tons of CO_2 emissions. Globally, the recycling of aluminum saves more than 100 million tons of CO_2 every year.

Basic property comparisons (approximate values or ranges)

Lower density than most high volume metals

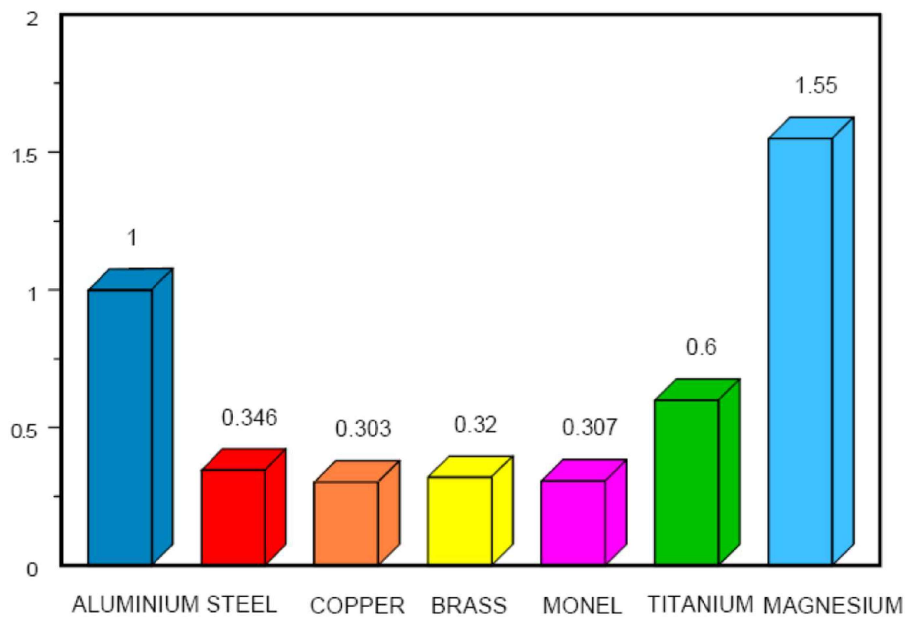
Lower modulus than most high volume metals and C-fibre composites

	Aluminum	Titanium	Steel	Mg	Aero composite (epoxy-C-fibre)	Auto composite (epoxy-glass fibre)	Unit
Density	**2.7**	4.5	7.9	1.7	1.7	1.8	g/cm^3
Elastic modulus	**70**	115	210	45	100 – 400	50 – 100	GPa
Approximate maximum use T°	250	600	600	200	200	200	°C
Electrical resistivity	**28**	420	96	44	10000	Huge	nΩ·m
Tensile yield strength	100 – 700	400 – 1200	200 – 2000	200 – 400	1000 – 2000	500 – 1000	MPa
Corrosion resistance	**Excellent**	Excellent	Poor, except stainless	Poor	Immune, but sensitive to humidity	Immune, but sensitive to humidity	

Low electrical resistivity

Good corrosion resistance vs. most metals

Volume per unit weight



Aluminum wrought alloy

	AA	Major Alloying Element	Atoms in Solution	Work Hardening	Precipitation Hardening	
Wrought Alloys	1xxx	None		X		Non-Heat Treatable Alloys
	3xxx	Mn				
	4xxx	Si	X	X		
	5xxx	Mg				
	6xxx	Mg + Si				Heat Treatable Alloys
	2xxx	Cu	X	(X)	X	
	7xxx	Zn				
	8xxx	Other				
Casting Alloys	1xx.x	Min. 99% Al				Non-Heat Treatable Alloys
	4xx.x	Si				
	5xx.x	Mg	X			
	3xx.x	Si + Mg (Cu)				Heat Treatable Alloys
	2xx.x	Cu				
	7xx.x	Zn	X		X	
	8xx.x	Sn				
	9xx.x	Unused				

Source: Aluminium Association, Washington, D.C.

A selection of common temper designations for aluminum alloys

XXXX	-F	as-fabricated	
	-O	annealed	

XXXX	-H1	Work-hardened only		NON-HEAT TREATABLE ALLOYS
	-H2	Work-hardened and partially annealed		
	-H3	Work-hardened and stabilized by low temperature treatment		
	-HX2	Quarter-hard	Degree of cold working	
	-HX4	Half-hard		
	-HX6	Three-quarter-hard		
	-HX8	Fully-hard		

XXXX	-T2	Cooled from an elevated temperature and naturally aged	HEAT TREATABLE ALLOYS
	-T4	Solution heat-treated and naturally aged	
	-T5	Cooled from an elevated temperature shaping process and artifically aged	
	-T6	Solution heat treated and artifically aged	
	-T8	Solution heat-treated, cold worked and aged	

2xxx (Al-Cu, Al-Cu-Mg)

Copper serves as the principle alloying element, gaining additional strength

High strength and toughness, but due to low levels of atmospheric corrosion resistance are generally clad with a high-purity alloy or 6xxx series alloy. It is commonly used on structures and components in the aircraft and transportation industries.

				Composition						
	ISO	JIS	DIN	Al	Cu	Cr	Zn	Mn	Mg	Si
2024	AlCuMg1	A2024	3.1355	Base	3.80-4.90	0.10 Max	0.25 Max	0.30-0.90	1.20-1.80	0.15 Max

3xxx (Al-Mn, Al-Mn-Mg)

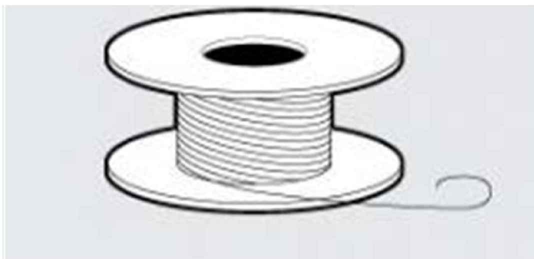
The series serves as general purpose alloys because it has moderate strength and good workability.

				Composition							
	ISO	JIS	DIN	Al	Cu	Cr	Zn	Mn	Mg	Si	Fe
3003	AlMn1Cu	A3003	3.0517	Base	0.05-0.20	-	0.10	1.00-1.50	-	0.60	0.70 Max
3004	AlMn1Mg1	A3004	3.0526	Base	0.25	-	0.25	1.00-1.50	0.80-1.30	0.30	0.70 Max

4xxx (Al-Si)

Silicon can be added to lower the melting point of these alloys without affecting brittleness

Excellent welding wire brazing alloys where a lower melting point is required. Widely applied as filler alloys, used in structural and automotive applications.

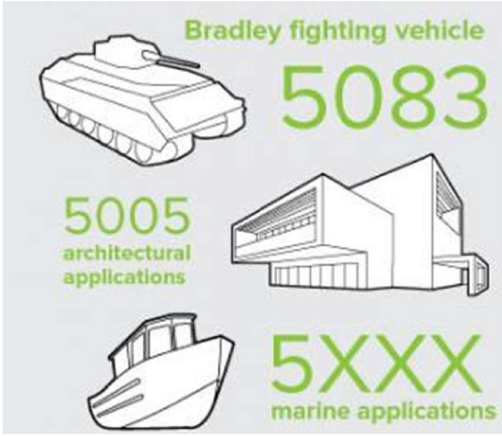


				Composition						
	ISO	JIS		Al	Si	Fe	Cu	Ni	Mg	Zn
4032	AlSi12MgCuNi	A4032		Base	11-13.5	1.00 Max	0.50-1.30	0.05-1.30	0.80-1.30	0.25 Max

5xxx (Al-Mg)

One of the most effective and widely-used alloying elements, magnesium adds a wealth of benefits in manufacturing

Moderate to high strength, good weldability, and resistance to corrosion in the marine environment. Because of this, Al-Mg alloys are widely used in building and construction, storage tanks, pressure vessels and marine applications.



				Composition							
	ISO	JIS	DIN	Al	Cu	Cr	Zn	Mn	Mg	Si	Fe
5083	AlMg4.5Mn	A5083	3.3547	Base	0.10 Max	0.05-0.25	0.25 Max	0.40-1.00	4.00-4.90	0.4 Max	0.40 max
5052	AlMg2.5	A5052	3.3523	Base	0.10 Max	0.15-0.35	0.10 Max	0.10 Max	2.20-2.80	0.25 Max	

6xxx (Al-Si-Mg)

Silicon and magnesium combine to feature excellent corrosion resistance

Veratile, heat treatable, highly formable, weldable and moderately high strength coupled with excellent corrosion resistance. Extrusion products from the 6xxx series are the first choice for architectural and structure applications.

				Composition							
	ISO	JIS	DIN	Al	Cu	Cr	Zn	Mn	Mg	Si	Fe
6061	AlMg1SiCu	A6061	3.3211	Base	0.15-0.40	0.04-0.35	0.25 Max	0.15 Max	0.80-1.20	0.40-0.80	0.70 Max

7xxx (Al-Zn)

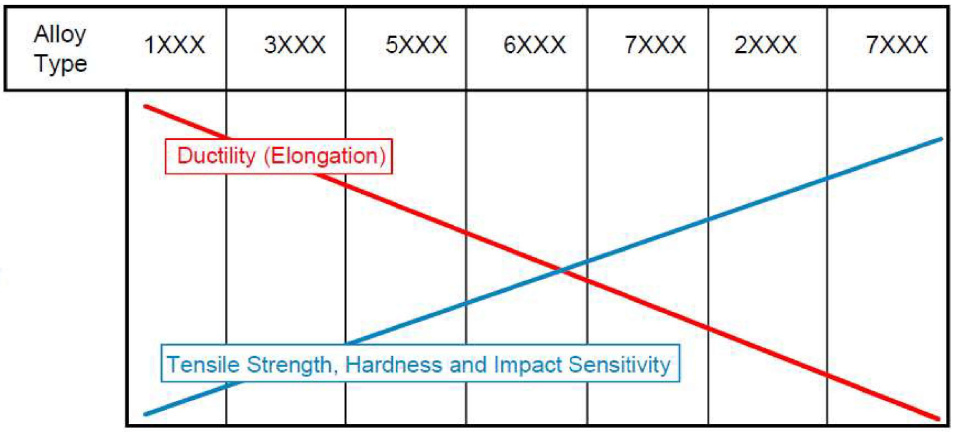
Zinc is the primary alloying agent, as well as small quantities of Mg, Cu or Cr to increase strength

Featuring extremely high strength and heat-treatable, the 7xxx series are utilized throughout the aircraft industry

				Composition							
	ISO	JIS	DIN	Al	Cu	Cr	Zn	Mn	Mg	Si	Fe
7022	AlZnMgCu0.5	A7022	3.4345	Base	0.50-1.00	0.10-0.30	4.30-5.20	0.10-0.40	2.60-3.70	0.50 Max	-
7075	AlZn6MgCu	A7075	3.4365	Base	1.20-2.00	0.18-0.28	5.10-6.10	0.30 Max	2.10-2.90	0.40 Max	0.50 Max

The effect of alloying elements on tensile strength, hardness, impact sensitivity and ductility

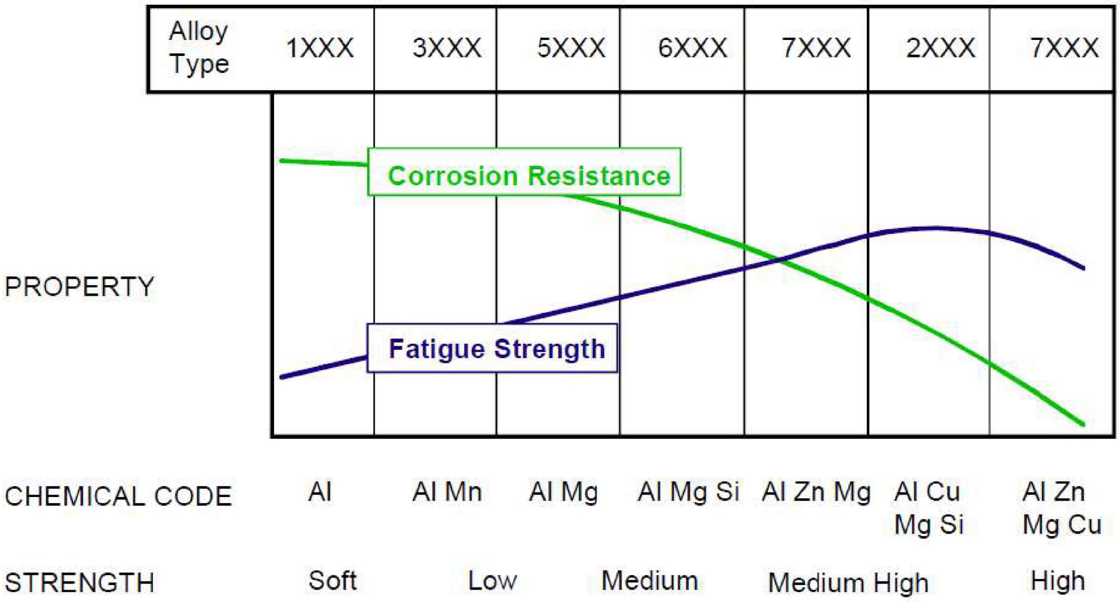
PROPERTY



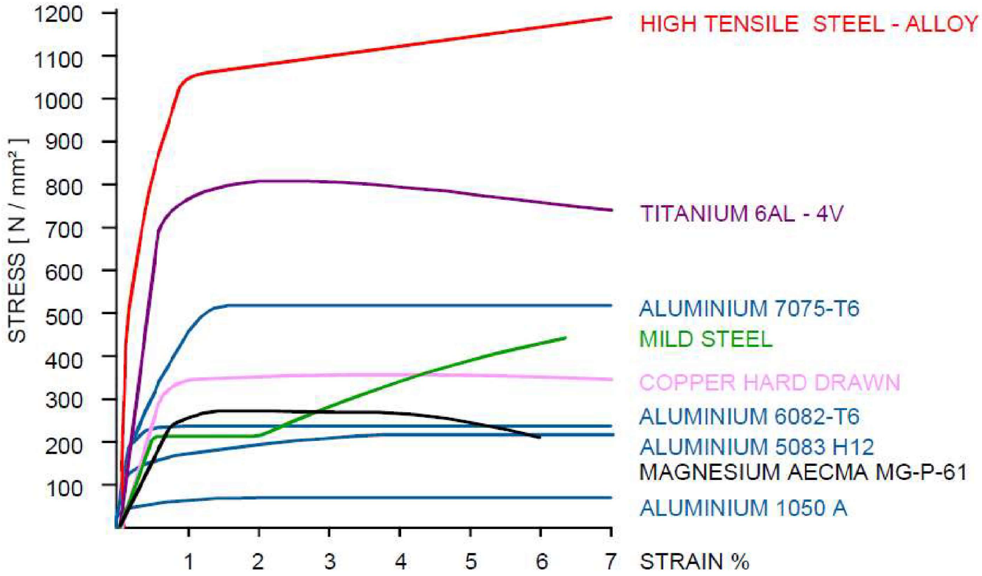
CHEMICAL CODE	Al	Al Mn	Al Mg	Al Mg Si	Al Zn Mg	Al Cu Mg Si	Al Zn Mg Cu
STRENGTH	Soft	Low		Medium	Medium High		High

The effect of alloying elements on weldability and anodizing

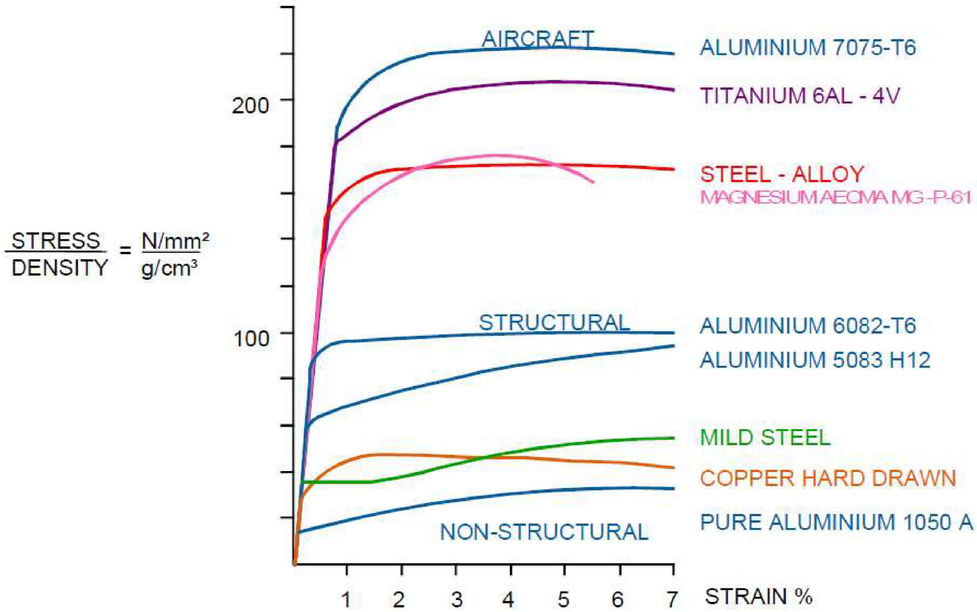
The effects of alloying elements on corrosion resistance and fatigue strength



Stress-strain curves of aluminum in comparison with various metals and alloys



Density-related strength of aluminum in comparison with various metals and alloys



Aluminum casting alloy

	AA	Major Alloying Element	Atoms in Solution	Work Hardening	Precipitation Hardening	
Wrought Alloys	1xxx	None		X		Non-Heat Treatable Alloys
	3xxx	Mn				
	4xxx	Si	X	X		
	5xxx	Mg				
	6xxx	Mg + Si				Heat Treatable Alloys
	2xxx	Cu	X	(X)	X	
	7xxx	Zn				
	8xxx	Other				
Casting Alloys	1xx.x	Min. 99% Al				Non-Heat Treatable Alloys
	4xx.x	Si				
	5xx.x	Mg	X			
	3xx.x	Si + Mg (Cu)				Heat Treatable Alloys
	2xx.x	Cu				
	7xx.x	Zn	X		X	
	8xx.x	Sn				
	9xx.x	Unused				

Source: Aluminium Association, Washington, D.C.

1 Die Casting Alloy Cross Reference Designations

Aluminum Alloy Specifications

Comm'l	UNS	ANSI AA	Former ASTM B85	SAE J452	Federal QQ-A-591Ⓑ	DINⒼ 1725	JIS H5302
360	A03600	360.0	SG100B	—	Ⓑ		
A360Ⓐ	A13600	A360.0	SG100A	309	Ⓑ	233	ADC3
380	A03800	380.0	SC84B	308	Ⓑ		
A380Ⓐ	A13800	A380.0	SC84A	306	Ⓑ	226AⒺ	ADC10 ⒸⒹ
383	A03830	383.0	SC102	383	Ⓑ	226AⒺ	ADC12 ⒸⒹ
384	A03840	384.0	SC114A	303	Ⓑ		ADC12 ⒸⒹ
A384Ⓐ	—	A384.0	—	—	Ⓑ		ADC12 ⒸⒹ
390	A23900	B390.0	SC174B	—	Ⓑ		
13	A04130	413.0	S12B	—	Ⓑ		
A13Ⓐ	A14130	A413.0	S12A	305	Ⓑ	231DⒻ	ADC1Ⓒ
43	A34430	C443.0	S5C	304	Ⓑ		
218	A05180	518.0	G8A	—	Ⓑ	341	

Ⓐ Similar to preceding entry with slight variations in minor constituents. Ⓑ The Federal specification for aluminum alloy die castings uses the Aluminum Association designations for individual alloys. Military designations superseded by Federal specifications. Ⓒ Japanese specifications allow 0.3 magnesium maximum. Ⓓ Japanese specifications allow 1.0 zinc maximum. Ⓔ DIN 1725 spec allows 1.2 max zinc and up to 0.5 max magnesium. Ⓕ DIN 1725 spec allows 0.3 max magnesium. Ⓖ Alloy compositions shown in DIN 1725 tend to be "primary based" and have low impurity limits making it difficult to correlate directly to U.S. alloys.

***Note:** Some of these standards are obsolete but included here for historical purposes. For closest cross-reference refer to the tables of foreign alloy designations and chemical constituencies at the end of this section.*

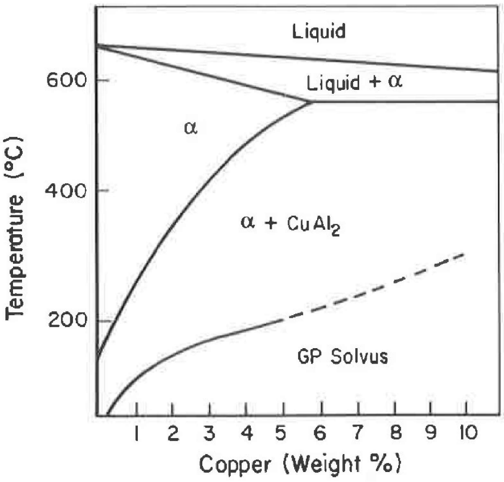
Comparison of Aluminium Alloy Name for Castings of Each Country							
Japan	U.S.A		U.K	Germany	France	ISO	EN
JIS	AA	ASTM	BS	DIN	NF		
H-5202-99			1490-88	DIN EN - ALCu4MgTi	NF EN 1706		
AC1B	204	204			A-U5GT	AL-Cu4MgTi	EN AC-21000
AC2A						AL-Si5Cu3	
AC2B	319	319	LM-4	EN AC-ALSi2(a)		AL-Si6Cu4	
AC3A	B413.0		LM-6	EN AC-ALSi10Mg(a)	A-S13	AL-Si12	EN AC-44200
AC4A	359			EN AC-ALSi8Cu3	A-S9G	AL-Si10Mg	EN AC-43000
AC4B	333	333					EN AC-46200
AC4C	356	356	LM-25	EN AC-ALSi7MG0.3	A-57G	AL-SiMg(Fe)	
AC4CH	A356.0	A356.0				AL-Si7Mg	EN AC-42100
AC4D	355	355	LM-16			AL-Si5Cu1Mg	
AC5A	242	242		EN AC-ALMg5	A-U4NT	AL-Cu4Ni2Mg2	
AC7A	514	514	LM-5	EN AC-ALSi12CuNiMg			EN AC-51300
AC8A	336	336	LM-13		A-S12UNG		
AC8B			LM-26		A-S10UG		EN AC-48000
AC8C	332	332					
AC9A			LM-29				
AC9B			LM-28		A-S18UNG		
SOURCES: Light Metal Association Aluminium Handbook 5th Edition							

Note: This Technical Data is taken from various Technical Books & is only as an advise to users. Users are requested to take proper guidance before basing any technical calculation on the above technical data. Mtlexs.com, or its Promoter, Directors, employees will in no way be responsible for any losses, damage etc. in any manner whatsoever.

Al-Cu alloy: 2xx

- The major characteristics of the 2xx.x series are:
  - Heat treatable sand and permanent mold castings
  - High strength at room and elevated temperatures; some high-toughness alloys
  - Approximate ultimate tensile strength range: 130 to 450 MPa
- The strongest of the common casting alloys is heat treated 201.0, which has found important application in the aerospace industry.
- The castability of the alloy is somewhat limited by a tendency to microporosity and hot tearing so that it is best suited to investment casting.
- Its high toughness makes it particularly suitable for highly stressed components in machine tool construction, in electrical engineering (pressurized switchgear castings), and in aircraft construction.

Al-Cu alloy: 2xx



		Composition, wt%												
												Others		
Alloy	Type(a)	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Sn	Each(b)	Total(b)	Al
100.1	Nominal	...	0.7	...	...	...	...	...	...	...	...	...	...	...
	Limits	0.15	0.6–0.8	0.10	(c)	...	(c)	...	0.05	(c)	...	0.03	0.10	bal
150.1	Nominal	...	...	...	...	...	...	...	...	...	...	...	...	...
	Limits	(d)	(d)	0.05	(c)	...	(c)	...	0.05	(c)	...	0.03	0.10	bal
170.1	Nominal	...	...	...	...	...	...	...	...	...	...	...	...	...
	Limits	(e)	(e)	...	(c)	...	(c)	...	0.05	(c)	...	0.03	0.10	bal
201.0(f)	Nominal	...	...	...	...	...	...	...	...	...	...	...	...	...
	Limits	0.10	0.15	4.0–5.2	0.20–0.50	0.15–0.55	...	...	...	0.15–0.35	...	0.05	0.10	bal
203.0	Nominal	...	...	5.0	0.25	...	...	1.5	...	0.20	...	...	...	...
	Limits(g)	0.30	0.50	4.5–5.5	0.20–0.30	0.10	...	1.3–1.7	0.10	0.15–0.25	...	0.05	0.20	bal
204.0	Nominal	...	...	...	...	0.25	...	...	...	0.22	...	...	...	...
	Limits	0.20	0.35	4.2–5.0	0.10	0.15	...	0.05	0.10	0.15–0.30	0.05	0.05	0.15	bal
A206.0	Nominal	...	...	4.6	0.35	0.25	...	...	...	0.22	...	...	...	...
	Limits	0.05	0.10	4.2–5.0	0.20–0.50	0.15–0.35	...	0.05	0.10	0.15–0.30	0.05	0.05	0.15	bal
208.0(h)	Nominal	3.0	...	4.0	...	...	...	...	...	...	...	...	...	...
	Limits	2.5–3.5	1.2	3.5–4.5	0.50	0.10	...	0.35	1.0	0.25	...	...	0.50	bal
222.0(h)	Nominal	...	...	10.0	...	0.25	...	...	...	...	...	...	...	...
	Limits	2.0	1.5	9.2–10.7	0.50	0.15–0.35	...	0.50	0.8	0.25	...	...	0.35	bal
224.0(h)	Nominal	...	...	5.0	0.35	...	...	...	...	...	...	...	...	...
	Limits(i)	0.06	0.10	4.5–5.5	0.20–0.50	...	...	...	...	0.35	...	0.03	0.10	bal
240.0	Nominal	...	...	8.0	0.5	6.0	...	0.5	...	...	...	...	...	...
	Limits	0.50	0.50	7.0–9.0	0.30–0.7	5.5–6.5	...	0.30–0.7	0.10	0.20	...	0.05	0.15	bal
242.0	Nominal	...	...	4.0	...	1.5	...	2.0	...	...	...	...	...	...
	Limits	0.7	1.0	3.5–4.5	0.35	1.2–1.8	0.25	1.7–2.3	0.35	0.25	...	0.05	0.15	bal
A242.0	Nominal	...	...	4.1	...	1.4	0.20	2.0	...	0.14	...	...	...	...
	Limits	0.6	0.8	3.7–4.5	0.10	1.2–1.7	0.15–0.25	1.8–2.3	0.10	0.07–0.20	...	0.05	0.15	bal
249.0(h)	Nominal	...	...	4.2	0.38	0.38	...	...	3.0	0.18	...	...	...	...
	Limits	0.05	0.10	3.8–4.6	0.25–0.50	0.25–0.50	...	...	2.5–3.5	0.02–0.35	...	0.03	0.10	bal

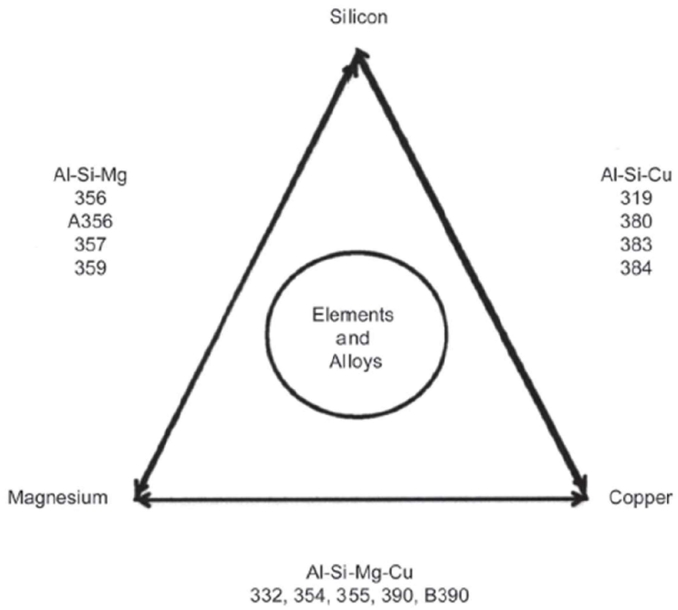
Al-Si- (Cu or Mg) alloys: 3xx

- The major characteristics of the 3xx.x series are:
  - Heat treatable sand, permanent mold, and die castings
  - Excellent fluidity, high-strength, and some high-toughness alloys
  - Approximate ultimate tensile strength range: 130 to 275 MPa
  - Readily welded
- The 3xx.x series of castings is one of the most widely used because of the flexibility provided by the high silicon content and its contribution to fluidity, plus their response to heat treatment, which provides a variety of high-strength options.

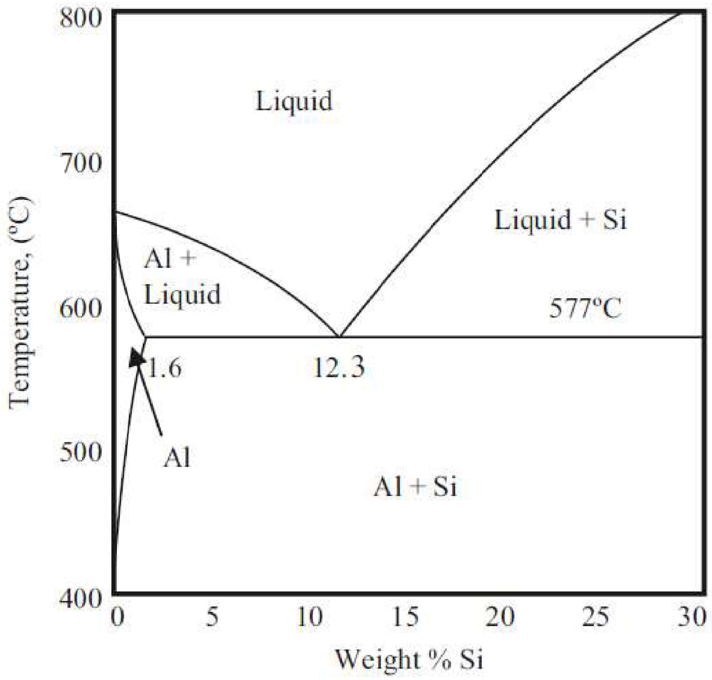
Al-Si- (Cu or Mg) alloys: 3xx

- In addition, the 3xx.x series may be cast by a variety of techniques ranging from relatively simple sand or die casting to very intricate permanent mold, investment castings, and the newer thixocasting and squeeze casting technologies.
- Primary Use. Among the workhorse alloys are 319.0 and 356.0/A356.0 for sand and permanent mold casting; 360.0, 380.0/A380.0, and 390.0 for die casting; and 357.0/A357.0 for many types of casting, including, especially, the relatively newly commercialized squeeze/forge cast technologies.

Al-Si- (Cu or Mg) alloys: 3xx



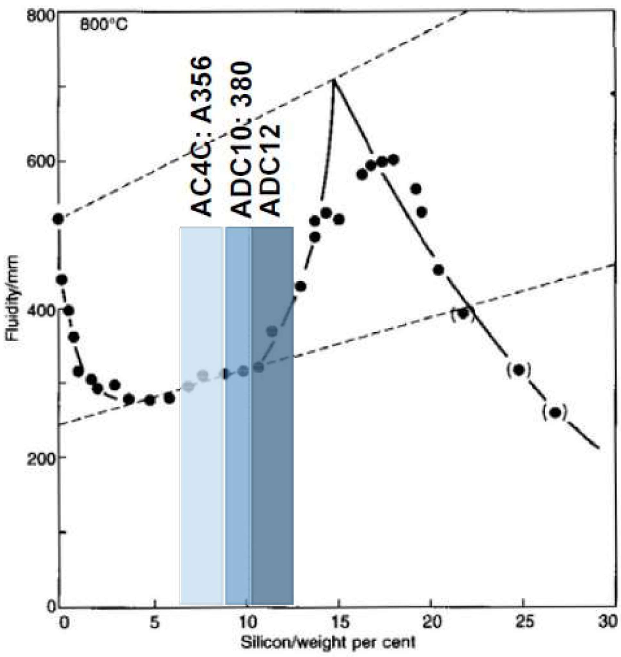
Al-Si phase diagram



มาตรฐาน AA	มาตรฐาน JIS	Si	Cu	Mg	Fe	Zn	Mn
A319.1	AC2A	5.0-7.0	3.0-5.0	0.55	0.90	2.0	0.20-0.65
A332.2	AC8A	10.5-13.5	0.8-1.5	0.9-1.5	0.60	0.35	0.35
A356.0	AC4C	6.5-7.5	0.02	0.30-0.45	0.15	0.07	0.10
380.2	ADC10	8.0-11.0	2.0-4.0	0.15-0.55	0.6-0.11	1.20	0.55
A360.2	AC4A	9.0-11.0	0.03	0.25-0.45	0.40	0.10	0.45
333.1	AC4B	7.5-9.5	2.0-3.5	0.15-0.65	0.7	1.2	0.15-0.65
413.2	AC3A	10.5-13.5	0.03		0.40	0.10	0.35
-	ADC12	10.5-12.0	1.5-3.5		1.3	1.0	0.5

หมายเหตุ: กลุ่ม 3XX.X โดยประกอบด้วย Al-Si-(Cu/Mg) และกลุ่ม 4XX.X ที่ประกอบด้วย Al-Si

Fluidity of Al-Si alloys



ชนิดของโลหะ	ความร้อนแฝงในการหลอมเหลว kJ/kg
ซิลิคอน	~1810
อะลูมิเนียม	~395
แมกนีเซียม	~370
เหล็ก	~275
ทองแดง	~210
สังกะสี	~100

Table 5.2. Alloying elements and alloy characteristics

(Ratings: 1=Excellent, 2=Very Good, 3 =Good, 4=Fair, 5=Poor)

Elements (Mg & Cu approximated)	Castability	Tensile & yield strengths	Fatigue strengths	Crashworthiness or elongation	Pressure tightness	Hot crack resistance	Elevated temperature strength	Stress corrosion resistance	Corrosion resistance	Machin-ability	Heat treating response	Die soldering	Wear resistance	Low coefficient of expansion	Alloy	HT
Silicon 5–8%																
+ Mg 0.25–0.45%	1	1	1	1	1	1	3	2	1	3	1	-	-	-	**A 356**	T6
+ Mg 0.45–0.6%	1	1	1	3	1	1	3	2	2	3	1	-	-	-	**357**	T6
Silicon 5–7%																
+ 0.1% Mg + 3–4% Cu	2	2	2	4	2	2	3	3	3	3	1	-	-	-	**319**	T6
+ 0.5% Mg + 1–1.5% Cu	1	1	1	3	1	2	3	2	2	3	1	-	-	-	**355**	T6
Silicon 8 –10%																
+ 0.5% Mg +1.6–2.0% Cu	1	1	1	3	2	2	2	3	3	3	1	-	-	-	**354**	T61
+ 0.5–0.7% + 0.1 Cu	1	1	1	2	1	2	3	2	2	3	1	-	-	-	**359**	T61
Silicon 8–10%																
+ 0.4–0.6% Mg + 0.1% Cu	1	2	2	3	1	1	2	2	2	3	-	2	-	-	**360**	F F F
+ 0.1% Mg + 3–4% Cu	2	2	1	3	2	2	2	3	3	3	-	1	-	-	**380**	
+ 0.1% Mg + 2–3% Cu	1	2	2	2	1	2	2	3	3	3	-	1	-	-	**383**	
Silicon 10–13%																
+ 0.5% Mg + 2–4% Cu	2	1	2	5	2	1	1	2	3	3	1	-	2	1	**332**	T6
+ 0.1% Mg + 1.0% Cu	1	4	2	3	2	3	3	2	2	4	-	2	-	-	**413**	F
Silicon 16–18%																
+ 0.5% Mg + 4–5% Cu	1	1	1	4	2	2	1	3	3	4	-	1	1	1	**390**	F
Magnesium																
7–8.5% Mg + 0.1% Cu	5	1	1	1	5	4	4	1	1	1	-	1	-	-	**518**	F
Copper																
4–5% Cu + 0.3% Mg	5	1	1	1	3	5	1	4	4	1	1	-	-	-	**206**	T4, T7
Manganese	Alloy should contain ½ the amount of iron to form intermetallic compound in microstructure (like Chinese script) to prevent deterioration in tensile strength and elongation. Manganese improves machinability.															
Iron	Max. 0.2–0.25% in primary: reduces elongation, machinability, fatigue, and tensile strength															
Titanium	Max 0.2–0.25%: refines grain; improves fatigue, tensile and yield strengths; improves feeding															
Strontium	Target 0.06%: modifies silicon (reduces silicon needle lengths), improves elongation and fatigue strength															
Zinc	1.0–3.0% in die casting alloys: reduces die soldering, 0.1% max in primary and 0.3% max in secondary, increases corrosion															
Chromium	0.15% max: reduces machinability															

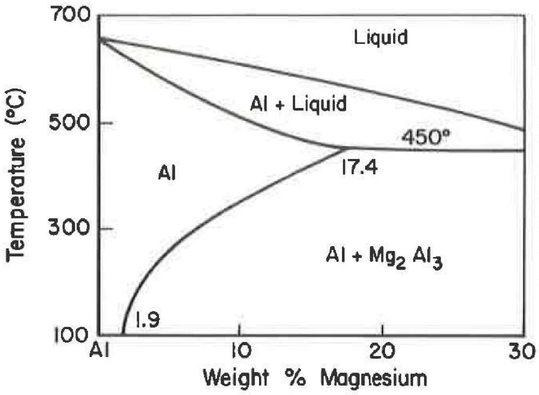
Aluminum-silicon alloy 4xx

- The major characteristics of the 4xx.x series are:
  - Non-heat-treatable sand, permanent mold, and die castings
  - Excellent fluidity, good for intricate castings
  - Approximate ultimate tensile strength range: 120 to 175 MPa
- Alloy B413.0 is notable for its very good castability and excellent weldability, which are due to its eutectic composition and low melting point of 700 °C.
- It combines moderate strength with high elongation before rupture and good corrosion resistance. The alloy is particularly suitable for intricate, thin-walled, leak-proof, fatigue-resistant castings.
- These alloys have found applications in relatively complex cast parts for typewriter and computer housings and dental equipment, and also for critical components in marine and architectural applications.

Aluminum-magnesium alloy 5xx

The major characteristics of the 5xx.x series are:

- Non-heat-treatable sand, permanent mold, and die castings
- Tougher to cast; provides good finishing characteristics
- Excellent corrosion resistance, machinability, and surface appearance
- Approximate ultimate tensile strength range: 120 to 175 MPa
- The common feature of this group of alloys is good resistance to corrosion.



Alloy	Type(a)	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Sn	Others Each(b)	Others Total(b)	Al
512.0	Nominal	1.8	...	...	...	4.0	...	...	...	...	...	...	...	...
	Limits	1.4–2.2	0.6	0.35	0.8	3.5–4.5	0.25	...	0.35	0.25	...	0.05	0.15	bal
513.0	Nominal	...	...	...	...	4.0	...	...	1.8	...	...	...	...	...
	Limits	0.30	0.40	0.10	0.30	3.5–4.5	...	...	1.4–2.2	0.20	...	0.05	0.15	bal
514.0	Nominal	...	...	...	...	4.0	...	...	...	...	...	...	...	...
	Limits	0.35	0.50	0.15	0.35	3.5–4.5	...	...	0.15	0.25	...	0.05	0.15	bal
518.0	Nominal	...	...	...	...	8.0	...	...	...	...	...	...	...	...
	Limits	0.35	1.8	0.25	0.35	7.5–8.5	...	0.15	0.15	...	0.15	...	0.25	bal
520.0	Nominal	...	...	...	...	10.0	...	...	...	...	...	...	...	...
	Limits	0.25	0.30	0.25	0.15	9.5–10.6	...	...	0.15	0.25	...	0.05	0.15	bal
535.0(m)	Nominal	...	...	...	0.18	6.8	...	...	...	0.18	...	...	...	...
	Limits	0.15	0.15	0.05	0.10–0.25	6.2–7.5	...	...	...	0.10–0.25	...	0.05	0.15	bal

Al-Mg alloy 5xx

- Alloys 512.0 and 514.0 have medium strength and good elongation and are suitable for components exposed to seawater or to other similar corrosive environments.
- These alloys often are used for door and window fittings, which can be decoratively anodized to give a metallic finish or provide a wide range of colors.
- Their castability is inferior to that of the aluminum-silicon alloys because of its magnesium content and, consequently, long freezing range. For this reason, it tends to be replaced by 355.0, which has long been used for similar applications.
- For die castings where decorative anodizing is particularly important, alloy 520.0 is quite suitable.

Al-Zn alloy 7xx

- The major characteristics of the 7xx.x series are:
  - Heat treatable sand and permanent mold castings (harder to cast)
  - Excellent machinability and appearance
  - Approximate ultimate tensile strength range: 210 to 380 MPa
- Primary Use. Because of the increased difficulty in casting 7xx.x alloys, they tend to be used only where the excellent finishing characteristics and machinability are important.
- Representative applications include furniture, garden tools, office machines, and farming and mining equipment.

Al-Sn alloy 8xx

The major characteristics of the 8xx.x series are:

- Heat treatable sand and permanent mold castings (harder to cast)
- Excellent machinability
- Bearings and bushings of all types
- Approximate ultimate tensile strength range: 105 to 210 MPa

Primary Use. 8xx.x alloys are relatively hard to cast and tend to be used only where their combination of superior surface finish and relative hardness are important.

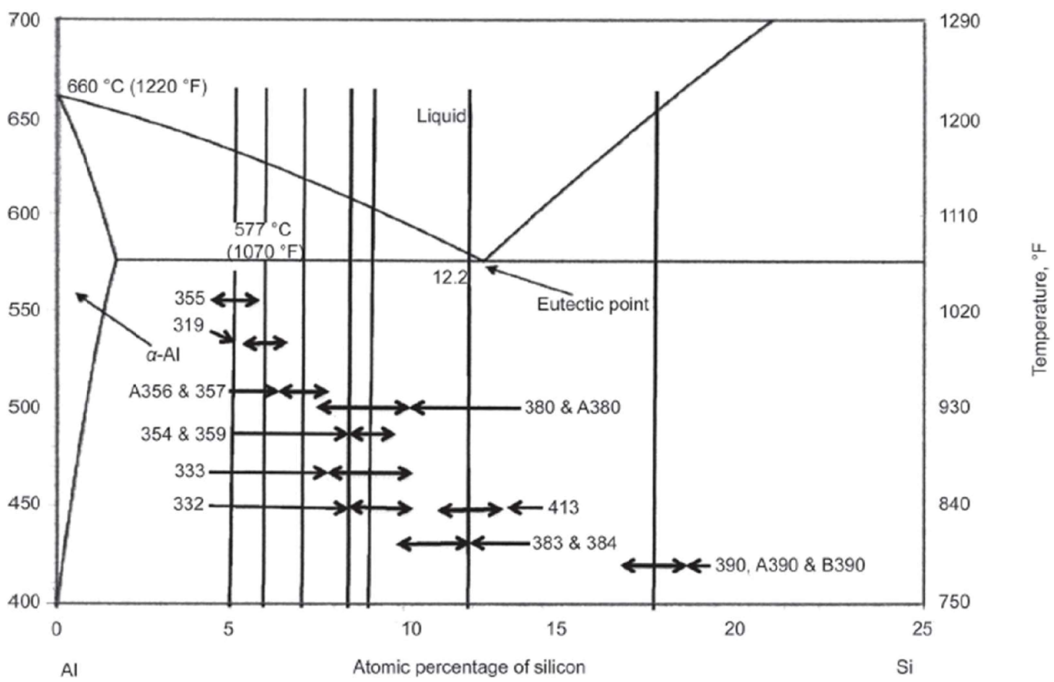
The prime example is for parts requiring extensive machining and for bushings and bearings.

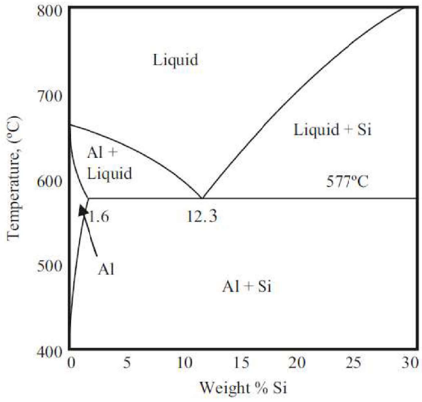
Characteristic ratings for cast aluminum alloys

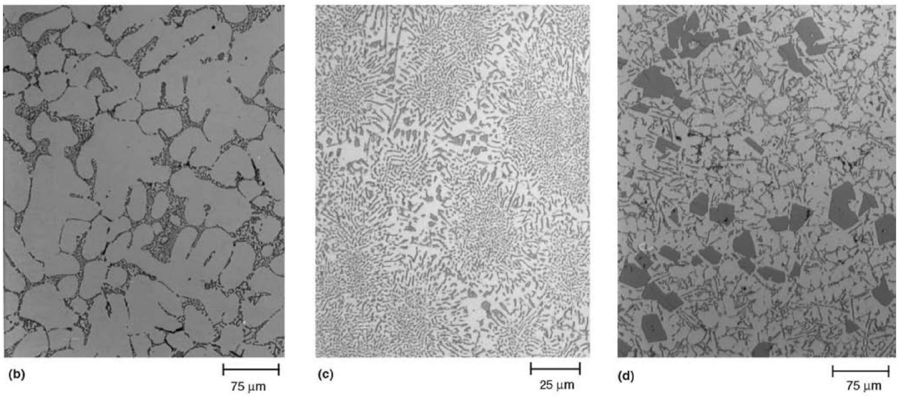
Class	Fluidity	Cracking	Tightness	Corrosion	Finishing	Joining
1*xx*.0				1	1	1
2*xx*.0	3	4	3	4	1–3	2–4
3*xx*.0	1–2	1–2	1–2	2–3	3–4	1–3
4*xx*.0	1	1	1	2–3	4–5	1
5*xx*.0	5	4	4–5	3	1–2	3
7*xx*.0	3	4	4	4	1–2	4
8*xx*.0	4	5	5	5	3	5

ratings from 1 (highest or best) to 5 (lowest or worst)

Al-Si alloy

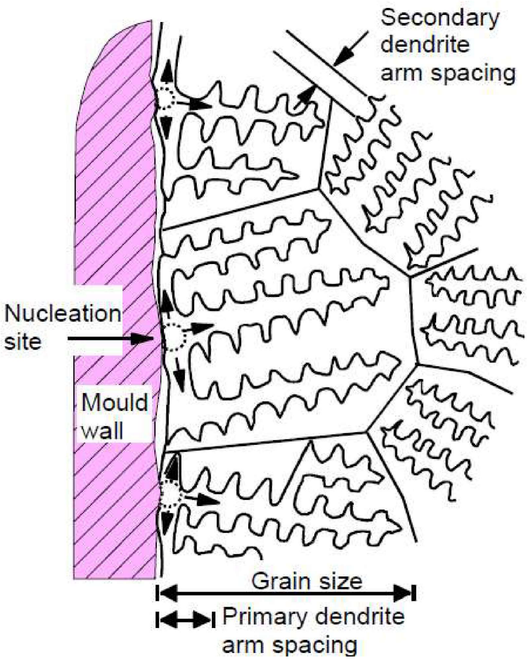






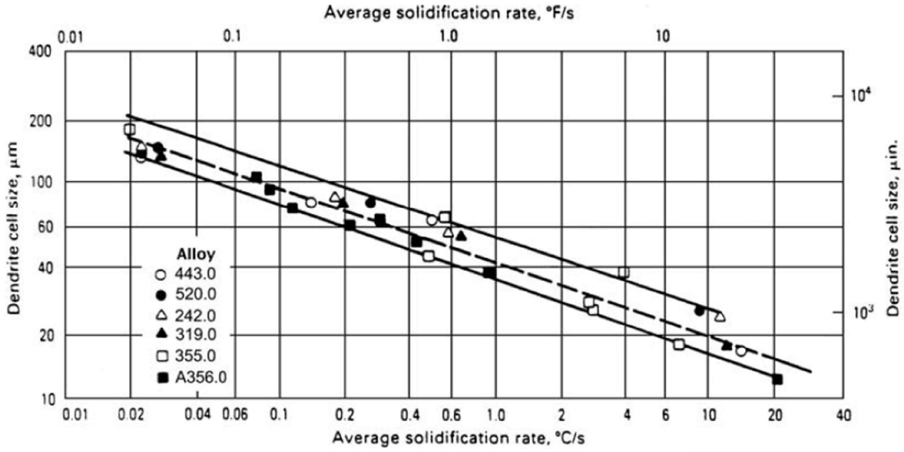
Hypoeutectic Al-Si

- Grain
- SDAS
- Eutectic Si



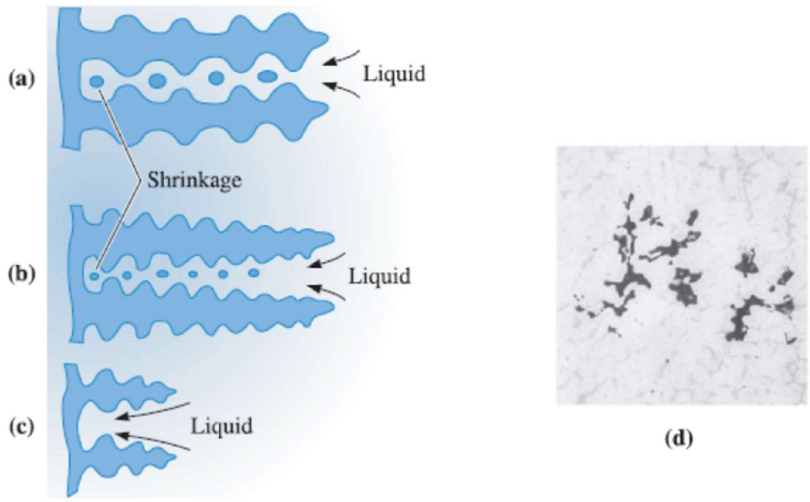
Dendrite Arm Spacing

Dendrite arm spacing and dendrite cell size as a function of local solidification rate.



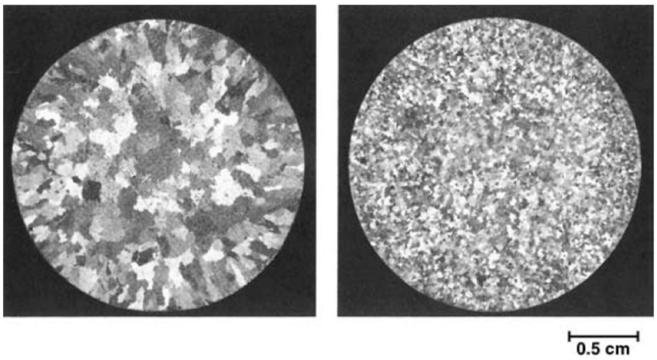
	Cooling rate		Dendrite arm spacing	
Casting processes	°F/s	°C/s	mils	µm
Plaster, investment	1.80	1	3.94–39.4	100–1000
Green sand, shell	18.0	10	1.97–19.7	50–500
Permanent mold	180.0	100	1.18–2.76	30–70
Die	1800	1000	0.20–0.59	5–15

Secondary Dendrite Arm Spacing



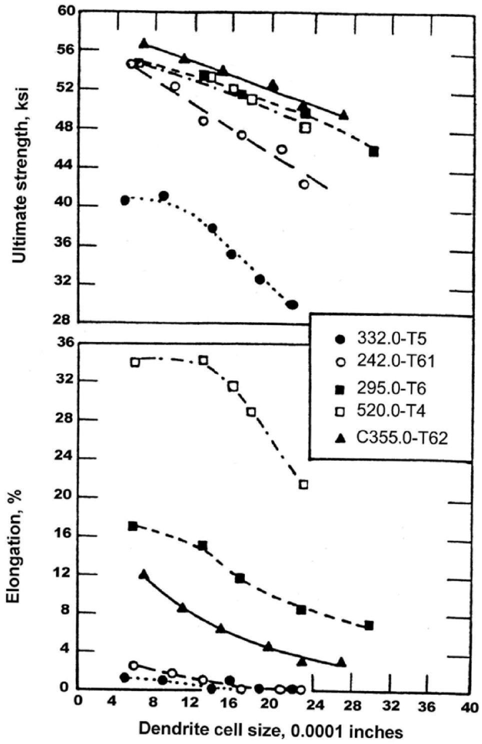
(a) Shrinkage can occur between the dendrite arms.
(b) Small secondary dendrite arm spacings result in smaller, more evenly distributed shrinkage porosity.
(c) Short primary arms can help avoid shrinkage.
(d) Interdendritic shrinkage in an aluminum alloy.

Grain Refinement

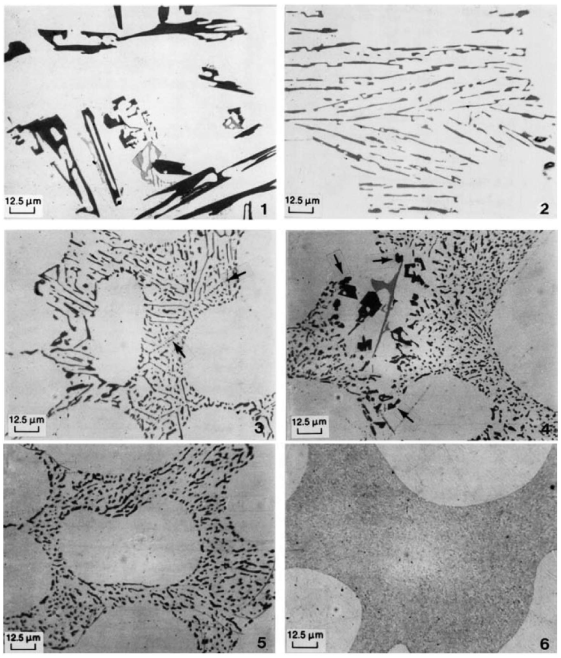


(a) (b)

As-cast Al-7Si ingots showing the effects of grain refinement. (a) No grain refiner. (b) Grain refined. Both etched using Poulton's etch.



Modification of Eutectic Si

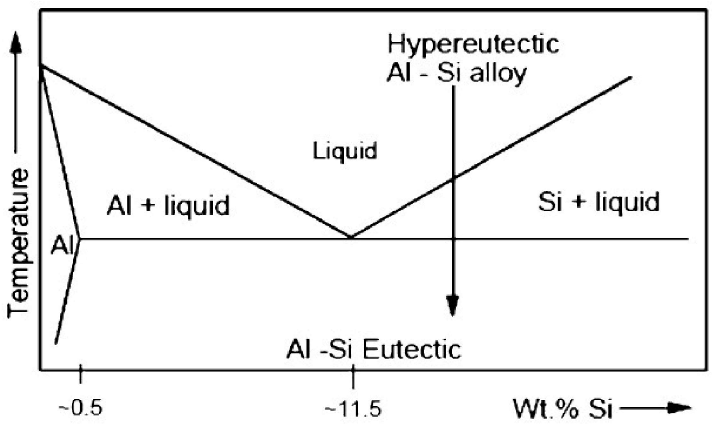


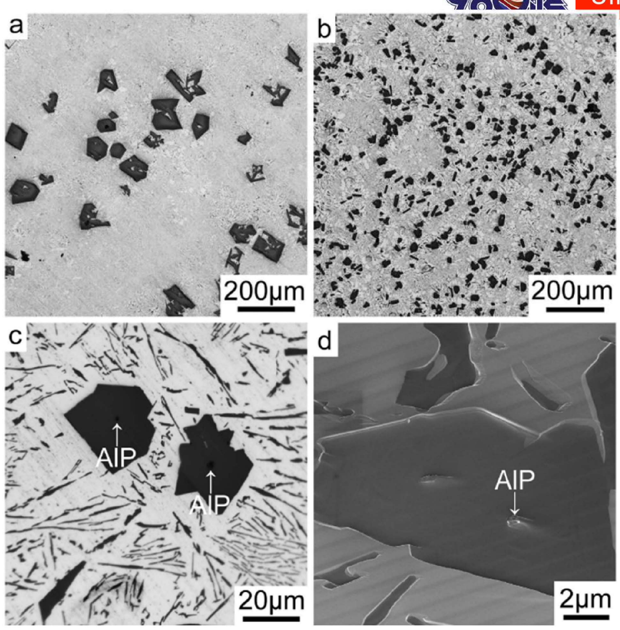
Class number	Structure	Description
1	Fully unmodified	Silicon is present in the form of large plates as well as in acicular form.
2	Lamellar	A finer lamellar structure, though some acicular Si may be present (but no large plates).
3	Partially modified	The lamellar structure starts to break up into smaller pieces.
4	Absence of lamellae	Complete disappearance of lamellar Si. Some acicular Si may still be present.
5	Fibrous Si eutectic (Fully modified)	Acicular Si is completely absent.
6	Very fine eutectic (Super modified)	The fibrous Si becomes so small that individual particles cannot be resolved under an optical microscopy.

Typical mechanical properties of modified and unmodified cast aluminum alloys

Alloy and temper	Product	Modification treatment	Tensile yield strength		Ultimate tensile strength		Elongation, %
			ksi	MPa	ksi	MPa	
13% Si	Sand cast test bars	None	...	...	18.0	124	2.0
		Na-modified	...	...	28.0	193	13.0
	Permanent mold test bars	None	...	...	28.0	193	3.6
		Na-modified	...	...	32.0	221	8.0
359.0	Permanent mold test bars	None	...	...	26.1	180	5.5
		0.07% Sr	...	...	30.5	210	12.0
356.0-T6	Sand cast test bars	None	30.1	208	41.9	289	2.0
		0.07% Sr	34.5	238	42.5	293	3.0
	Bars cut from chilled sand casting	None	30.9	213	41.2	284	4.4
		0.07% Sr	31.6	218	42.2	291	7.2
A356.0-T6	Sand cast test bars	None	26.0	179	40.0	226	4.8
		0.01% Sr	30.0	207	43.0	297	8.0
A444.0-T4	Permanent mold test bars	None	...	...	21.9	151	24.0
		0.07% Sr	...	...	21.6	149	30.0
A413.2	Sand cast test bars	None	16.3	112	19.8	137	1.8
		0.005–0.05% Sr	15.6	108	23.0	159	8.4
	Permanent mold test bars	None	18.1	125	24.4	168	6.0
		0.005–0.08% Sr	18.1	125	27.7	191	12.0
	Test bar cut from auto wheel	0.05% Sr	17.5	121	28.0	193	10.6
		0.06% Sr	18.2	126	28.0	193	12.8

Hypereutectic Al-Si alloy





Primary Si refinement

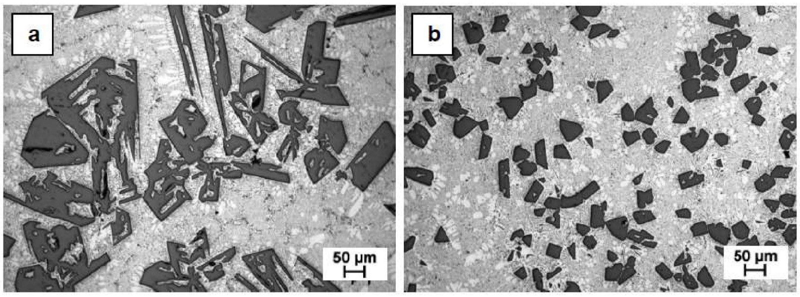
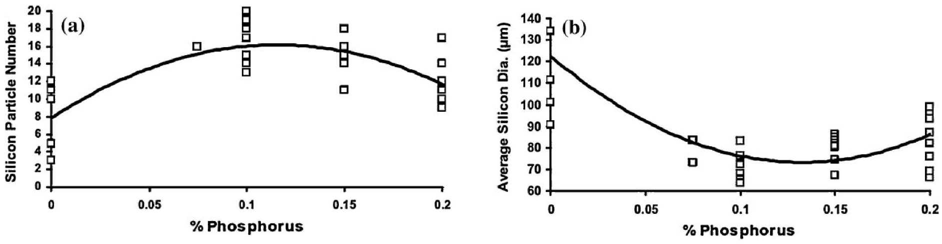
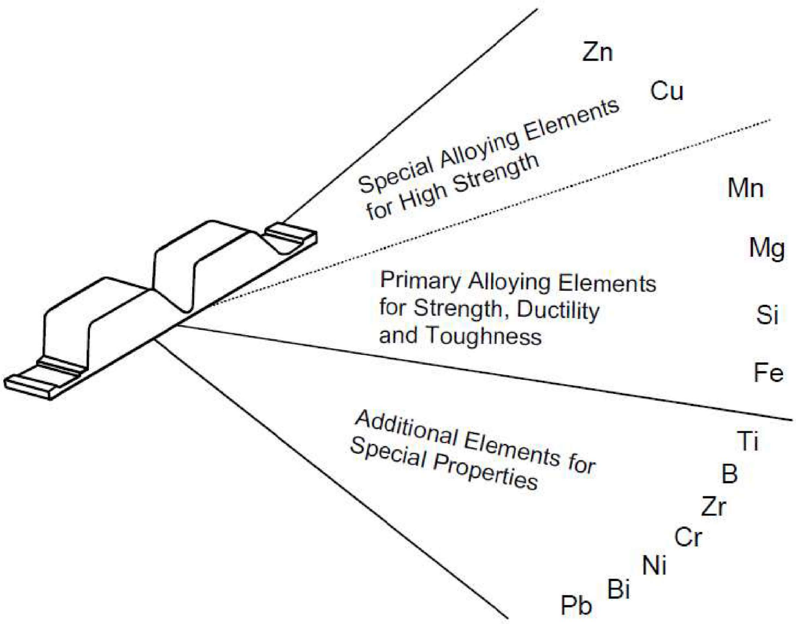


Figure 2.10 Optical micrographs of as-cast alloys that conducted in this thesis: (a) Al-30Si alloy, (b) Al-30Si with the addition of 400 ppm P.



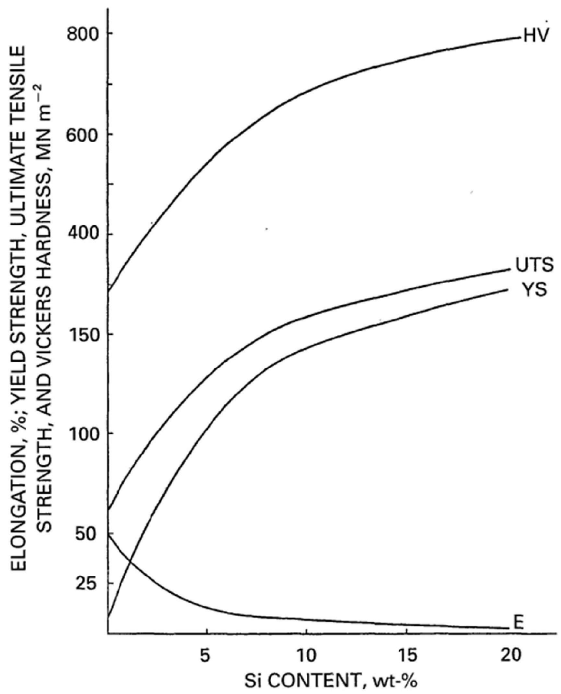
Effects of alloy composition



Silicon: Si

The mechanical properties of Al-Si alloys depend more on the distribution and the shape of the silicon particles than on the silicon content.

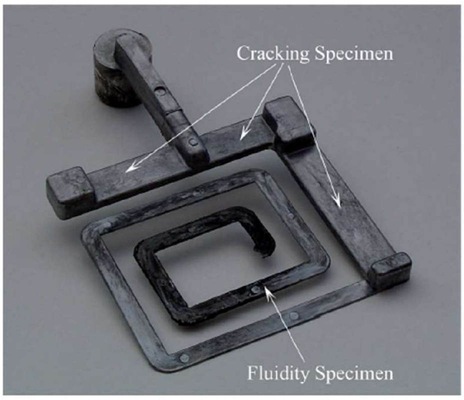
Alloys in which the silicon particles (eutectic or primary) are small, round, and evenly distributed are usually highly ductile.



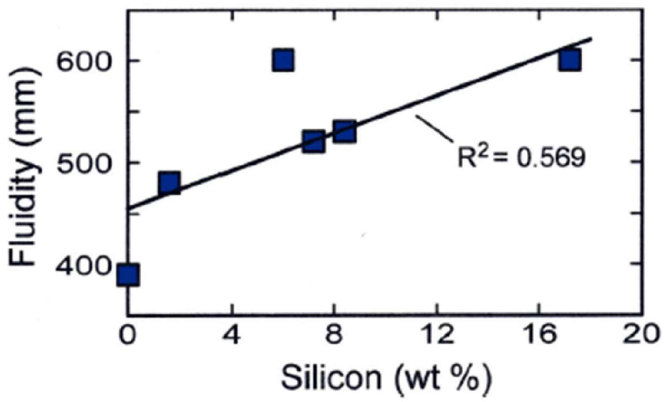
E elongation; HV Vickers hardness; UTS ultimate tensile strength; YS yield strength

Silicon: Si

- Si enhances castability. The fluidity, hot tear resistance and feeding are all improved.



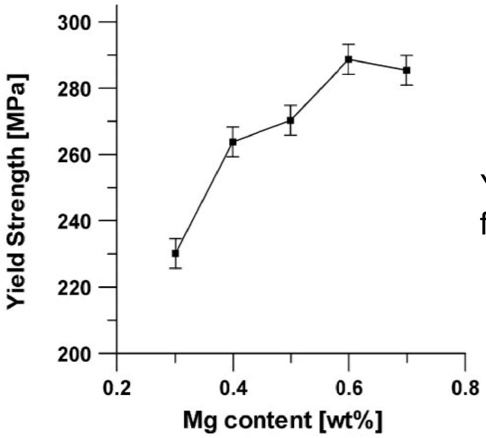
Die cast test casting



Die cast fluidity versus silicon content in six casting alloys.

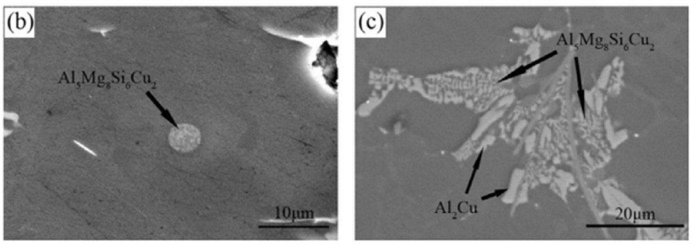
Magnesium: Mg

- When Mg is also added, Si forms a magnesium silicide compound (Mg_2Si). Hence, precipitation hardening of Al–Si–Mg containing castings is possible, and this increases strength.

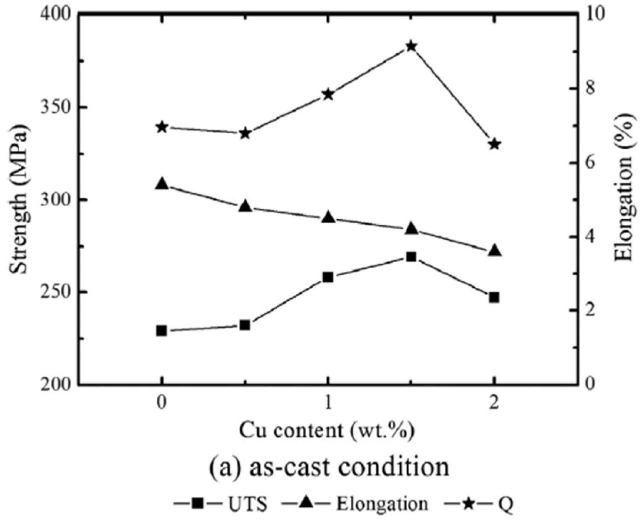


Yield strength versus nominal Mg content for a peak-aged Al–7Si–Mg alloy.

Copper: Cu



Al–11Si–0.3Mg alloys



(a) as-cast condition

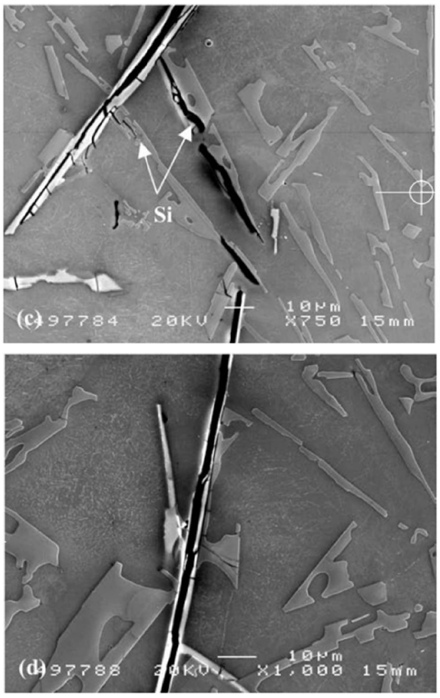
$Q = \sigma_{UTS} + k \log(E_f)$

Iron: Fe

- Liquid aluminum dissolves a considerable amount of iron. The solubility is 1.9% Fe at the melting point and increases with temperature.
- Only a small amount of iron is soluble in the solid: 0.05% Fe or 2.5% of the total iron dissolved in the liquid. In other words, most of the iron will remain in the liquid during solidification, until it precipitates as brittle intermetallic compounds. These compounds lower the strength and ductility.
- Solidified aluminum castings tend to form compounds with, and stick to, the steel die.

Example of soldering on a core pin after a production die casting run (photo courtesy of Mercury Marine). This buildup tears the casting at ejection and may results in dimensional and leaking defects.

Fe-rich Intermetallic



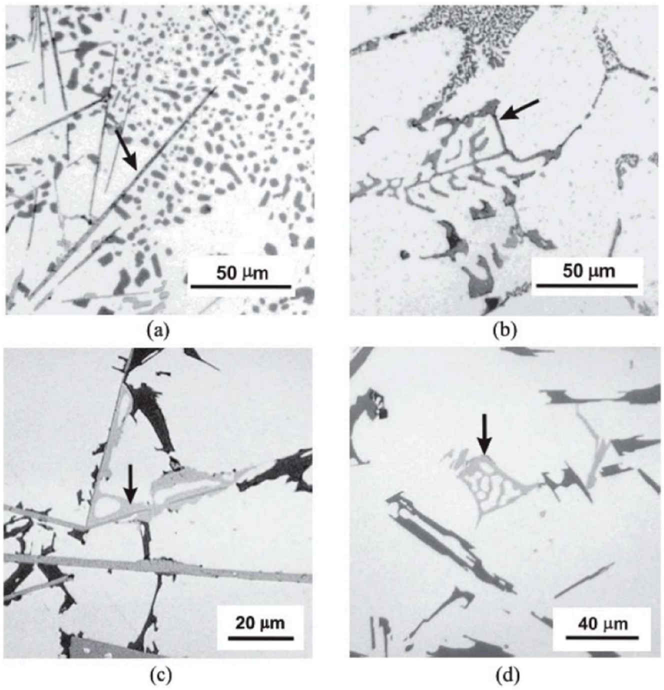
Effect of Fe on tensile properties

%Si	%Fe	UTS (ksi)	Elongation (%)
10.8	0.29	31.1	14
10.8	0.79	30.9	9.8
10.3	0.9	30.0	6
10.1	1.13	24.5	2.5
10.4	1.6	18.0	1.5
10.2	2.08	11.2	1

Fe-rich Intermetallic

platelets of β-AlFeSi

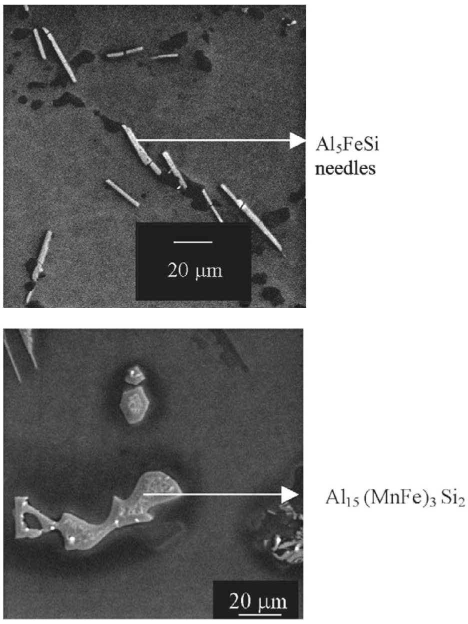
Chinese script α-Al(Fe,Mn)Si

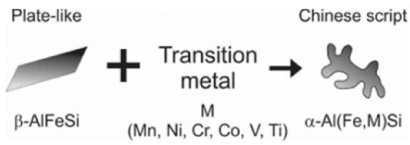


π-AlFeMgSi growing
From β-AlFeSi

Chinese script π-AlFeMgSi

Manganese: Mn

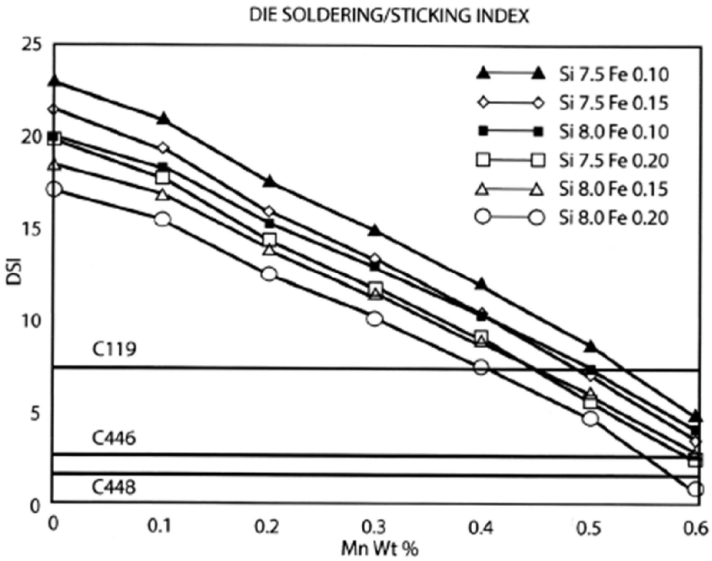




- The complex $Al_{15}(MnFe)_3Si_2$ compound has a different morphology. Instead of forming large plates, it is more compact. Hence, it affects the ductility less than Al_5FeSi plates.
- A ratio of Mn:2 Fe is usually recommended to transform the Fe-rich phases (β-phase) into an α-phase (Chinese script).

Manganese: Mn

- Mn-containing die casting alloys do offer improved die life.



Die soldering index (DIS) in several die casting alloys (Alcoa)

The lines for the three 'C' alloys indicate the performance of three commercially used Alcoa alloys.

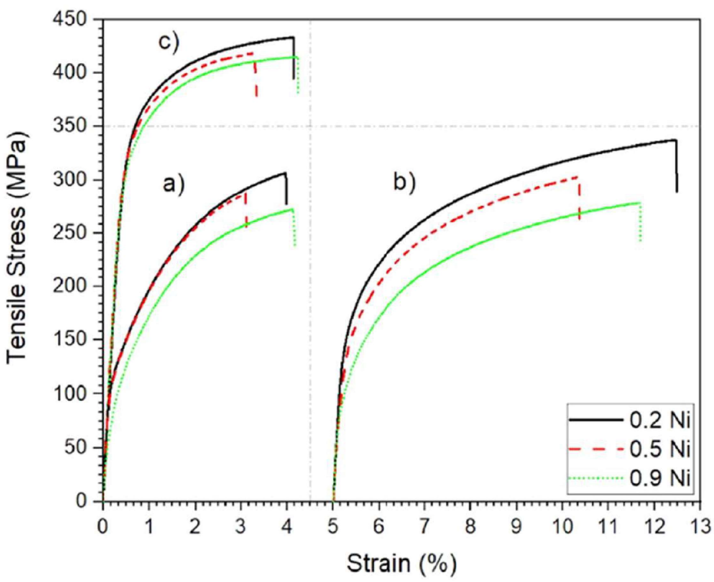
Nickel: Ni

- Nickel is added to some Al-Si alloys to increase tensile strength, yield strength at temperatures in the range 250–375 °C.
- The increase in strength is mainly due to the precipitation of the Al3Ni intermetallic

Average tensile test values of all samples.

Type	Alloys	0.2 YS (MPa)	UTS (MPa)	Elongation (%)
As-Cast	0.2Ni	141.97 ± 7.42	301.6 ± 8.84	3.44 ± 0.62
	0.5Ni	146.23 ± 14.29	296.54 ± 13.78	2.88 ± 0.28
	0.9Ni	96.5 ± 4.71	255.63 ± 11.87	3.47 ± 0.47
Natural Aged	0.2Ni	163.83 ± 12.77	332.93 ± 9.61	6.75 ± 0.66
	0.5Ni	150.17 ± 3.91	298.1 ± 4.23	4.86 ± 0.35
	0.9Ni	120.9 ± 3.96	270.87 ± 6.65	6.52 ± 0.16
Artificial aged	0.2Ni	341.37 ± 6.48	429.93 ± 7.42	3.63 ± 0.62
	0.5Ni	336.53 ± 4.07	416.43 ± 2.12	2.72 ± 0.39
	0.9Ni	321.53 ± 2.74	408.1 ± 5.43	3.34 ± 0.59

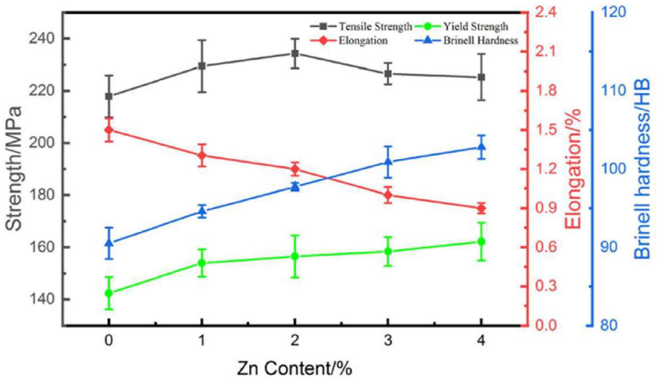
Al–12Si–4.5Cu alloys



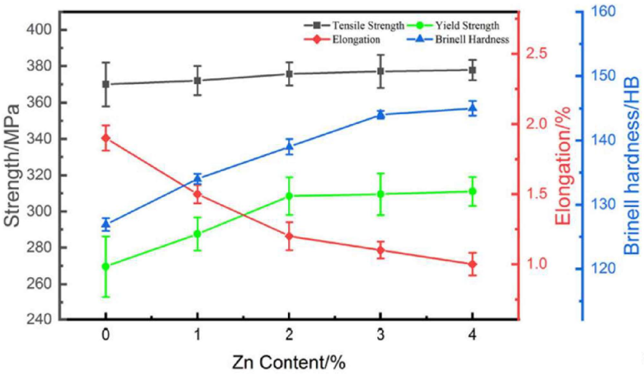
Zinc: Zn

- Zinc in amounts up to 1% in aluminum alloys is in solid solution and does not form any visibly detectable phases.
- Additions of zinc (Zn) in the range 1–4 wt% slightly improve the tensile properties in heat-treated (T5 or T6) Al-Si castings.
- The advantage of Zn is that it does not affect ductility.

As-cast Al-12.5Si-2Cu-1Mg alloys



Heat treated Al-12.5Si-2Cu-1Mg alloys



If I have seen further, it is by standing
ON THE SHOULDERS OF GIANTS.

- Sir Isaac Newton