Alüminyum Test Eğitim ve Araştırma Merkezi

Eylül 2016

Alüminyum Alaşımları Isıl İşlem Süreçleri: Analiz ve Sentez

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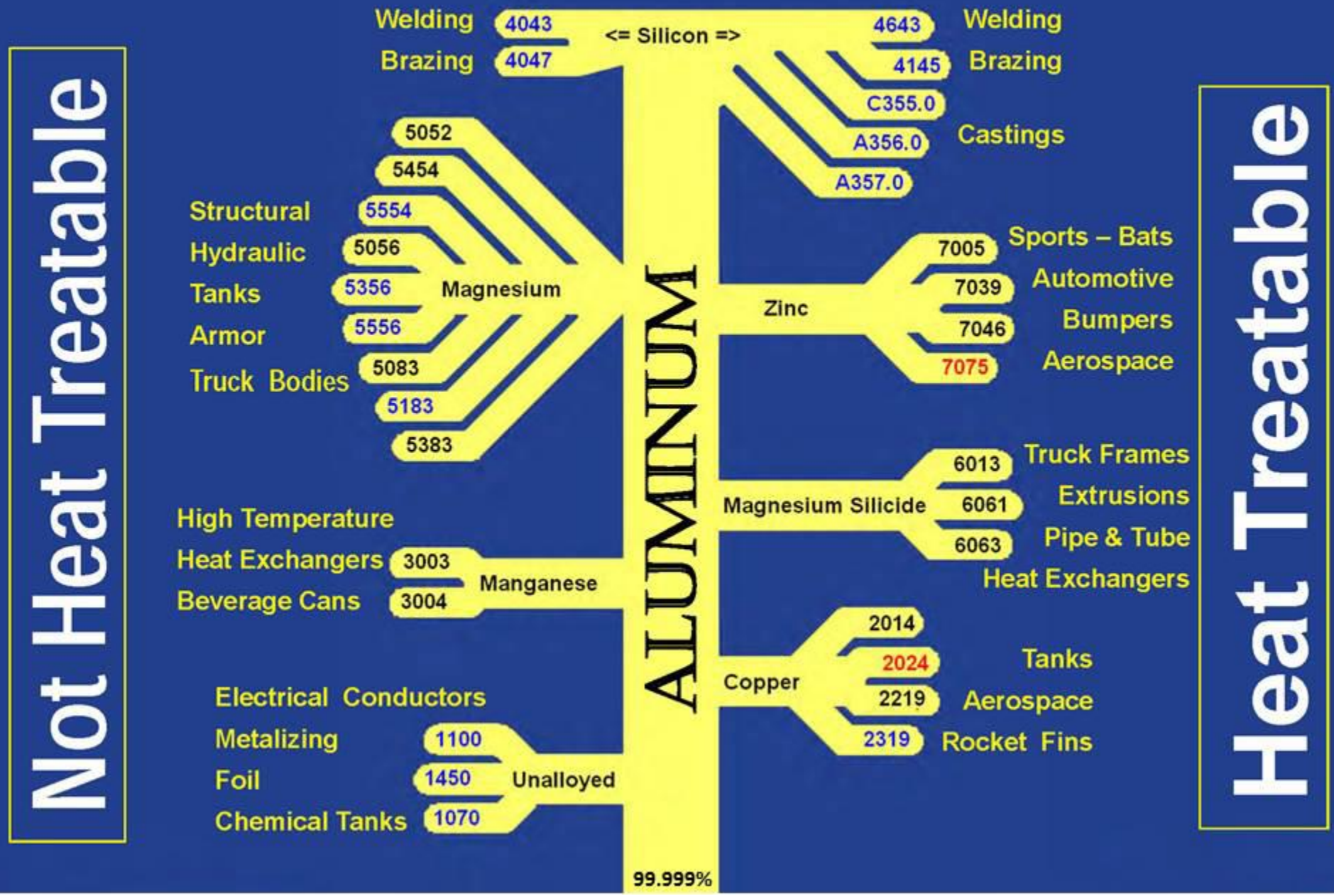
Aluminum Alloy Designation Tree



Alüminyum Alaşımlarında Mukavemet Artışı

Mukavemetlendirme

1) Soğuk Şekillendirme
2) Isıl İşlem

Soğuk Şekillendirme

- Isıl İşleme cevap vermeyen veya tek fazlı veya intermetalik içermeyen “sade” yapılı alaşımlar
- Mukavemetleri soğuk şekillendirme ile artırılabilir “deformasyon sertleşmesi” veya “dislokasyon çoğalması”
- H temper durumu ile gösterilirler

H Temperleri

TABLE 13-4 ■ ***Temper designations for aluminum alloys***

F As-fabricated (hot-worked, forged, cast, etc.)
O Annealed (in the softest possible condition)
H Cold-worked
H1x—cold-worked only. (x refers to the amount of cold work and strengthening.)
H12—cold work that gives a tensile strength midway between the O and H14 tempers.
H14—cold work that gives a tensile strength midway between the O and H18 tempers.
H16—cold work that gives a tensile strength midway between the H14 and H18 tempers.
H18—cold work that gives about 75% reduction.
H19—cold work that gives a tensile strength greater than 2000 psi of that obtained by the H18 temper.
H2x—cold-worked and partly annealed.
H3x—cold-worked and stabilized at a low temperature to prevent age hardening of the structure.
W Solution-treated
T Age-hardened
T1—cooled from the fabrication temperature and naturally aged.
T2—cooled from the fabrication temperature, cold-worked, and naturally aged.
T3—solution-treated, cold-worked, and naturally aged.
T4—solution-treated and naturally aged.
T5—cooled from the fabrication temperature and artificially aged.
T6—solution-treated and artificially aged.
T7—solution-treated and stabilized by overaging.
T8—solution-treated, cold-worked, and artificially aged.
T9—solution-treated, artificially aged, and cold-worked.
T10—cooled from the fabrication temperature, cold-worked, and artificially aged.

The letter *H* indicates:
strain hardened, cold-worked, hand-drawn, or rolled. Additional digits are added to the *H* to indicate the degree of strain hardening.
This letter designates a process of stretching or compressing in order to impart a particular temper.

- **H_1** 1/8 hard
- **H_2** 1/4 hard
- **H_3** 3/8 hard
- **H_4** 1/2 hard
- **H_5** 5/8 hard
- **H_6** 3/4 hard
- **H_7** 7/8 hard
- **H_8** Full hard

Isıl İşlem

- Çökelti sertleştirmesi veya yaşlanma
- (precipitation hardening or ageing)
- Isıl işleme cevap veren alaşımlara uygulanır
- T temper durumu

Heat Treatable Alloys
Temper Designations

Designation	Description	Application
O	Annealed, Recrystalized	Lowest Strength, High ductility
F	As Fabricated	Fabrication with no special control over thermal or strain hardening
W	Solution Heat Treatment	Unstable temper application with subsequent period of natural age
T1		Cooled and naturally aged
T2		Cooled, cold worked & Naturally aged
T3		Solution heat treated, cold worked & naturally aged
T4		Solution heat treated & naturally aged
T5		Cooled and artificially aged
T6		Solution heat treated and Stabilized
T7		Solution heat treated, stabilized to provide special property
T8		Solution heat treated, cold worked, artificially aged
T9		Solution heat treated, artificially aged, then cold worked
T10		Cooled, cold worked, then artificially aged

For a more extensive description see the table in AWS Welding Handbook, Vol 3, 8th Ed. Page 9

Heat treatment strategies

There are a number of ***heat treatment strategies***, which stimulate the formation of dispersed precipitates that ***resist cutting by dislocation***.

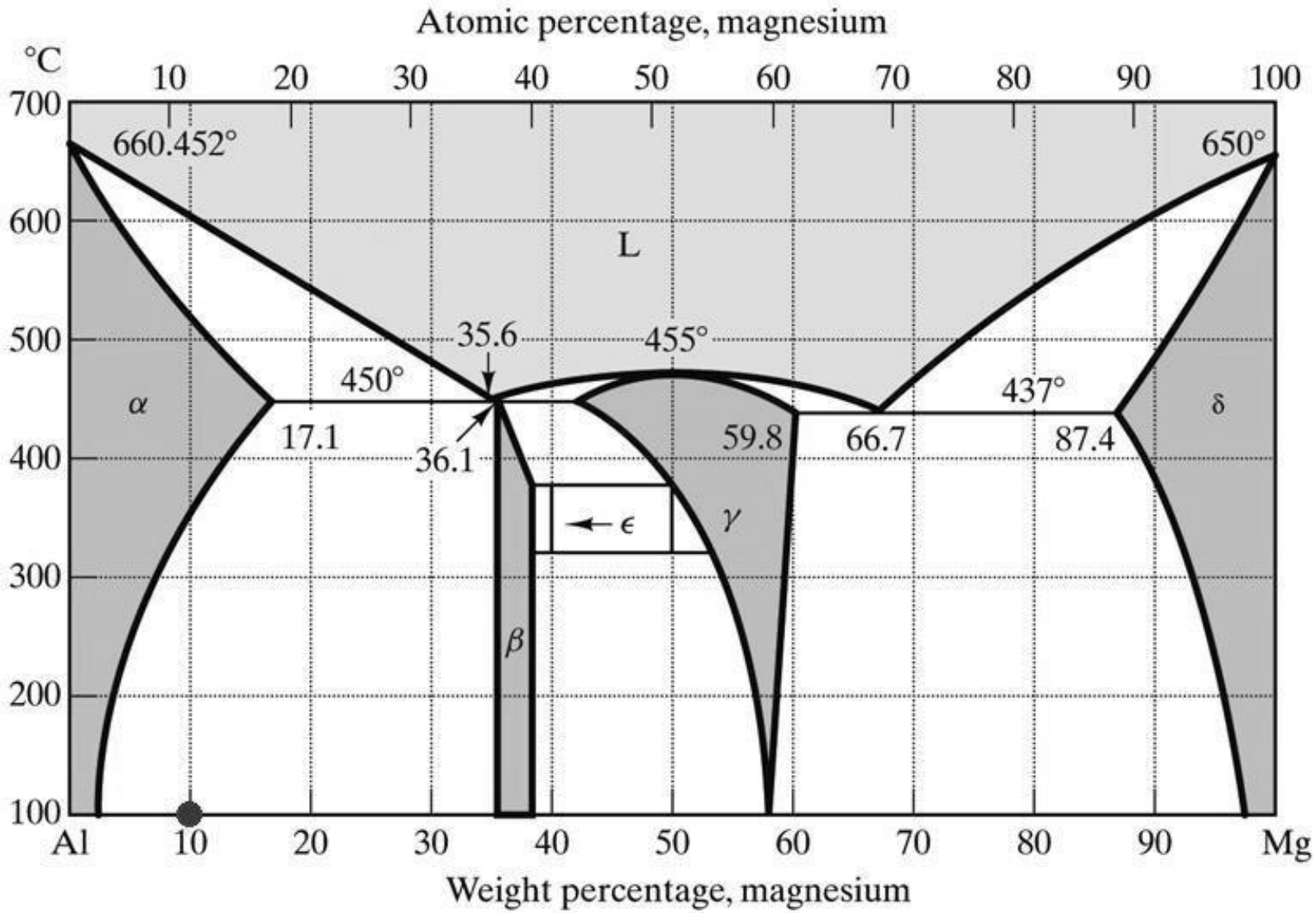
1) Duplex ageing first below and then above the GP zone solvus temperature, enabling the formation of finer dispersion of intermediate precipitates.
2) Co-precipitation of two phases, fine and coarse particles in which the former contributes to yield strength and the latter result in uniform plastic deformation.
3) Co-precipitation of two or more intermediate phases, having different crystallographic plane, influencing dislocation mobility.
4) Nucleation of uniform dispersions of intermediate precipitates by adding some particular trace elements.

Note: Suitable heat-treatment scheme can increase strength up to 40 times.

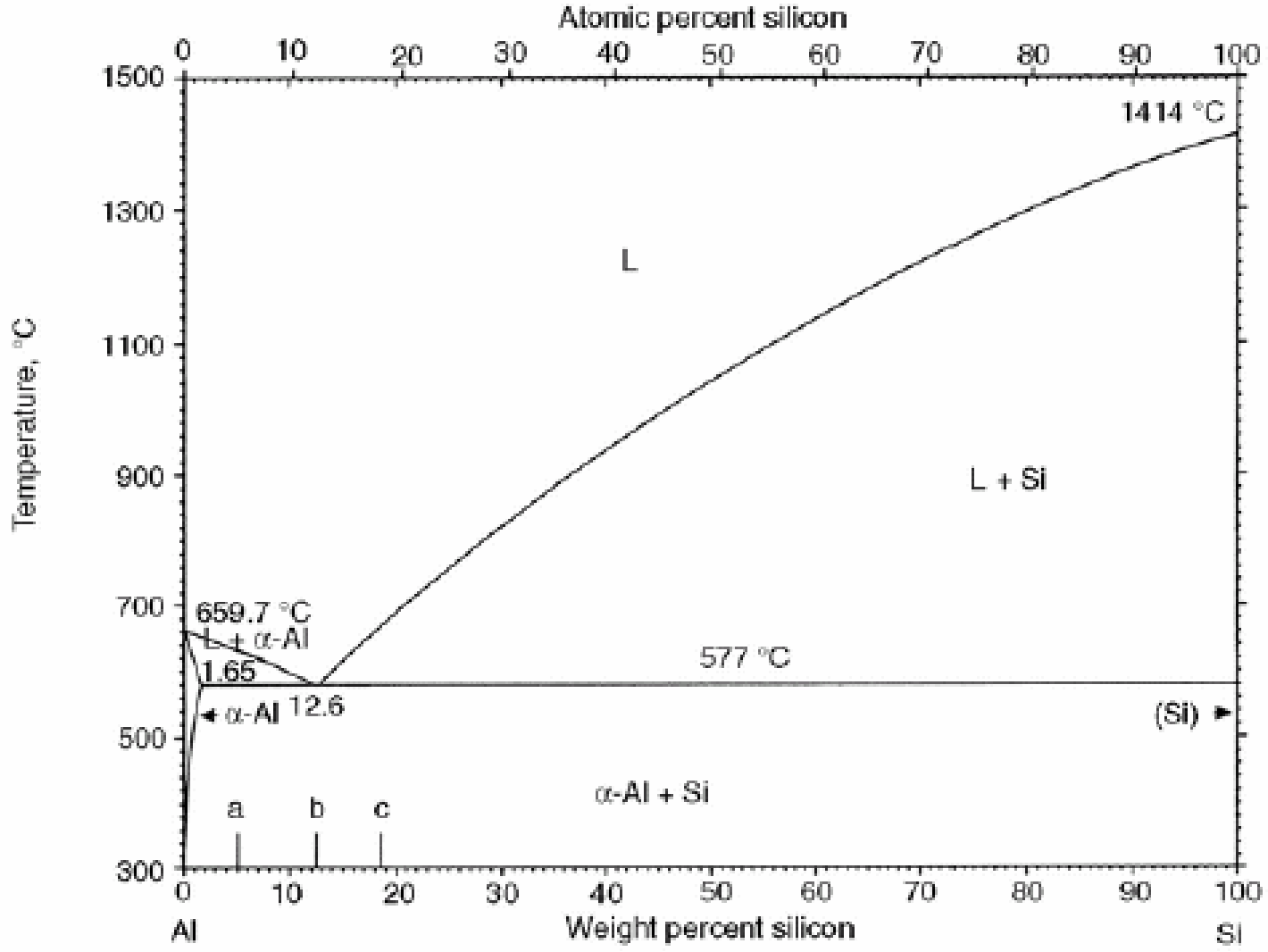
Çökelti Sertleştirmesi

Gerekli koşullar

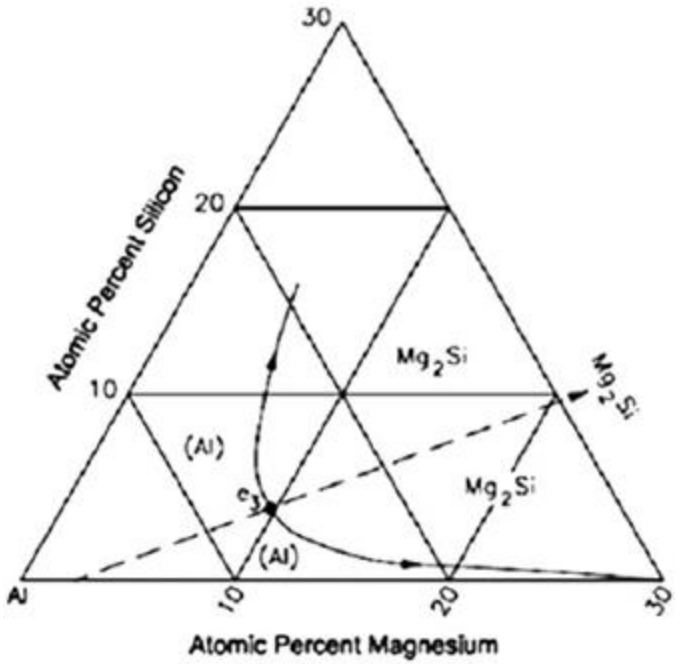
1) **Alaşım sisteminde katı eriyik bölgesi bulunmalı (solvüs eğrisi-çözünürlük sınır eğrisi) ve katı erirlik sıcaklık düştükçe azalmalı**



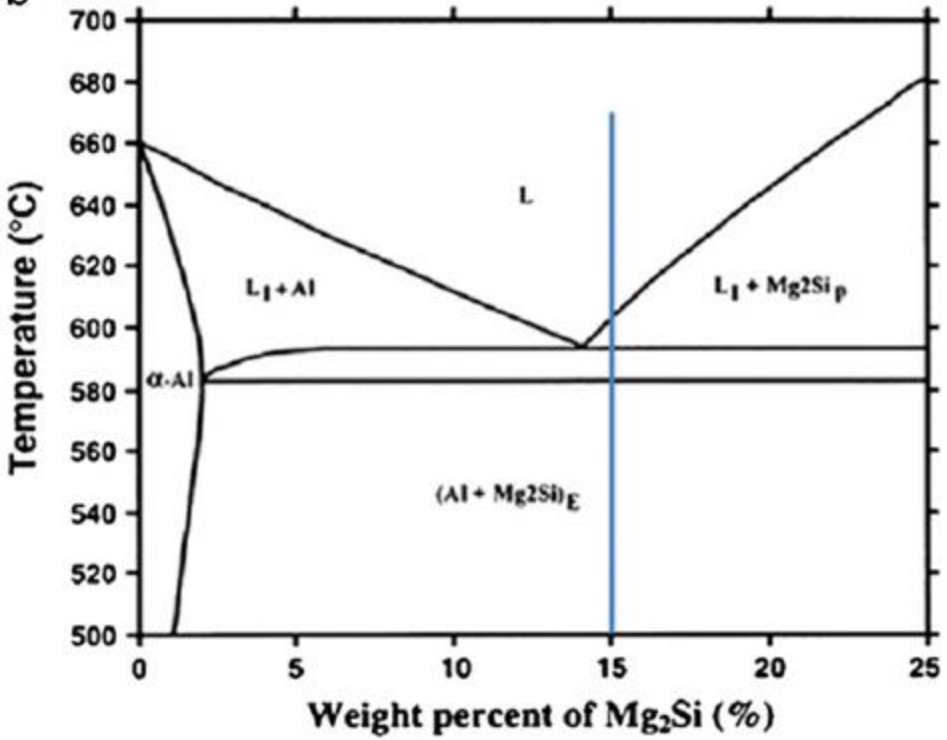
Al–Mg phase diagram

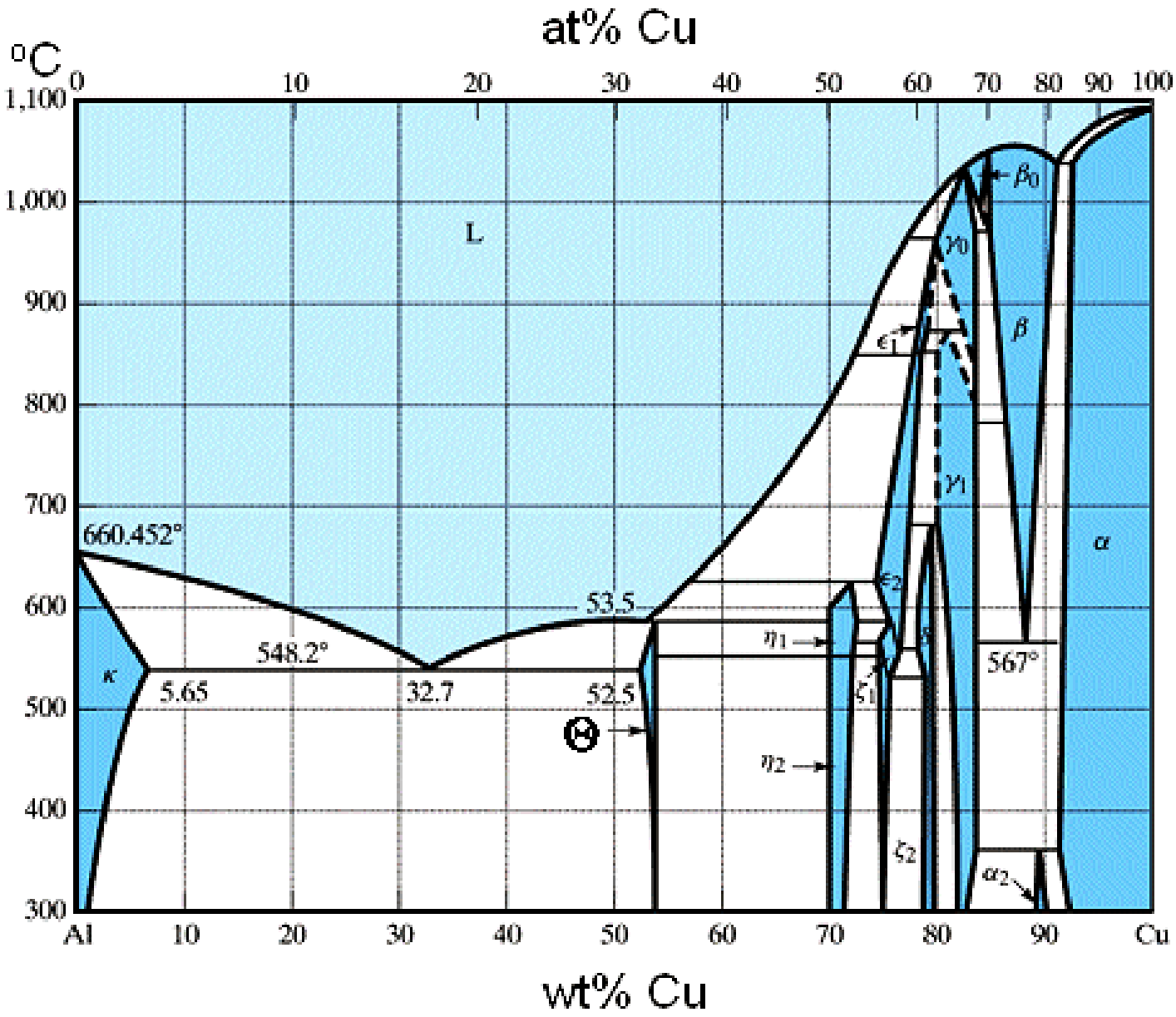

Atomic percent silicon
0
10
20
30
40
50
60
70
80
90
100
1500
1300
1100
900
700
500
300
Temperature, °C
1414 °C
L
L + Si
659.7 °C
L + α-Al
1.65
577 °C
α-Al
12.6
(Si)
α-Al + Si
a
b
c
Al
Weight percent silicon
Si

a


30
20
10
Atomic Percent Silicon
Mg2Si
Mg2Si
(Al)
e1
Mg2Si
(Al)
Al
10
20
30
Atomic Percent Magnesium

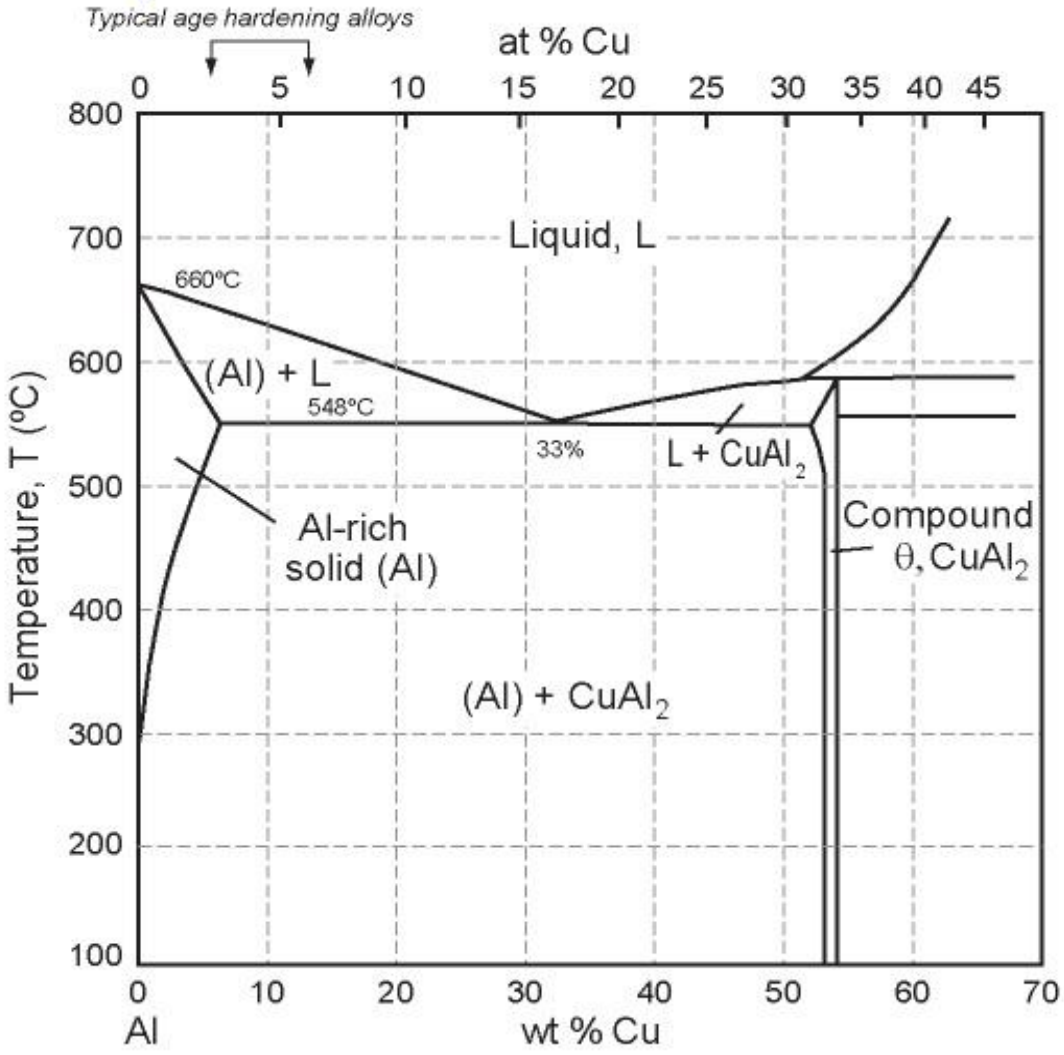
b

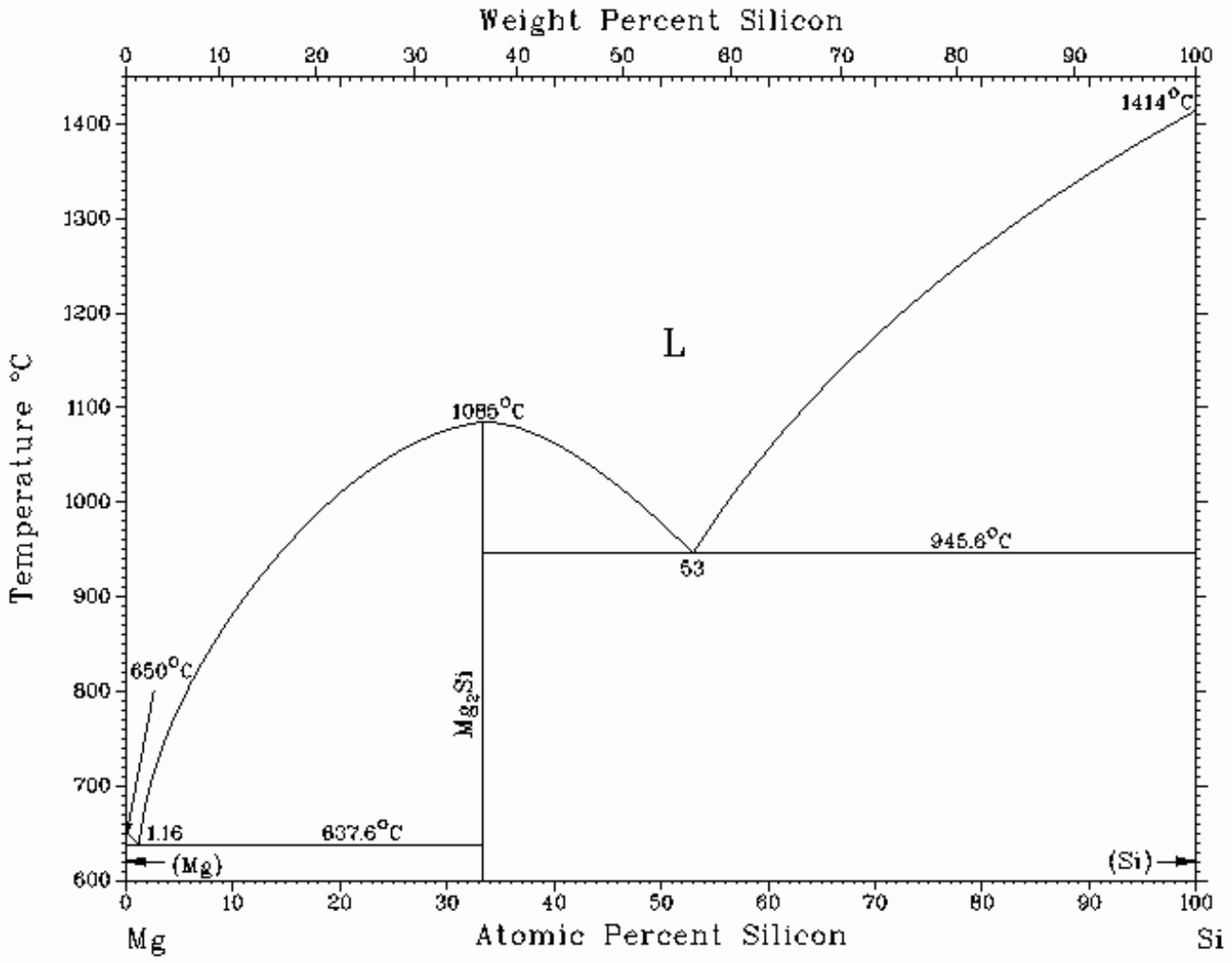

700
680
660
640
620
600
580
560
540
520
500
Temperature (°C)
L
L1 + Al
L1 + Mg2Si p
α-Al
(Al + Mg2Si)E
0
5
10
15
20
25
Weight percent of Mg2Si (%)

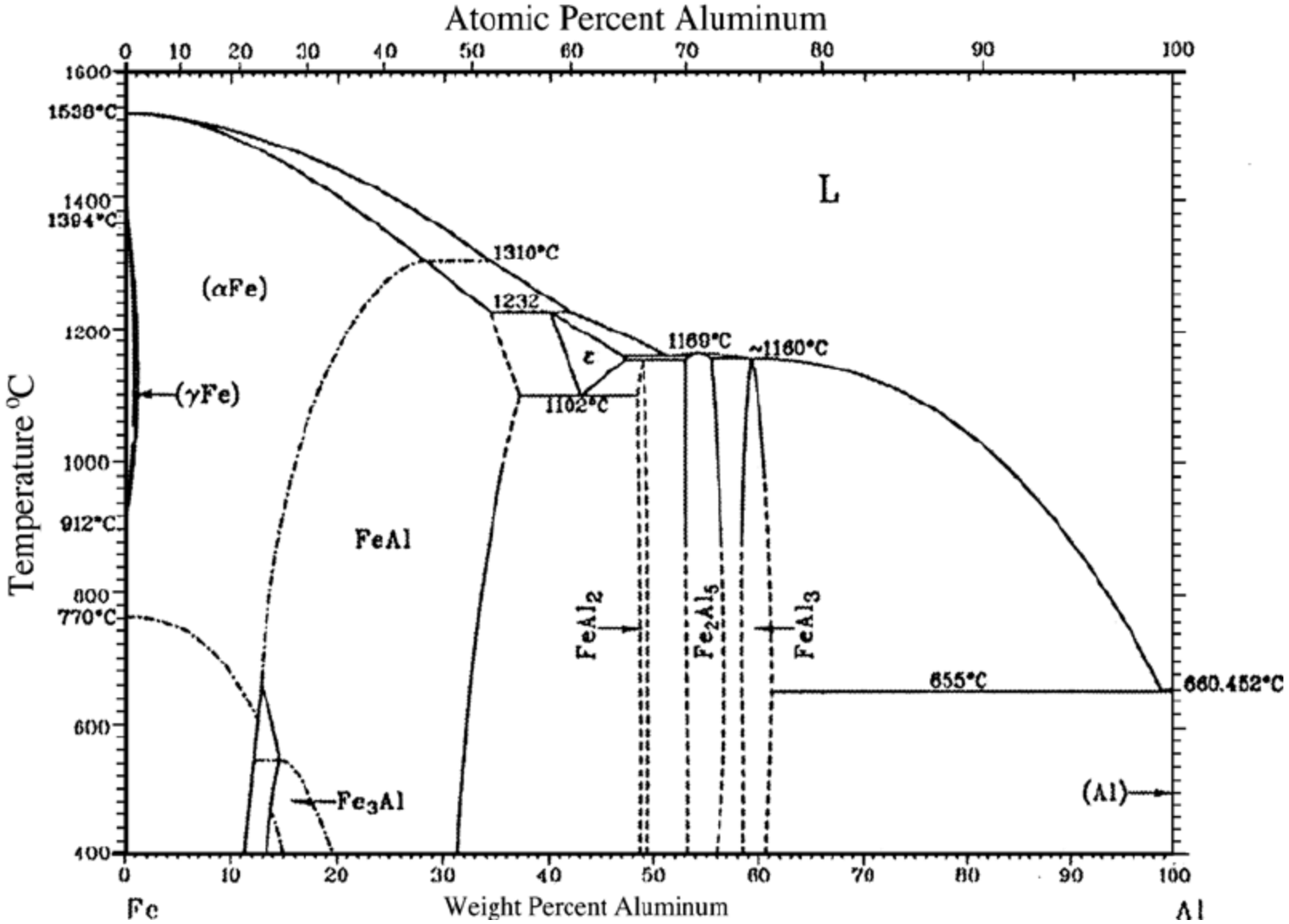


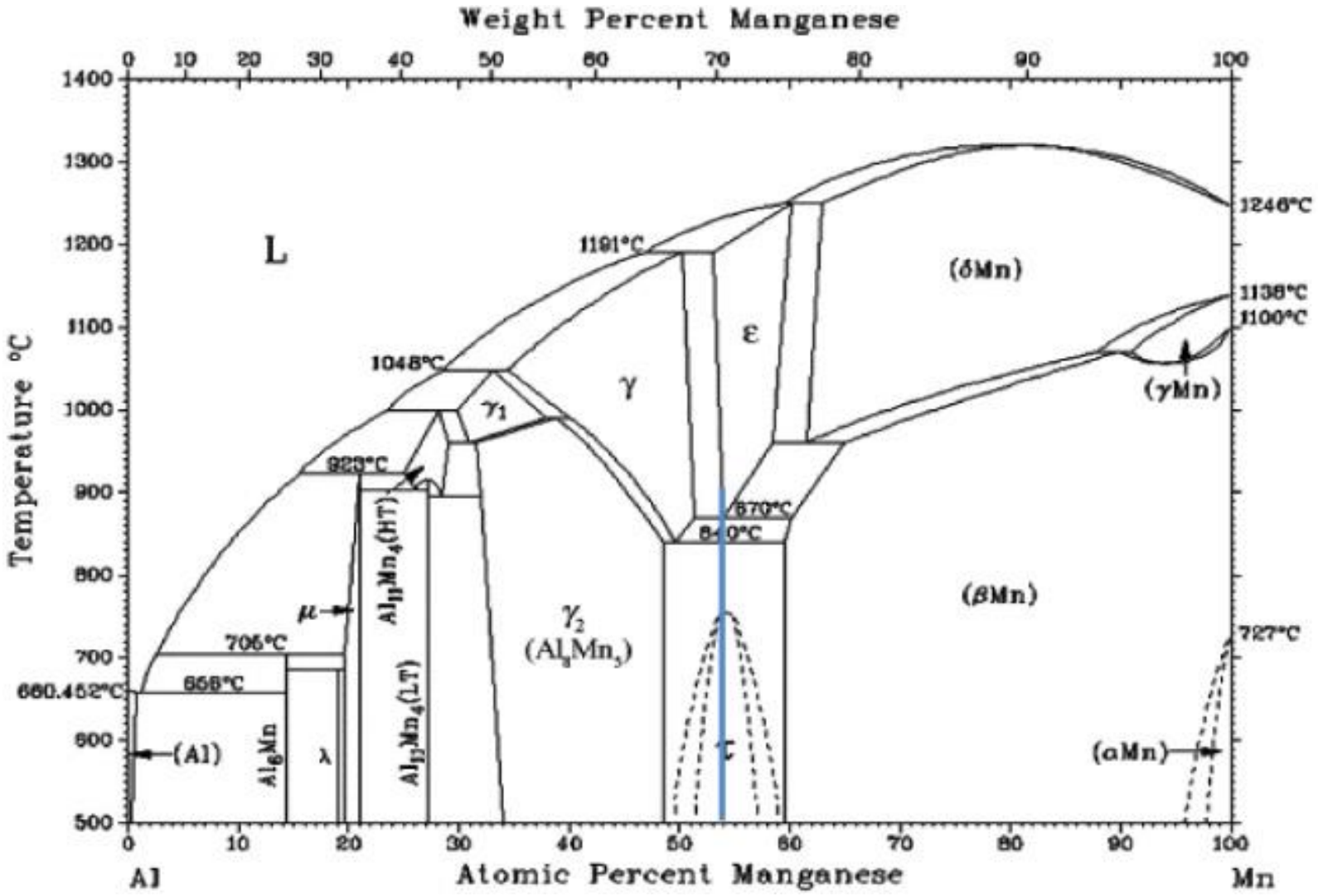
at% Cu
°C
0
10
20
30
40
50
60
70
80
90
100
1,100
1,000
900
800
700
600
500
400
300
L
660.452°
548.2°
5.65
32.7
53.5
52.5
κ
Θ
η1
η2
ζ1
ζ2
ε1
ε2
γ0
γ1
β0
β
α
α2
567°
Al
Cu
wt% Cu

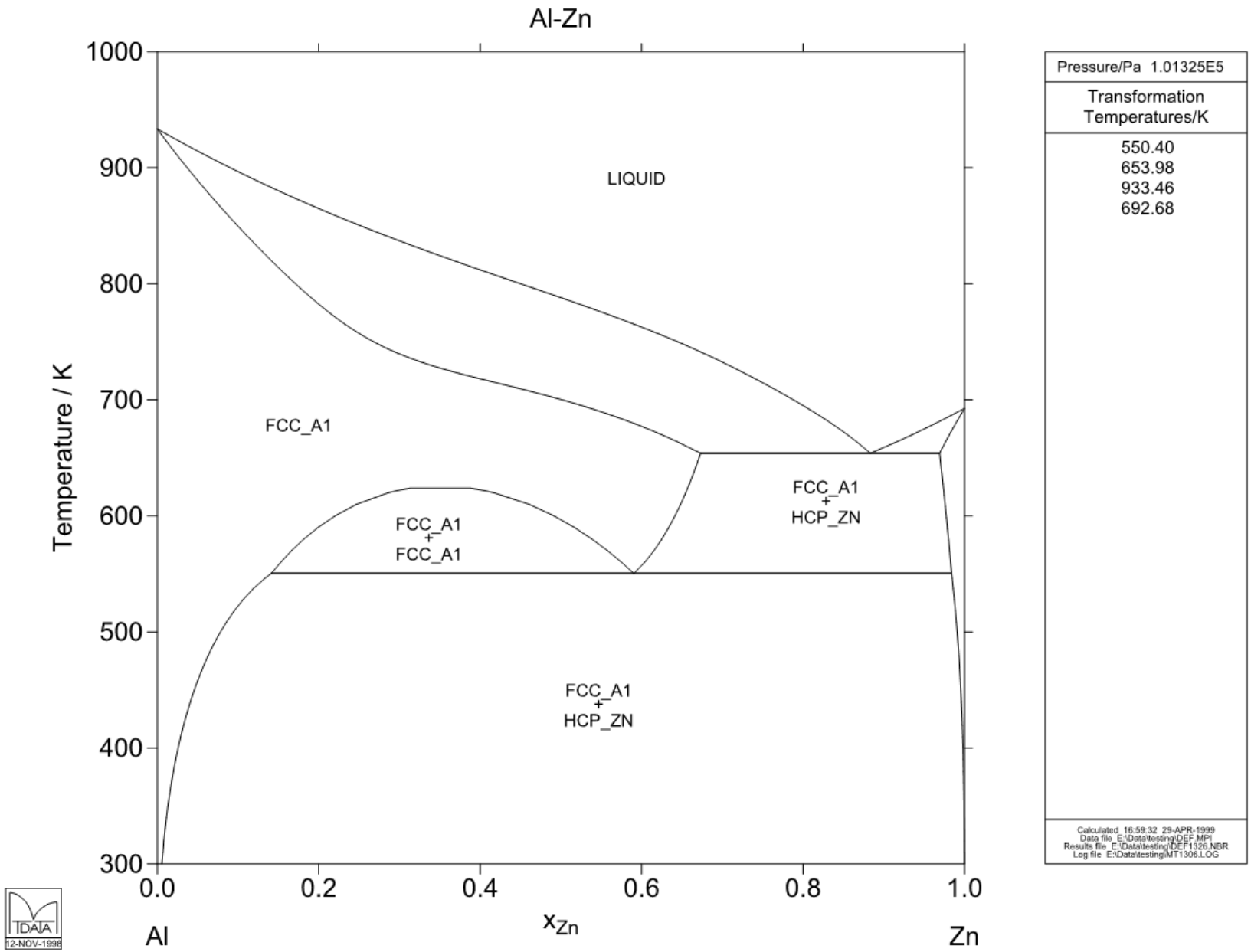
Phase diagram




Weight Percent Silicon
0
10
20
30
40
50
60
70
80
90
100
1414°C
1400
1300
1200
L
1100
1085°C
1000
945.6°C
900
53
650°C
800
Mg2Si
700
1.16
637.6°C
600
(Mg)
(Si)
Temperature °C
Mg
Atomic Percent Silicon
Si


Atomic Percent Aluminum
0 10 20 30 40 50 60 70 80 90 100
1600
1538°C
1400
1394°C
1200
1000
912°C
800
770°C
600
400
Temperature °C
L
1310°C
(αFe)
1232
1160°C
~1160°C
ε
(γFe)
1102°C
FeAl
FeAl2
Fe2Al5
FeAl3
655°C
660.452°C
Fe3Al
(Al)
0 10 20 30 40 50 60 70 80 90 100
Fe
Weight Percent Aluminum
Al

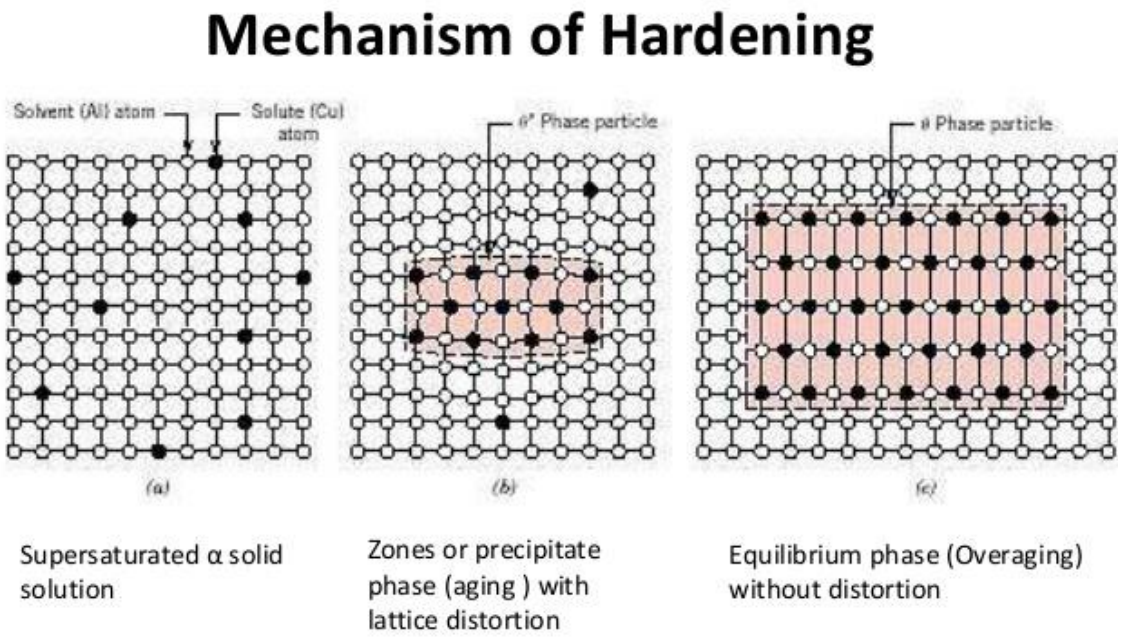

Weight Percent Manganese
Temperature °C
Atomic Percent Manganese
Al
Mn
L
1191°C
1246°C
(δMn)
1138°C
1100°C
(γMn)
1048°C
γ
γ1
ε
923°C
870°C
840°C
μ
705°C
658°C
660.452°C
(Al)
Al6Mn
λ
Al11Mn4(HT)
Al11Mn4(LT)
γ2
(Al8Mn5)
(βMn)
727°C
(αMn)
τ


Al-Zn
1000
900
800
700
600
500
400
300
Temperature / K
LIQUID
FCC_A1
FCC_A1
+
FCC_A1
FCC_A1
+
HCP_ZN
FCC_A1
+
HCP_ZN
0.0
0.2
0.4
0.6
0.8
1.0
Al
x_{Zn}
Zn
Pressure/Pa 1.01325E5
Transformation Temperatures/K
550.40
653.98
933.46
692.68
Calculated 16:59:32 29-APR-1999
Data file E:\Data\testing\DEF.MPI
Results file E:\Data\testing\DEF1326.NBR
Log file E:\Data\testing\MT1306.LOG
TDATA
12-NOV-1998

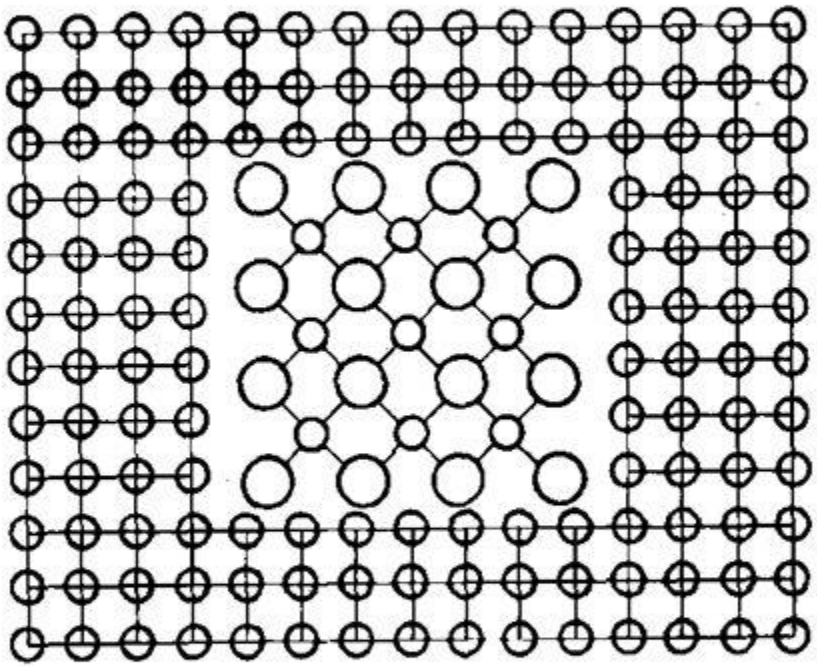
2) **Alaşım su alabilmeli veya alaşıma su verilebilmeli**

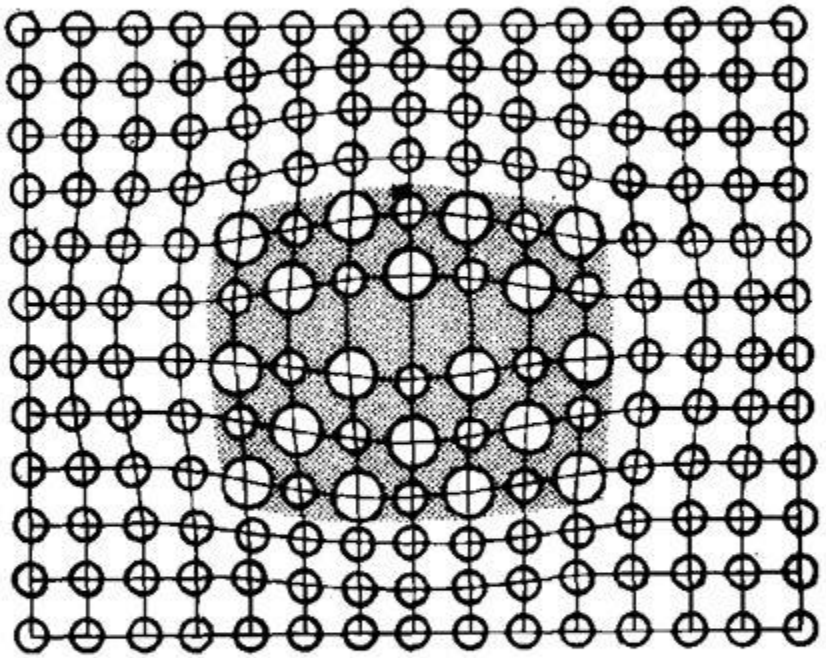
Yani, alaşıma yüksek sıcaklıkta kazandırılan yapı, hızlı soğutma sonucunda, oda sıcaklığında korunabilmeli

3) Matris ile çökelti partikülü koheran olmalı



Non-Coherent vs Coherent Precipitates





What is the difference in these two precipitates? Which would be more effective at blocking slip?

Difference between precipitation and Dispersion Strengthening

- Coherency occur in PS but No coherency presence in DS.
- DS stable at all temperatures but PS is not stables.
- Time factor not important for DS but PS time factor important.
- Any alloy can be made in case DS.
- In DS chemical stability is increase than PS.
- PS-isotropic and DS- Anisotropic

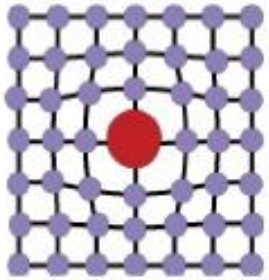


fig:3 Coherency PS

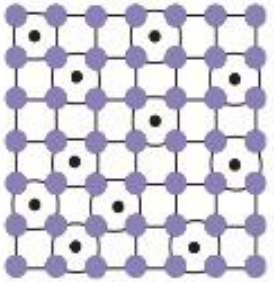
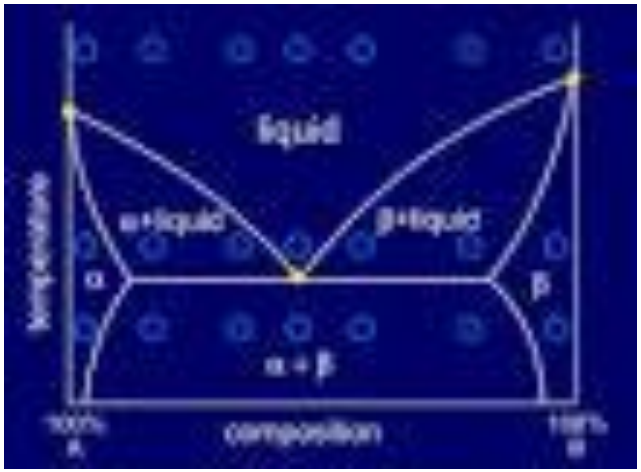
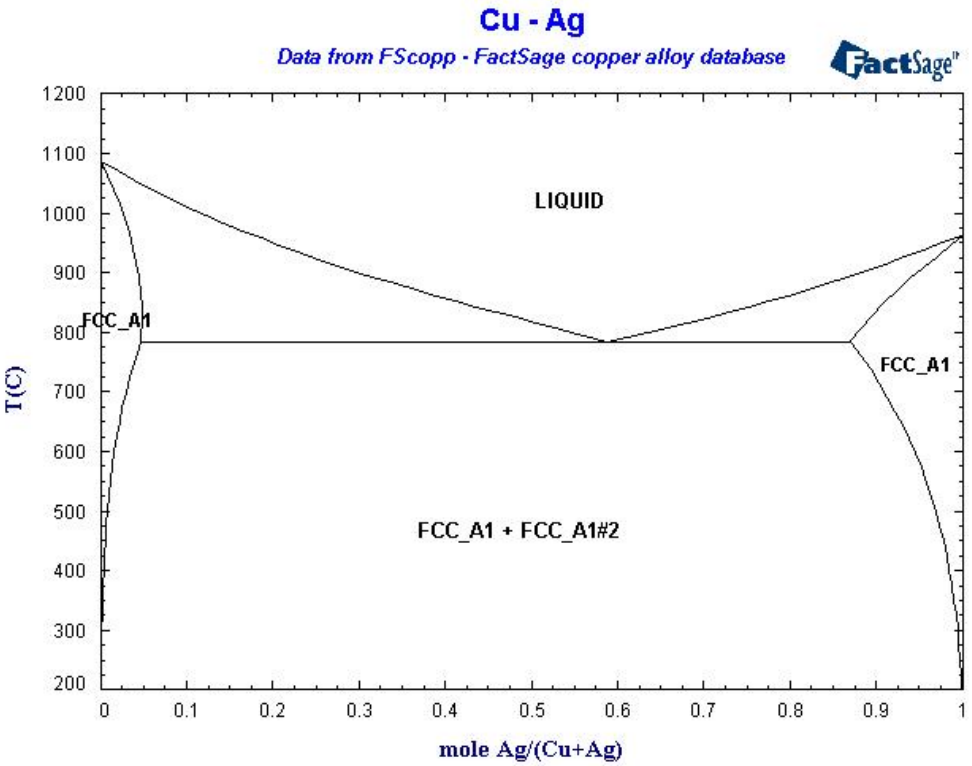


fig:4 No coherency DS

4) **Çökelti partikülü sert (intermetalik), matris yumuşak/sünek olmalı**

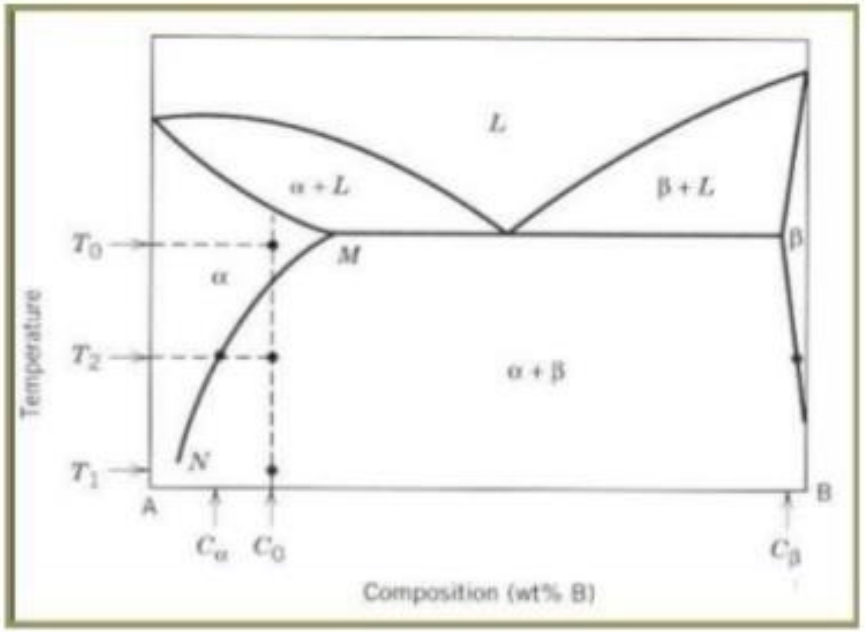




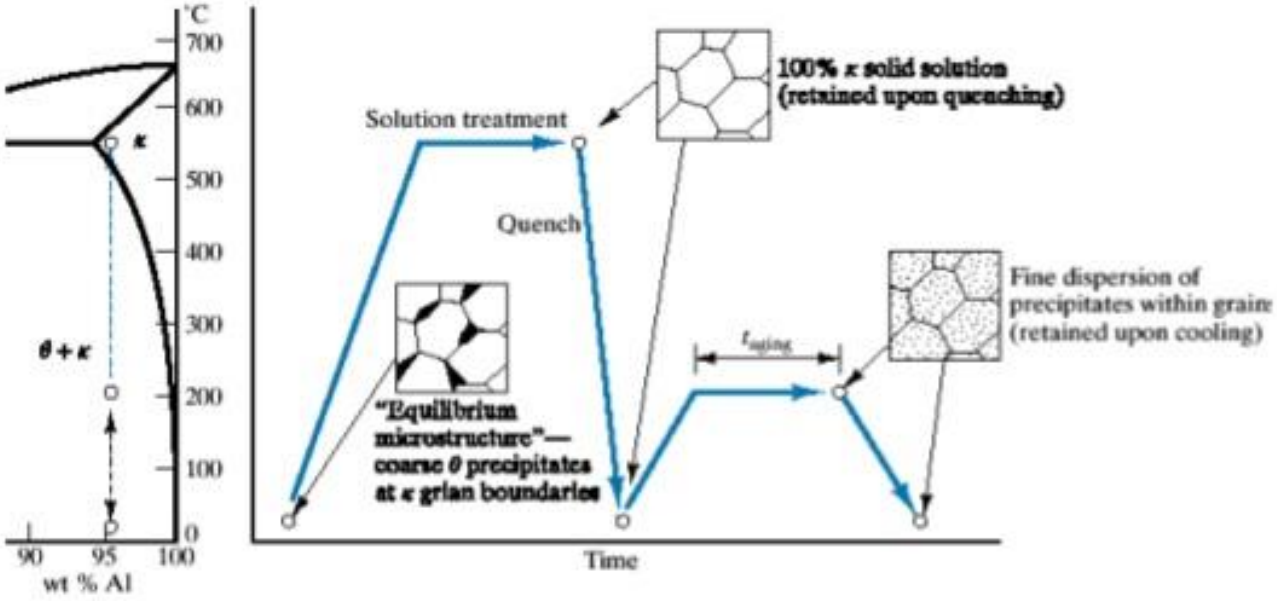
Operasyon

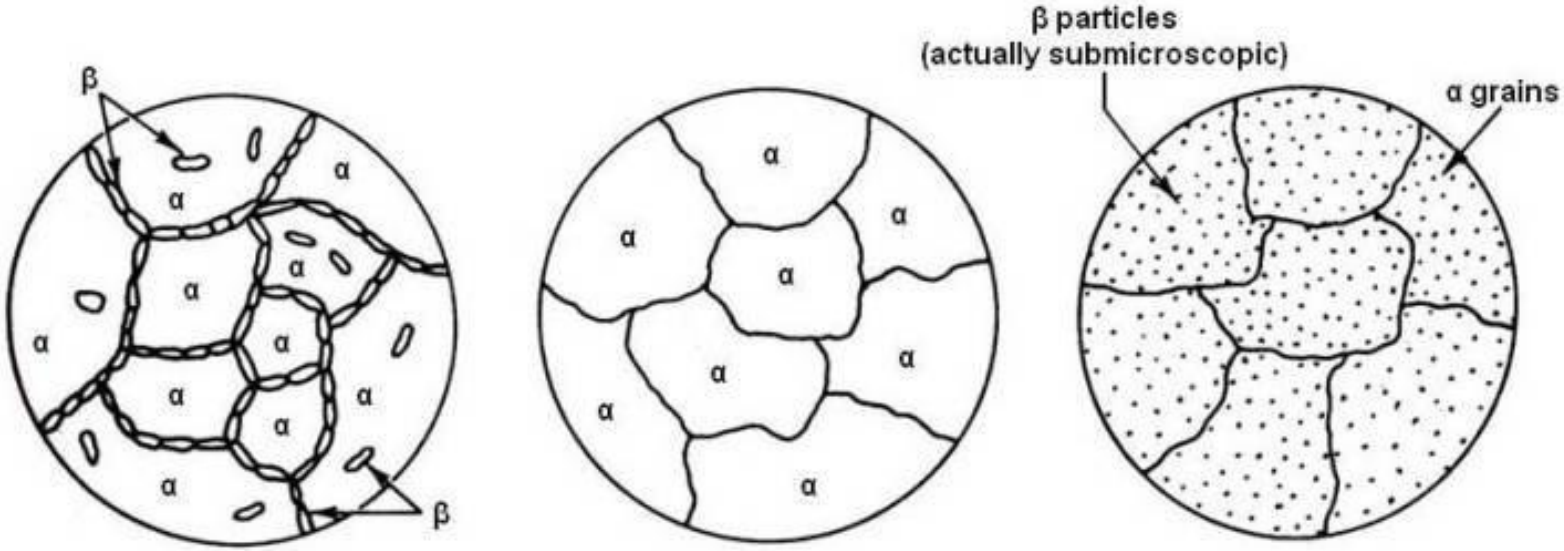
Precipitation Hardening

- A composition that can be precipitation hardened contains two phases at room temperature, but can be heated to a temperature that dissolves the second phase.



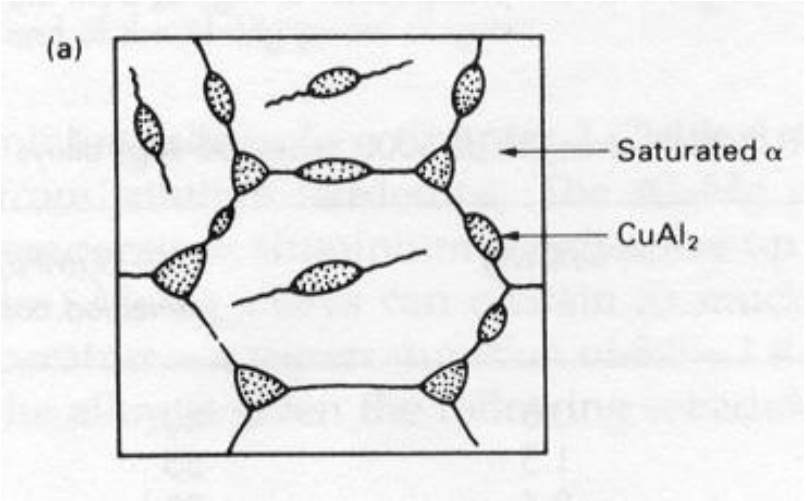
Steps in Precipitation Hardening

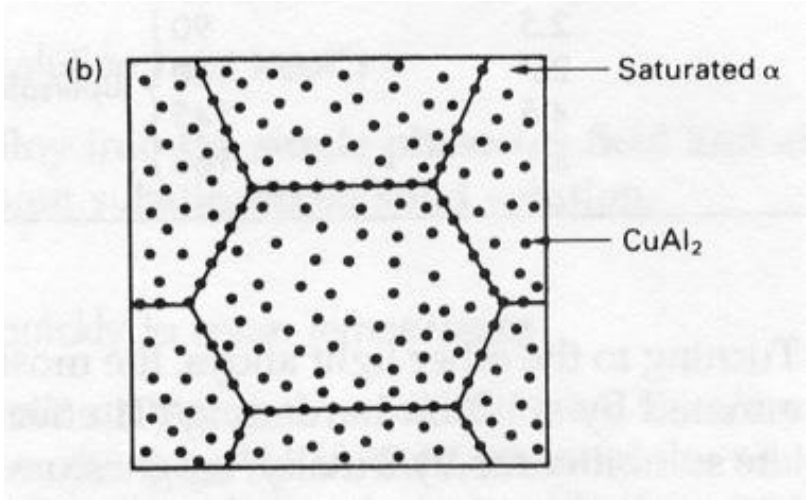




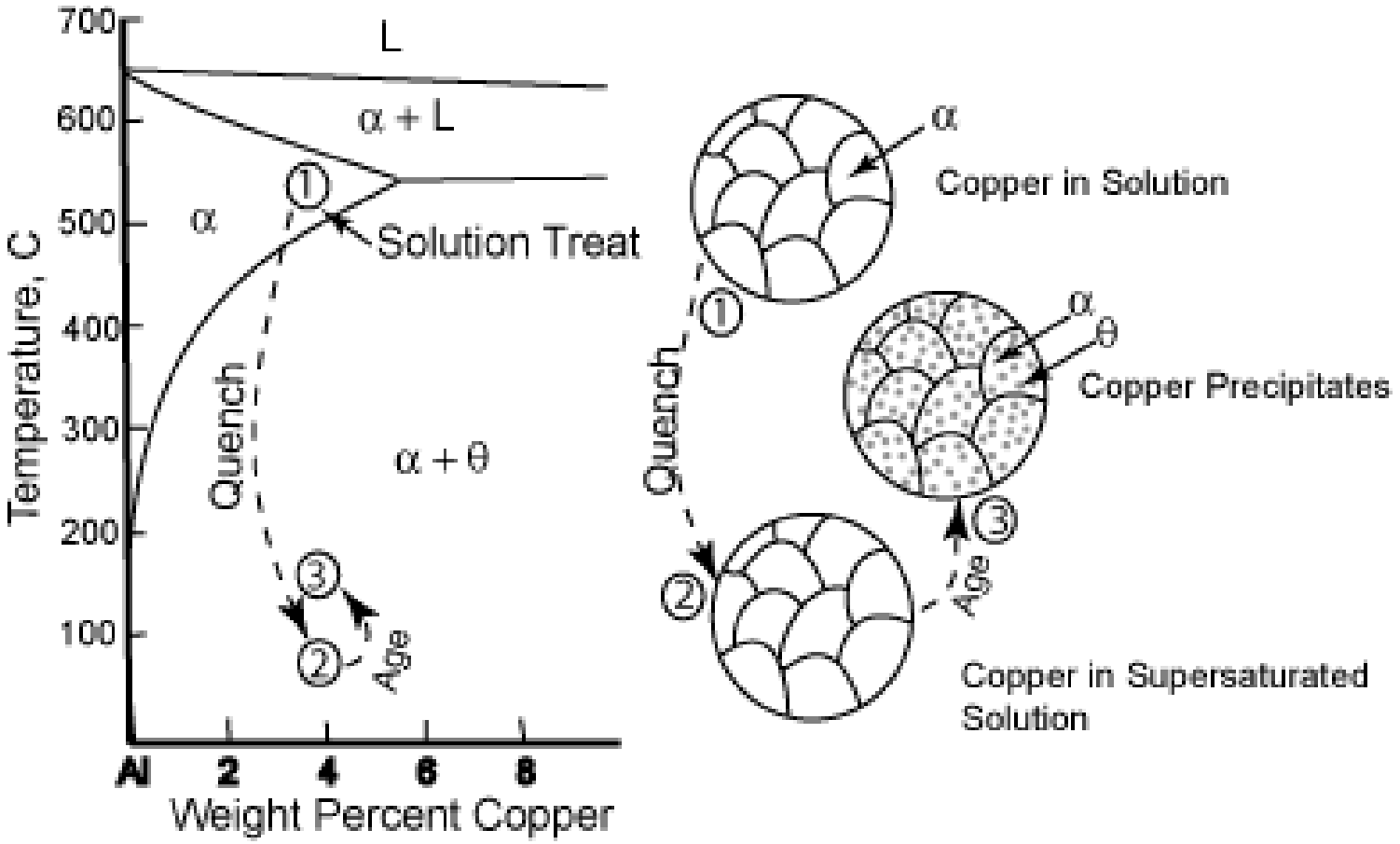
Microstructure of an 85A-15B alloy

Age (Precipitation) Hardening





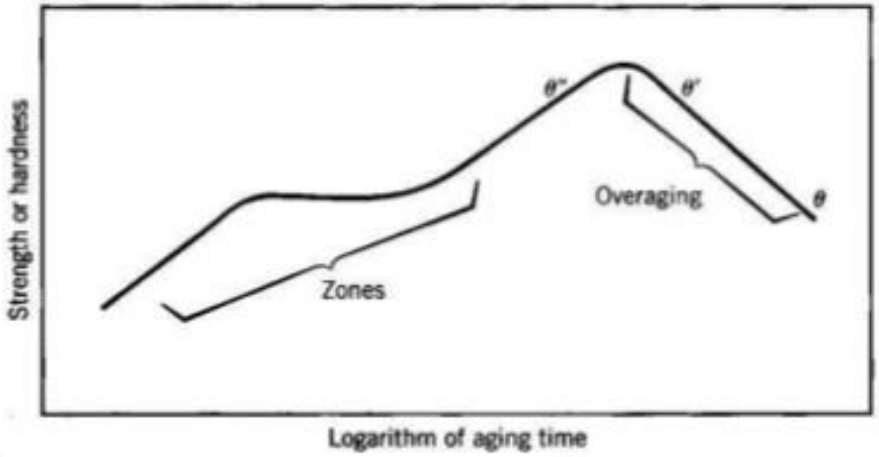
Room temperature microstructures in Al-4%Cu alloy.
(a) slow cooling; (b) moderately fast cooling


700
600
500
400
300
200
100
Temperature, C
L
α + L
α
α + θ
Solution Treat
Quench
Age
1
2
3
Al
2
4
6
8
Weight Percent Copper
α
Copper in Solution
θ
Copper Precipitates
Copper in Supersaturated Solution

Sertlik artışı

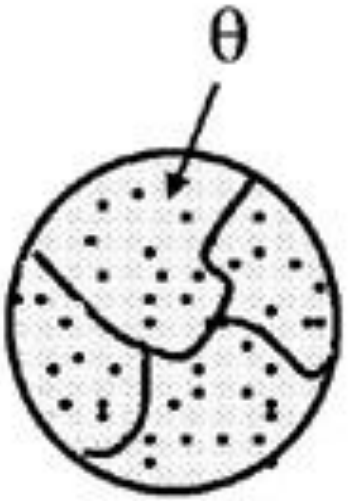
Precipitation Hardening

- aging can also occur at room temperature for some alloys (*natural aging*).
- Data represented as hardness or tensile strength vs aging time (log scale) for T-constant.
- Yield Strength increases as zones or precipitates form
- Strength reaches a peak value and then decreases (overageing)



Start:
α + coarse θ
(equilibrium at
room temperature)

After quench:
supersaturated α



Fine
precipitate θ
appears in α
to strengthen

Sıcaklığın etkisi

Effect of Aging Heat Treatment Time on the Strength of Aluminum Alloys

The operator of a furnace left for his hour lunch break without removing the Al-4% Cu alloy from the furnace used for the aging treatment. Compare the effect on the yield strength of the extra hour of aging for the aging temperatures of 190°C and 260°C.

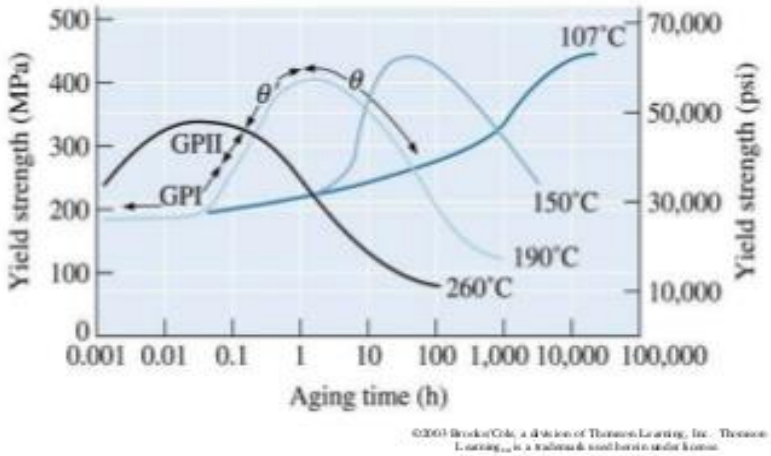


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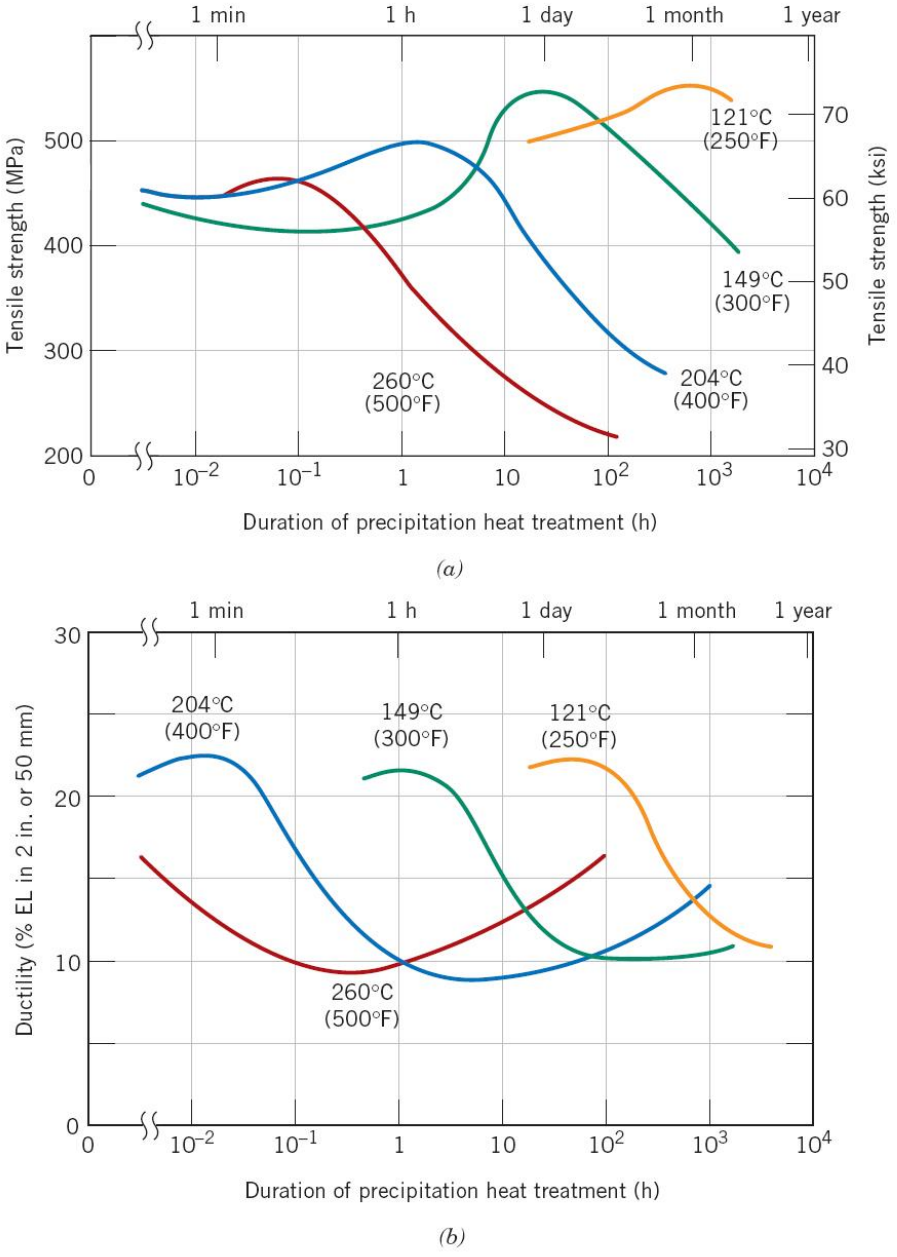
Fig – 2 The effect of aging temperature and time on the yield strength of an Al-4% Cu alloy.

Aşırı yaşlanma

Figure 11.27 The precipitation hardening characteristics of a 2014 aluminum alloy (0.9 wt% Si, 4.4 wt% Cu, 0.8 wt% Mn, 0.5 wt% Mg) at four different aging temperatures: (*a*) tensile strength, and (*b*) ductility (%EL). [Adapted from *Metals Handbook: Properties and Selection: Nonferrous Alloys and Pure Metals*, Vol. 2, 9th edition, H. Baker (Managing Editor), American Society for Metals, 1979, p. 41.]



Alüminyum Malzemelerin Isıl İşlemleri ve Süreç Analizleri

Heat treating of aluminum and aluminum alloys

The general types of heat treatments applied to aluminum and its alloys are:

- **Preheating or homogenizing**, to reduce chemical segregation of cast structures and to improve their workability;
- **Annealing,** to soften strain-hardened (work-hardened) and heat treated alloy structures, to relieve stresses, and to stabilize properties and dimensions;
- **Solution heat treatments**, to effect solid solution of alloying constituents and improve mechanical properties;
- **Precipitation heat treatments**, to provide hardening by precipitation of constituents from solid solution

- Heat treating processes for aluminum are **precision processes**.
- They must be carried out in furnaces properly designed and built to provide the thermal conditions required, and adequately equipped with control instruments to insure the desired continuity and uniformity of temperature-time cycles.
- To insure the final desired characteristics, process details must be established and controlled carefully for each type of product.

INGOT PREHEATING TREATMENTS (HOMOGENIZING)

The initial thermal operation **applied to ingots prior to hot working is referred to as "ingot preheating",** which has one or more purposes depending upon the alloy, product, and fabricating process involved.

One of the principal objectives **is improved workability.** The microstructure of most alloys in the as-cast condition is quite heterogeneous. This is true for alloys that form solid solutions under equilibrium conditions, and even for relatively dilute alloys

ANNEALING

- The distorted, dislocated structure resulting from cold working of aluminum is less stable than the strain-free, annealed state, to which it tends to revert. Lower-purity aluminum and commercial aluminum alloys undergo these structural changes only with annealing at elevated temperatures. Accompanying the structural reversion are changes in the various properties affected by cold working. These changes occur in several stages, according to temperature or time, and have led to the concept of different annealing mechanisms or processes.
- **Recovery**. The reduction in the number of dislocations is greatest at the center of the grain fragments, producing a subgrain structure with networks or groups of dislocations at the subgrain boundaries. With increasing time and temperature of heating, polygonization becomes more nearly perfect and the subgrain size gradually increases. In this stage, many of the subgrains appear to have boundaries that are free of dislocation tangles and concentrations.

ANNEALING

- Recovery annealing is also accompanied by changes in other properties of cold worked aluminum. Complete recovery from the effects of cold working is obtained only with recrystallization.
- **Recrystallization** is characterized by the gradual formation and appearance of a microscopically resolvable grain structure. The new structure is largely strain-free-there are few if any dislocations within the grains and no concentrations at the grain boundaries.
- **Grain Growth After Recrystallization**. Heating after recrystallization may produce grain coarsening. This can take one of several forms.

Annealing

- Annealing is applied to both grades to promote softening. Complete and partial annealing heat treatments are the only ones used for the non-heat treatable alloys. The exception is the 5000 series alloys which are sometimes given low temperature stabilisation treatment and this is carried out by the producer.
- Annealing is carried out in the range 300-410°C depending on the alloy. Heating times at temperature vary from 0.5 to 3 hours, conditional on the size of the load and the alloy type. Generally, the time need not be longer than that required to stabilise the load at temperature. Rate of cooling after annealing is not critical.
- Where parts have been solution heat-treated a maximum cooling rate of 20°C per hour must be maintained until the temperature is reduced to 290°C. Below this temperature, the rate of cooling is not important.

Solution Heat Treatment

- This is applicable to the heat treatable alloys and involves a heat treatment process whereby the alloying constituents are taken into solution and retained by rapid quenching. Subsequent heat treatment at tower temperatures i.e. ageing or natural ageing at room temperature allows for a controlled precipitation of the constituents thereby achieving increased hardness and strength.
- Time at temperature for solution treatment depends on the type of alloy and the furnace load. Sufficient time must be allowed to take the alloys into solution if optimum properties are to be obtained.
- .

Solution Heat Treatment

- The solution treatment temperature is critical to the success of the procedure. It is desirable that the solution heat treatment is carried out as close as possible to the liquidus temperature in order to obtain maximum solution of the constituents. Accurate furnace temperature and special temperature variation must be controlled to within a range of ±5°C for most alloys. Overheating must be avoided i.e. exceeding initial eutectic melting temperatures. Often the early stages of overheating are not apparent but will result in a deterioration of mechanical properties.
- Proper solution heat treatment of the aluminium alloys requires an expert knowledge of the alloy being treated plus the correct heat treatment plant

PRECIPITATION HARDENING

- **General Principles of Precipitation Hardening**. The heat treatable alloys contain amounts of soluble alloying elements that exceed the equilibrium solid solubility limit at room and moderately higher temperatures. The amount present may be less or more than the maximum that is soluble at the eutectic temperature.
- **Nature of Precipitates and Sources of Hardening**. Intensive research during the past forty years has resulted in a progressive accumulation of knowledge concerning the atomic and crystallographic structural changes that occur in supersaturated solid solutions during precipitation and the mechanisms through which the structures form and alter alloy properties. In most precipitation-hardenable systems, a complex sequence of time-dependent and temperature-dependent changes is involved.

PRECIPITATION HARDENING

- **Kinetics of Solution and Precipitation**. The relative rates at which solution and precipitation reactions occur with different solutes depend upon the respective diffusion rates, in addition to solubilities and alloy contents. Bulk diffusion coefficients for several of the commercially important alloying elements in aluminum were determined by various experimental methods.
- **Nucleation**. The formation of zones can occur in an essentially continuous crystal lattice by a process of homogeneous nucleation. Recent investigations provide evidence that a critical vacancy concentration is required for this process and that a nucleation model involving vacancy-solute atom clusters is consistent with certain effects of solution temperature and quenching rate.
- The nucleation of a new phase is greatly influenced by the existence of discontinuities in the lattice. Since in polycrystalline alloys grain boundaries, subgrain boundaries, dislocations, and interphase boundaries are locations of greater disorder and higher energy than the solid-solution matrix, they are preferred sites for nucleation of precipitates.

Quenching

- **Quenching** Quenching is in many ways the most critical step in the sequence of heat treating operations. The objective of quenching is to preserve as nearly intact as possible the solid solution formed at the solution heat treating temperature, by rapidly cooling to some lower temperature, usually near room temperature.
- **Critical Temperature Range**. The fundamentals involved in quenching precipitation-hardenable alloys are based on nucleation theory applied to diffusion-controlled solid state reactions. The effects of temperature on the kinetics of isothermal precipitation depend principally upon degree of supersaturation and rate of diffusion.
- **Quenching Medium**. Water is not only the most widely used quenching medium but also the most effective. It is apparent that in immersion quenching, cooling rates can be reduced by increasing water temperature. Conditions that increase the stability of a vapor film around the part decrease the cooling rate; various additions to water that lower surface tension have the same effect.

Quenching

- The usual quenching medium is water at room temperature. In some circumstances slow quenching is desirable as this improves the resistance to stress corrosion cracking of certain copper-free Al-Zn-Mg alloys.
- Parts of complex shapes such as forgings, castings, impact extrusions and components produced from sheet metal may be quenched at slower quenching rates to improve distortion characteristics.
- Thus a compromise must be considered to achieve a balance of properties in some instances. Quenchants used in slower quenching applications include water heated to 65-80°C, boiling water, aqueous solutions of polyalkalene glycol or forced air blast.

Quenching

- This is a critical operation and must be carried out to precise limits if optimum results are to be obtained. The objective of the quench is to ensure that the dissolved constituents remain in solution down to room temperature.
- The speed of quenching is important and the result can be affected by excessive delay in transferring the work to the quench. The latitude for the delay is dependant on section and varies from 5 to 15 seconds for items of thickness varying from 0.4mm to 12.7mm. Generally, very rapid precipitation of constituents commences at around 450°C for most alloys and the work must not be allowed to fall below this temperature prior to quenching.
- Another factor to be considered in quenching is the work load and the ability of the quenchant to extract the heat at sufficient rate to achieve the desired results.

Age Hardening

- **Aging at Room Temperature (Natural Aging)**
- Most of the heat treatable alloys exhibit age hardening at room temperature after quenching, the rate and extent of such hardening varying from one alloy to another. No discernible microstructural changes accompany the room-temperature aging, since the hardening effects are attributable solely to the formation of zone structure within the solid solution.
- Since the alloys are softer and more ductile immediately after quenching than after aging, straightening or forming operations may be performed more readily in the freshly quenched condition.

Age Hardening

- **Precipitation Heat Treating (Artificial Aging)**
- The effects of precipitation on mechanical properties are greatly accelerated, and usually accentuated, by reheating the quenched material to about 100 to 200°C. The effects are not entirely attributable to a changed reaction rate; as mentioned previously, the structural changes occurring at the elevated temperatures differ in fundamental ways from those occurring at room temperature. These differences are reflected in the mechanical characteristics and some physical properties. A characteristic feature of elevated-temperature aging effects on tensile properties is that the increase in yield strength is more pronounced than the increase in tensile strength. Also ductility, as measured by percentage elongation, decreases. Thus, an alloy in the T6 temper has higher strength but lower ductility than the same alloy in the T4 temper.

Age Hardening

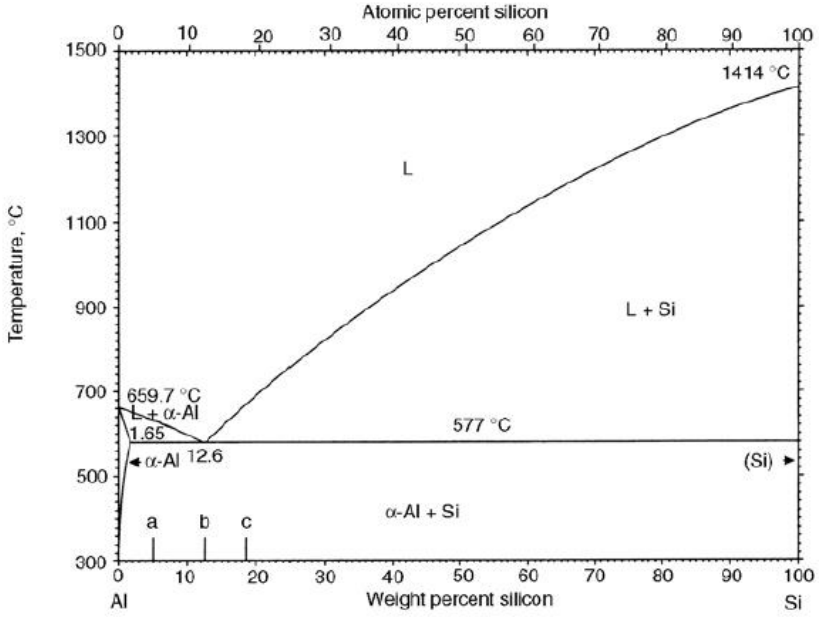
- After solution treatment and quenching, hardening is achieved either at room temperature (natural ageing) or with a precipitation heat treatment (artificial ageing). In some alloys sufficient precipitation occurs in a few days at room temperature to yield stable products with properties that are adequate for many applications. These alloys sometimes are precipitation heat treated to provide increased strength and hardness in wrought and cast alloys. Other alloys with slow precipitation reactions at room temperature are always precipitation heat treated before being used.
- In some alloys, notably those of the 2xxx series, cold working of freshly quenched materials greatly increases its response to later precipitation treatment. Mills take advantage of this phenomenon by applying a controlled amount of rolling (sheet and plate) or stretching (extrusion, bar and plate) to produce higher mechanical properties. However, if the higher properties are used in design, reheat treatment must be avoided.

Age Hardening

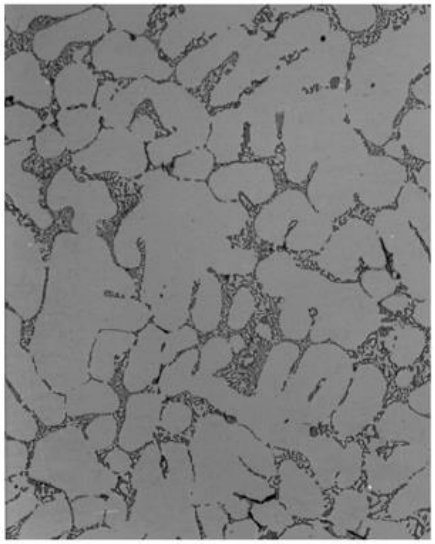
- Where natural ageing is carried out the time may vary from around 5 days for the 2xxx series alloys to around 30 days for other alloys. The 6xxx and 7xxx series alloys are considerably less stable at room temperature and continue to exhibit changes in mechanical properties for many years. With some alloys, natural ageing may be suppressed or delayed for several days by refrigeration at -18°C or lower. It is common practice to complete forming, straightening and coining before ageing changes material properties appreciably. Conventional practice allows for refrigeration of alloys 2014 - T4 rivets to maintain good driving characteristics.
- The artificial ageing or precipitation heat treatments are low temperature long time processes. Temperatures range from 115-200°C and times from 5-48 hours. As with solution treatment accurate temperature control and spatial variation temperatures are critical to the process and generally temperatures should be held to a range of ±7°C.
- The change of time-temperature parameters for precipitation treatment should receive careful consideration. Larger particles or precipitates result from longer times and higher temperatures. The objective is to select the cycle that produces the optimum precipitate size and distribution pattern. Unfortunately, the cycle required to maximise one property, such as tensile strength, is usually different from that required to maximise others such as yield strength and corrosion resistance. Consequently, the cycles used represent compromises that provide the best combination of properties.

- **Precipitation Heat Treating Without Prior Solution Heat Treatment**
- Certain alloys that are relatively insensitive to cooling rate during quenching can be either air cooled or water quenched directly from a final hot working operation. In either condition, these alloys will respond strongly to precipitation heat treatment.
- **Precipitation Heat Treating Cast Products**
- The mechanical properties of permanent mold, sand, and plaster castings of most alloys are greatly improved by solution heat treating, quenching, and precipitation heat treating, using practices analogous to those employed for wrought products.

Mikroyapı Analizi

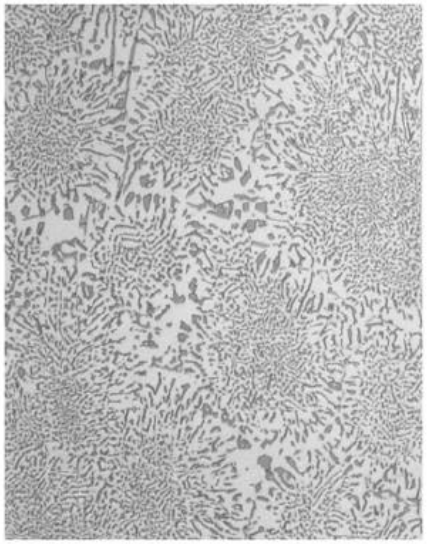


(a)



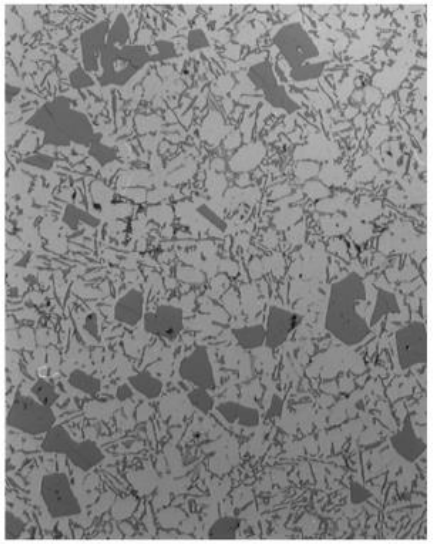
(b)

75 μm



(c)

25 μm



(d)

75 μm

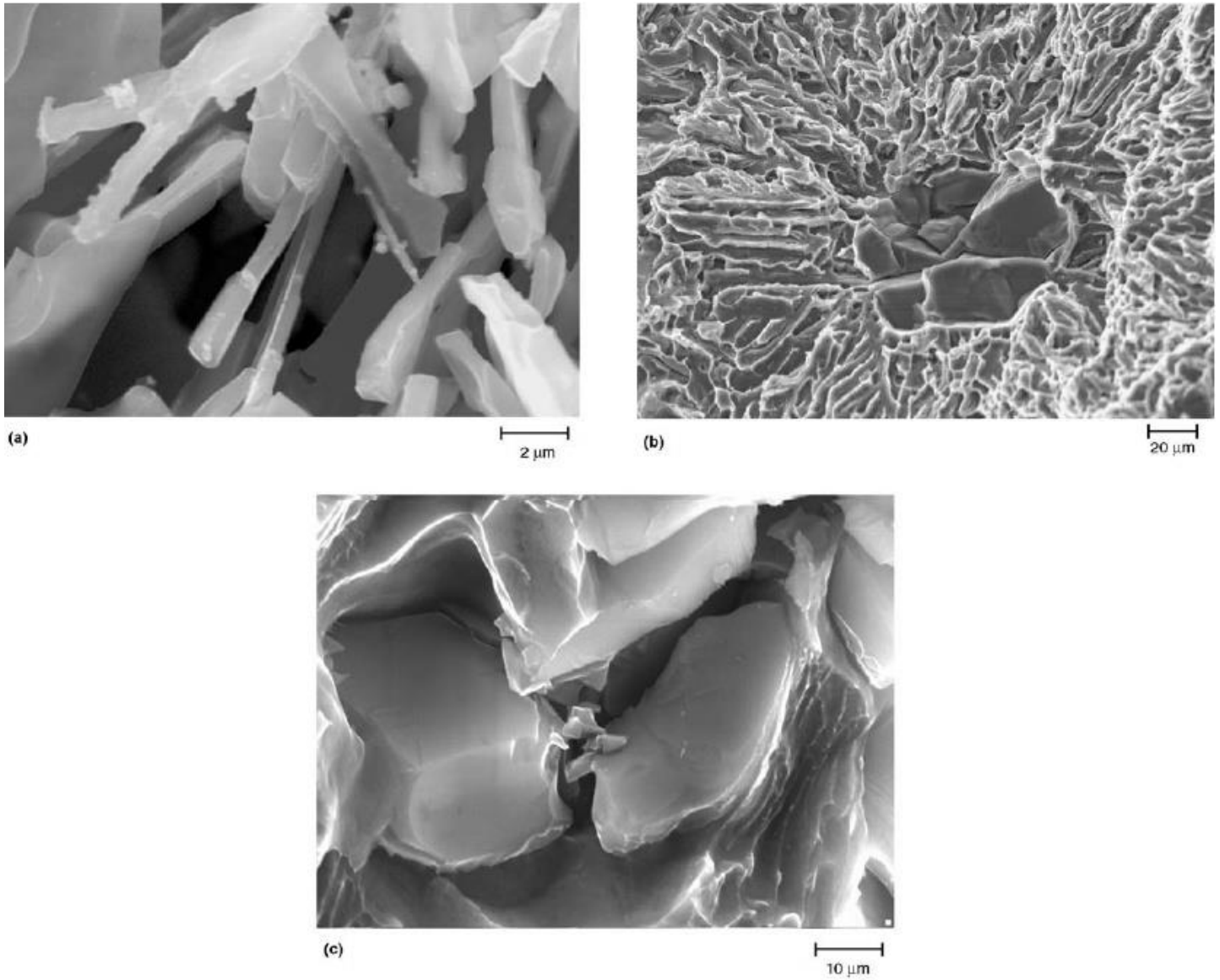
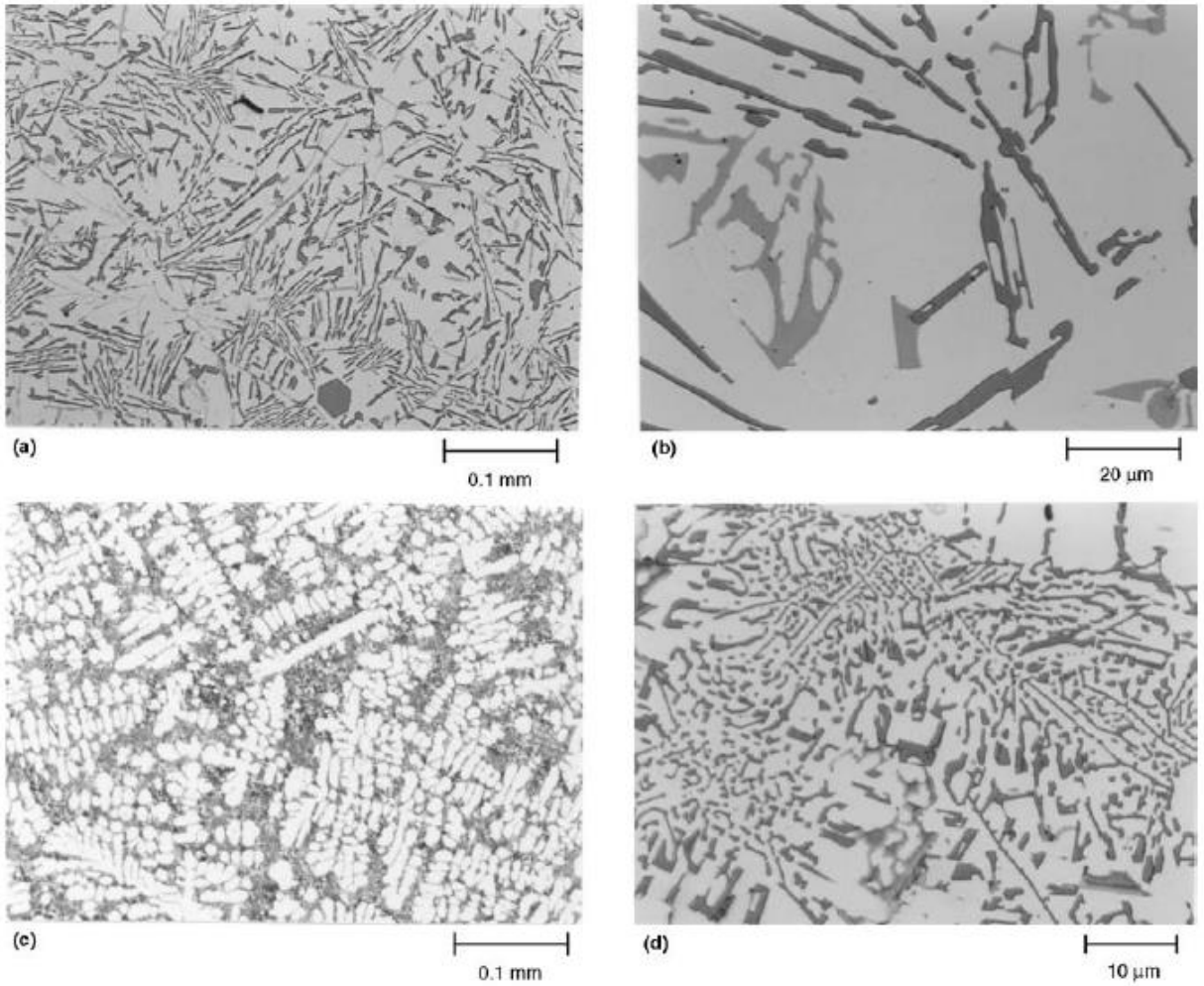


Fig. 1.3 Morphology of the silicon crystals in aluminum-silicon alloys. (a) Silicon crystals in eutectic as-cast alloy. Scanning electron micrograph (SEM). 6500×. (b) Primary silicon crystals in hypereutectic as-cast alloy. SEM. 400×. (c) Silicon crystals in hypoeutectic alloy modified, after heat treatment. SEM. 1500×

Composition and Properties

Alloy	Designation	Chemical composition (main components), wt%						Properties(a)	
		Si	Cu	Mg	Mn	Ni	Fe	R_m, MPa	A_5, %
As-examined	AlSi13Mg1CuNi	11.5–13.0	0.8–1.5	0.8–1.5	. . .	0.8–1.3	0.8	220	0.5
Aluminum Association standard (b)	336.0	11.0–13.0	0.50–1.5	0.7–1.3	0.35 max	2.0–3.0	1.2 max	214	0.5

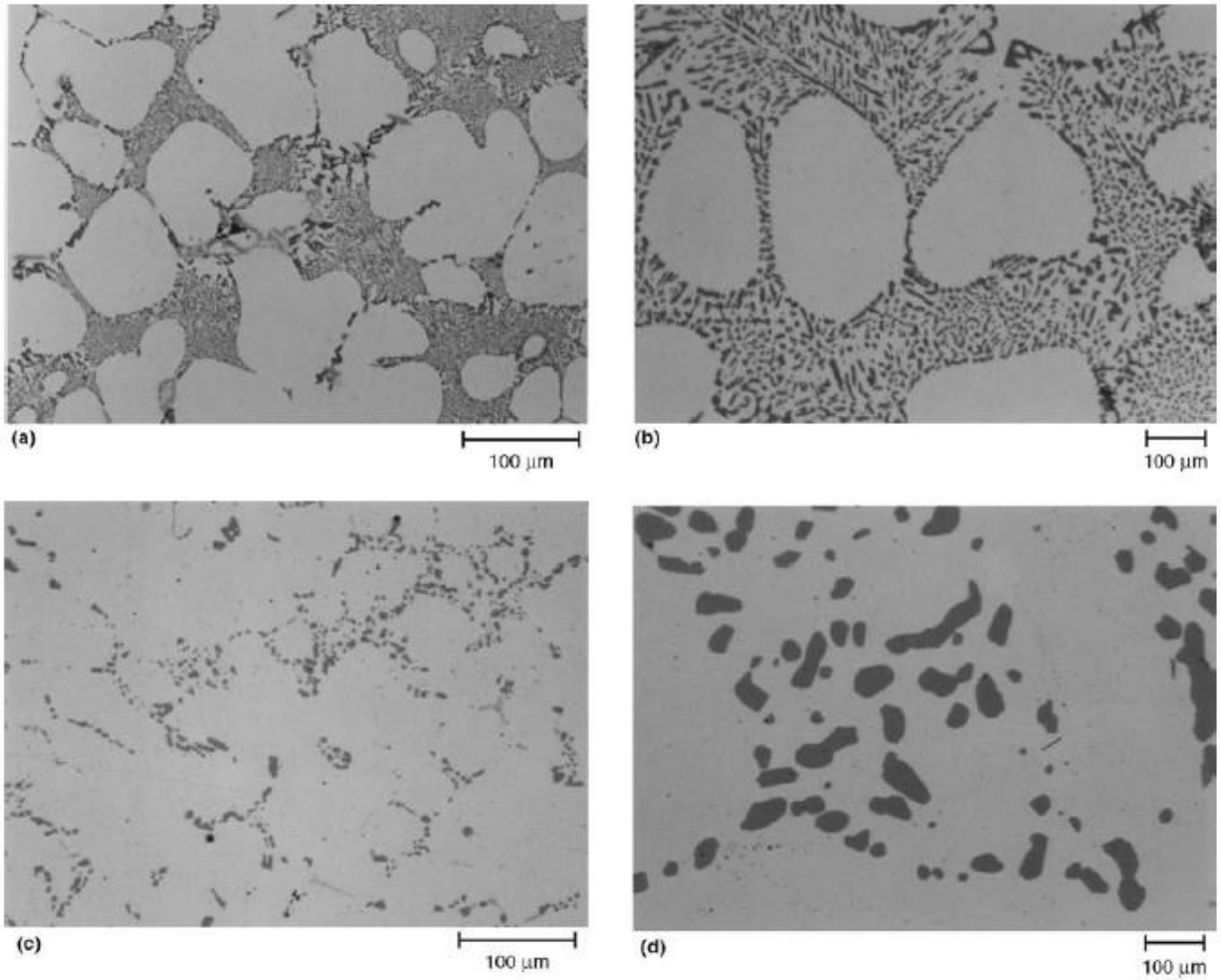


g. 4.1 Microstructures of AlSi13Mg1CuNi (Alloy 336.0). Light microscope micrographs; etched with 1% HF. (a) As-cast (F). 150×. (b) As-cast (F). 750× (c) As-cast modified. 150×. (d) As-cast modified, 1200×

Composition and Properties

Alloy	Designation	Chemical composition (main components), wt%						Properties(a)	
		Si	Cu	Mg	Mn	Ni	Fe	R_m, MPa	A_5, %
As-examined	AlSi7Mg	6.0–8.0	. . .	0.25–0.4	0.1–0.5	. . .	0.9 (max)	210	2
Aluminum Association standard(b)	356.0	6.5–7.5	0.25 max	02–0.45	0.35 max	. . .	0.6 max	228	5

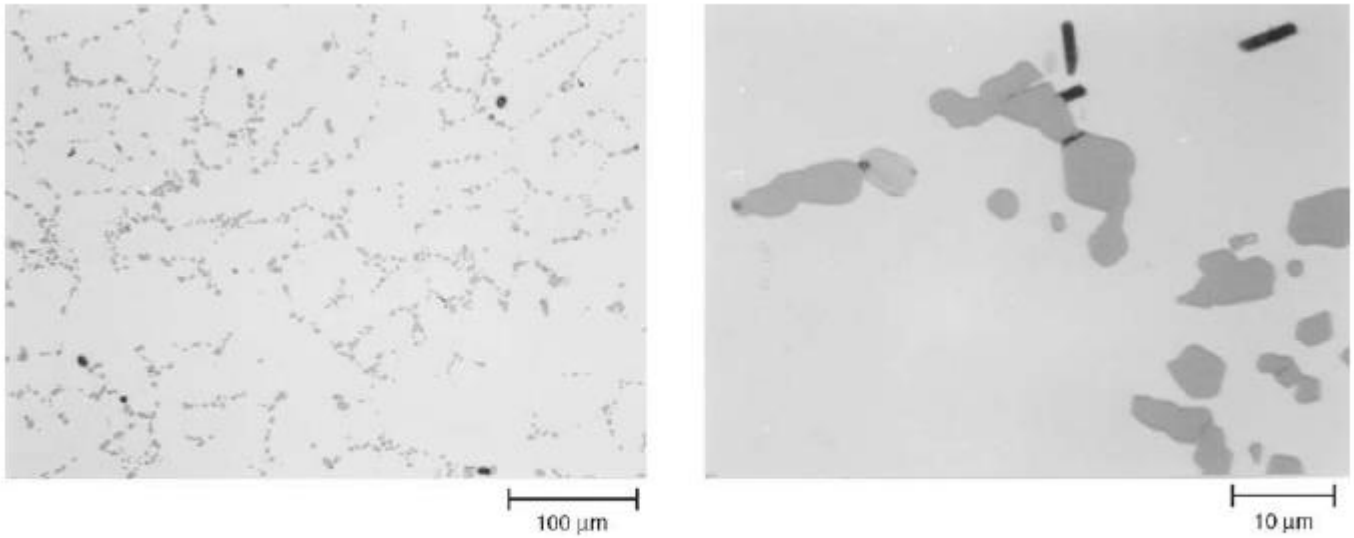
Microstructures



g. 6.1 Microstructures of AlSi7Mg (Alloy 356.0). Light microscope micrographs; etched with 1% HF. (a) As-cast modified, 150×. (b) As-cast modified, 750× (c) After heat treatment (T6), 150×. (d) After heat treatment (T6), 750×

Composition and Properties

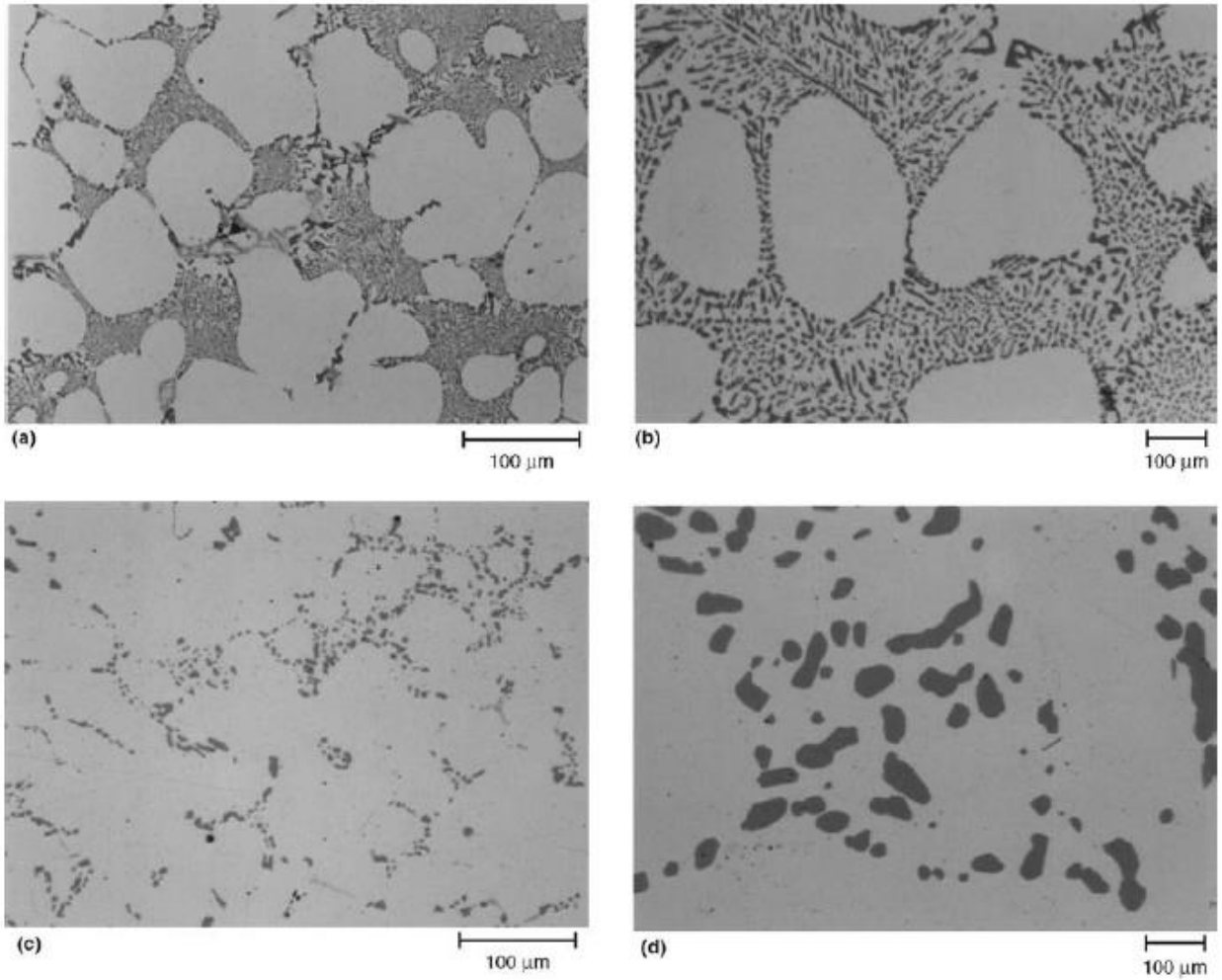
Alloy	Designation	Chemical composition (main components), wt%						Properties(a)	
		Si	Cu	Mg	Mn	Ni	Fe	R_m, MPa	A_5, %
As-examined	AlSi5Cu	4.5–5.5	1.0–1.5	0.35–0.6	0.2–0.5	. . .	0.9 max	200	0.5
Aluminum Association standard(b)	355.0	4.5–5.5	1.0–1.5	0.40–0.6	0.5 max	. . .	0.6 max	186	3



Microstructures of AlSi5Cu (Alloy 355.0). Light microscope micrographs; etched with 1% HF. (a) After heat treatment (T6), 150×. (b) After heat treatment (T6), 1200×

Composition and Properties

Alloy	Designation	Chemical composition (main components), wt%						Properties(a)	
		Si	Cu	Mg	Mn	Ni	Fe	R_m, MPa	A_5, %
As-examined	AlSi7Mg	6.0–8.0	. . .	0.25–0.4	0.1–0.5	. . .	0.9 (max)	210	2
Aluminum Association standard(b)	356.0	6.5–7.5	0.25 max	02–0.45	0.35 max	. . .	0.6 max	228	5

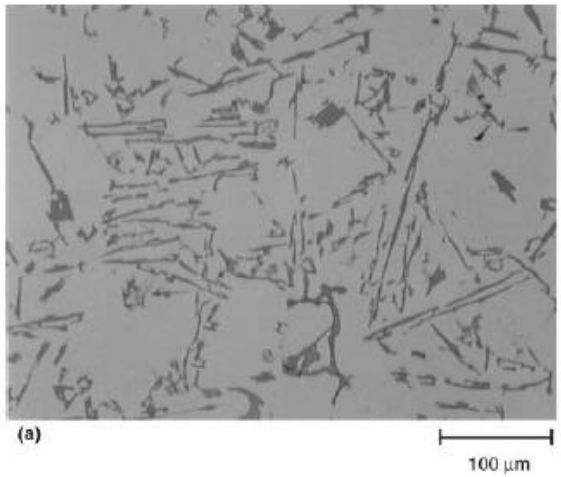


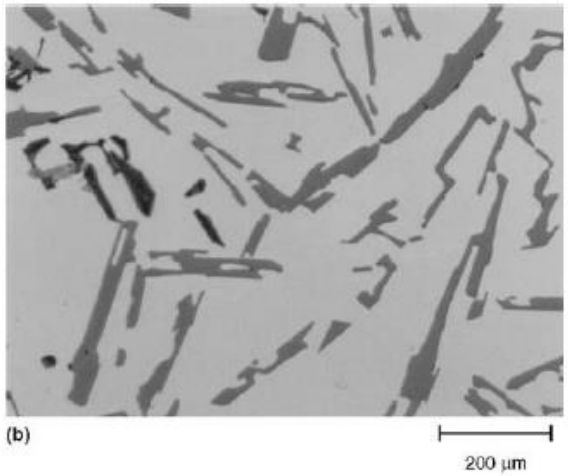
.1 Microstructures of AlSi7Mg (Alloy 356.0). Light microscope micrographs; etched with 1% HF. (a) As-cast modified, 150×. (b) As-cast modified, 75
(c) After heat treatment (T6), 150×. (d) After heat treatment (T6), 750×

Composition and Properties

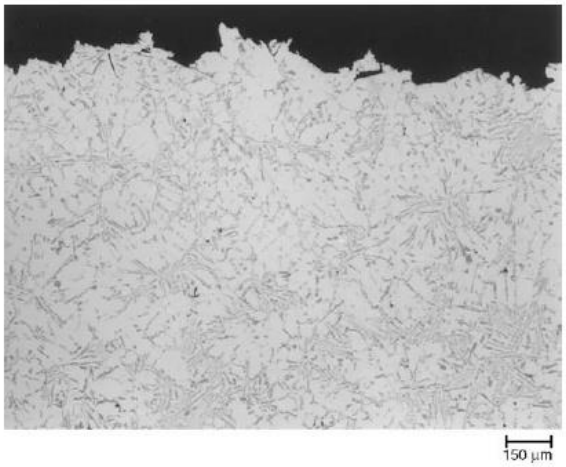
Alloy	Designation	Chemical composition (main components), wt%						Properties(a)	
		Si	Cu	Mg	Mn	Ni	Fe	R_m, MPa	A_5, %
As-examined	AlSi9Mg	8.5–10.5	. . .	0.25–0.4	0.2–0.5	. . .	0.9 max	240	2.5
Aluminum Association standard(b)	359.0	8.5–9.5	0.20 max	0.0.50–0.7	0.10 max	. . .	0.20 max	310	4

Microstructures





7.1 Mi 750×



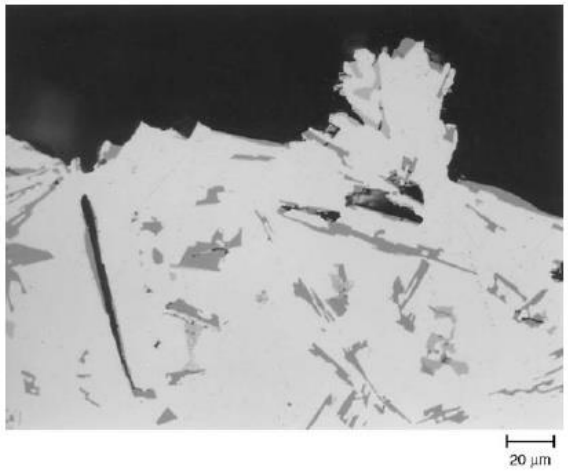


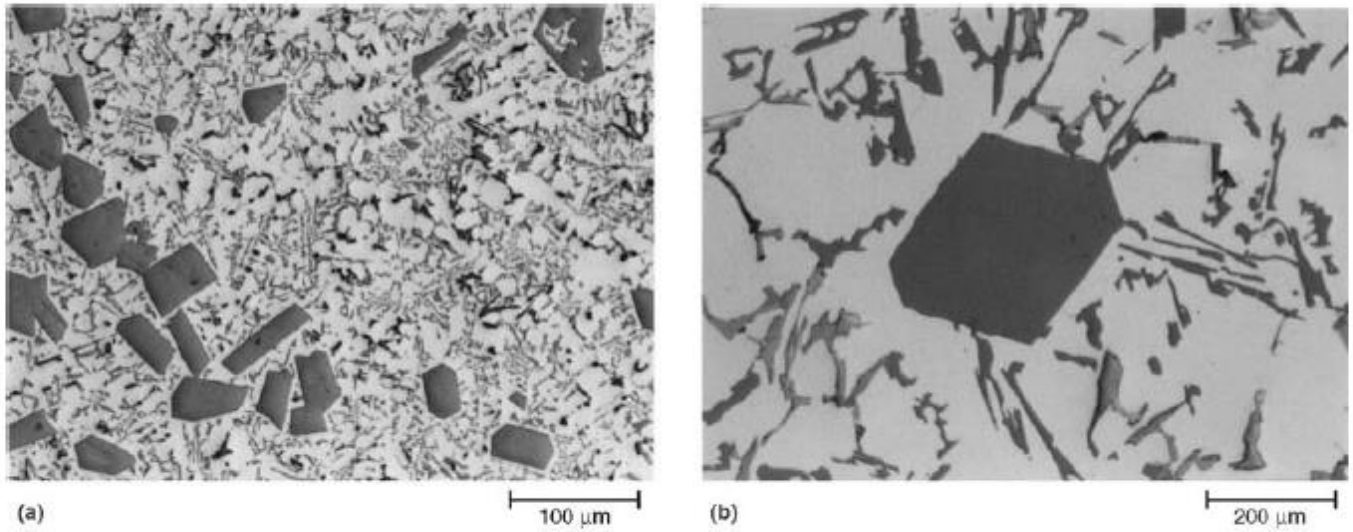
Fig. 7.2 Fracture profile of specimen after static tensile test (rim zone of the specimen). Zigzag line of the main crack reflects the morphology of the fractured micronecks, the shear edges of the α-aluminum solid solution and the cleavage lines in the precipitates of the eutectic silicon. Secondary cracks are visible as well. 50×

Fig. 7.3 Detail of the profile visible in Fig. 7.2. Cleavage lines in the precipitates of silicon and intermetallic phase α-Al(FeMn)Si are visible on the main profile line and in the secondary cracks. Zigzag element of the profile reveals the line of the fractured micronecks in regions of the α-aluminum solid solution. 400×

Composition and Properties

Alloy	Designation	Chemical composition (main components), wt%						Properties(a)	
		Si	Cu	Mg	Mn	Ni	Fe	R_m, MPa	A_5, %
As-examined	AlSi21CuNi	20.0–23.0	1.1–1.5	0.5–0.9	0.1–0.3	0.8–1.1	0.6 max	200	0.2
Aluminum Association standard(b)	390.0	16.0–18.0	4.0–5.0	0.45–0.65	0.10 max	...	1.3 max	200	...

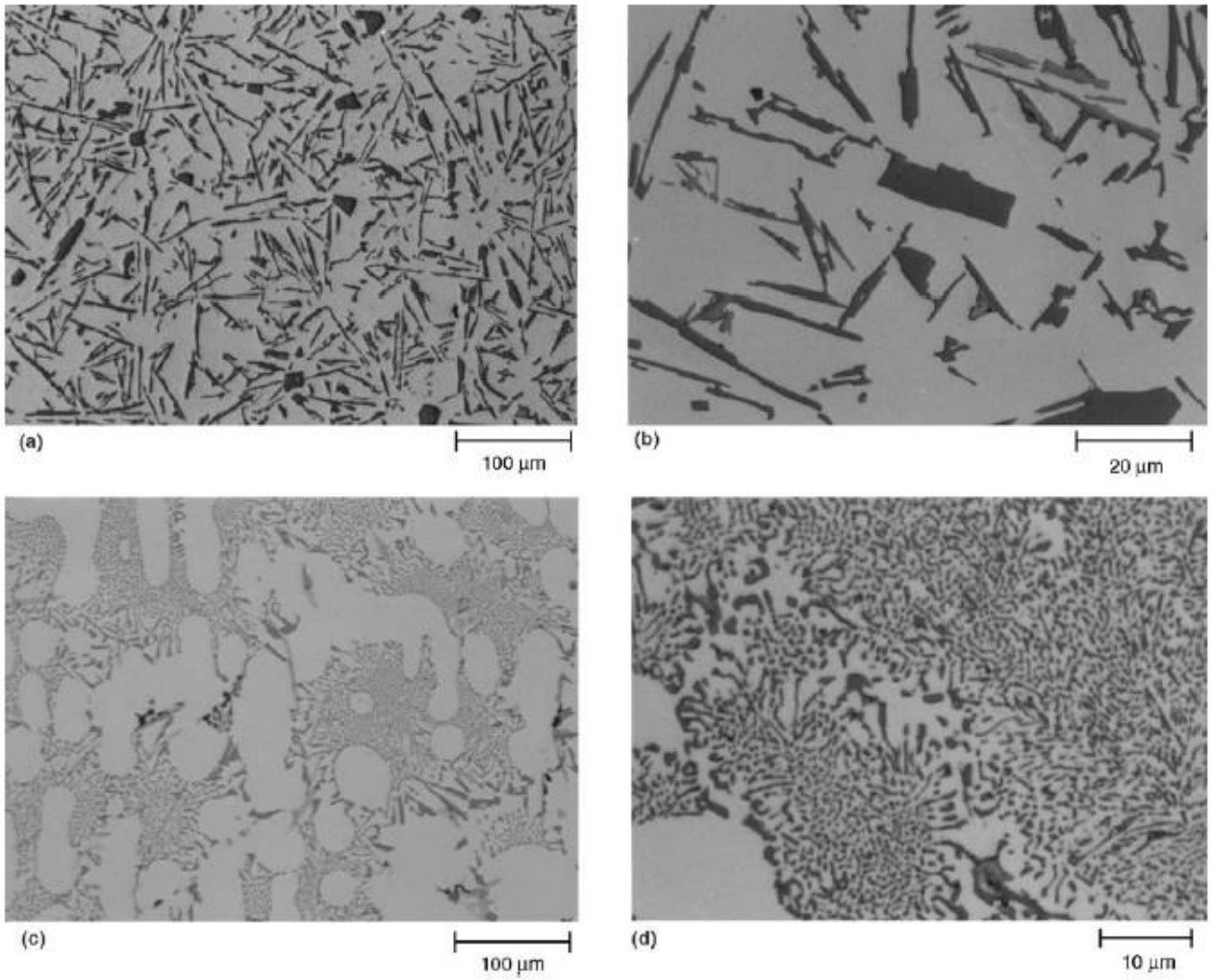
Microstructures



ig. 8.1 Microstructures of AlSi21CuNi (Alloy 390.0). Light microscope micrographs; etched with 1% HF. (a) As-cast modified, 150×. (b) As-cast modifie 750×

Composition and Properties

Alloy	Designation	Chemical composition (main components), wt%						Properties(a)	
		Si	Cu	Mg	Mn	Ni	Fe	R_m, MPa	A_5, %
As-examined	AlSi11	10.0–13.0	...	...	...	...	1.0 max	200	6
Aluminum Association standard	413.0	11.0–13.0	1.0 max	0.10 max	0.35 max	0.50 max	2.0 max	293	2.5



9.1 Microstructures of AlSi11 (Alloy 413.0). Light microscope micrographs; etched with 1% HF. (a) As-cast (F), 150×. (b) As-cast (F), 750×. (c) As-cas modified, 150×. (b) As-cast modified, 1200×

Material Defects on Fracture Surfaces

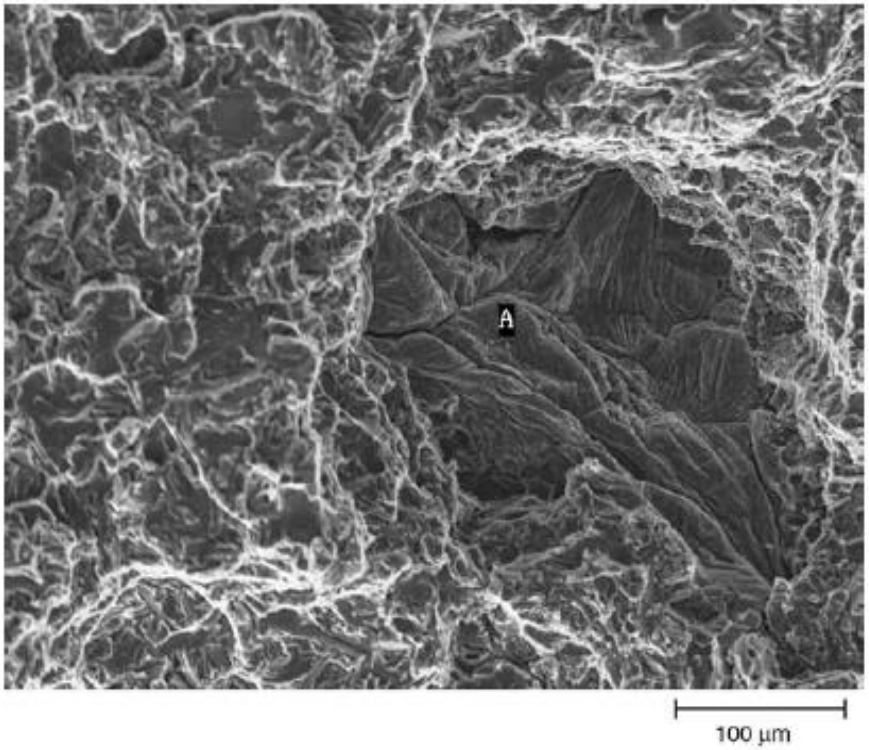


Fig. 10.3 Oxide films on the intercrystalline fracture surface after V-notch impact test at 21 °C (70 °F). Secondary cracks were formed around the defect. Alloy 356.0 (AlSi7) nonmodified, permanent mold casting. 200×

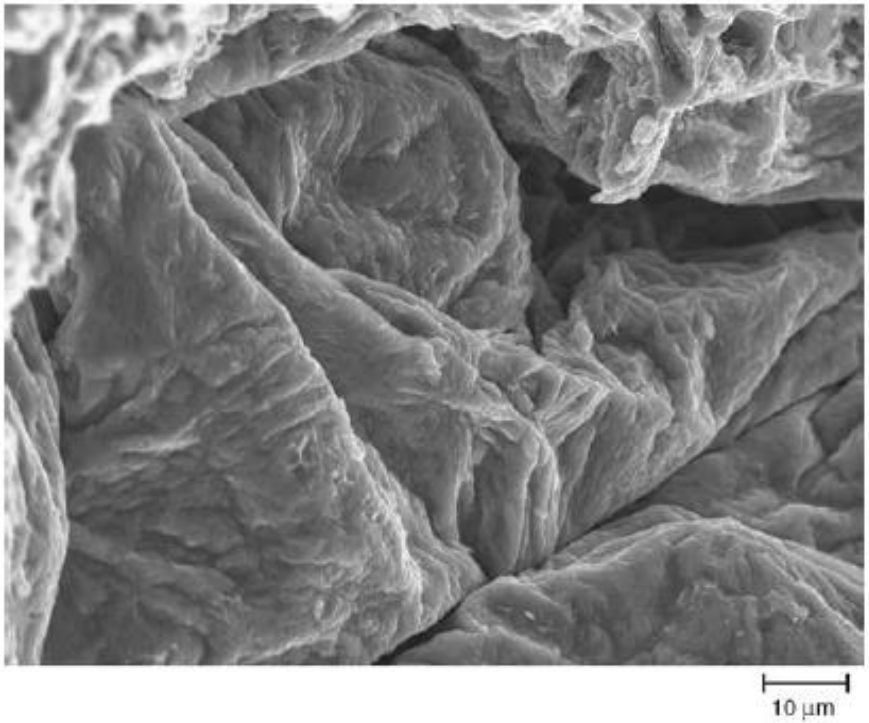


Fig. 10.4 Detail of [A] in Fig. 10.3. The intercrystalline fracture is covered with oxide film. Internal discontinuities are present on the border of the crystallites. 1000×

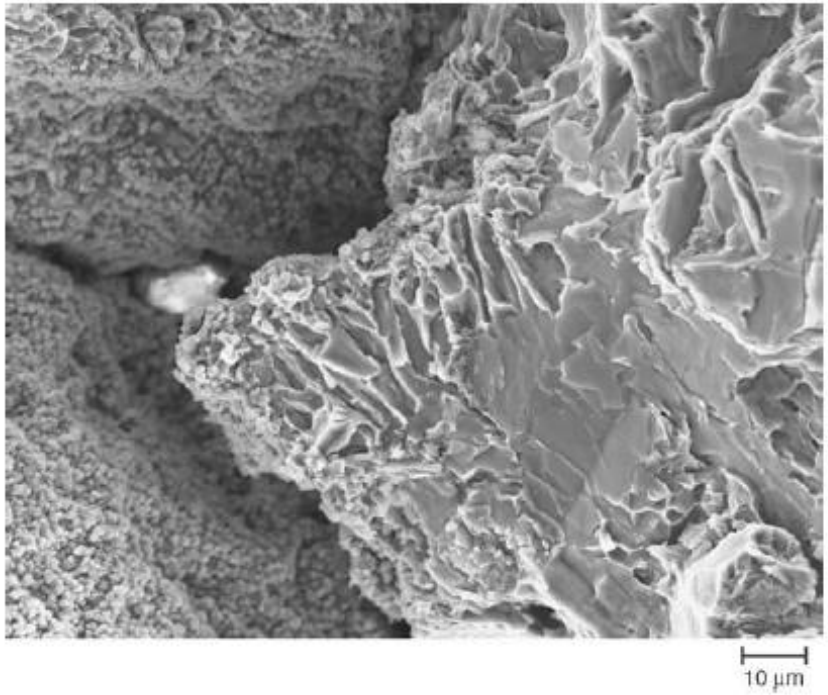


Fig. 10.19 Detail of [B] in Fig. 10.16. Internal cracks are present on the inside surface of the shrinkage discontinuity. The fracture near the defects is transcrystalline. 800×

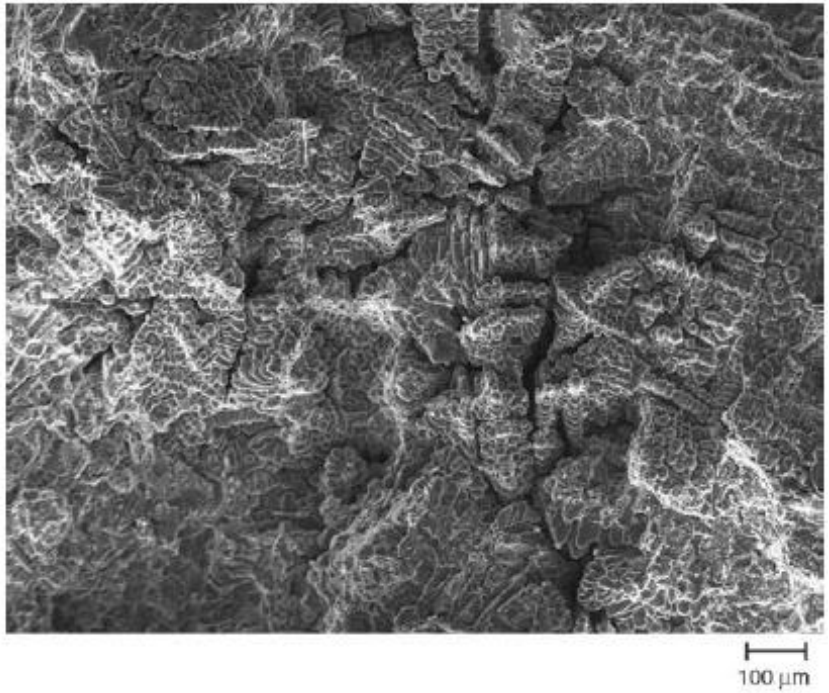


Fig. 10.20 The surface of the interdendritic shrinkage on the fracture after V-notch impact test at 21 °C (70 °F). Secondary cracks are present in the interdendritic spaces. Alloy 356.0 (AlSi7Mg), refined, modified, permanent mold casting. 70×

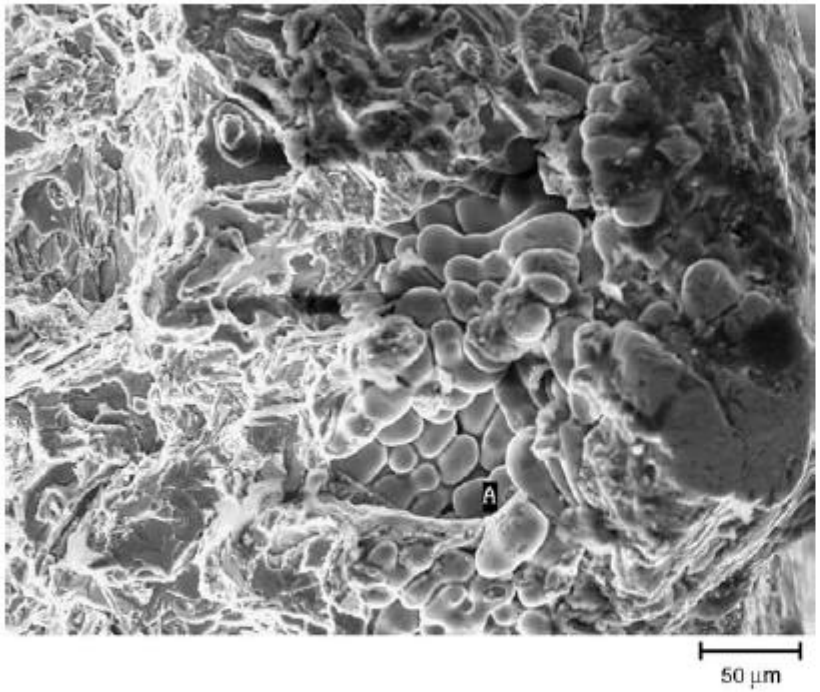


Fig. 10.21 The internal surface of the interdendritic shrinkage on the fracture after V-notch impact test at 21 °C (70 °F). Secondary cracks are present in the interdendritic spaces. Alloy 356.0 (AlSi7Mg), refined, modified, permanent mold casting. 250×

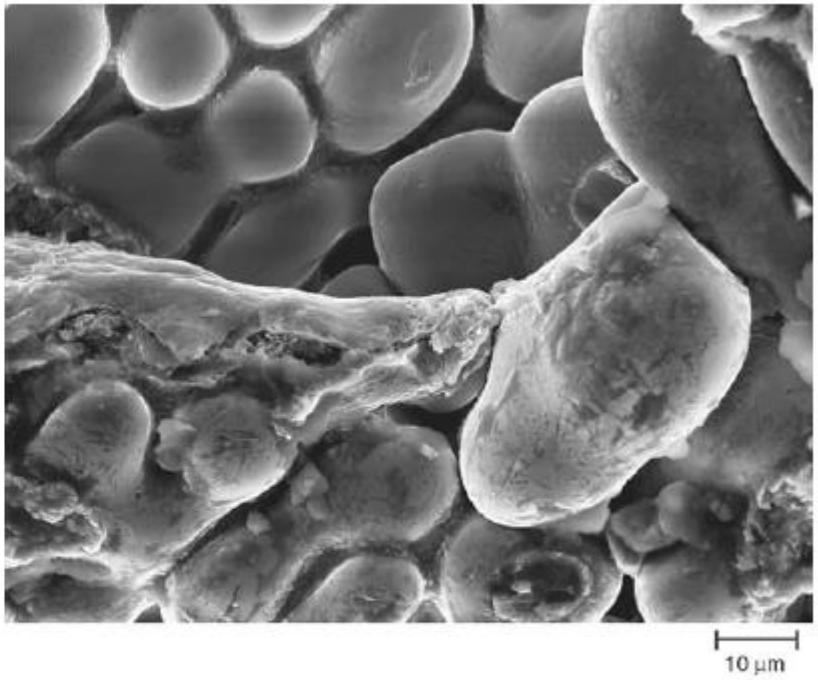


Fig. 10.22 Detail of [B] in Fig. 10.21. Morphology of the interdendritic fracture. The zones of the retained cohesion in matrix can be observed. 1000×

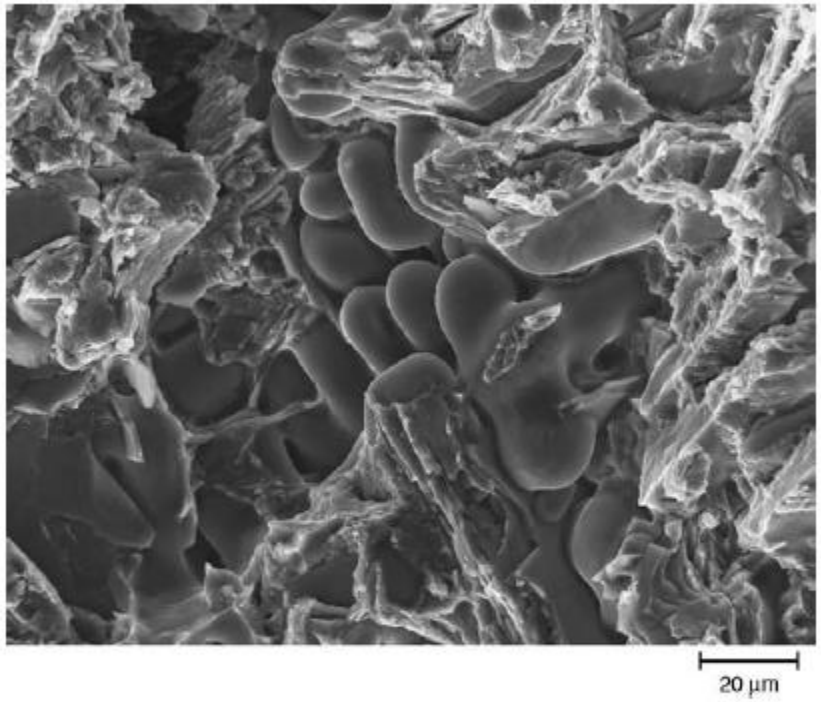


Fig. 10.23 Morphology of the interdendritic shrinkage on the surface after V-notch impact test at 21 °C (70 °F). Transcrystalline fracture is visible in the eutectic regions. Alloy 356.0 (AlSi7Mg), refined, modified, permanent mold casting. 600×

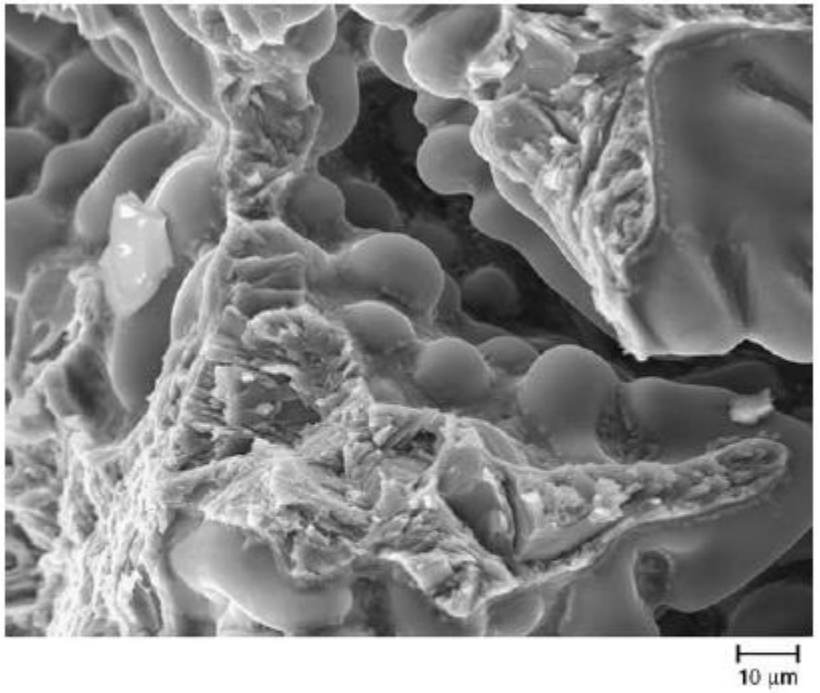


Fig. 10.24 Morphology of the interdendritic shrinkage on the fracture surface after V-notch impact test at 21 °C (70 °F). In the eutectic regions the transcrystalline fracture is visible. Alloy 356.0 (AlSi7Mg), refined, modified, permanent mold casting. 800×

Alüminyum Test Eğitim ve Araştırma Merkezi

Eylül 2016