Hornos y técnicas de fusión

0185 Metalurgia de aleaciones coladas base aluminio

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Refinación de grano

Forma del grano (macroestructura)

Normalmente se desea una estructura de grano equiaxiado y fino en las piezas coladas de aluminio.

El tipo y tamaño de granos formados son determinados por:

la composición de la aleación, rapidez de solidificación y la adición de aleaciones maestras (refinadores de grano), los cuales proveen sitios para la nucleación heterogénea de grano.

Efectos de los refinadores de grano.

Un refinador de tamaño de grano promueve la sanidad de las piezas coladas minimizando la contracción por solidificación, la ruptura en caliente y la porosidad por hidrógeno. Las ventajas de la efectividad del refinamiento de grano son:

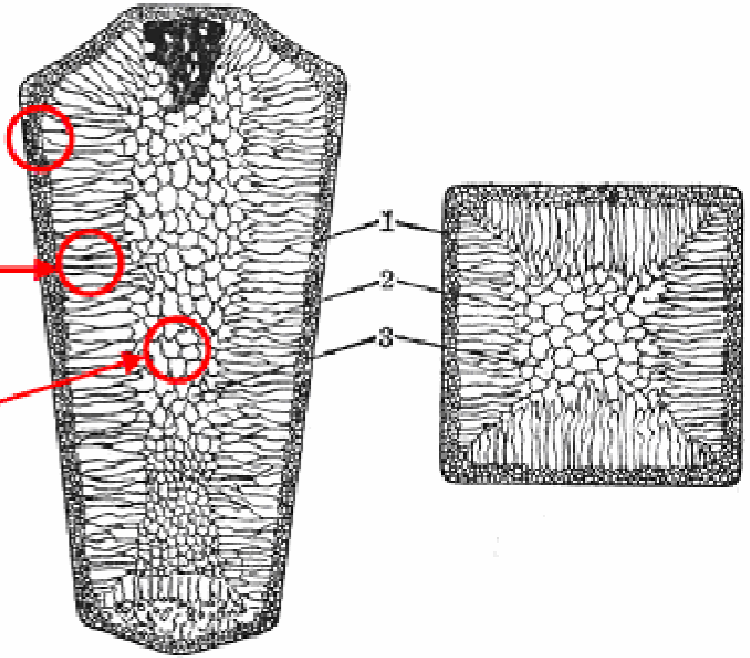
- Mejora de las características de alimentación.
- Mejora de las propiedades mecánicas
- Incremento de la resistencia a la presión (recipientes)
- Mejora de la respuesta a los tratamientos térmicos
- Mejora en la apariencia después de terminados químico, electroquímico y mecánico, superficial

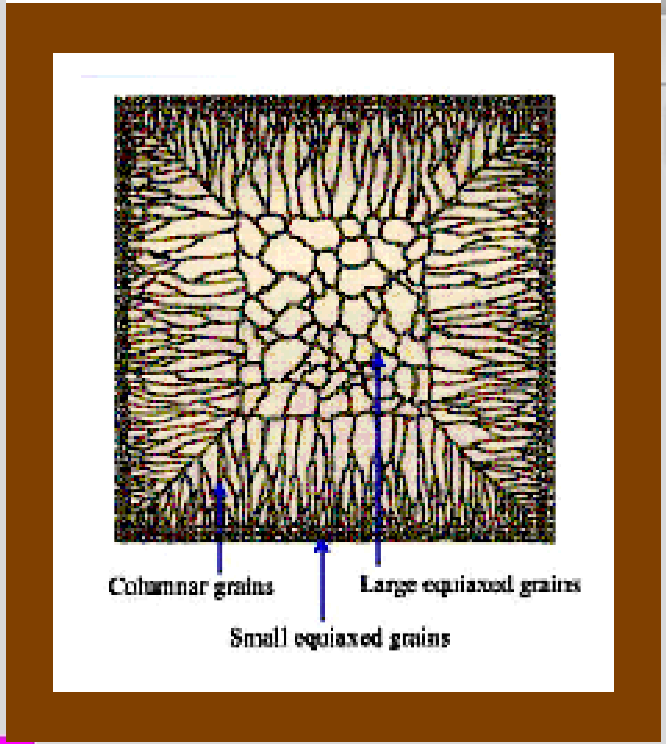
5.1. Structure of ingots and castings

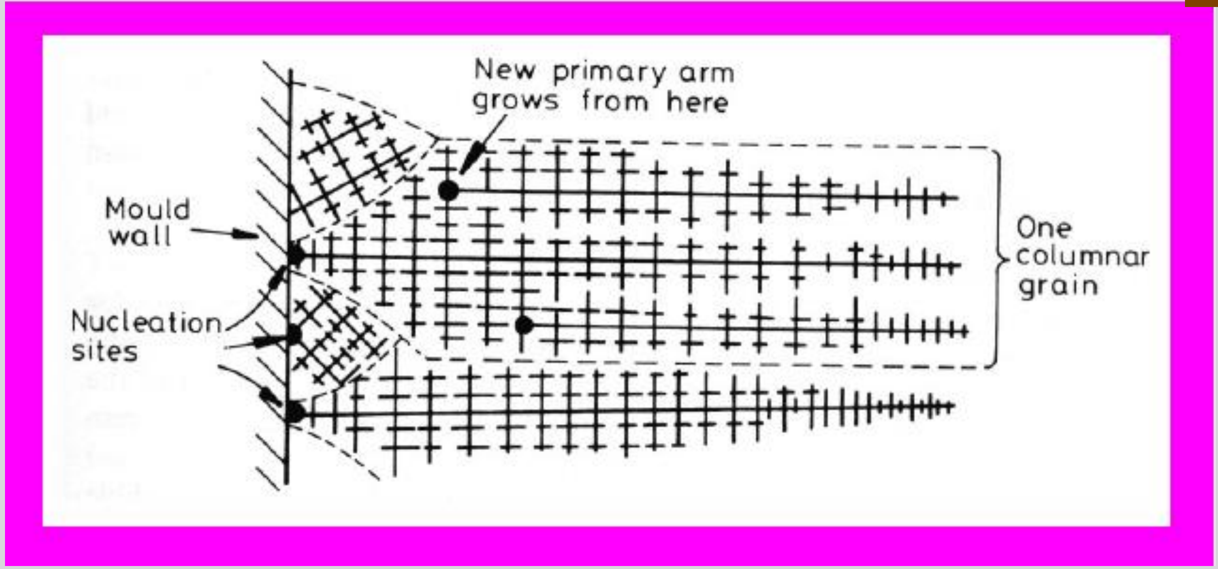
Chill zone: fine equiaxed grains or random orientations

Columnar zone: large columnar grains of certain orientations formed under directional cooling (temperature gradient)

Equiaxial zone: located in the middle of the casting, contains large equiaxial grains (lack of temperature gradient



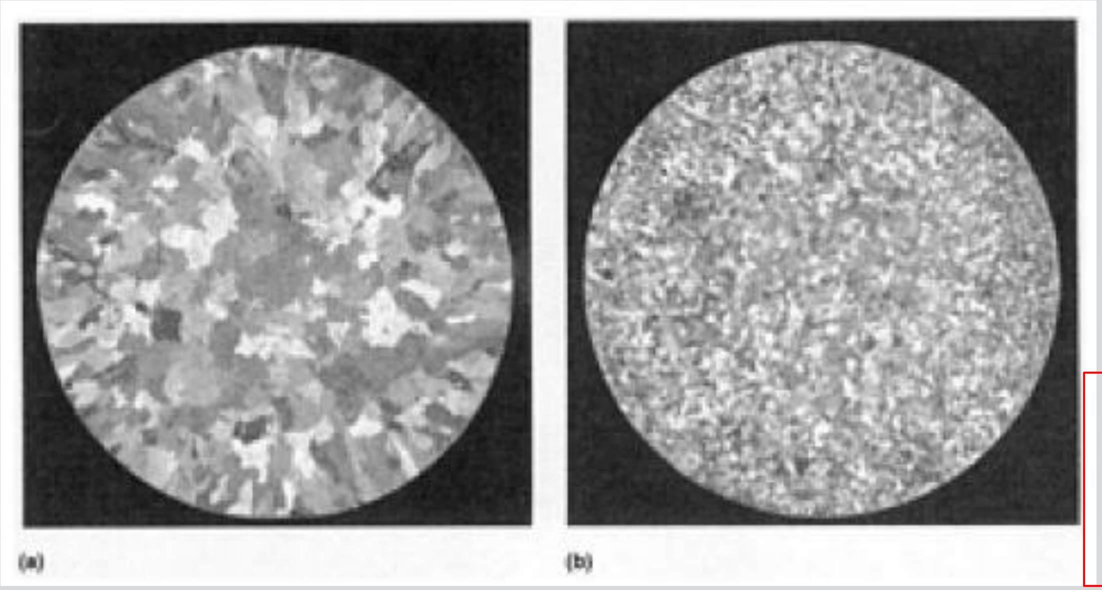

Columnar grains
Large equiaxed grains
Small equiaxed grains


New primary arm grows from here
Mould wall
Nucleation sites
One columnar grain

Bajo condiciones normales de solidificación la mayoría de los aleaciones comerciales sin refinadores de grano desarrollan estructura gruesas columnares y/o estructuras gruesas equiaxiales.

La estructura de grano grueso columnar es menos resistente a la fractura durante la solidificación y el enfriamiento en la postsolidificación que la estructura de grano bien refinado.

Esto es debido a la poca resistencia a las fuerzas de tensión, a altas temperaturas, que se esperan como un resultado de la aumentada sensitividad a la formación de limites de grano en estructuras de grano gruesas

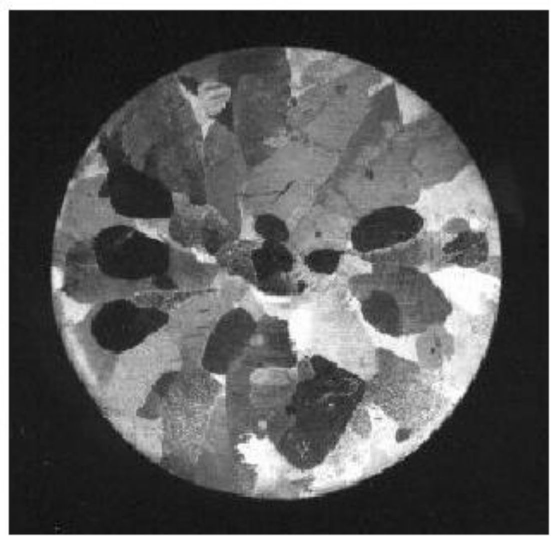


Al-7Si
a) Sin refinador
b) Con refinador

Grain Refiners

Grain refinement of aluminum provides a number of technical and economic advantages, including reduced ingot cracking, better ingot homogeneity, better mechanical deformation characteristics and improved mechanical properties. Grain refining elements, titanium and boron, were originally introduced into molten metal as refractory titanium alloy and a corrosive complex potassium metal fluoride salts. Use of these materials resulted in inconsistent performance and detrimental side effects, such as, corrosion of furnace refractories, risk of inclusions and unpredictable grain refining response. These side effects and uncertainties were eliminated when master alloy companies together with aluminum producing companies developed a master alloy, which included aluminum, titanium and boron in precise quantities.

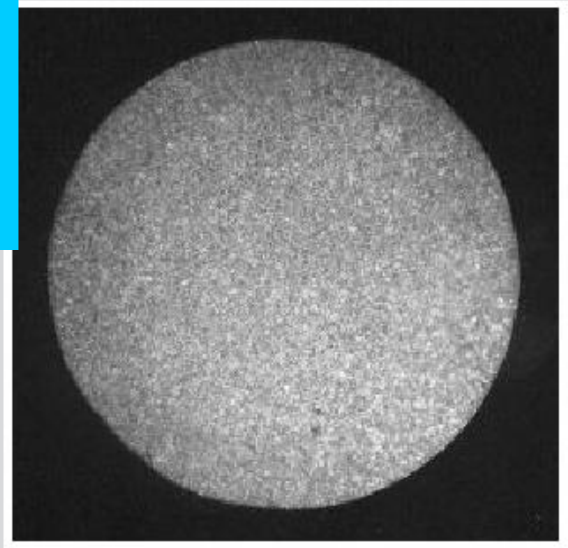
Because the alloys were originally provided in ingot form, the product was added to the melting furnace 30 to 60 minutes before casting. The next improvement in grain refiners was the development in 1972 by the master alloy companies of a rod feeder and a fast-acting aluminum alloy grain refiner that could be produced in 3/8 inch diameter rod form. This improved product could then be added to the molten metal stream enroute to the casting station. With the introduction of each new product (ingot then rod) the required quantity of grain refiner was reduced because of the improved recovery of the grain refining ingredients and better furnace utilization was achieved, which translates to lower costs for the industry.



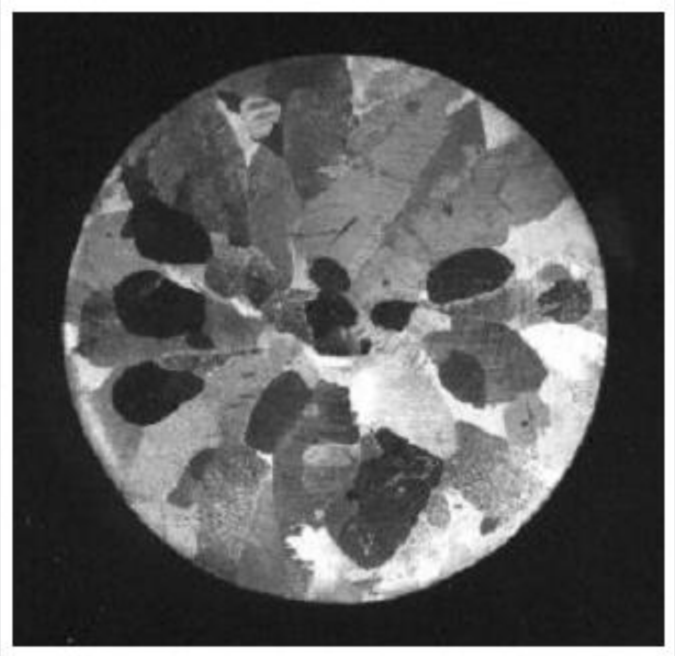
99.9% aluminum ungrainrefined. The nominal grain size is 4500µm.

AlTiB: Fed automatically into the launder and dissolved by the molten metal as it passes from the furnace to the casting station !!

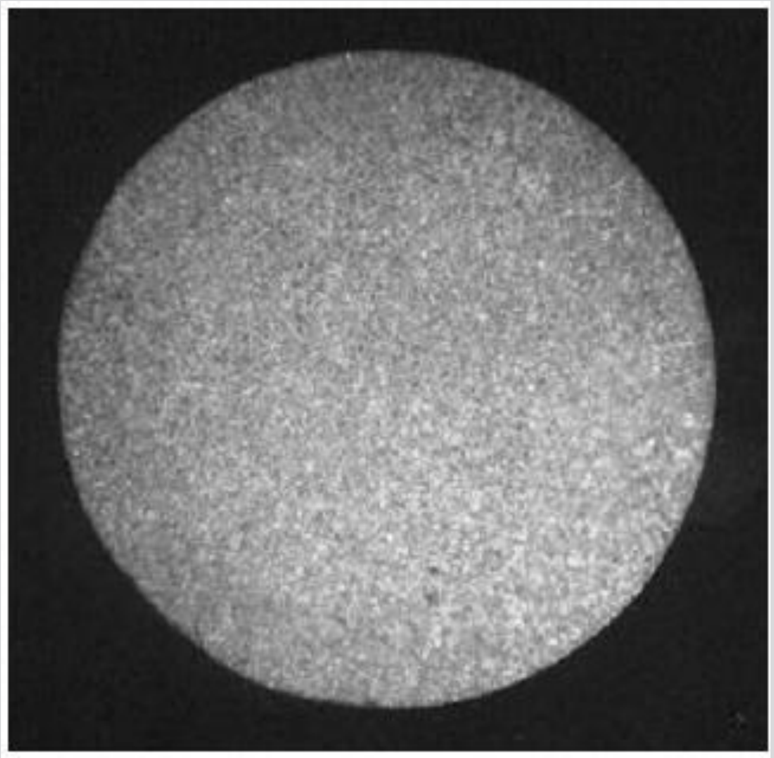
Remember Matter???



99.9% aluminum grain refined with 0.008% Titanium added as 5%Ti-1%B-Al The nominal grain size is 120µm.



Aluminio 99.9% sin refinador de grano, atacado con reactivo de Poulton.
El tamaño de grano nominal es de 4500μ



Aluminio 99.9%, con refinamiento de grano . Ti = 0.008% adicionado a través de barras de 5%Ti – 1%B – Al. Reactivo de Poulton. El tamaño de grano nominal es de 120μ

Método químico
Dos elementos refinadores de granos para aluminio y aleaciones

Ti y B
Estos elementos forman boruros y titanuros de aluminio (nucleación heterogénea). Al_3Ti AlB_2

Ti Efecto no permanente fusión tras fusión
B Efecto permanente

Cantidades:
Sólo Ti = 0.08% - 0.18%

Sólo B = 0.01% - 0.03%

B y Ti : Ti = 0.03% - 0.08%
B = 0.001% – 0.005%

Aluminium-titanium (AlTi)

Alloy	Application	Composition	CEN-spec	AA-spec	Colour code	Datasheet*
AlTi5	Supporting grain refinement in wrought aluminium alloys and foundry alloys	5% Ti balance Al	-	-	red	available
AlTi6	Supporting grain refinement in wrought aluminium alloys and foundry alloys	6% Ti balance Al	AM-92202	H2206	red	available
AlTi10	Supporting grain refinement in wrought aluminium alloys and foundry alloys	10% Ti balance Al	AM-92204	H2210	red/ black	available
Ti80	Supporting grain refinement in wrought aluminium alloys and foundry alloys	80% Ti balance Al and/or flux	-	-	red	available

Formas:

Aluminium-boron (AlB)

Alloy	Composition	CEN-spec	AA-spec	Colour code	Datasheet*
AlB3	3% B balance Al	AM-90500	H2203	yellow	available
AlB4	4% B balance Al	AM-90502	H2204	2x yellow	available
AlB5	5% B balance Al	AM-90504	H2217	2x yellow	available
AlB6	6% B balance Al	-	-	yellow/ grey	available
AlB8	8% B balance Al	-	-	yellow/ black	available

Formas

Aluminium-titanium-boron (AlTiB)

Alloy	Application	Composition	CEN-spec	AA-spec	Colour code	Datasheet*
AlTiB5/1	multi purpose grain refiner for aluminium alloys	5% Ti 1% B balance Al	AM-92256	H2252	green	available
AlTiB3/1	grain refiner for aluminium alloys	3% Ti 1% B balance Al	AM-92250	H2214	green/ brown	available
AlTiB5/0.2	grain refiner for wrought aluminium alloys	5% Ti 0.2% B balance Al	AM-92252	H2207	green/ black	available

Formas

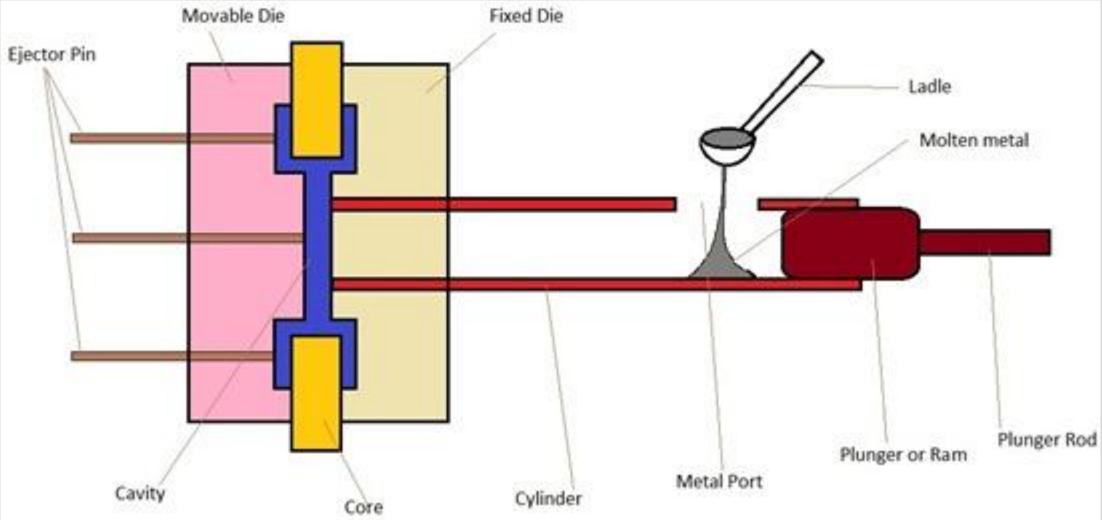


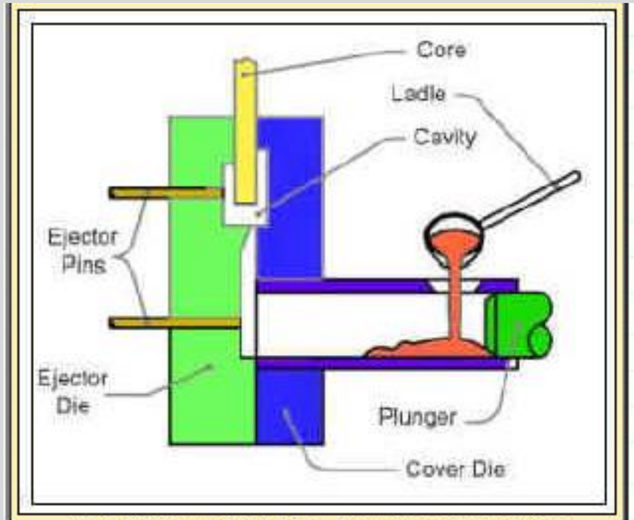


Actualmente, éstos materiales refinadores de grano, se agregan al final dentro del horno. Un poco antes de vaciar el horno.

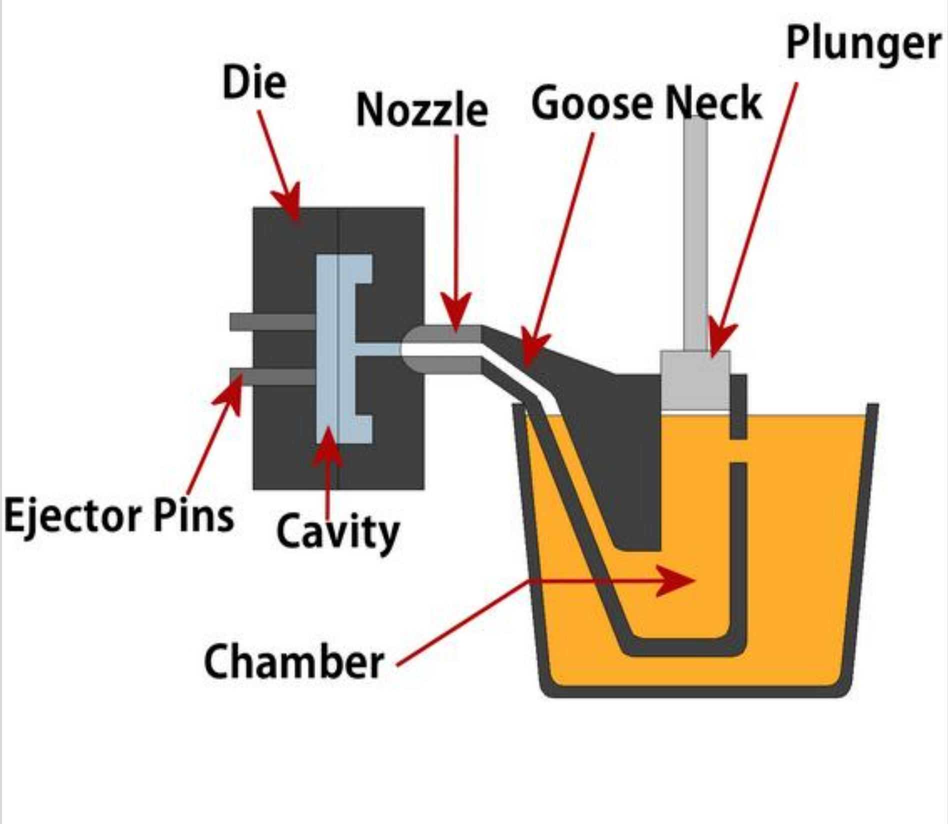

REFINACIÓN DE GRANO
Temperatura (°C)
664
662
660
658
656
654
652
650
0
50
100
150
200
250
Tiempo (segundos)
Al-0.2%Ti
Al-0.1%tI
Al-SIN Ti

Cámara fría





Cold Chamber Die Casting Machine



Modificación

Exclusiva aleaciones Al-Si

Modificación

Concepto: cambio de la morfología del Si eutéctico acicular o en forma de placas a globular fibroso, debido al cambio en la cinética de crecimiento del Si

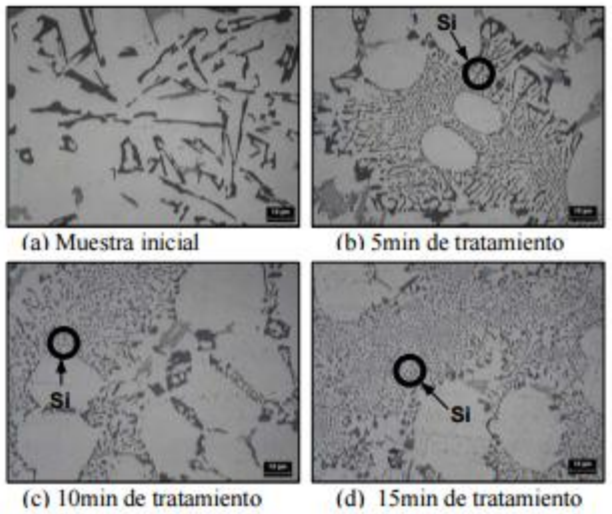


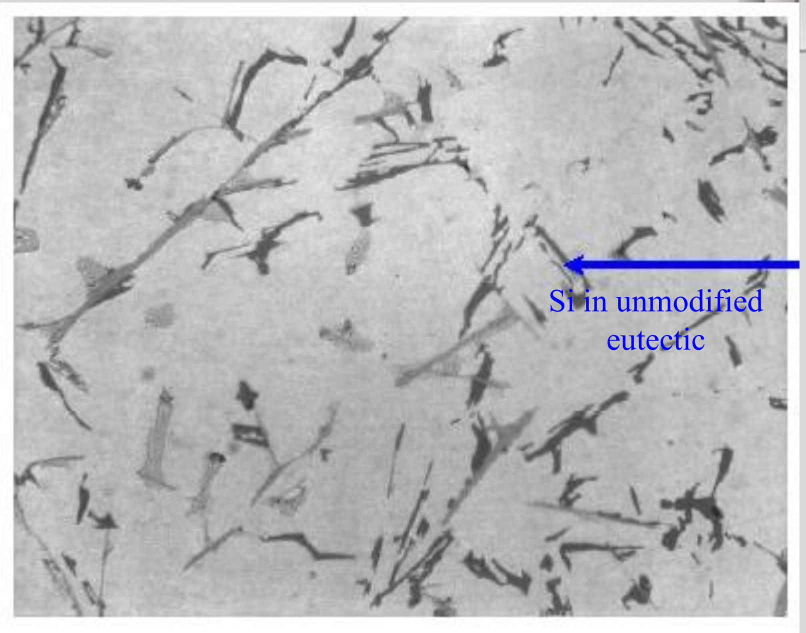
Figura. 3. Micrografías (1000X), mostrando la modificación microestructural del silicio eutéctico conforme aumenta la concentración de Sr en la aleación.

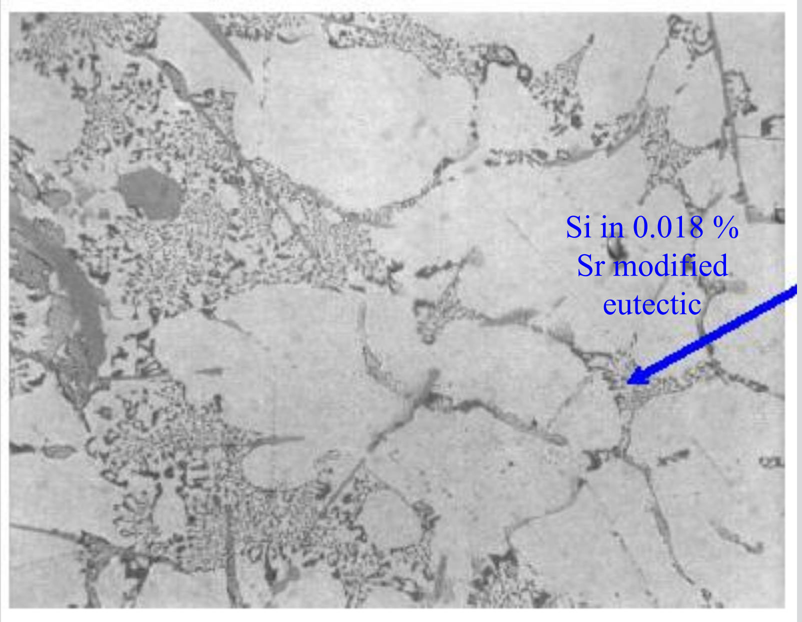
Modification in Aluminum Castings

The silicon content in most aluminum castings is in the range of 5 to 12%. When castings of melts of these alloys are not modified, coarse platelet crystals of the aluminum silicon eutectic phase form in the casting during solidification. These particles are brittle and tend to reduce the strength and ductility of the casting. Modification of the silicon phase produces a silicon phase that is fibrous and finely dispersed. Ductility of the castings improves markedly and the tendency for cracking or brittle fracture is less.

For many years, sodium was the only means available for modification of aluminum silicon alloys. However, sodium is a very reactive metal. It can react when exposed to air and can burn violently during addition to molten aluminum silicon alloy.

Therefore, close control of the addition level is difficult. Some foundrymen have been known to use antimony as a modifier, however, antimony is toxic and not recommended. The search by master alloy producers for alternative elements for modifying aluminum silicon castings revealed that strontium could be used in place of sodium. Fortunately, none of the special precautions required in the use and handling of sodium apply to strontium. Strontium alloyed with aluminum is produced and supplied by the master alloy companies. The alloy is available in several forms for furnace addition, or in rod form for addition to the liquid aluminum stream which eliminates furnace contamination.





Aluminium silicon casting alloys are essential to the automotive, aerospace and engineering sectors. Al-Si alloys allow complex shapes to be cast; however the silicon forms brittle needle-like particles which reduce impact strength in cast structures. As an additive to Al-Si casting alloys, strontium improves strength, enhances mechanical properties and disperses porosity as it modifies the eutectic structure. The modified alloy displays a finer, less needle-like microstructure.

Advantages of Strontium Additions to Aluminium Alloys

Strontium modification is essential in the production of structurally sound and dimensionally accurate Al-Si castings and fabricated products. Strontium offers clear advantages over sodium- or antimony-based alloy additives, including safer addition, better recovery, reduced fade and a fume-free application.

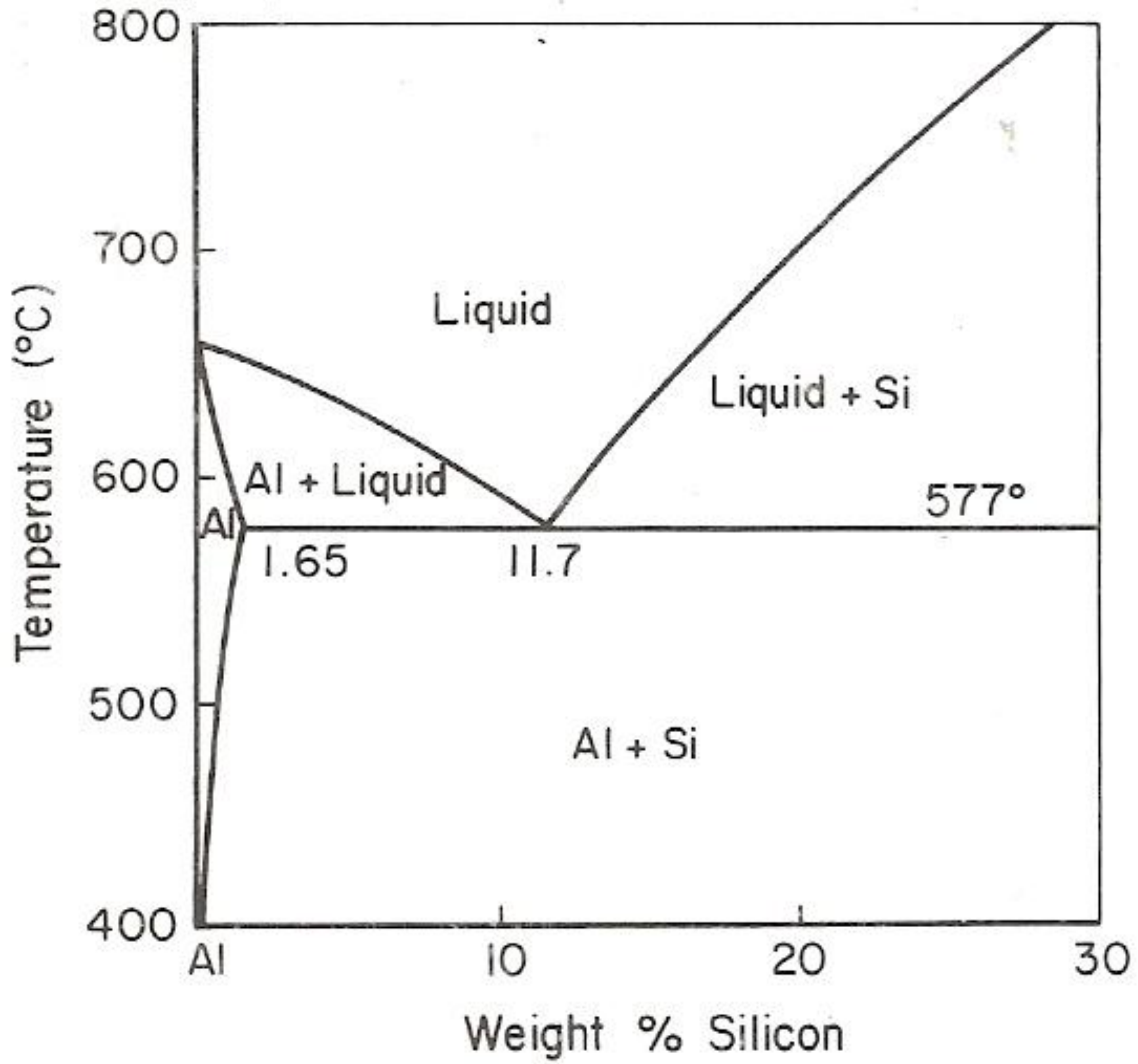
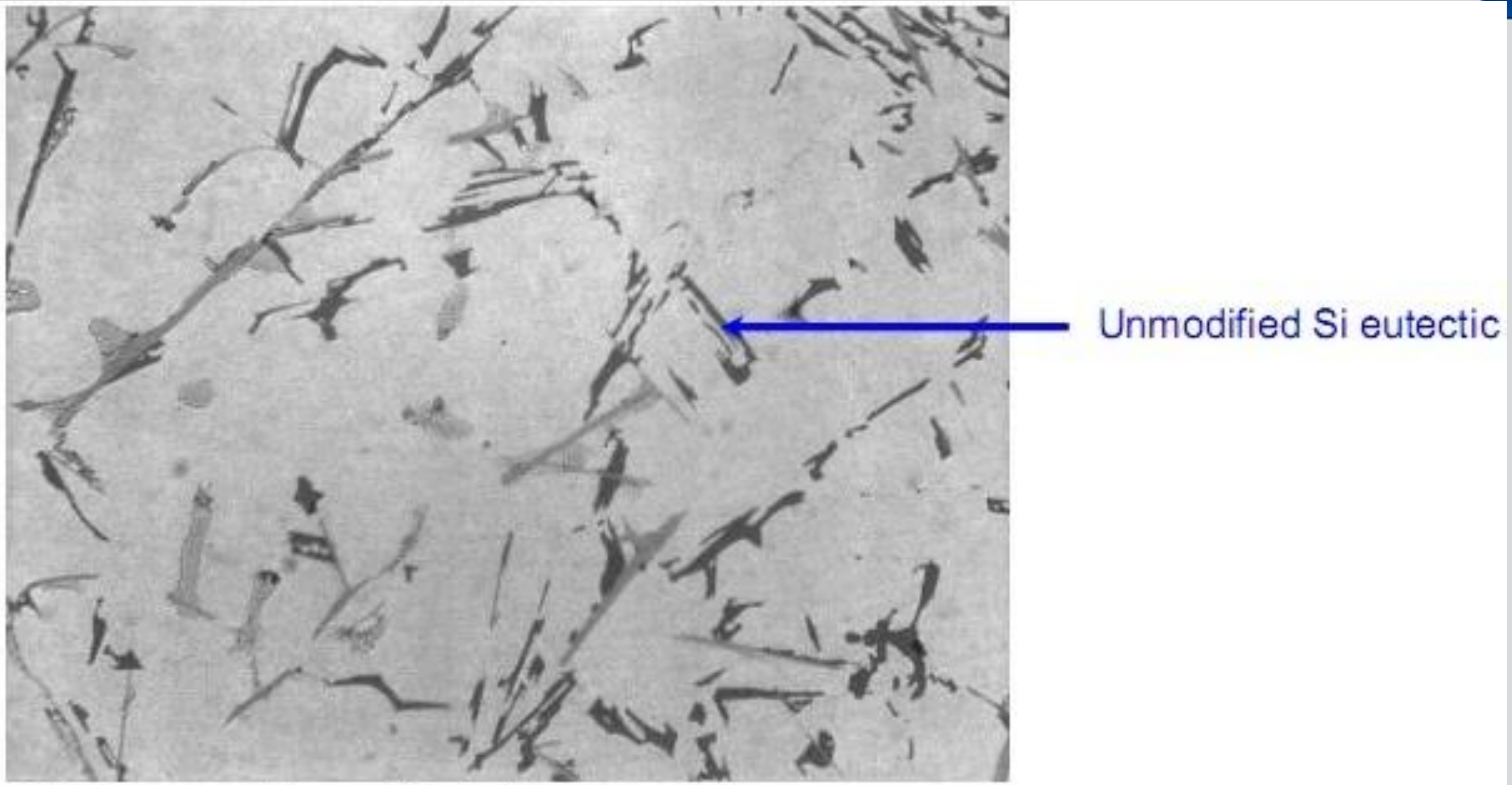
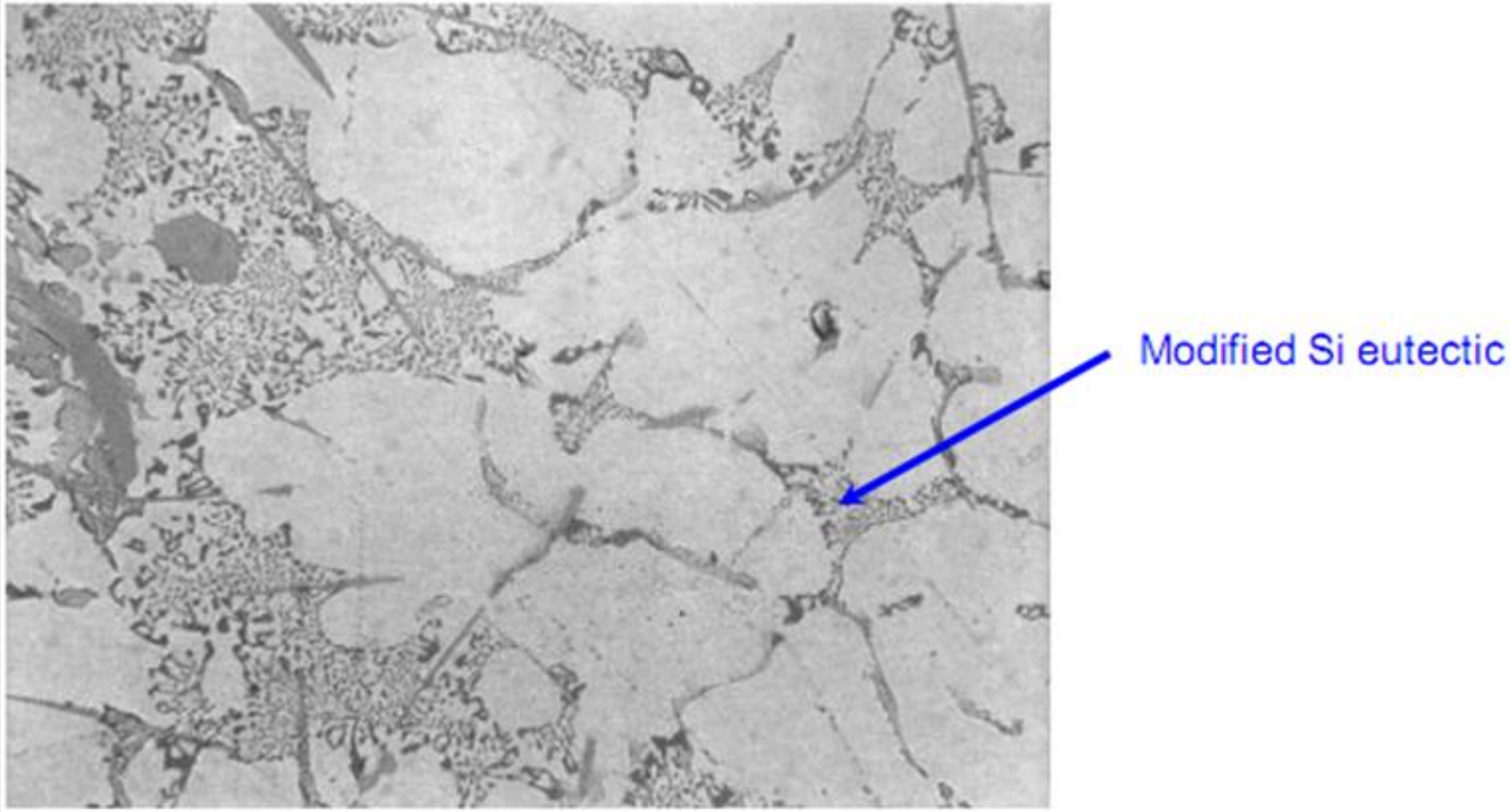


Figure 2.1. Equilibrium binary Al-Si phase



319.0. Unmodified silicon particles are very dark gray. The idiomorphic form of eutectic silicon diminishes the ductility of the alloy.



319.0 with 0.018%Sr. Fully modified silicon particles are very dark gray. The fibrous form of eutectic silicon enhances the ductility of the alloy.

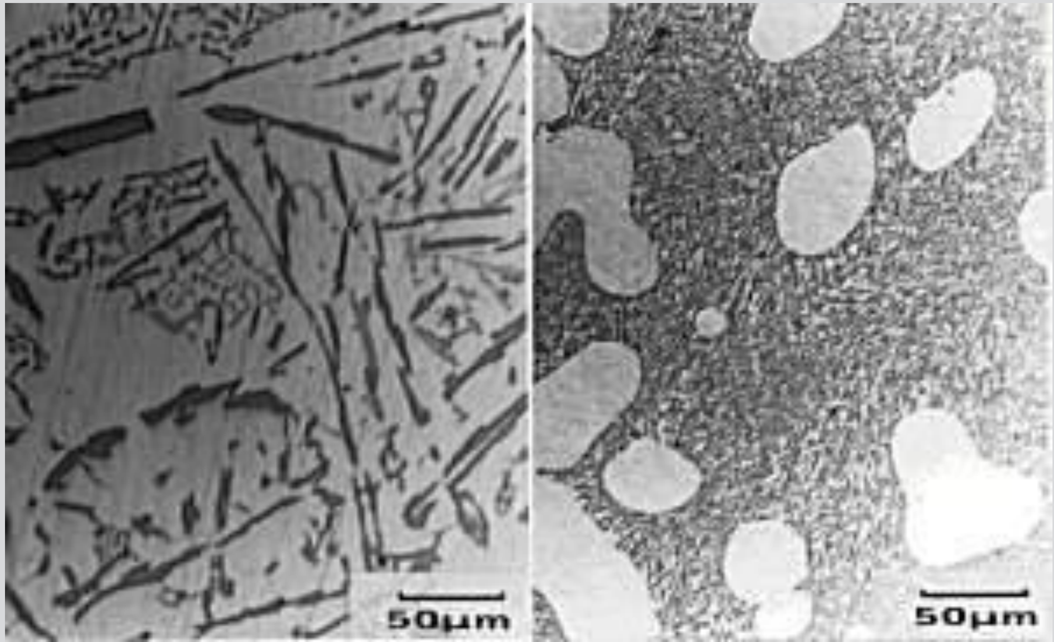
Aleaciones de aluminio-silicio para fundición son esenciales para el sector de la ingeniería automotriz, aeroespacial y las aleaciones de Al-Si permiten formas complejas para ser fabricadas; sin embargo, la forma de las partículas de silicio en forma de aguja son duras y frágiles, reducen la resistencia al impacto en piezas de fundición. La adición de estroncio en aleaciones Al-Si mejora su resistencia, mejora las propiedades mecánicas y dispersa la porosidad ya que modifica la estructura eutéctica. La aleación modificada muestra una estructura eutéctica más fina, menos microestructura acicular.

Advantages of Strontium Additions to Aluminium Alloys
Strontium modification is essential in the production of structurally sound and dimensionally accurate Al-Si castings and fabricated products. Strontium offers clear advantages over sodium- or antimony-based alloy additives, including safer addition, better recovery, reduced fade and a fume-free application.

Strontium is used to modify the aluminum-silicon eutectic. Effective modification can be achieved at very low addition levels, but a range of recovered strontium of 0.008 to 0.04% is commonly used. Higher addition levels are associated with casting porosity, especially in processes or in thick-section parts in which solidification occurs more slowly. Degassing efficiency may also be adversely affected at higher strontium levels.

La relación entre la tensión superficial de aleaciones Al-Si y las modificaciones microestructurales ha sido   demostrado por el analisis teorico y validado por analisis microestructural . La tensión superficial es controlada principalmente por la cantidad de el modificador y el tiempo de modificación es menos importante. También se encontró que la temperatura de modificación tiene poco efecto sobre la microestructura de estas aleaciones. De forma experimental se estableció entre la tensión superficial y el grado de modificación

Cuando la tensión superficial esta arriba de 530 mN/m, ocurre una modificación parcial. Cuando la tensión superficial esta entre 400 mN/m y 530 mN/m, ocurre una modificación moderada. Cuando la tensión superficial esta por debajo de 400 mN/m, entonces ocurre una excelente modificación



Metallurg Aluminium’s Strontium Aluminium Master Alloys

Metallurg Aluminium’s proven strontium aluminium master alloys, in 3.5%, 10%, 12% and 15% concentrations, are the optimum choice for strontium foundry additions. Their cost-effective alloy composition, ease of use and reliability make them an essential part of advanced foundry practice – reducing total cost and increasing yields.

Alloy	AA*/CEN** Designation	Color Code
Sr 3.5%	H2012/93800	1 light blue stripe
Sr 10%	H2007/93804	2 light blue stripes
Sr 12%	-/-	3 light blue stripes
Sr 15%	-/-	2 light blue and 1 orange stripe

AA* - The Aluminium Association
CEN* - Comité Européen de Normalisation

Aluminium-strontium (AlSr)

Alloy	Application	Composition	CEN-spec	AA-spec	Colour code	Datasheet*
AlSr3.5	Modification of AlSi alloys	3.5% Sr balance Al	AM-93800	H2012	light blue	available
AlSr5	Modification of AlSi alloys	5% Sr balance Al	AM-93802	-	light blue/ yellow	available
AlSr10	Modification of AlSi alloys	10% Sr balance Al	AM-93804	H2007	2x light blue	available
AlSr15	Modification of AlSi alloys	15% Sr balance Al	-	-	2x light blue/ orange	available

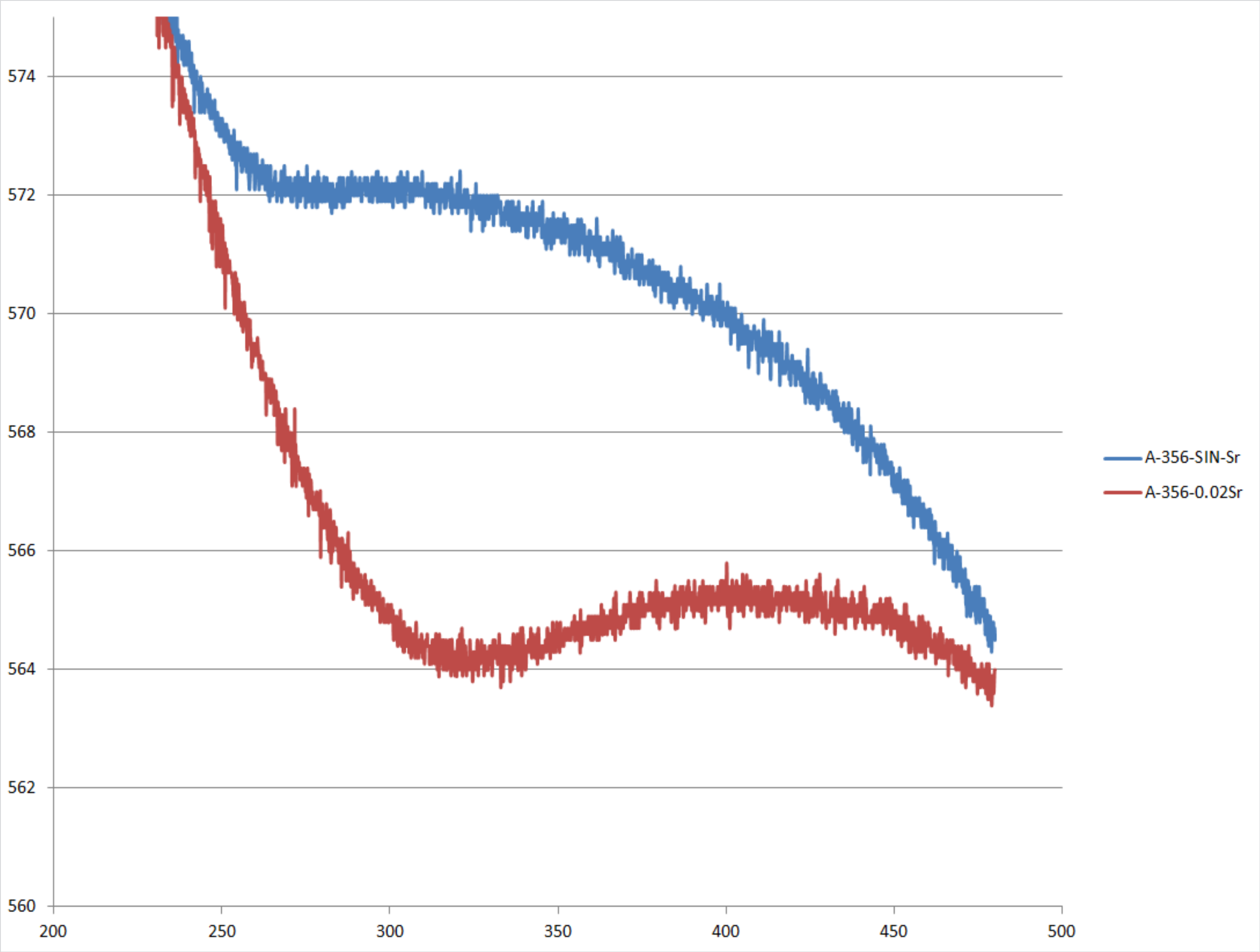
Formas

Aluminium-strontium-titanium-boron (AlSrTiB)

Alloy	Application	Composition	CEN-spec	AA-spec	Colour code	Datasheet*
AlSr3.5Ti1B0.2	Modification of AlSi alloys	3.5% Sr 1% Ti 0.2% B balance Al	-	-	light blue/ black	available
AlSr10T1B0.2	Modification of AlSi alloys	10% Sr 1% Ti 0.2% B balance Al	AM-93850	H2017	light blue/ red	available

Formas:





574
572
570
568
566
564
562
560
200
250
300
350
400
450
500
A-356-SIN-Sr
A-356-0.02Sr

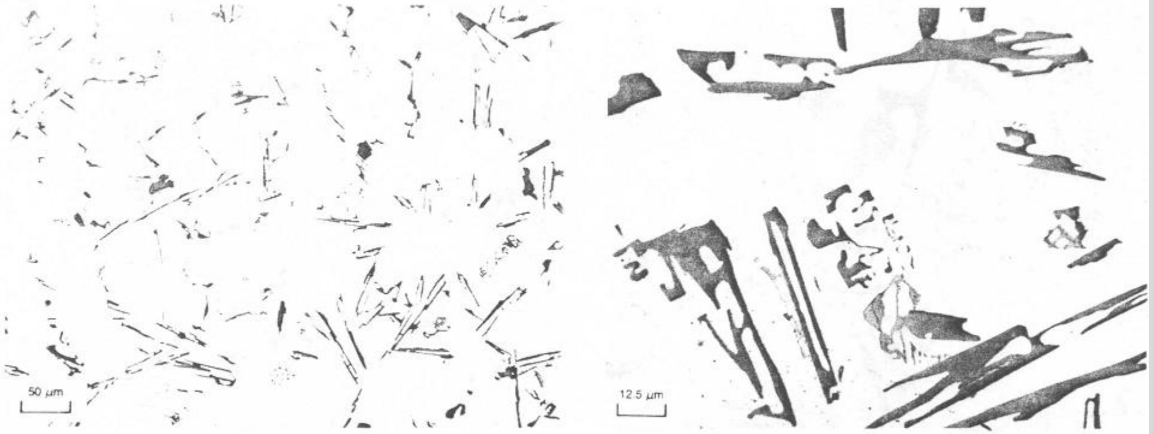


Fig. 3-35. Fully unmodified structure of Al-Si alloy. #1 on scale. [Photos for Figs. 3-35 to 3-40 courtesy of G.K. Sigworth.]

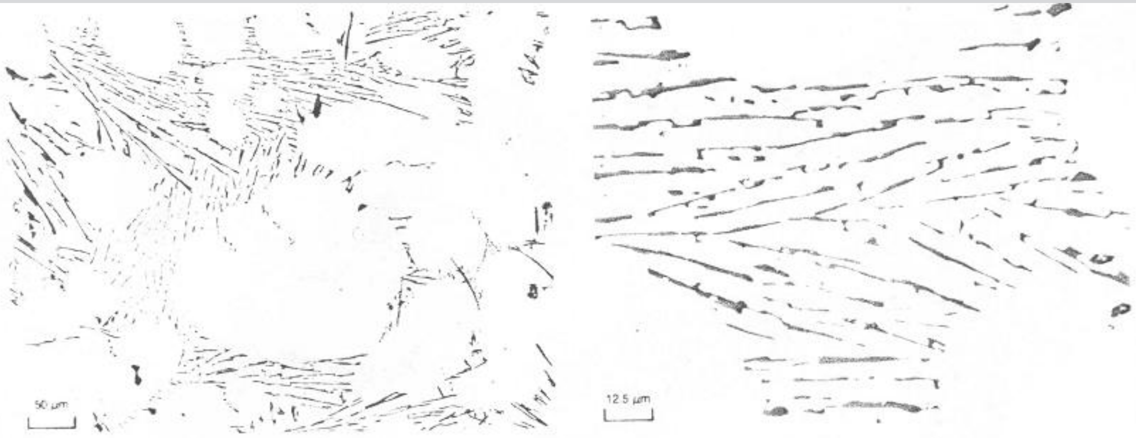


Fig. 3-36. Lamellar structure of Al-Si alloy. #2 on scale.

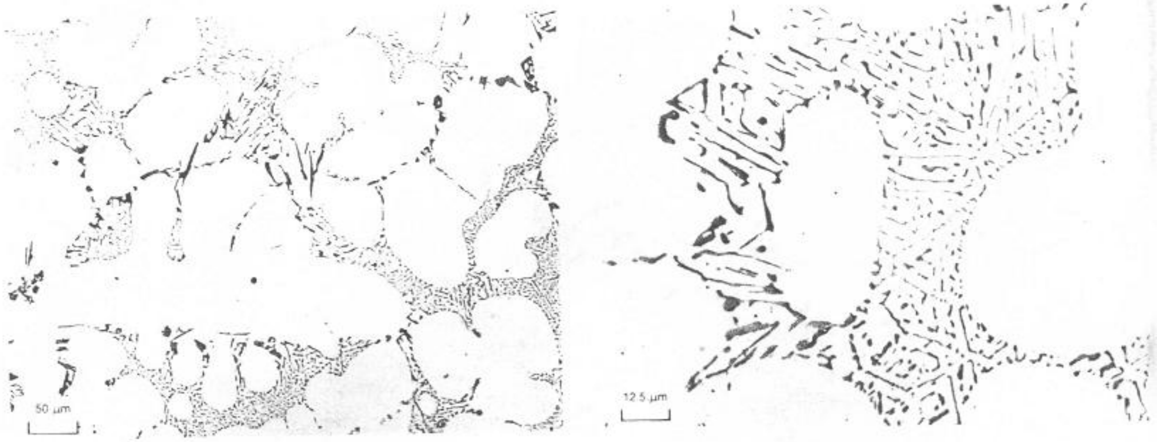


Fig. 3-37. Partial modification of Al-Si alloy. #3 on scale.

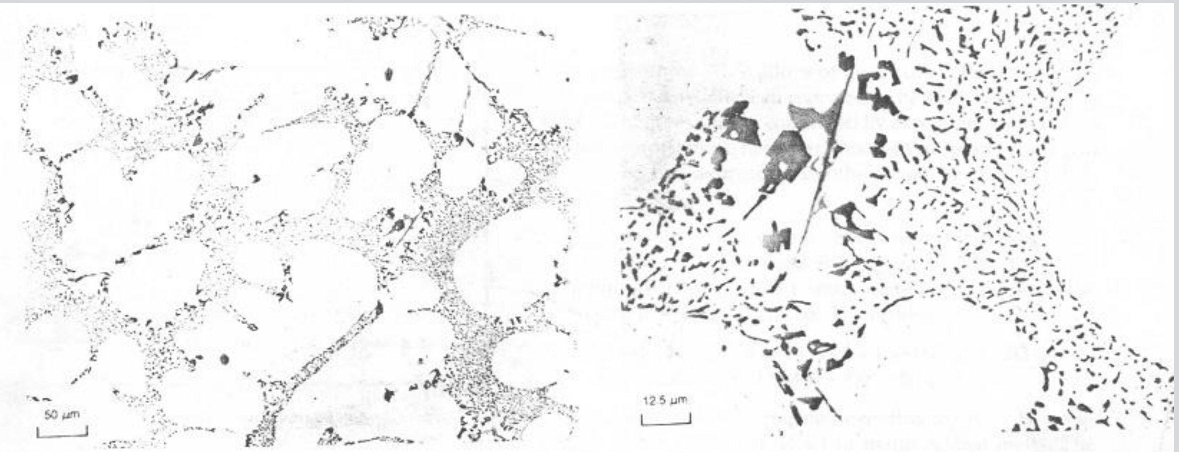


Fig. 3-38. Absence of lamellar structure in Al-Si alloy. #4 on scale.

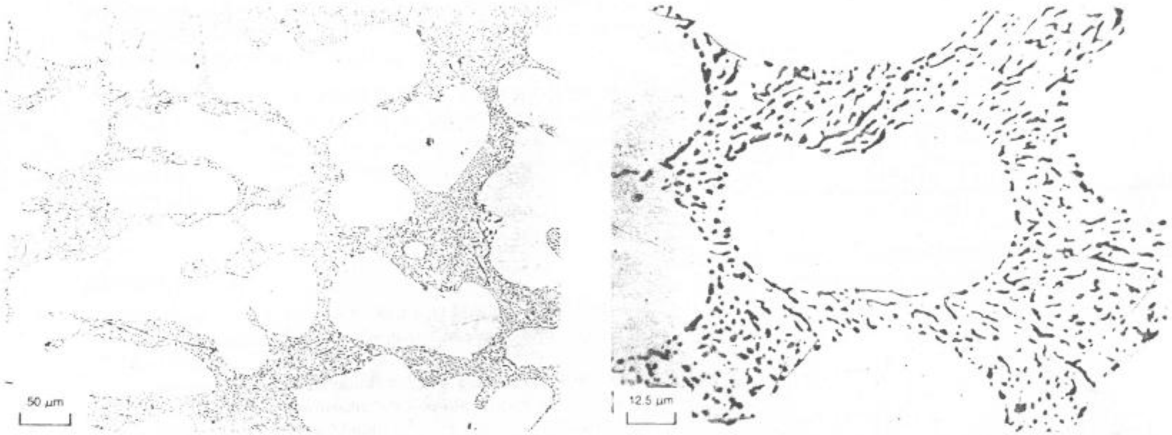


Fig. 3-39. Fibrous silicon eutectic in Al-Si alloy. #5 on scale.

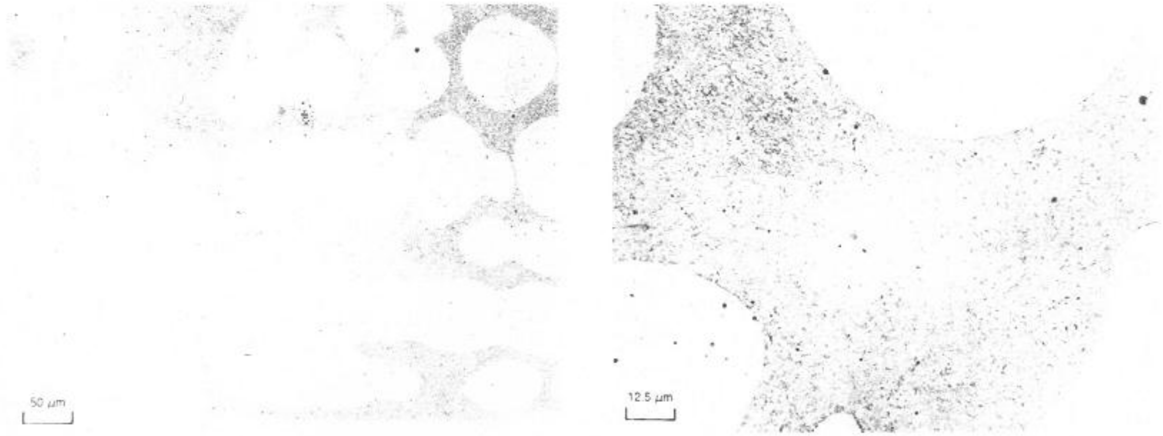
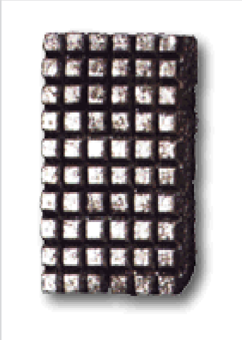


Fig. 3-40. Very fine structure of Al-Si alloy. #6 on scale.

Técnica de fusión

Consideraciones para carga de materiales



Nikkin Flux

KB Alloys

Milward
Aluminum & Copper Alloying Additives

FOSECO

Preparación y acondicionamiento de materias primas

- Limpieza (aceite, humedad, tierra, arena, grado de oxidación, etc.)
- Tamaño (de acuerdo al tamaño del horno)
- Estado físico (pedacería, sólidos masivos, rebaba, paca, etc.)
- Precalentamiento (de acuerdo a la aleación a fundir)
- Selección de la mezcla de la carga (lingote, chatarra, derrames, retornos, pacas, otros)
- Selección de materiales auxiliares: fundentes, refinadores, modificadores

Secuencia de carga y fusión

Selección de la carga y acondicionamiento → Balance de carga → Carga, fusión y "ajuste" → Colada con la CQ correcta

Cargas en horno de crisol

- Lingote primario o secundario (Composición similar a la deseada)
- Metales vírgenes (puros), para ajustes
- Retornos (chatarra interna composición química conocida)
- Chatarra externa (necesita certificación química)

❖ Aleaciones madre y endurecedoras (master alloy o hardeners alloys): aleaciones de bajo punto de fusión para introducir aleantes, refinadores de grano, modificadores, etc.

Cantidad de retornos en la carga

- Depende de la eficiencia de metal en la planta
- Retornos finos (rebabas y polvo) se evita utilizarlos, reprocesado aparte
- Retornos masivos se reutilizan (Sistemas de colada y alimentación, piezas defectuosas)
- % de retornos entre 15 y 50 %

Métodos de refinación de grano y modificación de eutéctico

RESUMEN

Uso de sales (solas o mezclas):

- Refinadores: K_2TiF_6 y KBF_4 ,
- Modificadores: sales con sodio, sodio metálico envasado al vacío

Uso de aleaciones maestras:

- Refinadores: Al-Ti, Al-Ti-B,
- Modificadores: Al-Sr, Al-Si-Sr

REDUCED PRESSURE TEST

This is the most common method (Figure 2) which many non-diecasting foundries use today, and it is becoming increasingly prevalent in diecasting as well as a simple means of evaluating metal quality. It provides a semi-quantitative measure of overall melt cleanliness, as well as 'hydrogen gas' content, in the following manner. It is well recognized that inclusions nucleate hydrogen porosity. In the reduced pressure test, the presence of inclusions will assist any hydrogen present to develop an exaggerated visualization of pores, evident when the sample is sectioned after solidification. After the sample has been collected and allowed to solidify under reduced pressure, the specific gravity of the sample can be determined by Archimedes principle to give an apparent density. This can then be compared to theoretical density, and relative to samples prepared *without* reduced pressure, an estimate of hydrogen content can be determined. After the specific gravity or density has been determined, the sample can be sectioned and observed visually to assess the exaggerated porosity induced by the reduced pressure. This can be compared with certain industry rating charts, or a foundry-specific rating system. It must be emphasized, however, that what is assessed is general melt cleanliness rather than absolute hydrogen content.

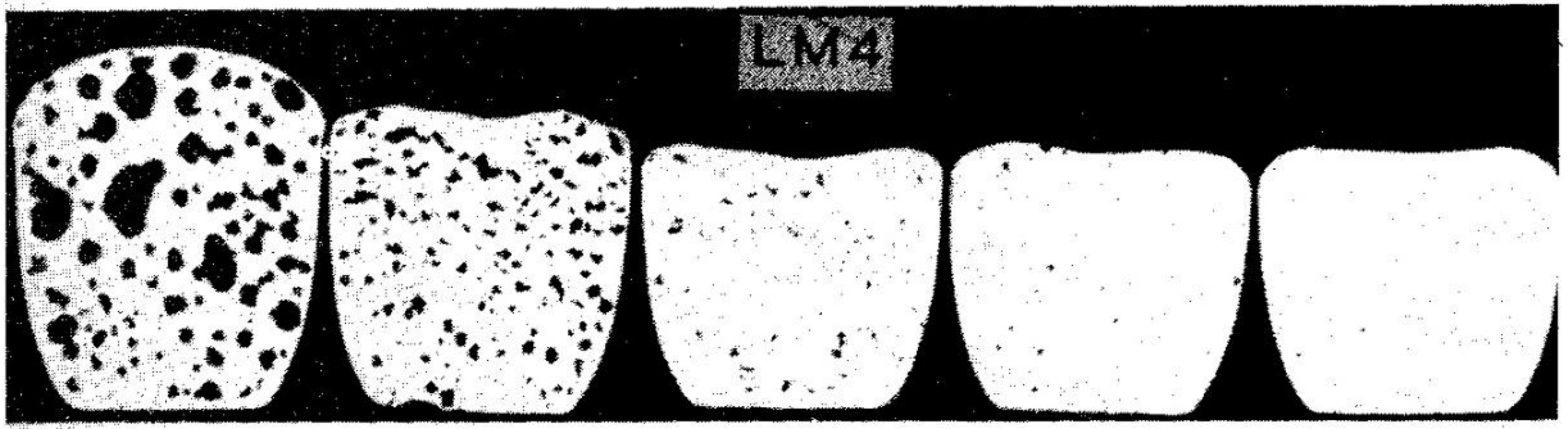
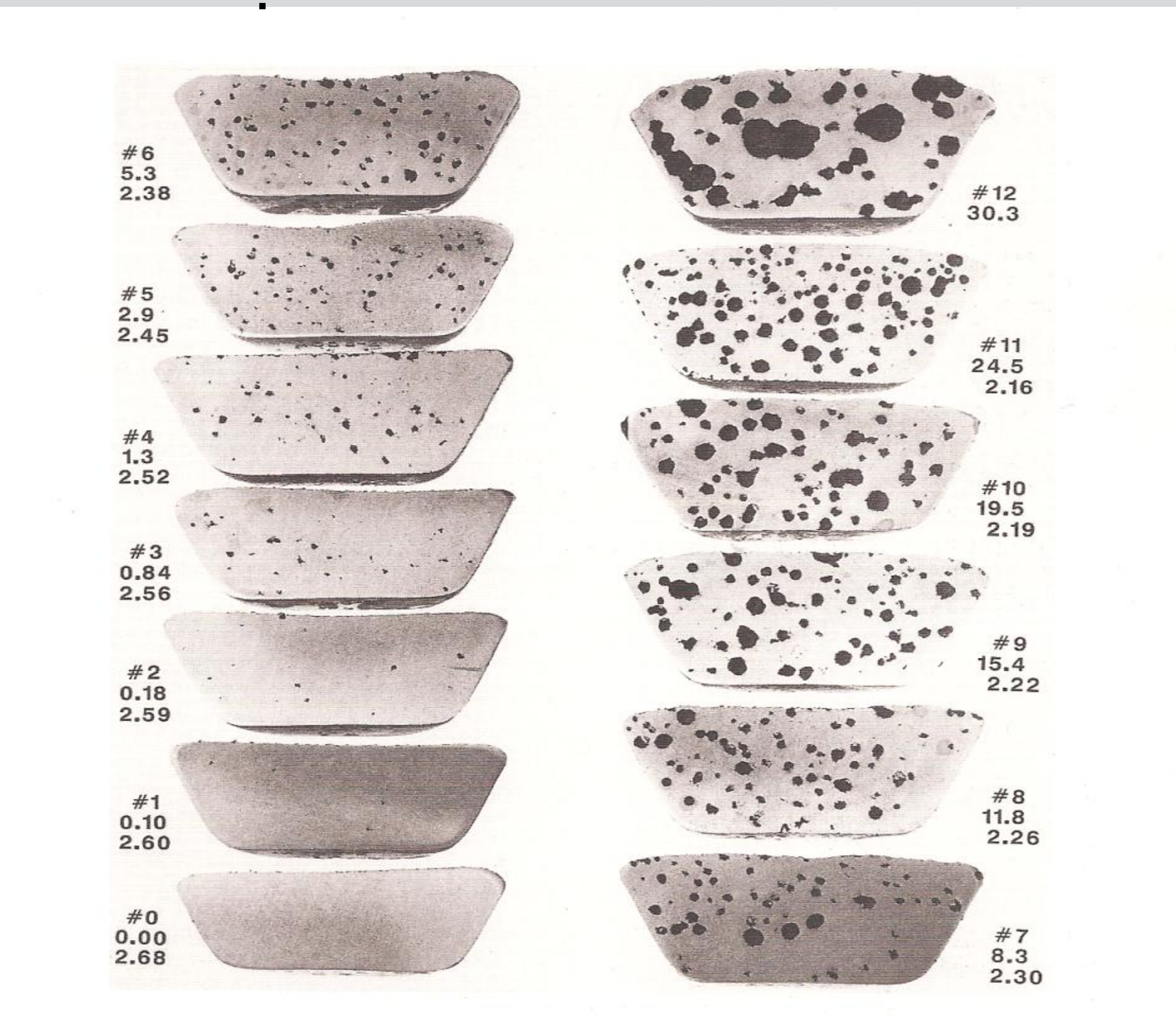


Figure 8.38. Reduced pressure test for gas content in molten metal: series of specimens of varying gas contents in an aluminium alloy (courtesy of Institute of British Foundrymen)

Control de calidad de metal liquido
Prueba de presión reducida, para evaluar contenido de hidrógeno en aluminio

Estándar de control de porosidad:

1) El número del centro indica el porcentaje del área de la porosidad.
2) El número inferior indica la densidad.



Ensayos para medición de hidrógeno en Al y aleaciones

ALSCAN

The Alscan technique measures true hydrogen content in a melt sample in real time (approximately 15 minutes) by means of a carrier gas collecting hydrogen, and thermal conductivity measurement. While not a measurement of molten metal cleanliness per se, this is an excellent tool to gain quantitative information on hydrogen content of the melt. Even in high pressure diecasting with its rapid solidification, porosity

LABORATORY HYDROGEN ANALYSIS

An alternative method to measure hydrogen content is to take a melt sample and cast a permanent mold test bar, for example the Ransley pin mold. This sample is subsequentlyanalyzed in the laboratory by vacuum sub-fusion equipment to capture the hydrogen gas that evolves from the sample during the analysis.

QUALIFLASH

This is a qualitative fluidity test device (Figure 3) which passes a specific volume of metal at a given temperature through a coarse, cellular 'test' filter into a stepped collector pan. The more fluid the metal, the greater the number of 'steps' climbed by the molten metal. A shop-floor result can be achieved in five minutes or less, but the process is sensitive to both temperature and specific alloy as well as melt cleanliness.

Figure 3: The Qualiflash test measures molten metal fluidity semi-quantitatively.

Evalúa la limpieza de la aleación líquida (inclusiones) se complementa con análisis metalográfico

Evalúa la limpieza de la aleación líquida (inclusiones) se complementa con análisis metalográfico

Figure 4: The Prefil Footprinter provides real-time analysis of metal cleanliness relative to accumulated industry data. (N-Tec)

Medida de la limpieza relativa de una masa fundida de aluminio en comparación con un nivel de inclusión de referencia para una aleación dada, de un proceso de producción o una determinada fase en el proceso. El sistema se basa en la filtración de una muestra de aluminio líquido a través de un filtro fino de cerámica porosa, bajo estrictas condiciones. El resultado de la prueba es un gráfico de la curva el peso del metal se filtra en función del tiempo.

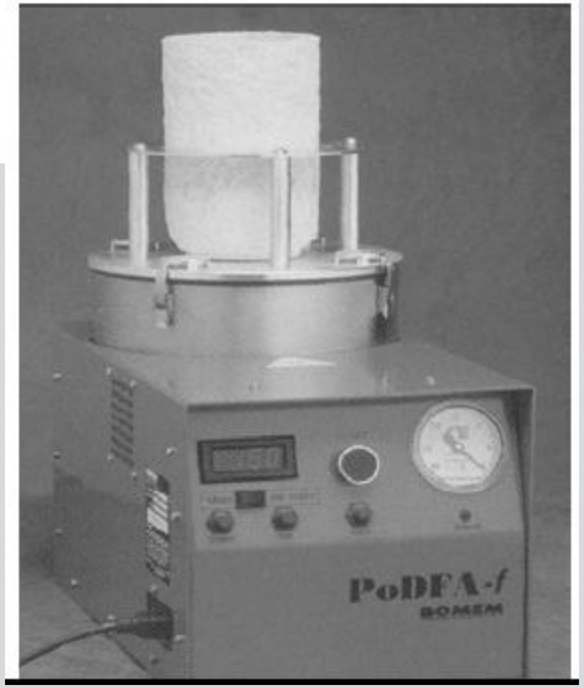
Funcionamiento, El uso de un crisol equipado con un disco de filtro poroso en la parte inferior es el primer pre-calentado y se instala en una cámara de presión. Posteriormente, el operador toma una muestra de metal líquido con una cuchara, vierte en el crisol, se cierra la cámara de presión y comienza la prueba.

El sistema se aplica presión en la cámara cuando la temperatura del metal alcanza el valor especificado para la prueba, obligando a que el metal líquido fluya a través del disco de filtro poroso.
La construcción de una base de datos permite determinar la variación de la limpieza metal que se encuentra en un lugar específico. La base de datos se utiliza como una comparación o referencia, proporcionando así una huella del proceso. Los resultados de metal a prueba en el mismo lugar puede ser juzgado en contra del punto de referencia pre-establecido como un control de calidad.

PODFA

Shown schematically in Figure 5, this test is similar to the second-stage of the Prefil. A small quantity of metal is caused to flow under pressure through a fine-grade test filter. The inclusion content concentrated on the surface of the test filter is then examined metallographically. The LAIS (Liquid Aluminum Inclusion Sampler) is a similar device. All three—Prefil, PodFA, and LAIS—require off-line analysis and therefore their main usefulness is in process development, analyzing benefits of varying process parameters, and they are not useful as real-time production tools. Correlations of results between these three techniques can be difficult.

Figure 5: The PodFA test is a common method to evaluate metal cleanliness using metallography on the collected sample.



Evalúa la limpieza de la aleación líquida (inclusiones) se complementa con análisis metalográfico

MECHANICAL TESTING

Mechanical properties (tensile and yield strength, elongation, fatigue strength) can be determined by casting test bars and comparing results of filtered versus unfiltered metal. Figure 6 displays a useful 5-bar test mold, bottom fed, which affords permanent mold solidification conditions. A single pour provides reasonable 'significance' of the validity of the 5-data point average result.

Figure 6: A multiple test bar mold is used to cast specimens for mechanical testing. (N-Tec)

FEEDING AND SHRINKAGE TESTS

A simple spiral fluidity test can be performed by pouring metal at a given temperature into a spiral mold. The distance the metal travels before solidification can then be used as a measure of fluidity, filtered metal vs. unfiltered metal. A more sophisticated test is the Tatur Test (Figure 7), which meausres shrinkage and porosity distribution as a function of (1) hydrogen concentration, (2) alloy/structure/solidification, and (3) metal cleanliness.

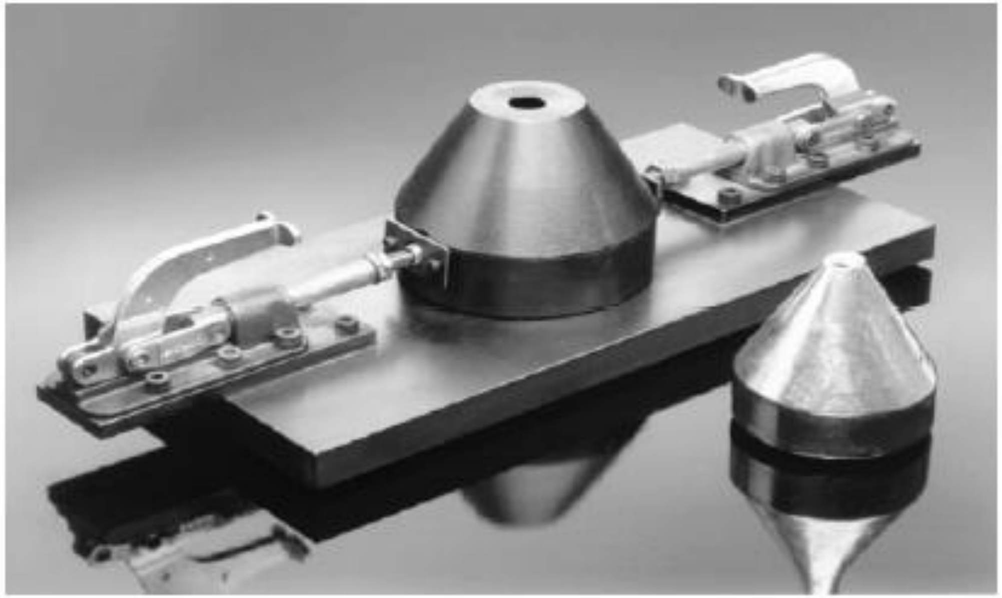


Figure 7: The Tatur test measures shrinkage and porosity. (N-Tec).

K-MOLD

This is a simple shop-floor, real-time test procedure comprised of casting metal into a notched bar chill mold (Figure 8) and visually examining macro defects (coarser inclusions, gross oxides, and gas bubbles) on the fracture surface in a series of bars. The K-factor is the number of defects seen per number of fracture surfaces examined. This test method originated in Japan and is used extensively there. Many US foundries and and diecasters are now evaluating this test technique both as a process development tool as well as an ongoing production go/no-go step for casting or additional treatment necessary prior to casting.

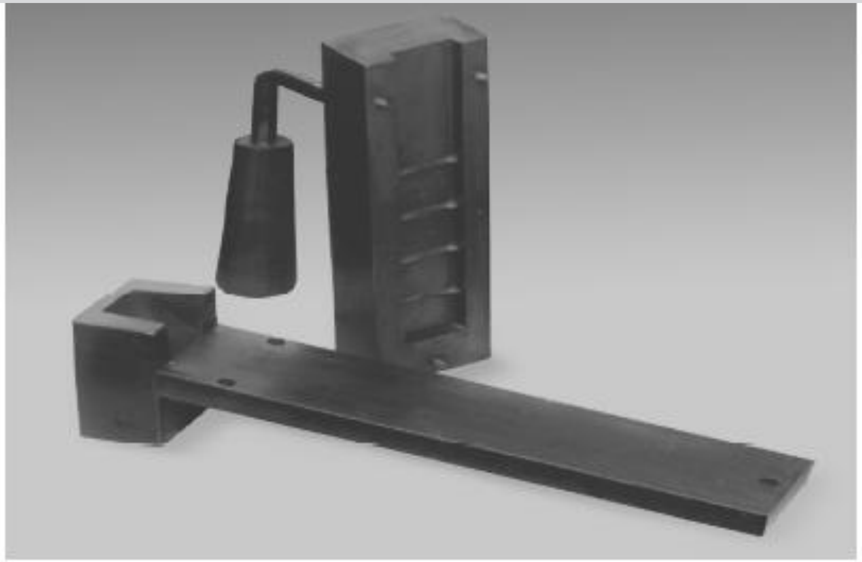
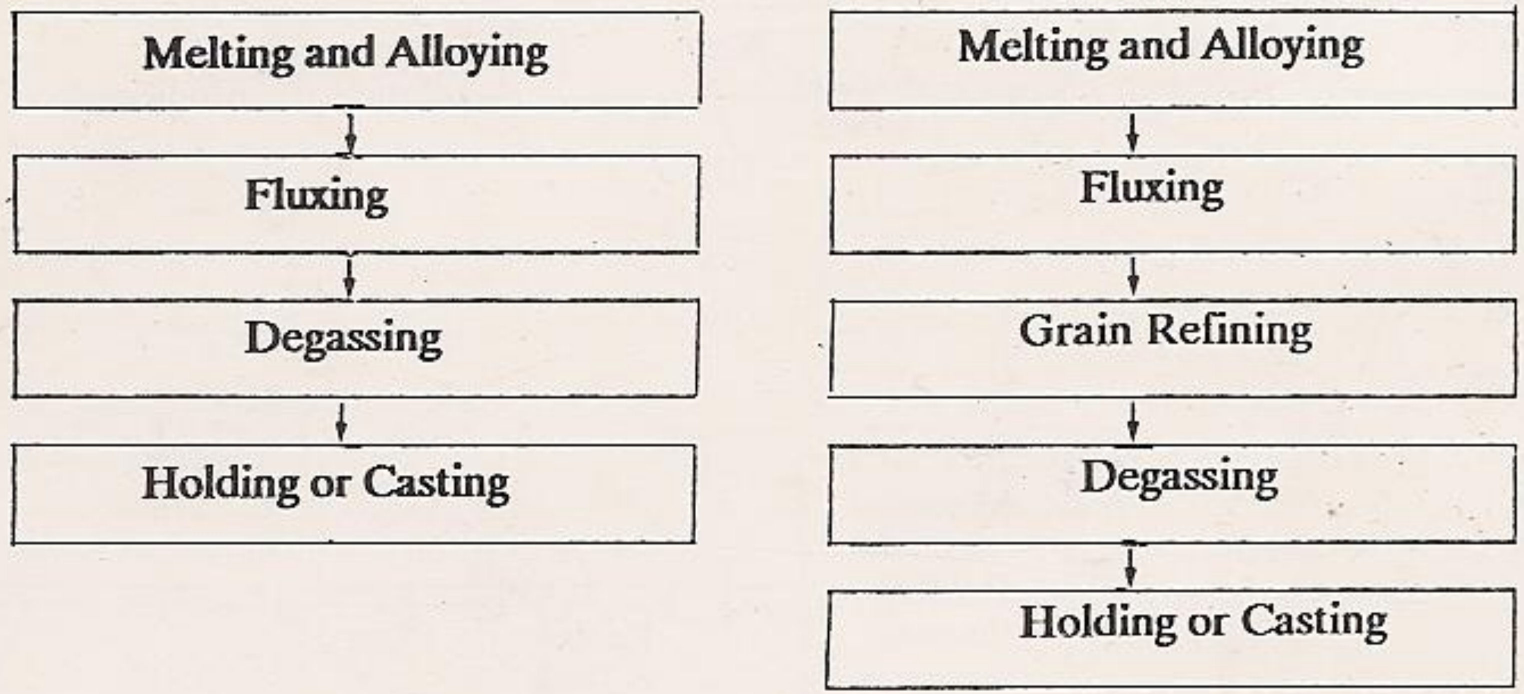


Figure 8: The K-Mold is a simple shop-floor, real-time test which evaluates macro-cleanliness.

Secuencia en las Técnica de fusión

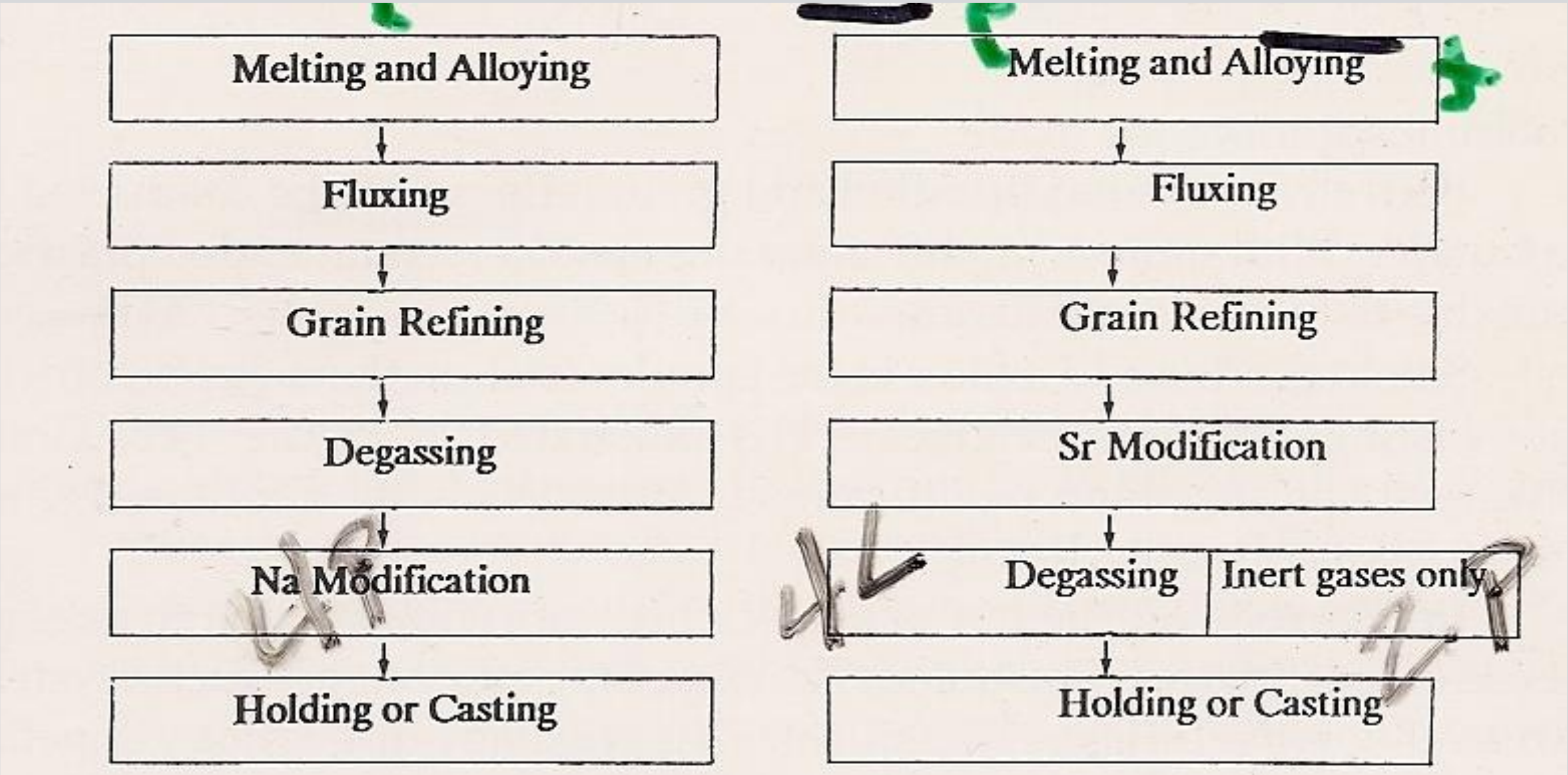
Typical smelter processing schedules.



(a) without grain refining and modification

(b) with grain refining and without modification

Typical smelter processing schedules.



(c) with grain refining and Na modification

(d) with grain refining and Sr modification

Aluminio y aleaciones

Se tienen tres tratamientos del metal líquido

- Desgasificación
- Refinamiento de grano
- Modificación

Todas las aleaciones base aluminio, excepto las Al-Si, llevan dos tratamientos del metal líquido:

- Desgasificación
- Refinamiento de grano

A las aleaciones Al-Si, además de los dos anteriores, se les debe de efectuar:

- Modificación

Ahora bien, ¿Cuál es la secuencia correcta?

Aleaciones bases aluminio, excepto Al-Si.

a) - Desgasificación
- Refinamiento de grano

b) - Refinamiento de grano
- Desgasificación

Para aleaciones Al – Si

a) - Desgasificación
- Refinamiento de grano
- Modificación

b) - Refinamiento de grano
- Desgasificación
- Modificación

c) - Modificación
- Refinamiento de grano
- Desgasificación

d) - Modificación
- Desgasificación
- Refinamiento de grano