

# Solidification Structures of Aluminum Alloys

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ALUMINUM-BASE ALLOYS constitute a group of cast materials second only to ferrous castings in tonnage. Aluminum alloys have gained increasing markets in the automotive and aircraft industry. New alloys are still under development, since there are still wide possibilities of improving their properties by using simple, affordable techniques, such as alloying and heat treating. A wide range of materials can be added to aluminum (Ref 1): zinc, magnesium, copper, silicon, iron, lithium, manganese, nickel, silver, tin, and titanium. The solid solubility of these elements in aluminum varies considerably. Some elements are used as solid-solution strengtheners, others form desirable intermetallic compounds. The most common alloy systems are aluminum-silicon, aluminum-copper, and aluminum-magnesium. Some typical solidification microstructures for these alloying systems are given in the following sections.

## Basic Microstructures of Aluminum-Base Alloys

**Aluminum-Silicon Alloys.** The equilibrium phase diagram of the binary aluminum-silicon

system is similar to that in Fig. 16(b) of the article "Fundamentals of Solidification" in this Volume, representing partial solid solubility with a eutectic reaction. The eutectic invariant is at 11.7% Si and 577 °C (1070 °F). Typical examples of hypoeutectic, eutectic, and hypereutectic aluminum-silicon commercial alloys are given in Fig. 1 (Ref 2).

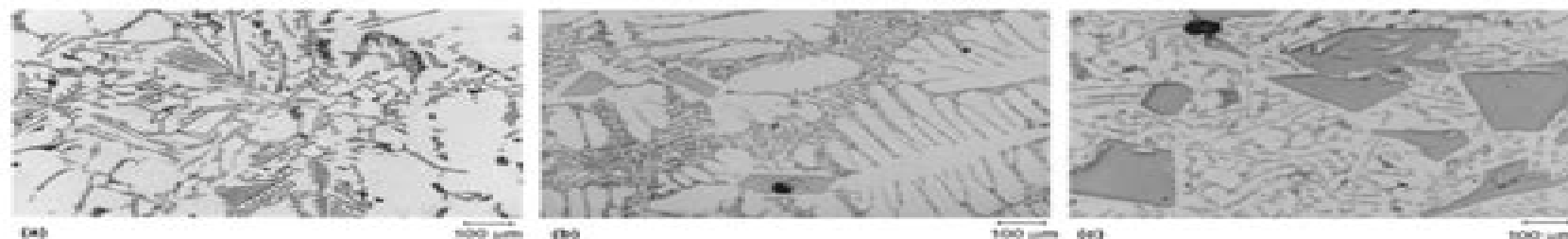
Binary eutectic or hypoeutectic aluminum-silicon alloys are characterized by good castability and corrosion resistance. However, the aluminum-silicon alloys are seldom binary. Strengthening of aluminum-silicon alloys is achieved by adding small amounts of other elements, such as copper, magnesium, or iron. Higher iron contents can promote the formation of brittle plates of  $AlFeSi$  or other complex intermetallics in the presence of manganese. This may have a negative influence on the mechanical properties.

**Aluminum-Copper Alloys.** The equilibrium diagram of the binary aluminum-copper system is given in Fig. 2. These alloys are typical solid-solution alloys generally containing 4 to 6% Cu and some magnesium. After a solution treatment,  $CuAl_2$  particles precipitate from the quenched alloy, as seen in Fig. 2. The level of impurities can affect both the microstructure and

microstructure. This is demonstrated in Fig. 3 and 4 for a nominal Al-4.5Cu-0.25Mg alloy with a small amount of silver (0.7%) and titanium, respectively. Titanium addition considerably decreases the grain size.

**Aluminum-Magnesium Alloys.** The corner of the phase diagram of practical interest is similar to that of aluminum-copper alloys, with the maximum solubility of magnesium in aluminum at 17.4% Al. Some typical examples of aluminum-magnesium commercial alloys are given in Fig. 5.

**Other Multicomponent Aluminum Alloys.** Investigations of higher-order multicomponent alloys solidification are rather limited. Sophisticated methods are used to identify phases and their orientation. An example of the microstructure of the Al 7050 alloy containing 11 elements is given in Fig. 6 (Ref 3). The dark areas are  $\alpha$ -aluminum phase and the bright areas are quaternary sigma ( $\sigma$ ) phase ( $AlCuZn_2Mg$ ), ternary  $\beta$  phase ( $Al_2MgCu$ ), or/and binary  $\theta$  phase ( $Al_2Cu$ ). These phases were identified using optical metallography, scanning electron microscopy (SEM), x-ray map, and electron probe microanalysis (EPMA) techniques. The dendrite arms are separated by sigma,  $\beta$ ,  $\theta$ , and/or eutec-



**Fig. 1** Typical microstructures of hypoeutectic, eutectic, and hypereutectic aluminum-silicon commercial alloys. (a) Hypoeutectic aluminum-silicon alloy (Al-5.7%Si, alloy type A319). Fan-shaped  $Al_2Cu$  ( $AlFeSi$ )-Si<sub>2</sub> phase growing in competition with the  $\alpha$ -aluminum phase, silicon crystals,  $Al_2Cu$ , and areas with complex eutectics. Etchant: 0.5% HF. Original magnification: 110 $\times$ . (b) Eutectic aluminum-silicon alloy (Al-11.9%Si, alloy type A339).  $\alpha$ -aluminum dendrites, primary silicon particles, and areas with complex eutectics. Etchant: 0.5% HF. Original magnification: 110 $\times$ . (c) Hypereutectic aluminum-silicon alloy (Al-12%Si, alloy type A390). Large primary silicon particles, eutectic silicon crystals, and  $Al_2Cu$  phase in a matrix of  $\alpha$ -aluminum phase. Etchant: 0.5% HF. Original magnification: 110 $\times$ .

# Solidification Of Aluminum Alloys

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## **Solidification Of Aluminum Alloys:**

*Solidification Characteristics of Aluminum Alloys: Wrought alloys* Lennart Bäckerud, Ella Król, Jarmo Tamminen, 1986

Solidification of Aluminum Alloys Men G. Chu, Douglas A. Granger, Qingyou Han, 2004-03 This volume addresses progress in the application of solidification principles to the production of aluminum alloys Topics include microstructure evolution phase formation and solidification path analysis grain refinement micro macro segregation mechanical behavior properties in the mushy state solidification cracking tearing gas shrinkage porosity formation effect of impurities trace elements and the impact of cast structure on the subsequent fabrication and properties of finished products Paper on the experimental or theoretical simulation of solidification aspects of casting processes including direct chill casting continuous casting shaped casting semi solid processing and other advanced casting technologies are also included as well as examples showing the use of solidification principles to solve industrial problems From [http://www.tms.org/Meetings/Annual\\_04/AnnMtg04Home.html#target\\_blank2004](http://www.tms.org/Meetings/Annual_04/AnnMtg04Home.html#target_blank2004) TMS Annual Meeting a to be held in Charlotte North Carolina March 14-18 2004 *Report of the Research Group for Rapid Solidification of Aluminum Alloys* Keikin zoku Shogakukai. Research Group for Rapid Solidification of Aluminum Alloys, 1987

### **Solidification of Aluminum and Aluminum Alloys at High Levels of Undercooling**

Stephen Edward LeBeau, 1982 *Casting Aluminum Alloys* Michael V Glazoff, Vadim S Zolotarevsky, Nikolai A Belov, 2010-07-07 Casting Aluminum Alloys summarizes research conducted at Moscow Institute of Steel and Alloy during many decades in part together with Alcoa Inc The research covered areas of the structure properties thermal resistance corrosion and fatigue of aluminum alloys in industrial manufacturing Emphasis on interconnection among phase equilibria thermodynamics and microstructure of alloys Systematic overview of all phase diagrams with Al that are important for the development of casting aluminium alloys Diagrams processing windows of important technological properties such as castability molten metal fluidity tendency to hot pre solidification cracking porosity Mathematical models for alloy mechanical properties facilitating the down selection of best prospect candidates for new alloy development New principles of design of eutectic casting aluminium alloys Examples of successful novel casting alloy development including alloys for high strength applications alloys with transition metals and novel alloys utilizing aluminium scrap

**Solidification of Aluminum Alloys Under Pressure** Stuart Zane Uram, 1957 *Solidification Characteristics of Aluminum Alloys* Lars Arnberg, American Foundrymen's Society, L. Bäckerud, Guocai Chai, 1996 **Solidification Characteristics of Aluminum Alloys** Guocai Chai, Jarmo Tamminen, 1990-01-01 **Aluminum Alloy Castings** John Gilbert Kaufman, Elwin L. Rooy, 2004-01-01 J G Gil Kaufman is currently president of his consulting company Kaufman Associates

**Casting and Solidification of Light Alloys** Alexander Vorozhtsov, 2020-12-15 Investigation of the effect of casting and crystallization on the structure and properties of the resulting light alloys and in particular research connected with detailed analysis of the microstructure of light alloys obtained using various external influences of ultrasonic vibration magnetic and mechanical

processing on the casting and crystallization are discussed Research on the study of introduction of additives modifiers reinforcers including nanosized ones etc into the melt during the crystallization process the technological properties of casting fluidity segregation shrinkage etc the structure and physicommechanical properties of light alloys are also included

**Physical Metallurgy of Direct Chill Casting of Aluminum Alloys** Dmitry G. Eskin,2008-04-17 Pulling together information previously scattered throughout numerous research articles into one detailed resource this book connects the fundamentals of structure formation during solidification with the practically observed structure and defect patterns in billets and ingots The author examines the formation of a structure properties and defects in the as cast material in tight correlation to the physical phenomena involved in the solidification and the process parameters Compiling recent results and data the book discusses the fundamentals of solidification together with metallurgical and technological aspects of DC casting It gives new insight and perspective into DC casting research *Aluminum and Aluminum Alloys* Joseph R. Davis,1993-01-01 This one stop reference is a tremendous value and time saver for engineers designers and researchers Emerging technologies including aluminum metal matrix composites are combined with all the essential aluminum information from the ASM Handbook series with updated statistical information *Rapidly Solidified Powder Aluminum Alloys* Morris E. Fine,E. A. Starke,1986 *Solidification of Aluminum Alloys at Micro Gravity* Peter C. Pachikara (University of Manitoba student),1990

**Solidification of Aluminum Alloys** Men G. Chu,Douglas A. Granger,Qingyou Han,2004-03-01 This volume addresses progress in the application of solidificationprinciples to the production of aluminum alloys Topics includemicrostructure evolution phase formation and solidification pathanalysis grain refinement micro macro segregation mechanicalbehavior properties in the mushy state solidificationcracking tearing gas shrinkage porosity formation effect ofimpurities trace elements and the impact of cast structure on thesubsequent fabrication and properties of finished products Paperson the experimental or theoretical simulation of solidificationaspects of casting processes including direct chill casting continuous casting shaped casting semi solid processing andother advanced casting technologies are also included as well asexamples showing the use of solidification principles to solveindustrial problems From ahref [http://www.tms.org/Meetings/Annual\\_04/AnnMtg04Home.html#target\\_blank2004](http://www.tms.org/Meetings/Annual_04/AnnMtg04Home.html#target_blank2004) TMS Annual Meeting a to be held inCharlotte North Carolina March 14 18 2004

Application of Rapid Solidification Techniques to Aluminum Alloys C. G. Lebi,R. Mehrabian,ILLINOIS UNIV AT URBANA-CHAMPAIGN.,ILLINOIS UNIV AT URBANA-CHAMPAIGN DEPT OF METALLURGY AND MINING ENGINEERING.,S. C. Hsu,S. Kou,1978 This portion of the program was conducted for the purpose of developing a predictive model of heat flow and solidification for aluminum alloys produced under the high cooling rate conditions achievable in atomization processes It is a combined experimental and theoretical study of the relationship between the important solidification variables e g cooling rate temperature gradients interface shape and velocity supercooling and transformation kinetics and the structure of rapidly solidified aluminum alloy powders This report covers that portion of the investigations

which addressed the characterization of the thermal history of rapid solidification in metal droplets and its effects on powder microstructure The main effort was focused on modelling the heat flow during solidification and relationships were established between the atomization parameters the growth kinetics the interface velocity and undercooling and other important variables Numerical solutions based on the enthalpy model were developed and their results compared to the trends predicted from the Newtonian model The analysis covered situations of isothermal solidification at the melting temperature as well as those where significant undercoolings are necessary for nucleation and growth The implications of single vs multiple nucleation were also discussed The concepts developed from the heat flow analysis were coupled to microstructural observations in Aluminum alloy powders mostly in the submicron size range It was shown that reducing the particle size decreases the extent of segregation promotes multiple nucleation and the formation of twins during solidification Interdendritic Flow During Solidification of Aluminum Alloys Thomas Squire Pivonka,1963

Solidification of Aluminum Alloys Reinforced with Externally Cooled Continuous Graphitic Fibers Hwan-Goo Seong,2005

**Casting Aluminum Alloys** Michael V Glazoff,Alexandra Khvan,Vadim S Zolotarevsky,Nikolai A Belov,Alan Dinsdale,2018-09-03 Casting Aluminum Alloys Second Edition the follow up to the fall 2007 work on the structure properties thermal resistance corrosion and fatigue of aluminum alloys in industrial manufacturing discusses findings from the past decade including sections on new casting alloys novel casting technologies and new methods of alloys design The book also includes other hot topics such as the implementation of computational technologies for the calculation of phase equilibria and thermodynamic properties of alloys the development of software for calculation of diffusion processes in aluminum alloys computational modeling of solidification microstructure and texture evolution of multi component aluminum materials In addition to changes in computational predictive abilities there is a review of novel casting aluminum alloy compositions and properties as well as descriptions of new casting technologies and updates to coverage on the mechanical properties of aluminum casting alloys Presents a discussion of thermodynamic calculations used for assessing non equilibrium solidifications of casting aluminum alloys Expands coverage of mathematical models for alloy mechanical properties helping facilitate the selection of the best prospective candidate for new alloy development Contains a new section that describes the self consistent evaluation of phase equilibria and thermodynamic properties of aluminum alloys **An Investigation of the Solidification of Aluminum Alloys by Autoradiography and Other Techniques** Arthur B. Michael,1952

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