

# Solidification Structures of Aluminum Alloys

Doru M. Stefanescu and Roxana Ruxanda, The University of Alabama

**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).

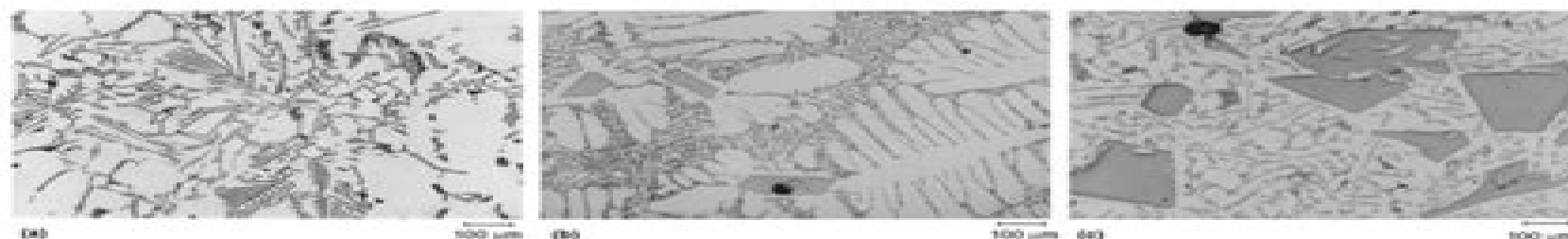
Binary eutectic or hypoeutectic aluminum-silicon alloys are characterized by good castability and corrosion resistance. However, the aluminum-silicon alloys are seldom binary. Strengthening of aluminum-silicon alloys is achieved by adding small amounts of other elements, such as copper, magnesium, or iron. Higher iron contents can promote the formation of brittle plates of  $\text{AlFeSi}$  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,  $\text{CuAl}_2$  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  $\text{Al-4.5Cu-0.25Mg}$  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 ( $\text{AlCuZn}_2\text{Mg}$ ), ternary  $\beta$  phase ( $\text{Al}_2\text{MgCu}$ ), or/and binary  $\theta$  phase ( $\text{Al}_2\text{Cu}$ ). 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,  $\beta$ , 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  $\text{Al}_2\text{Cu-AlFeSi}_3\text{Si}$  phase growing in competition with the  $\alpha$ -aluminum phase, silicon crystals,  $\text{Al}_2\text{Cu}$ , 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-15%Si, alloy type A390). Large primary silicon particles, eutectic silicon crystals, and  $\text{Al}_2\text{Cu}$  phase in a matrix of  $\alpha$ -aluminum phase. Etchant: 0.5% HF. Original magnification: 110 $\times$ .

# Solidification Of Aluminum Alloys

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