

Solidification During Casting of Metal-Matrix Composites

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METAL-MATRIX COMPOSITES (MMC's) are engineered combinations of two or more materials in which reinforcing phases are dispersed in a metal or an alloy. Structurally, cast MMC's consist of continuous or discontinuous fibers (designated by the subscript *f*), whiskers (*w*), or particles (*p*) in a metal or an alloy that solidifies in the restricted spaces between the reinforcing phase (or phases) to form the bulk of the matrix. There are several cast materials, such as aluminum-silicon alloys and cast irons, that exhibit two-phase microstructures in which the volume and shape of the phases are governed by phase equilibria and that have a long history of foundry production. Modern cast MMC's differ from these traditional materials in that any selected volume, shape, and size of reinforcement can be introduced into the matrix, even beyond the permissible limits presented by the phase diagrams.

By carefully controlling fiber size, shape, surface properties, volume fraction, and distribution of the reinforcement and by controlling the solidification conditions, MMC's can be synthesized having a tailored set of useful engineering properties. For example, as shown in Table 1, combinations of very high specific strength and specific modulus, beyond those of conventional monolithic alloys, are achievable. Table 2 summarizes the applications of several commonly used MMC's and the properties that make them suitable for

their applications. Microstructural design and synthesis procedures have been developed to achieve unique combinations of properties, including improved elevated-temperature and fatigue strengths, increased damping ability, tailored electrical and thermal conductivities,

reduced wear rates, and targeted coefficients of thermal expansion. These tailored properties provide opportunities for a variety of new applications for MMC's that were not possible using conventional materials. For more information about MMC types and their applications, see the

Table 1 Specific strength and specific modulus of some metal matrices, reinforcements, and metal-matrix composites

Material	Reinforced fiber reinforcement, wt%	Specific strength, N m/kg	Specific modulus, N m/kg
Al-10Si/Al ₂ O ₃	60	30,000	1.04×10^7
Al ^a	0	4,780-6,200	4.40×10^6
Ti-6Al-4V/AlN ^b	—	—	—
Al ^a	24	42,137	1.77×10^7
Al ^a	23	32,622	—
Al ^a	20	26,139	—
Al ^a /carbon fiber ^c	30	30,140	6.53×10^6
Al ^a /Al ₂ O ₃	—	11,440	2.23×10^6
Ti-6Al-4V ^a	—	17,149	1.59×10^6
Al ^a	100	26,431	1.567×10^6
Al ^a /K ₂ O	100	6.07×10^4	2.19×10^6
Al ^a /SiC ₁	100	30,000	1.175×10^6
Al ^a	100	1,334 $\times 10^4$	1.62×10^6
C ^a	100	1,418 $\times 10^4$	1.23×10^6
Al ^a	100	36,436	1.08×10^6
Al ^a	100	14,074	1.79×10^6
Al ^a /Al ₂ O ₃	—	9,000	1.01×10^6
Al ^a	50	5,203	1.66×10^6
Al ^a /Al ₂ O ₃	—	—	—
Al ^a	50	6,363	1.090×10^6
Al ^a	50	1,403	—

Table 2 Selected potential applications of cast metal-matrix composites

Composite	Applications	Special Features
Aluminum/graphite	Bearings	Chemical stability with lubricating, composite Cu, Pb, Sn, Zn, etc.
Aluminum/graphite, aluminum/Si ₃ N ₄ , aluminum/SiC-Al ₂ O ₃	Aerospace pistons, cylinder bores, piston rings, connecting rods	Reduced wear, minimizing cold start, ignition, composite (Sn, Zn) improved efficiency
Copper/graphite	Winding systems of cranes	Excellent conductivity and anti-wear properties
Aluminum/SiC	Thrust-bearing supports	High compressive wear
Aluminum/iron or carbon reinforcements	—	Strength materials
Aluminum/carbon fiber	Turbine compressor fan spacers, wire ties	Low thermal expansion, high-temperature strength, good specific strength and specific stiffness
Aluminum/iron, aluminum/SiC, aluminum/SiC	Cutting tools, machine elements, impellers	Hard, aluminum-reinforced materials
Aluminum/Al ₂ O ₃ , aluminum/Al ₂ O ₃	Low-cost, low-energy materials	—

Solidification Of Metal Matrix Composites

David Kirk



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