

# 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 iron, 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	Amount of fiber/reinforcement, vol %	Specific strength, N m/kg	Specific modulus, N m/kg
Al-10Al <sub>2</sub> O <sub>3</sub>	—	30,000	$7.59 \times 10^7$
—	40	4,950–6,000	$4.400 \times 10^7$
Ti-20Al <sub>2</sub> O <sub>3</sub> (p)	—	—	$3.77 \times 10^7$
—	25	47,337	—
—	25	50,000	—
Injection (Thermix)	—	26,339	—
Aluminum	30	26,340	$6.53 \times 10^7$
6061 Al	—	11,440	$2.53 \times 10^7$
2024 Al	—	17,340	$3.59 \times 10^7$
SiC <sub>f</sub>	100	70,435	$5.507 \times 10^8$
SiC <sub>w</sub>	100	$6.67 \times 10^7$	$2.19 \times 3.29 \times 10^8$
Al <sub>2</sub> O <sub>3</sub>	100	80,000	$5.175 \times 10^8$
K <sub>2</sub> O	100	$1.554 \times 10^7$	$1.62 \times 10^7$
C <sub>60</sub>	100	$1.493 \times 10^7$	$1.25 \times 10^7$
SiC <sub>p</sub>	100	86,459	$8.08 \times 10^7$
W <sub>2</sub> C	100	140,754	$1.79 \times 10^7$
Aluminum	—	—	—
—	50	8,000	$7.03 \times 10^7$
—	50	5,200	$5.44 \times 10^7$
Al <sub>2</sub> SiC	—	—	—
—	50	6,300	$1.090 \times 10^8$
—	50	3,400	—

Table 2 Selected potential applications of cast metal-matrix composites

Composites	Applications	Special features
Aluminum/graphite	—	—
Aluminum/graphite, aluminum/si-Al <sub>2</sub> O <sub>3</sub> , aluminum/SiC-Al <sub>2</sub> O <sub>3</sub>	Boatings	Chemical, lightness, self-lubricating, corrosion Cu, Pb, Sn, Zn, etc.
Aluminum/SiC	Automobile pistons, cylinder bores, piston rings, connecting rods	Reduced wear, increasing cold start, lightness, corrosion (Sn, Zn)
Copper/graphite	—	Improved efficiency
Aluminum/SiC	Sliding bearings of cranes	Excellent conductivity and lubricating properties
Aluminum/si or carbon microfibers	Thrust-bearing impellers	High compressive wear
Magnesium/graphite fibers	—	Lightweight materials
Aluminum/silicon, aluminum/SiC, aluminum/silicon	Turbine compressors for space vehicles	Low thermal expansion, high-temperature strength, good specific strength and specific stiffness
Aluminum/silicon, aluminum/SiC, aluminum/silicon	Cutting tools, machine elements, impellers	Hard, abrasion-resistant materials
Aluminum/SiC, aluminum/silicon	Low-cost, low-energy materials	—

# Solidification Of Metal Matrix Composites

**Awadh B. Pandey, Kevin L.  
Kendig, Thomas J. Watson**



## **Solidification Of Metal Matrix Composites:**

*Microstructure Formation During Solidification of Metal Matrix Composites* P. K. Rohatgi, 1993 This collection of papers from Materials Week 92 held in Chicago USA November 1992 identifies and defines the fundamental principles of solidification of metal matrix composites Areas of discussion include nucleation growth heat flow particle pushing interface stability and segregation during solidification of metal matrix composites

**Solidification Processing of Metal Matrix Composites** Nikhil Gupta, Warren H. Hunt, 2006-11-10 Solidification Processing of Metal Matrix Composites MMCs focuses primarily on microcomposites but also covers macrocomposites nanocomposites and foams There are four main areas detailed fundamentals of solidification synthesis which examines issues related to stir mixing pressure infiltration transfer of particles or fibers through gas liquid and liquid solid interfaces and particle fiber interactions with fluids processing and microstructures which focuses on microstructure formation during solidification of MMC under different conditions such as nucleation growth heat transfer microsegregation macrosegregation and interactions between solidifying interfaces particles and fibers and properties of solidification processing covering the relationship between the microstructures and properties Comparisons are made between properties of solidification processed composites and monolithic and composites made by solid and vapor phase processes It also details the application of solidification processed MMCs revealing current and future applications especially in automotive aerospace railroad thermal management electromechanical machinery and recreational equipment sectors

*Solidification of Metal Matrix Composites* P. K. Rohatgi, 1990

*Solidification Processing of Reinforced Metals* R. Asthana, 1998-04-06 Much of the success of composites can be attributed to the development of innovative processes Many useful composites are envisaged by materials scientists but the problem of how to make them is often the greater hurdle This process oriented book focuses on the basic principles of composite fabrication Upon studying these processes one is immediately struck by the diversity of ideas and techniques In some cases these have been borrowed from other technologies and were designed for use with quite different materials In other cases some very clever new means have been developed which take account of the characteristics of metals and ceramics and the higher temperatures which are typically involved in their processing

**Solidification of Particulate Reinforced Metal Matrix Composites** CSA Journal Division, Materials Information (Information service), Cambridge Scientific Abstracts, Inc, British Library. Document Supply Centre, Linda Hall Library. Document Services, 2002\*

*Solidification of Particulate Reinforced Metal Matrix Composites, 2007 Ed* Technology Research Editors, 2007-01-01

**Solidification Rate Effects in Metal-matrix Composites** Andreas Michael Borchert, 1991

**Interface Propagation in the Solidification of Metal Matrix Composites** James Edward Simpson, 1999

**Numerical Modeling of Solidification of Metal Matrix Composites with Natural Convection** E. K. Lee, 2002

*Heat and Mass Transport in the Solidification of Metal Matrix Composites* Bechir Moussa, 2000

*Numerical Simulation of Solidification of Reinforced Metal Matrix Composites* Eng Kwong Lee, 2003

**Solidification of Particulate Reinforced Metal Matrix Composites** Craig Emerson, 2009-01-01      **Nucleation Phenomenon During Solidification of Metal Matrix Composites**, 1994 A detailed analysis of possible interfaces in cast aluminum silicon base reinforced particle composites containing SiC Al<sub>2</sub>O<sub>3</sub> and C indicates that several different kinds of interfaces can form The reinforcements may be totally surrounded by primary phase or primary silicon or by the eutectic between Al and Si In addition in some cases some of the original coatings or their reaction products in the case of coated particles like nickel or nickel aluminum intermetallics in nickel coated reinforcements Cu or Cu aluminum intermetallics in Cu coated reinforcements may also form the interface The reaction between dispersoids and the alloy itself can form a complex interface These different interfaces have also been experimentally observed in the microstructures of cast particulate composites with the exception of primary  $\alpha$  aluminum surrounding the reinforcement The absence of  $\alpha$  aluminum on the reinforcements is attributed to possible lack of nucleation persistent lateral growth and a thermal lag between the reinforcement and the matrix Estimates of works of adhesion for the different interfaces observed in cast composites have been made using the London Van der Waal equation correlated to the properties of the composites and used to identify the possibilities of further improving these properties      *Solidification of Particulate Reinforced Metal Matrix Composites* Technology Research Editors, 2006-01-01      **Affordable Metal-Matrix Composites for High Performance Applications II** Awadh B. Pandey, Kevin L. Kendig, Thomas J. Watson, 2013-09-23 This book will include papers on recent research carried out in the field of metal matrix composites MMCs Processing microstructure and mechanical properties of MMCs and unreinforced matrix alloys will be covered with a focus on aluminum titanium nickel and copper MMCs Those involved in the research of MMCs and unreinforced alloys particularly in aerospace space and automotive materials research will find this volume indispensable From Materials Science Technology 2003 to be held in Chicago Illinois November 9 12 2003      *Semi-Solid Processing of Alloys and Composites* Shahrooz Nafisi, Reza Ghomashchi, 2020-06-18 Semi solid metal SSM processing as a viable alternative manufacturing route to those of conventional casting and forging has not yet been fully exploited despite nearly half a century since its introduction to the metal industry The slow pace of adopting SSM routes may be due to various reasons including capital costs profit margins and most importantly the lack of detailed analysis of various SSM processes in open literature to confidently establish their advantages over more conventional routes Therefore the SSM community must disseminate their findings more effectively to generate increased confidence in SSM processes in the eyes of our industrial leaders As such we have embarked on the task to invite the leaders in SSM research to share their findings in a Special Issue dedicated to semi solid processing of metals and composites SSM processing takes advantage of both forming and shaping characteristics usually employed for liquid and solid materials In the absence of shear forces the semi solid metal has similar characteristics to solids i e easily transferred and shaped by applying a defined force the viscosity is reduced and the material flows like a liquid These unique dual characteristics have made SSM routes attractive

alternatives to conventional casting on an industrial scale With the intention of taking full advantage of SSM characteristics it is crucial to understand SSM processing including topics such as solidification and structural evolution flow behavior through modelling and rheology new processes and process control alloy development and properties in general This Special Issue focuses on the recent research and findings in the field with the aim of filling the gap between industry and academia and to shed light on some of the fundamentals of science and technology of semi solid processing Science and Technology of Rapid Solidification and Processing M.A. Otooni, 2012-12-06 This book represents a collection of papers presented at the NATO Advanced Research Workshop NATO ARW on Science and Technology of Rapid Solidification and Processing held at Hotel Thayer West Point Military Academy New York N Y during June 21 24 1994 The workshop was attended by over forty scientists representing several NATO member countries as well as representatives from Japan China PRC Taiwan and India The purpose of this NATO ARW conference was to review the major advances made in most recent years in both the theoretical and experimental areas of rapid solidification technology and processing In accordance with the NATO ARW format the agenda for the conference was so arranged to offer in depth presentation of the latest developments in the subject area as well as to encourage follow up discussions by the participants There were seven sessions each opened with a lecture by an invited guest speaker Sessions 1 4 covered two days of the conference and focused mainly on Processing Technologies of Rapid Solidification and Thermodynamic Properties Practical Applications Sessions 4 6 concentrated on Thermodynamics of Metastable Alloys Relaxation Diffusion Magnetic and Electric Properties Fundamentals Session 6 was devoted to the Structural Characterization of Supercooled Melts Ultra Fine Polycrystalline Materials New Innovations and Techniques There were two equally important aspects of this NATO ARW conference which must be mentioned Firstly this is the first NATO ARW conference on Science and Technology of Rapid Solidification and Processing held in the United States

### **The Redistribution of Reinforcements During the Solidification Processing of Metal Matrix Composites**

Andrew Richard Kennedy, 1993 *The Solidification Microstructures of Al-Si Based Metal Matrix Composites* Nega Setargew, 1995 **Handbook of Composite Reinforcements** Stuart M. Lee, 1996-12-17 Dieses umfassende einbändige Handbuch behandelt alle Aspekte der Verstärkung von Werkstoffen angefangen von handfesten Themen wie dem manuellen Lay up Prozeß bis zu theoretischen Diskussionen über Rheologie und Modellbildung Das Nachschlagewerk ist ein Auszug aus der sechsbändigen International Encyclopedia of Composites und bietet das theoretische und praktische Wissen von renommierten Experten aus Industrie Forschung und staatlichen Instituten in einem handlichen und informativen Handbuch Fasern Herstellungsverfahren und Typen der Werkstoffverstärkung werden detailliert behandelt aber auch Themenbereiche wie z B die Beziehungen der Eigenschaften Fertigung hybride Verstärkungen und Modellbildung Ingenieure Materialwissenschaftler und Technologen werden das Composite Reinforcement Handbook als wichtiges Werkzeug schätzen lernen

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