

# 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                                | Amount of fiber/reinforcement, vol % | Specific strength, N m/kg | Specific modulus, N m/kg       |
|---|--------------------------------------|---------------------------|--------------------------------|
| Al-6.5Al <sub>2</sub> O <sub>3</sub>    | 60                                   | 30,000                    | $7.59 \times 10^7$             |
| Al                                      | 60                                   | 4,950-6,200               | $4.40 \times 10^7$             |
| Ti-20Al <sub>2</sub> O <sub>3</sub> (K) | —                                    | —                         | —                              |
| Ti                                      | 25                                   | 47,337                    | $3.77 \times 10^7$             |
| Al                                      | 25                                   | 50,000                    | —                              |
| Injection (Thermix)                     | 30                                   | 26,330                    | —                              |
| Aluminum                                | 30                                   | 26,330                    | $6.53 \times 10^7$             |
| Al-10.5Al <sub>2</sub> O <sub>3</sub>   | —                                    | 11,400                    | $2.53 \times 10^7$             |
| Ti-0.5Al                                | —                                    | 17,340                    | $3.39 \times 10^7$             |
| Al <sub>2</sub> O <sub>3</sub>          | 100                                  | 70,435                    | $3.507 \times 10^8$            |
| SiC <sub>f</sub>                        | 100                                  | $6.67 \times 10^7$        | $2.19 \times 3.29 \times 10^8$ |
| Al <sub>2</sub> O <sub>3</sub> /Al      | 100                                  | 80,000                    | $3.475 \times 10^8$            |
| Al <sub>2</sub> O <sub>3</sub>          | 100                                  | 1,334 $\times 10^7$       | $1.62 \times 10^8$             |
| C <sub>f</sub>                          | 100                                  | $1.433 \times 10^8$       | $1.25 \times 10^8$             |
| SiC <sub>f</sub>                        | 100                                  | 86,400                    | $1.08 \times 10^8$             |
| W <sub>f</sub>                          | 100                                  | 140,704                   | $1.79 \times 10^8$             |
| Aluminum                                | —                                    | —                         | —                              |
| Al                                      | 50                                   | 8,000                     | $7.03 \times 10^7$             |
| Al <sub>2</sub> O <sub>3</sub>          | 50                                   | 5,300                     | $5.44 \times 10^7$             |
| Al <sub>2</sub> SiC <sub>f</sub>        | —                                    | —                         | —                              |
| Al                                      | 50                                   | 6,300                     | $1.092 \times 10^8$            |
| SiC <sub>f</sub>                        | 50                                   | 3,400                     | —                              |

Table 2 Selected potential applications of cast metal-matrix composites

| Composites  | Applications  | Special features  |
|---|---|---|
| Aluminum/graphite   | Bearings  | Chemical, physical, self-lubricating, consistent Cu, Pb, Sn, Bi, etc.                           |
| Aluminum/graphite, aluminum/si-Al <sub>2</sub> O <sub>3</sub> , aluminum/SiC-Al <sub>2</sub> O <sub>3</sub> | Automobile pistons, cylinder bores, piston rings, connecting rods | Reduced wear, increasing cold start, optimum compression Ratio, improved efficiency             |
| Copper/graphite   | Winding elements of electric                                      | Excellent conductivity and antistatic properties  |
| Aluminum/SiC  | Thrust-bearing impellers  | High compressive wear   |
| Aluminum/si or carbon microfibers   | —   | 500-kg/m <sup>3</sup> materials   |
| Magnesium/graphite fibers   | Turbine compressors for space vehicles                            | Low thermal expansion, high-temperature strength, good specific strength and specific stiffness |
| Aluminum/graphite, aluminum/SiC, aluminum/silica  | Cutting tools, machine elements, impellers                        | Hard, abrasion-resistant materials  |
| Aluminum/silica, aluminum/si  | Low-cost, low-energy materials                                    | —   |

# Solidification Of Metal Matrix Composites

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## **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 of Metal Matrix Composites**

P. K. Rohatgi,1990 **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 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 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 **Heat and Mass Transport in the**

**Solidification of Metal Matrix Composites** Bechir Moussa,2000 *Solidification Rate Effects in Metal-matrix Composites* Andreas Michael Borchert,1991 *Solidification of Particulate Reinforced Metal Matrix Composites, 2007 Ed* Technology Research Editors,2007-01-01

**Interface Propagation in the Solidification of Metal Matrix Composites** James Edward Simpson,1999 **Metal Matrix Composites** Anne Isabelle Mertens,Stanislav Kolisnychenko,2023-11-16

Aggregated Book **Metal-Matrix Composites** T. S. Srivatsan,Pradeep K. Rohatgi,Simona Hunyadi Murph,2022-02-09

This collection brings together engineers scientists scholars and entrepreneurs to present their novel and innovative contributions in the domain specific to metal matrix composites and on aspects specific to processing characterization mechanical behavior measurements failure behavior and kinetics governing microstructural influences on failure by fracture Topics include but are not limited to Metals and metal matrix composites Nano metal based composites Intermetallic based composites Contributions in the above topics connect to applications in industry relevant areas automotive nuclear and clean energy aerospace failure analysis biomedical and healthcare and heavy equipment machinery and goods

**Numerical Modeling of Solidification of Metal Matrix Composites with Natural Convection** E. K. Lee, 2002 *Numerical Simulation of Solidification of Reinforced Metal Matrix Composites* Eng Kwong Lee, 2003 [Metal Matrix Composites](#)

Suneev Anil Bansal, Virat Khanna, Pallav Gupta, 2022-08-23 This book gives in depth coverage of Metal Matrix Composites MMCs focusing on micro and nano reinforcements including hybrid structures and applications like tribological and corrosion behavior heat exchanger and so forth Each chapter covers different perspectives of micro nano reinforcement and related applications Major topics covers include new age reinforcement fracture and corrosion behavior tribological elastic elastoplastic and thermal behavior of MMCs Features Presents detailed analysis on new age reinforcements in Metal Matrix Composites MMCs Discusses application based analysis of MMCs Covers details about convergence of hybrid composite from conventional alloys Includes mechanisms and effects of various reinforcement on pertinent properties Reviews properties and applications of various MMCs This book aims at graduate students researchers and professionals in micro nano science technology mechanical engineering industrial engineering metallurgy and composites

*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

**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. [Metal Matrix Composites in Industry](#) Alexander Evans, Christopher San Marchi, Andreas Mortensen, 2013-11-27. Metal matrix composites are making tangible inroads into the real world of engineering. They are used in engineering components such as brake rotors, aircraft parts, combustion engines, and heat sinks for electronic systems. Yet outside a relatively limited circle of specialists, these materials are mostly unknown. Designers do not as a rule think of using these materials in part because access to information is difficult as these materials have not really entered engineering handbooks. *Metal Matrix Composites in Industry* is thus useful to engineers who wish to gain introductory knowledge of these materials and who want to know where to find them. Additionally, it provides researchers and academics with a survey of current industrial activity in this area of technology. [Metal Matrix Composites](#) J. Paulo Davim, 2014-10-24. Metal Matrix Composites (MMCs) have found an increased use in various industries due to their special mechanical and physical properties. They are a composite material with at least two constituent parts, one being a metal and the other a reinforcing material, made by dispersing a reinforcing material into a metal matrix. The markets are telecommunications, automotive, power semiconductor, optoelectronics, military and aerospace, heavy transportation, space systems, and satellites, medical, and industrial lighting. Applications within these markets include microwave, microelectronic packaging, laser diode, HB LED, and advanced radar.

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## **Table of Contents Solidification Of Metal Matrix Composites**

1. Understanding the eBook Solidification Of Metal Matrix Composites
  - The Rise of Digital Reading Solidification Of Metal Matrix Composites
  - Advantages of eBooks Over Traditional Books
2. Identifying Solidification Of Metal Matrix Composites
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Solidification Of Metal Matrix Composites
  - User-Friendly Interface
4. Exploring eBook Recommendations from Solidification Of Metal Matrix Composites
  - Personalized Recommendations
  - Solidification Of Metal Matrix Composites User Reviews and Ratings
  - Solidification Of Metal Matrix Composites and Bestseller Lists
5. Accessing Solidification Of Metal Matrix Composites Free and Paid eBooks
  - Solidification Of Metal Matrix Composites Public Domain eBooks
  - Solidification Of Metal Matrix Composites eBook Subscription Services
  - Solidification Of Metal Matrix Composites Budget-Friendly Options
6. Navigating Solidification Of Metal Matrix Composites eBook Formats
  - ePub, PDF, MOBI, and More
  - Solidification Of Metal Matrix Composites Compatibility with Devices
  - Solidification Of Metal Matrix Composites Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Solidification Of Metal Matrix Composites
  - Highlighting and Note-Taking Solidification Of Metal Matrix Composites
  - Interactive Elements Solidification Of Metal Matrix Composites
8. Staying Engaged with Solidification Of Metal Matrix Composites

- Joining Online Reading Communities
- Participating in Virtual Book Clubs
- Following Authors and Publishers Solidification Of Metal Matrix Composites
- 9. Balancing eBooks and Physical Books Solidification Of Metal Matrix Composites
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Solidification Of Metal Matrix Composites
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Solidification Of Metal Matrix Composites
  - Setting Reading Goals Solidification Of Metal Matrix Composites
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Solidification Of Metal Matrix Composites
  - Fact-Checking eBook Content of Solidification Of Metal Matrix Composites
  - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
- 14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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