JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

A REVIEW ON LIQUID STATE PROCESSING TECHNIQUES OF METAL MATRIX COMPOSITES.

Poornima K[1], Dr. Kori Nagaraj[2]

1 Research scholar, Mechanical engineering Department, RYMEC, Bellary, Visvesvaraya technological university, Belagavi, Karnataka, India

2 Research Guide, Professor and HOD Mechanical engineering Department, RYMEC, Bellary, Visvesvaraya technological university, Belagavi, Karnataka, India

Abstract:

The production processes have a significant influence on the mechanical properties as well as the cost of production. Liquid state processing of MMC's is eye-catching to many industries as they are relatively simple and economical. These processes include either the infiltration methods of molten metal into preforms or fibre pack or by the casting methods such as mixing of molten metal with reinforcement particles This section gives an overview of the various liquid state processing techniques available for the production of MMCs.

Introduction :

The production processes for MMCs can be classified according to whether they are based on primary processes such as treating the metal matrix in a liquid or a solid form or others (including semi-solid, in situ and others) as shown in Fig.1. The production processes have a significant influence on the mechanical properties as well as the cost of production. Particulate-reinforced MMC materials may be produced either through bulk processing or applied as coatings. This section aims to discuss MMCs materials produced only liquid state processing. This section gives an overview of the various processes available for the production of MMCs.[1]

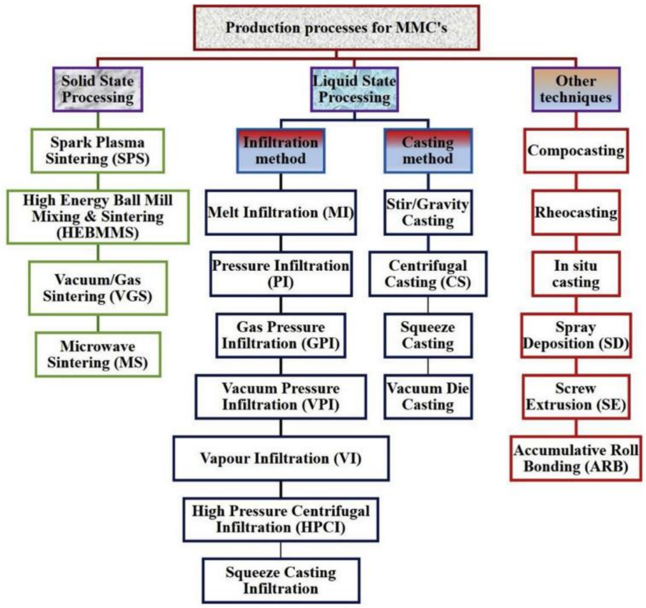

Figure1: classification of production processes for MMCs.[1]

Solid state processing/powder metallurgy : Solid state fabrication of MMCs is the process of bonding matrix material and reinforcements due to mutual diffusion arising between them in solid states at a higher temperature and under pressure.[1]

Liquid state processing Liquid state processing of MMC's is eye-catching to many industries as they are relatively simple and economical. These processes include either the infiltration methods of molten metal into preforms or fibre pack or by the casting methods such as mixing of molten metal with reinforcement particles. Infiltration methods include melt, pressure, gas pressure, vacuum pressure, vapour, high pressure centrifugal and squeeze casting. Casting methods include processes such as stir gravity, stir squeeze, stir vacuum and centrifugal casting.

Infiltration methods Infiltration is a permeation of molten metal into a preform by the infiltration process. The infiltration can be achieved either by melt infiltration otherwise called as pressureless infiltration or by pressure infiltration.

In melt infiltration, reinforcements are first placed in the die, and the molten alloy is then penetrated on to it and permitted to solidify without any external pressure.

In the pressure infiltration process, external pressure is applied directly or through an inert gas, vacuum pressure, vapour, centrifugal force, and squeeze infiltration.[1]

1.1. **Melt infiltration**. Fig. 2 shows a typical setup used for melt infiltration. Gecu et al. [2] studied 304 SS chips which were added to the molten A356 alloy through melt infiltration method performed at 730 °C. It was identified that the sufficient preheating temperature improved the tribological properties of the composites.[3]

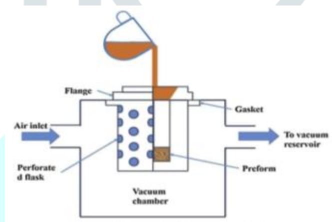

Figure2:melt infiltration(Redrawn from[3])

1.2.Pressure infiltration. Pressure infiltration process is used for making high reinforcement content in which molten metal or alloy is solidified in a mould packed with a reinforcement material. This process is shown in Fig. 3.[4,15,16,17]

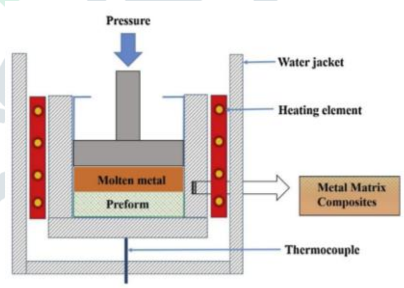

Figure3:Pressureinfiltration(Redrawn from[4])

1.3.Gas pressure infiltration. Gas pressure infiltration is a forced infiltration method of liquid phase fabrication of MMCs, using a pressurized gas for applying pressure on the molten metal and forging it to penetrate a preformed dispersed phase. This process is shown in Fig 4.[5,19,20]

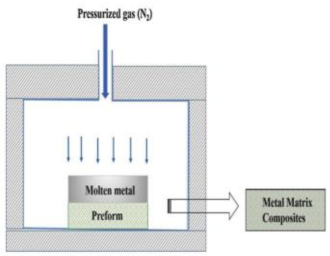

Figure4:Gas Pressure infiltration(Redrawn from [5])

1.4.Vacuum pressure infiltration. Vacuum pressure infiltration process is carried out using increased gas pressure. The reinforcing preform is placed in a mould consisting of a metal cylinder. A vacuum pump is connected between the mould and the metal bath. When the vacuum pump is switched on, molten metal is drawn into the preform. This process is shown in Fig 5.[6]

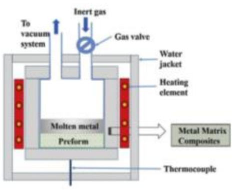

figure5:Vacuum pressure infiltration(Redrawn from [6])

1.5.**Vapor infiltration.** Vapour infiltration is a process in which matrix material is infiltrated into fibrous preforms with the aid of reactive gases at elevated temperature to form a reinforced composite. Vapour deposition is particularly useful for porous substrates, whereby the solid materials such as carbon, SiC, and other porous materials are infiltrated by matrix material from a mixture of CH4 in an H2 carrier gas at the elevated temperature illustrated in figure6.[14,24]

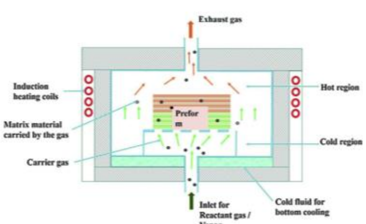

figure6: Vapour infiltration(redrawn from[7])

1.6.High-pressure centrifugal infiltration. High-pressure centrifugal infiltration is a process in which a mould containing packed ceramic preform located at the end of an elongated runner is rotated. By controlling the metal level above the preform in the runner to be higher and constant throughout the infiltration process, significantly higher pressures are obtained. To fabricate MMCs, infiltration can also be achieved by using a high-pressure centrifugal force. Wannasin and Flemings [8] designed and constructed the high-pressure centrifugal infiltration equipment for the fabrication of MMC and is shown in figure7.

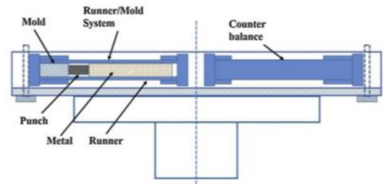

Figure7:High-pressurecentrifugal infiltration(redrawn from [8])

1.7.Squeeze casting infiltration. Squeeze casting infiltration method is a process of applying a ram force to the molten metal. Aluminium is in a molten state and infiltrates the preform from the top end to the bottom end under the squeeze pressure. This method is similar to that of a conventional squeeze casting technique.

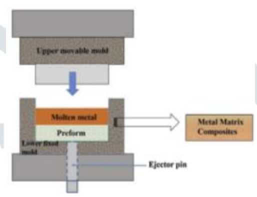

figure8: Squeeze casting infiltration(redrawn from [9])

2.Casting methods Casting is one of the primary and established manufacturing processes that are capable of producing complex shapes in a variety of materials economically. In the casting process, molten metal is poured into a mould or a cavity and allowed to solidify to form a predefined shape. Primary applications include lathe bed, the structure of the milling machine, IC engine components, etc. The casted components generally have high compressive strength. This method is considered as cheapest among all manufacturing processes.

2.1Stir/gravity casting. Stir casting is a process of mixing dispersed phase ceramic particles or short fibres with a molten matrix metal using mechanical stirring. Ravikumar et al. [10] fabricated A6063/TiC composite by using stir gravity casting method as shown in Fig. 9 and reported that the addition of reinforcement into the matrix improved the mechanical properties such as hardness and tensile strength.[28]

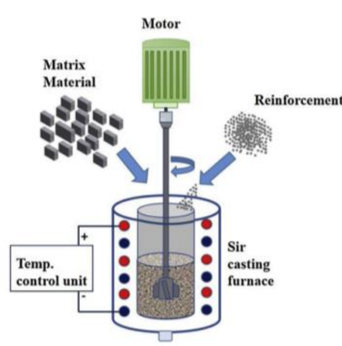

Figure9: Stir casting process(redrawn from [10])

2.2 Centrifugal casting. Centrifugal casting is a method of producing cast material by driving the molten metal into a fast rotating mould. Centrifugal casting is a relatively economical process in which the metal is flung out towards the mould surface by centrifugal force under substantial pressure. It is mainly classified into horizontal and vertical axis centrifugal casting. Fig. 10 shows a typical horizontal centrifugal casting machine.[27,28]

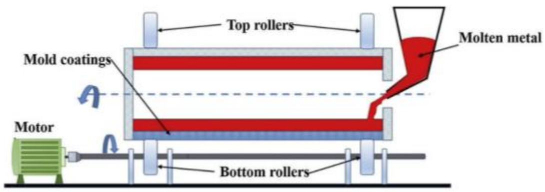

Figure10: horizontal centrifugal casting machine(redrawn from [11]).

2.3 Squeeze casting. Squeeze casting is a combination of casting and hydraulic forging as schematically shown in Fig. 18. In this process, the liquid metal is poured into the die and immediately forged using the hydraulic press at high pressure. The runway is connected between bottom pouring and the mould to transfer molten metal from the furnace to the die.[23,24,25].

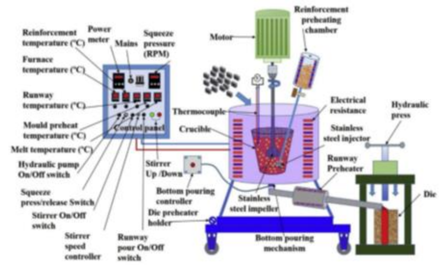

Figure 11: Squeeze casting process(redrawn from [12])

2.4 Vacuum die casting. In vacuum die casting, the die is kept at a vacuum condition to remove the gases from the melt. The schematic diagram of this process is shown in Fig. 19. The main advantages of this method is reduced porosity in the casting by reducing gasses in the melt. Strength and cast density are increased through this process.[13]

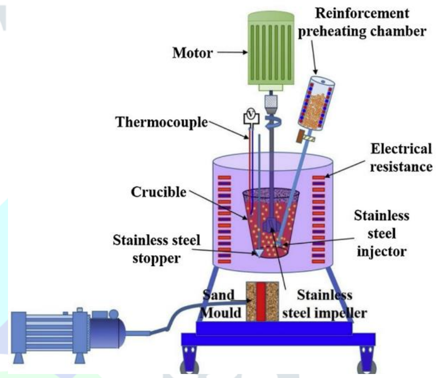

Figure12: vacuum die casting process(redrawn from [13])

Comparison of the various production processes:

Following table compares the various production processes used in the production of MMCs with their advantages and disadvantages. The properties and applications are more specific to the particular combination of matrix and reinforcement mentioned in the MMCs column and so should not be considered as general.

Table1: comparision of various production processes

process	MMCs	Properties	Advantages	Disadvantages	applications	References
MI	Al/Ti3SiC	Hardness 751 HV, Compressive strength 750 MPa	Improved wear property Cost-effective Ultra-high-temperature capability	Limited temperature and depth causes blockage in infiltration	Space, defense and industrial	[3]
PI	Al/GNPs	Tensile 250 MPa	Improved tribological property Economical for large-scale production	High tooling cost High porosity Not suitable for large casting	Piston engines Wheels Electric motor housing	[4]
GPI	Aluminium alloy AlSi12/ Metallic glass		Improved thermal conductivity Capable for high melt temperature Possible to produce any combination of matrix and reinforcement For	Production rate lower than squeeze casting Cost of high pressurized inert gas Slower	Brake callipers, hydraulic components	[5]

			manufacturing large composite parts	solidification proces		
VPI	2D-Cf/A	Tensile 281.2 MPa	Reduced porosity Improved ultimate tensile strength Near net shaped composite can be obtained	Slower solidification process Lack of wettability	Electronic packaging	[6]
VI	SiCnw/SiC		Low residual stress Complex shapes can be produced Improved mechanical properties Minimum fibrous damage	Low production rate Very high porosity level High production and capital cos	Heat exchangers, burner and flame tubes	[14]
HPCI	Sn-15 wt% Pb/SiC, TiC and Al_2O_3		Higher production rate, larger part size compared to gas pressure Variety of part geometry, part size compared to squeeze casting	Requires ultra powerful drive system Additional processing time require	Conrod for the control surface	[8]
Squeeze casting infiltration	AlSi12/Al2O3	Hardness 492 HV10	Improves wettability Homogeneity Less shrinkage porosity Reduced casting defects	limited flexibility in part geometry Less productivity High pressure and tooling cost	Engine block, brake disc, piston, fuel pipe, rack housing, suspension arm, brake calliper, pump case,flange,connecting rod	[23]
Stir/gravity casting	A356 (Al-Si7Mg)/10% fly ash	Tensile 45–62 MP	Simplest process Suitable for mass production Suitable for fully mechanized casting	Additional heat treatment required to get good mechanical properties,relatively slow process	Manifolds, cylinder heads, water pump housing	[27,28]
Centrifugal casting	Al–B–Mg	Hardness 80 – 90	Better mould filling Dense grain structure Virtually free from porosity Hollow interiors without cores High mechanical strength Wall thickness can be controlled	Poor casting at inner surface	Automotive piston , Sewerage pipes Brake rotors Paper mill rolls Textile mill rolls Nozzles Liners for IC engines [89]	[27,28]
Squeeze casting	AA7050 (AlZn6CuMgZr)/ 0.3% graphene	UTS 255 MPa	Uniform distribution of reinforcement particle at 0.3% graphene	additional setup and so increases the cost of production	Aerospace and automotive industries as well as for thermal management	[12]
Vacuum casting	AA6061 (AlMg1SiCu)-31% B4C	UTS 340 MPa	B4C particles are uniformly distributed and well dispersed within the matrix material.	Additional attachment and higher cost of vacuum pump and connections	Automotive, aerospace, the military a nuclear industry.	[13]

Conclusion: Among the production methods, stir/squeeze casting is the most economical for the production of MMCs. The stir casting process is simplest, economical and most commercially used technique in liquid state processing. There are some challenges associated with the stir casting process, primarily to maintain wettability (intimate bonding between liquid and solid phase). Secondarily to produce MMC with a homogeneous distribution of the particles, less porosity, and excellent mechanical properties is also a challenge.

Competing interests: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References:

1. *Ramanathan Arunachalam, Pradeep Kumar Krishnan, Rajaraman Muraliraja. A review on the production of metal matrix composites through stir casting – furnace design, properties, challenges and research opportunities. Journal of Manufacturing Process 42 (2019)213-245.*
2. *Gecu R, Atapek ŞH, Karaaslan A. Influence of preform preheating on dry sliding wear behavior of 304 stainless steel reinforced A356 aluminum matrix composite produced by melt infiltration casting. Tribol Int 2017. https://doi.org/10.1016/j.triboint.2017.06.040.*
3. *Zhou C, Wu X, Ngai TL, Li L, Ngai S, Chen Z. Ceram Int 2017. https://doi.org/10.1016/j.ceramint.2017.12.212.*
4. *Yang W, Zhao Q, Xin L, Qiao J, Zou J, Shao P, et al. Microstructure and mechanical properties of graphene nanoplates reinforced pure Al matrix composites prepared by pressure infiltration method. J Alloys*

Compd 2018;732:748–58. https://doi. org/10.1016/j.jallcom.2017.10.283.

5. Lichtenberg K, Weidenmann KA. Effect of reinforcement size and orientation on the thermal expansion behavior of metallic glass reinforced metal matrix composites produced by gas pressure infiltration. Thermochim Acta 2017;654:85–92. https://doi.org/10.1016/j.tca.2017.05.010
6. Ma Y, Qi L, Zheng W, Zhou J, Ju L. Effect of specific pressure on fabrication of 2DCf/Al composite by vacuum and pressure infiltration. Trans Nonferrous Met Soc China 2013;23:1915–21. https://doi.org/10.1016/S1003-6326(13)62677-1
7. Han Q, Setchi R, Evans SL. Synthesis and characterisation of advanced ball-milled Al-Al2O3 nanocomposites for selective laser melting. Powder Technol 2016;297:183–92. https://doi.org/10.1016/j.powtec.2016.04.015
8. Wannasin J, Flemings MC. Fabrication of metal matrix composites by a highpressure centrifugal infiltration process. J Mater Process Technol 2005;169:143–9. https://doi.org/10.1016/j.jmatprotec.2005.03.004
9. Garcia EM, Lins VFC, Matencio T. Metallic and oxide electrodeposition. Modern surface engineering treatments. 2013. https://doi.org/10.5772/55684.
10. Ravikumar K, Kiran K, Sreebalaji VS. Micro structural characteristics and mechanical behaviour of aluminium matrix composites reinforced with titanium carbide. J Alloys Compd 2017;22. https://doi.org/10.1016/j.jallcom.2017.06.309.
11. Adelakin TK, Suárez OM. Study of boride-reinforced aluminum matrix composites produced via centrifugal casting. Mater Manuf Process 2011;26:338–45. https:// doi.org/10.1080/10426910903124829.
12. Venkatesan S, Anthony Xavior M. Tensile behavior of aluminum alloy (AA7050) metal matrix composite reinforced with graphene fabricated by stir and squeeze cast processes. Sci Technol Mater 2018. https://doi.org/10.1016/j.stmat.2018.02. 005.
13. Li Y, Li Q, Li D, Liu W, Shu G. Fabrication and characterization of stir casting AA6061—31% B4C composite. Trans Nonferrous Met Soc China 2016;26:2304–12. https://doi.org/10.1016/S1003-6326(16)64322-4.
14. Han D, Mei H, Xiao S, Xia J, Gu J, Cheng L. Porous SiCnw/SiC ceramics with unidirectionally aligned channels produced by freeze-drying and chemical vapor infiltration. J Eur Ceram Soc 2016. https://doi.org/10.1016/j.jeurceramsoc.2016. 10.015
15. Blucher JT. Discussion of a liquid metal pressure infiltration process to produce metal matrix composites. J Mater Process Technol 1992;30:381–90. https://doi. org/10.1016/0924-0136(92)90227-J.
16. Cook AJ, Werner PS. Pressure infiltration casting of metal matrix composites. Mater Sci Eng A 1991;144:189–206. https://doi.org/10.1016/0921-5093(91) 90225-C.
17. Guo C, He X, Ren S, Qu X. Effect of (0–40) wt. % Si addition to Al on the thermal conductivity and thermal expansion of diamond/Al composites by pressure in filtration. J Alloys Compd 2016;664:777–83. https://doi.org/10.1016/j.jallcom. 2015.12.255.
18. Narciso J, Molina JM, Rodríguez A, Louis E. Effects of infiltration pressure on mechanical properties of Al-12Si/graphite composites for piston engines. Composites Part B 2016. https://doi.org/10.1016/j.compositesb.2016.01.022.
19. Li C, Wang X, Wang L, Li J, Li H, Zhang H. Interfacial characteristic and thermal conductivity of Al/diamond composites produced by gas pressure in filtration in a nitrogen atmosphere. Mater Des 2016;92:643–8. https://doi.org/10.1016/j. matdes.2015.12.098.
20. Che Z, Wang Q, Wang L, Li J, Zhang H, Zhang Y, et al. Interfacial structure evolution of Ti-coated diamond particle reinforced Al matrix composite produced by gas pressure in filtration. Composites Part B 2017;113:285–90. https://doi.org/10. 1016/j.compositesb.2017.01.047.
21. Mu Y, Li H, Deng J, Zhou W. Temperature-dependent electromagnetic shielding properties of SiCf/BN/SiC composites fabricated by chemical vapor infiltration process. J Alloys Compd 2017;724:633–40. https://doi.org/10.1016/j.jallcom. 2017.07.084.
22. Maj J, Basista M, Węglewski W, Bochenek K, Strojny-nędza A, Panzner T, et al. Effect of microstructure on mechanical properties and residual stresses in interpenetrating aluminum-alumina composites fabricated by squeeze casting. Mater Sci Eng A 2018;715:154–62. https://doi.org/10.1016/j.msea.2017.12.091
23. Alhashmy HA, Nganbe M. Laminate squeeze casting of carbon fiber reinforced aluminum matrix composites. J Mater 2015;67:154–8. https://doi.org/10.1016/j. matdes.2014.11.034.
24. Beffort O, Long S, Cayron C, Kuebler J. Alloying effects on microstructure and mechanical properties of high volume fraction SiC-particle reinforced Al-MMCs made by squeeze casting infiltration.ComposSciTechnol 2007;67:737–45. https://doi.org/10.1016/j.compscitech.2006.04.005.
25. Rohatgi PK, Weiss D, Gupta N. Applications of fly ash in synthesizing low-cost MMCs for automotive and other applications. JOM 2006;58:71–6.
26. Shabani MO, Heydari F. Influence of solutionising temperature and time on spherodisation of the silicon particles of AMNCs. Int J Mater Prod Technol 2018;57:336–49
27. Kingsley T, Suárez OM. Study of boride-reinforced aluminum matrix composites produced via centrifugal casting. Mater Manuf Process 2011:338–45. https://doi. org/10.1080/10426910903124829.
28. Huang X, Liu C, Lv X, Liu G, Li F. Aluminum alloy pistons reinforced with SiC fabricated by centrifugal casting. J Mater Process Technol 2011;211:1540–6. https://doi.org/10.1016/j.jmatprotec.2011.04.006