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ABOUT THE PRODUCING ROUTES OF HYBRID METAL MATRIX COMPOSITES

BY

CĂTĂLIN URSU*, CIPRIAN STEGARU, OCTAVIAN ANDRONIC and MĂDĂLINA S. POPA

“Gheorghe Asachi” Technical University of Iaşi, Romania,
Doctoral School of Faculty of Machine Manufacturing and Industrial Management

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Abstract. Due to the mechanical properties, the metal matrix composites (abbreviated in text as MMCs) become serious candidate materials for various top industries as aerospace or automotive. Reinforced MMCs have attracted interest as a result of their relatively low cost and characteristic properties. Reinforcement particles can be oxides, carbide, nitrides or oxynitrides. Strengthening in metal matrix composites is strong influenced by dislocations in the matrix, dislocations produced by differential thermal contraction, geometrical constraints and post-process plastic deformations. For optimizing the structure and properties of reinforced MMCs various processing techniques were developed in last years. The methods utilized to processing the particulate reinforced MMCs can be defined as depending by the temperature of the metallic matrix during fabrication. Depending of the matrix temperature, the processes can be classified into next 3 categories: (a) liquid phase processes, (b) solid state processes, (c) bi-phase(solid-liquid) processes.

Keywords: metal matrix composites; reinforcement; physical properties; processing methods.

*Corresponding author; *e-mail*: Ursu_catalin2002@yahoo.com

1. Introduction

Composite materials are defined as mixtures of at least two compatible components, convenient selected and oriented, which have synergistic properties, superior to those specific to each component separately. Metal matrix composites (MMC) have been successfully applied in aerospace industries since 1970s and in the middle of 1980s these materials reached the automobile industry (Mohan *et al.*, 2002). These materials are based on a metal matrix, usually aluminium, magnesium or titanium matrix, reinforced with a disperse phase, particles, fibres or whiskers, of silicon carbide, aluminium oxide etc. The most important advantages of metal matrix composites are increased strength, decreased weight, higher service temperature, improved wear resistance, higher elastic module etc. Traditional machining of MMC imposes some problems as excessive tool wear, poor surface finish and affected surface integrity. The cutting processes of MMCs requires the using of hard coated, diamond or carbide armed tools (Tosun and Muratoglu, 2004; Iosub *et al.*, 2010; Suresh and Moorthi, 2013).

The MMCs become an important class of materials for structural applications, wear-resistant devices, thermal-resistant parts or electrical apparatus. This appears as a consequence of due to their superior strength-to-weight ability and strength-to-cost low ratio by comparison to classic commercial alloys. Al-based particulate reinforced MMCs has imposed as an important class of high performance material in aerospace, automotive and chemical branches due of its increased strength, high elastic modulus and wear resistance (Bodunrin *et al.*, 2015). Aluminum matrix hybrid composites (abbreviated as AMHC) are a recent generation of MMCs that have the ability of satisfying the demands of newest engineering application because of their improved mechanical properties and of the relatively low cost of production. The right combination of reinforcing materials with the matrix is driving to high capabilities of the final product.

2. Liquid Phase Processes (LPP)

In LPP the ceramic particulates are incorporated into a molten metallic matrix using various techniques, followed by mixing and casting of the resulting MMC. Inside the multitude of techniques available for discontinuous MMCs, stir casting process (SCP) is a frequently used route. The advantages of this method consists in high flexibility and easy usability to mass production at relatively low cost. The main challenge of this process is the obtaining of a smooth distribution of the particulates in the metal matrix. In SCP of the composites materials inclusion of the reinforcement material. Preceding to add the reinforcement particles, the melt should be degased by a suitable medium to avoid the oxidation. The second step is the solidification of the molted mixture under suitable conditions for obtaining the optimum distribution of the phases in the cast matrix. In the stir casting with bottom pouring technique, the mold is kept just below the furnace with an opening at the bottom for pouring. This type of arrangement enhances the incorporation of particulates and reduces the time of pouring. The reduction in time of pouring and due to a better particulate introduction to the mold the composite properties are more nearer to improvement. In Fig. 1 (Rohatgi, 1991; Skibo *et al*., 1988) is shown the matrix material melted in a crucible by heating it in a crucible furnace. The stirring is activated by means of a motor at the top of the stirrer. Reinforcement is added to the matrix after stirring the matrix material for a certain amount time. Preheating is also carried out to avoid thermal distortion of the composite material production, the reinforcement material is mixed with the molten metal by stirring.

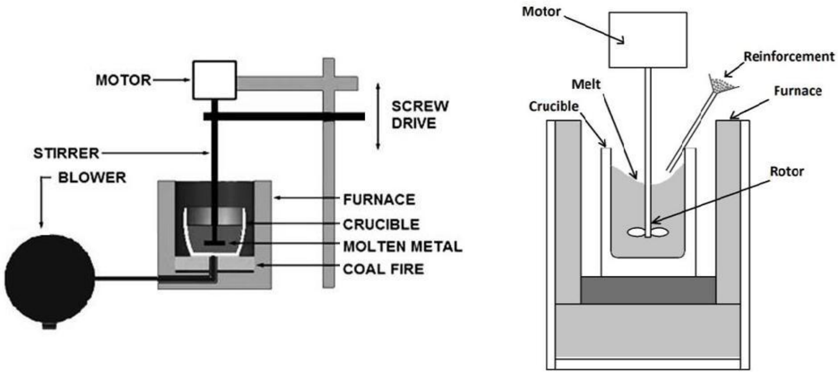

Fig. 1 – Stir casting method for producing MMCs (Rohatgi, 1991; Skibo *et al*., 1988).

Mixing techniques are used for introducing and homogeneously dispersing the discontinuous phase since most of the ceramic reinforcement materials are denser compared to matrix alloy, otherwise the reinforcement material may settle at the bottom of the crucible if not agitated properly. Mixing techniques generally used for mixing of ceramic reinforcement into a melt are:

a) Adding particles to a stirred molten alloy;

b) Injection of the discontinuous phase into the melt with an injection gun;

c) Dispersion of pellets or briquettes of a discontinuous phase (Skibo *et al*., 1988).

Stir casting is attractive since a conventional metal processing route is used and is the cheapest route for MMCs fabrication. Some of the important factors that need attention during stir casting are:

a) Is hard to achieve a constant and smooth distribution of the reinforcements;

b) Chemical reactions between two main substances (matrix and reinforcement substances) and reaction of matrix and reinforcement substances with atmospheric elements;

c) Porosity in the cast metal matrix composites;

d) Wetting. Phenomena between a metal and a liquid when the strength of the interfacial bond exceeds the surface tension of the liquid. The measure of wettability is given by the contact angle θ formed between a solid and a liquid, as defined by Young's equation $\gamma_{sg} = \gamma_{lg} \cos \theta + \gamma_{sl}$, where γ_{sg}, γ_{lg} and γ_{sl} are the interfacial energies between solid-liquid-gas phases. The energy of wetting, work of adhesion $W_{ad} = \gamma_{lg}(1+\cos \theta)$ is defined as the energy required to separate a unit area of the solid-liquid interface - see Fig. 2 (Sijo and Jayadevan, 2016).

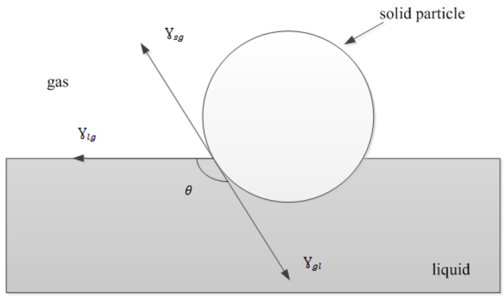

Fig. 2 – Schematic of contact angle formed between solid, liquid and gas phases.

3. Solid Phase Processes (SPP)

The manufacturing of particulate reinforced MMCs from different powders, involves a number of stages before the final consolidation. Some of this methods-powder metallurgy (PM) and high energy rate processing (HERP) are detailed in next sections.

3.1. Powder Metallurgy (PM)

The PM is applied to a great variety of ceramic-metal-metalloid mixtures. The mechanical properties of an extruded composite containing SiC whiskers and particulates are shown in Table 1 (Sijo and Jayadevan, 2016). The results show that PM processed A1-SiC MMCs exhibit higher strengths.

Table 1

Typical Properties of PM Al/Sic Composites (Room Temperature)

	Material	Process	Yield MPA	Elongation %	E MPA
1	6061-T6	Extrusion	255	17	70
2	(20% SiCw)	PM+Extrusion	440	4	120
3	(30% SiCw)	PM+Extrusion	570	2	140
4	(20% SiCp)	PM+Extrusion	415	6	97

SPP as usual consists in the blending of rapidly solidified powders with particulates, platelets or whiskers, using some steps, as shown in Fig. 3 (Bodunrin *et al*., 2015). These steps are the sieving of powders, blending with the reinforcement phases pressing to approx. 75% density, degassing and consolidation. The final consolidation method can be the extrusion, forging, or sintering. In the Ceracon process half of the PTM is poured into a preheated die, and the preform is placed into the die. The die is then filled completely with the remainder of the heated PTM. A pressure of 180 ksi (1.24 GPa) is applied to consolidate the preform. After pressing, the part is removed, and the hot PTM is recycled to the PTM heater.

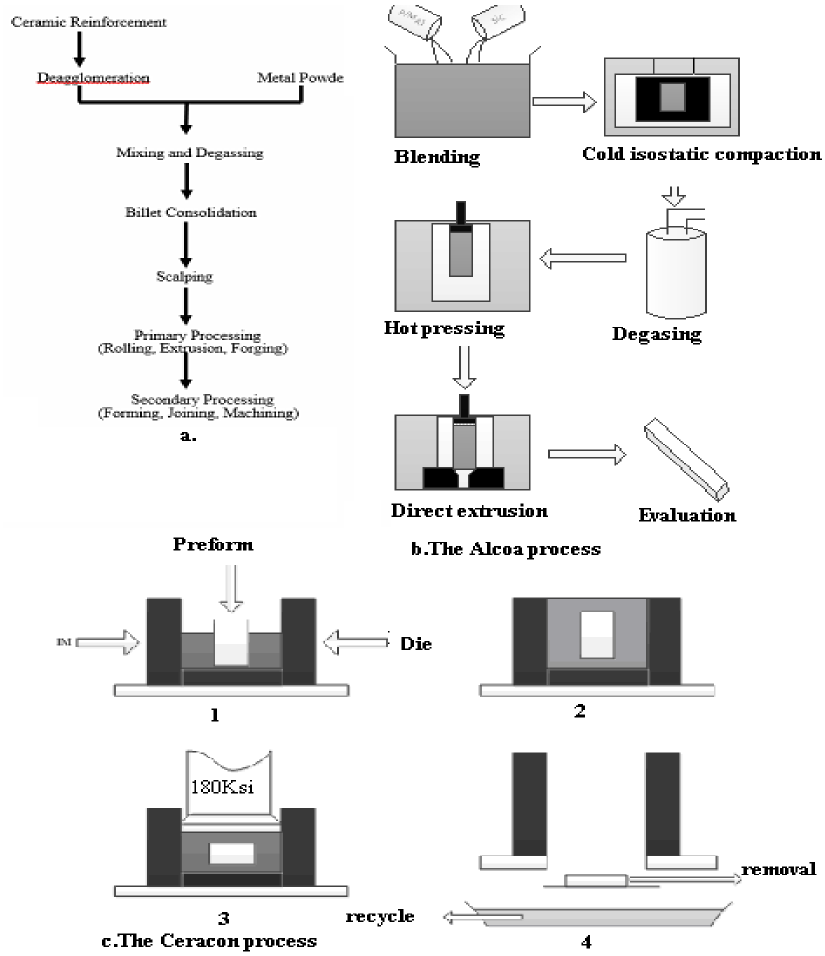

Fig. 3 – Processing of particulate reinforced MMCs from blended elemental powders (*a*) The typical flow of operations (*b*) powder metallurgy processing by Alcoa® (*c*) powder metallurgy processing by Ceracon®.

3.2. High Energy Rate Processing (HERP)

High energy rate processing method is successfully used to consolidate rapidly quenched powders containing a fine distribution of ceramic particulates. This approach entail the consolidation of a metal ceramic mixture by application of a high energy in a very short period of time.

4. Two-Phase Processes (LSP)

4.1. The Osprey Deposition

In this process, the reinforcement is introduced into molten alloy which is atomized by high pressure inert gas jet. The mixture is deposited on a substrate in the form of a reinforced MMC billet. The process combines the blending and consolidation steps of the PM process and thus promises savings in MMCs production (Fig. 4).

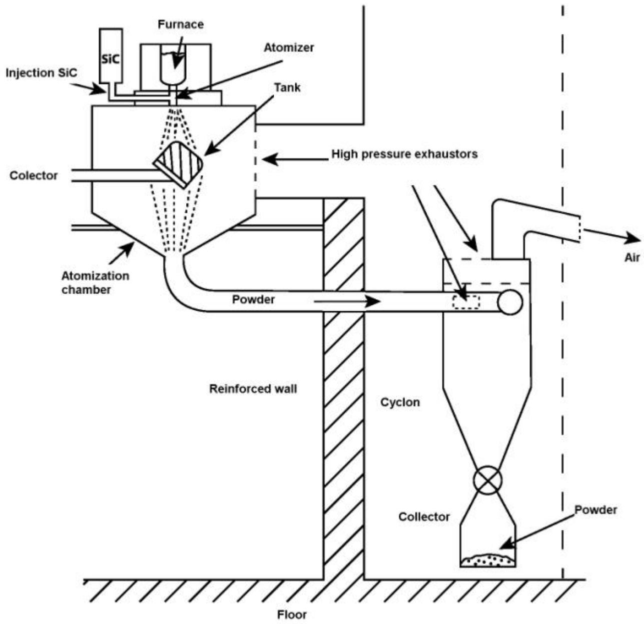

Fig. 4 – Schematic diagrams of Osprey technique (Ibrahim *et al*., 1991).

4.2. Variable Co-Deposition of Multi-Phase Materials (VCM)

In VCM processing, the matrix material is restructured as a fine dispersion of droplets by using a high pressure gas jet, one or more jets of strengthening phases are injected into the atomized spray. The strictly control of the environment during the process avoid the oxidation phenomena (see Fig. 5).

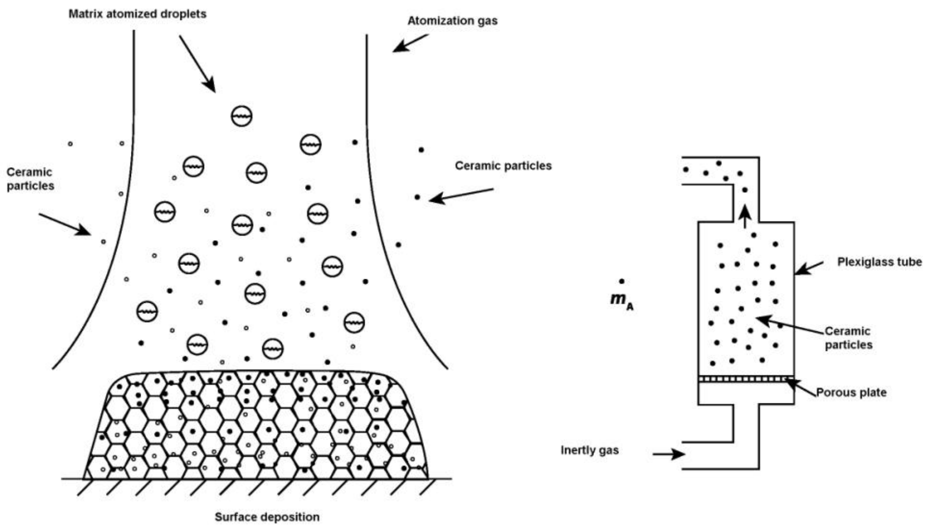

Fig. 5 **–** Schematic diagram of the variable co-deposition process (a) gas flow, (b) fluidized bed (Ibrahim *et al*., 1991; Gupta *et al*., 1990).

5. Conclusions

Regarding the processing of particulate reinforced MMCs, a variety of techniques were developed and improved over the past years. A review of the available literature shows that these processing techniques are classified as a function of the aggregation stage of the metallic matrix during processing. The liquid phase, solid phase and bi-phase (solid-liquid) processes are currently available.

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DESPRE METODELE DE PRODUCERE A COMPOZITELOR HIBRIDE CU MATRICE METALICĂ

(Rezumat)

Proprietățile fizico-mecanice ale materialelor compozitelor cu matrice metalică (CMM) le-au făcut atractive pentru industria aerospațială și auto. CMM-urile armate cu particule au atras atenția industriei datorită proprietăților mecanice deosebite, la costuri relativ reduse. Materialele de ranforsare includ carburi, nitruri și oxizi. În ceea ce privește proprietățile fizice, forța de coeziune în compozitele cu matrice metalice este strâns legată de dislocațiile din matrice, dislocații provenind de la contracția termică diferențiată, de constrângerile impuse de geometria piesei și de deformarea plastică survenită în timpul eventualelor prelucrări mecanice ulterioare. În efortul de a optimiza structura și proprietățile CMM-urilor armate cu particule, tehnicile de prelucrare au evoluat în ultimii 20 de ani. Metodele utilizate pentru fabricarea MMC-urilor armate cu particule pot fi grupate în funcție de temperatura matricei metalice în timpul procesării. În consecință, procesele pot fi clasificate în trei categorii: (a) procese în fază lichidă, (b) procese în fază solidă și (c) procese bifazice (solid-lichid).