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Production methods of ceramic-reinforced Al-Li matrix composites: A review

Kaiqiang Zhang** [a], **Ho Won Jang** [b], **Quyet Van Le** [c]*

[a] *School of Chemistry and Chemical Engineering, Nanjing University, Nanjing 210023, China*
[b] *Department of Materials Science and Engineering, Seoul National University, Seoul, Republic of Korea*
[c] *Institute of Research and Development, Duy Tan University, Da Nang, 550000, Vietnam*

A B S T R A C T

Recently, the increasing need for good quality, high performance, and low-cost materials has directed research towards composite materials rather than monolithic materials. In the case of metal matrix composites (MMCs), composites based on aluminum matrix have been widely developed for the automobile and aerospace industry as well as structural applications due to having a low cost, high wear resistance, and high strength to weight ratio. Moreover, a facile and economical method for the production of the composites is a very important factor for expanding their application. Ceramic reinforcements such as graphite, silicon carbide, alumina, and fly ash particulates can be introduced in metal matrices. Moreover, there has been considerable interest in developing Al-Li alloys and composites because of having high specific strength and high specific modulus. The present article has focused on the development of aluminum-lithium alloy composites as well as their production methods.

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1. Introduction

Composite materials are composed of two or more separate phases that have sufficient bonding together and exhibit their distinctive characteristics [1, 2]. MMCs are composites containing continuous metallic matrices in which one or more reinforcement components with different concentrations are dispersed [3-10]. By decreasing the size of the reinforcement, a given enhancement of composite properties could be achieved with the incorporation of a smaller amount of the reinforcement [11]. MMCs are categorized based on different factors including the matrix (e.g., titanium, copper aluminum), the reinforcement material (e.g. graphite, Al_2O_3, SiC), the shape of reinforcement (e.g., whiskers, particles, fibers), and the manufacturing process (e.g., stir casting, infiltration, diffusion bonding, powder metallurgy). Most metals are duc-

**Corresponding author: Quyet Van Le; E-mail: levanquyet@dtu.edu.vn*
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tile, exhibit high thermal and electrical conductivity, while ceramics are brittle, conductivity. However, most ceramics exhibit high stiffness and stability even at high temperatures, while most metallic materials have limited service life even at moderate temperatures. At high temperatures, microstructural changes and deterioration of mechanical properties occur in metals. The most common type of MMCs is the incorporation of ceramics in metallic matrices. Ceramic reinforced metal composites are expected to possess distinct benefits over mono-phased metals and their alloys. MMCs benefit from ductility and toughness of metallic matrix and high-temperature stability, stiffness, and low thermal expansion of the ceramic reinforcements to meet the required properties for applications in which both metals and ceramics would fail independently [9, 10, 12-15].

Various metals and metal alloys can be utilized as a matrix for the fabrication of MMCs. The main factor that determines a proper material as the matrix is the requirements of a specific application [16]. Nickel, copper, cobalt, magnesium, titanium, aluminum, silver, and their alloys are among common matrix materials [5, 17, 18]. As a result of improved stiffness, enhanced strength, wear resistance, improved abrasion, and reduced density, aluminum matrix composites (AMCs) are better candidates compared to existing materials employed for functional and structural applications [19, 20]. Recently, Al-Li alloy has attracted the researchers' attention due to its good wettability properties. Because of providing good strength and bonding in MMCs, metal alloys are preferred as the matrix materials instead of metals [21]. Li is a lightweight metal with a density of 0.54 g/cm^3, which is highly soluble in aluminum, and by adding 1% of this metal, the density of the aluminum alloy decreases by 3%. Additionally, amongst all soluble metals in Al, the addition of 1% of Li leads to 6% increase in the elastic modulus. The other advantage of Al-Li alloys is that they respond to age hardening [22].

The performance limits of Al-Li alloys, such as Al-8090, are significantly improved by the incorporation of ceramic particles as reinforcements [23]. Aluminum oxide (Al_2O_3) and silicon carbide (SiC) are prevalent reinforcements used in these alloys. The addition of SiC as a reinforcement leads to the increase in wear resistance, hardness, the tensile strength, and density of Al and its alloys [24]. Different methods can be used to prepare different types of MMCs including in-situ fabrication techniques, liquid-state methods, solid-state methods, and semisolid-state methods. Fig. 1 illustrates different preparation methods of MMCs [25].

2. Aluminum matrix composites

Copper, cobalt, magnesium, titanium, aluminum, and their alloys are common matrix metals in MMCs. Generally, the metal matrices are reinforced by brittle ceramic material, such as SiC, B_4C, and more recently, TiC [26-28]. Al matrix composites (AMCs) consist of the pure Al or its alloys reinforced with a non-metallic ceramic material including AlN, B_4C, SiO_2, SiC, and Al_2O_3. Because of good thermal and electrical conductivities, high damping capacity, low density, and good corrosion resistance, Al alloys are more prevalent than the pure metal. AMCs have shown promising properties to be used in various engineering divisions such as structural and functional applications. Depending on the chemical composition of the Al matrix and reinforcement proportion, various mechanical properties could be achieved. Among AMCs, those reinforced by particulates are attracting researchers due to their relatively low cost and isotropic properties [10].

Mazaheri et al. [29] fabricated Al-B_4C, Al-TiC-B_4C, and Al-TiC hybrid composites and compared their mechanical properties. According to the results, Al/TiC/B_4C composite exhibited the highest hardness, Al-B_4C composite exhibited the highest tensile and yield strength, and maximum elongation was obtained for Al-TiC composite. A359/Al_2O_3 composite was developed using the electromagnetic stir casting process by Kumar et al. [30]. They reported an increase in the hardness values from 46 HRC for pure alloy to 72.8 HRC. Additionally, they reported the tensile strength of 103.7 N/mm^2 and 148.7 N/mm^2 for the pure alloy and the composite, respectively. Akbari et al. [31] reinforced A356 alloy with milled nano Al_2O_3 and Al particles and with Cu particles and nano Al_2O_3. The results demonstrated that ultimate tensile strength and compressive strength of the prepared composites were superior to the pure alloy. The enhancement of mechanical properties was more significant for the Al/Al_2O_3/Cu composite. The mechanical properties of the AL7075-B_4C composite were studied by Baradeswarn et al. [32]. It was shown that the hardness, compressive strength, and ultimate tensile strength of the synthesized composite increased with an increase in a volume percentage of the reinforcement. In other research, Selvam et al. [33] reinforced 6061 aluminum alloy with SiC and Fly Ash by stir casting and evaluated its mechanical properties. With the increase in the proportion of the SiC particles, tensile strength, and macro hardness of the composite were enhanced.

3. Aluminum-lithium alloys

Due to excellent characteristics including corrosion resistance, low density, high toughness, and good strength, Al alloys are employed in important applications of aerospace field. The commonly used alloys in these applications are Al-Zn-Mg-Cu and Al-Cu-Mg alloys, which have the capability of precipitation hardening. One of the most important aluminum alloys with precipitation hardening ability is Al-Li alloys. Adding a primary alloying element of Li to Al reduces the density and improves

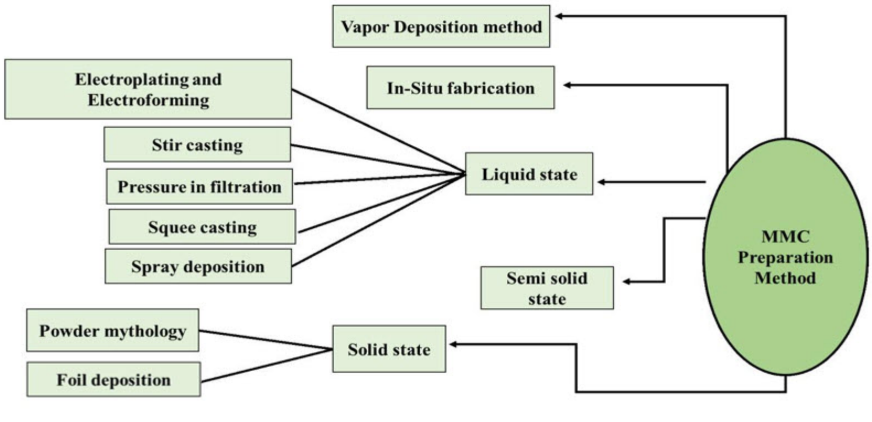

Fig. 1. MMCs preparation methods.

the elastic modulus of the alloy. Therefore, the major application of this development has been the aerospace industry. Similar to Al-Zn-Mg-Cu and Al-Cu-Mg alloys, Al-Li alloys have precipitation hardening ability. However, the incorporated precipitation hardening mechanism of these alloys is far more complicated than that of conventional Al alloys [34]. Although Al alloys offer good properties for various applications, improving one property in aluminum alloys usually is at the expense of degrading another property. For instance, the improvement of an alloy strength without a decrease in the toughness is challenging. Due to the possibility of cold work after solutionizing and thermal treatments after cold working, the Al-Li alloys could achieve enhanced combinations of properties [35]. The addition of Li to Al leads to a reduction of density by 3 % per 1 wt% and an increase in the elastic modulus by 6 % per 1 wt%. A combination of characteristics including increased specific stiffness, specific strength, good cryogenic, and fatigue properties provide the possibility for Al-Li alloys to be used in aerospace structural applications such as the external tank of Space Shuttle and fuel tanks of launch vehicles [36-38]. The first attempts to develop Al-Li alloys began in early 1920 [39]. AA2020 with the composition of Al-1.1Li-4.5Cu-0.5Mn-0.2Cd was the first commercial alloy, which was introduced in 1958. AA2020 was utilized for the Northrop RA-5C Vigilante aircraft tails and wing skins, however, it was withdrawn in the 1960s due to concerns about its fracture toughness. During this time, research attempts in the former Soviet Union resulted in the fabrication of the 1420 alloy (Al-2.0Li-5.3 Mg-0.5Mn) and VAD-23 (Al–1.1Li-5.3Cu-0.6Mn-0.17Cd). These three alloys were the first generation of these aluminum-lithium alloys. The concerns about the potential threat arouse from the replacement of Al alloys by composites reinforced with carbon fibers led to research work on novel Al–Li alloys in the 1970s. However, the development of the second generation of aluminum-lithium alloys was unsuccessful due to thermal instability, low short transverse properties, and unacceptable degrees of property anisotropy. Working on the third generation alloys based on aluminum-lithium commenced in the late 1980s, and developments continued. These recently developed Al-Li alloys are promising alloys to replace common Al alloys used in aerospace structures [40]. The most effective way used to reduce the structural weight of aircraft is by decreasing the density of materials. Lithium is one of the handful of elements that is highly soluble in Al with a low density of 0.54 g/cm^3. The reduction of density is significant, as adding each 1% of this element leads to the reduction of Al density by 3%. The other superiority of Li over the more soluble alloying elements in Al is that it results in a remarkable enhancement in the elastic modulus. Age hardening response is additional advantage of Al-Li alloys [22]. Yuan et al. [41] investigated the influence of thermomechanical and normal heat treatments on the fracture toughness and mechanical properties of a new generation of aluminum-lithium alloy (2A97). They aimed to enhance the relationships of fracture toughness, ductility, and strength to make them proper candidates for applications in the aeronautical industries.

The primary attempt of the Al-Li 2A97 alloy was to be used for forgings and plates employed as aerospace material. However, this alloy has some problems such as yielding low fracture toughness and ductility in T8 temper while possessing high tensile strength, and yielding a fracture toughness and high ductility in T6 temper while having low strength. Investigations revealed that the fracture toughness and ductility were enhanced in this alloy by 4% deformation after under aging at low temperatures [41].

4. Fabrication of ceramic-reinforced Al-Li matrix composites

4.1 Liquid-state processes

There are different methods for the development of MMCs using liquid state processes [25]. Using a liquid route, metals with relatively low melting temperatures, such as Al and its alloys, could be easily incorporated as a matrix material. By processes in the liquid state, including stir casting, and squeeze casting, greater freedom in the design of components and manufacturing can be provided [14].

4.1.1. Liquid infiltration

In the liquid infiltration process, a fiber bundle is infiltrated by molten metal. Due to difficulties related to the wetting of the ceramic phase by the liquid metal, fabrication of MMCs by simple liquid infiltration is not easy. The significant degradation of fiber properties can occur due to reactions between the molten metal and fiber during the infiltration of a fiber preform. To enhance wetting and control the reactions between the phases, fibers can be coated prior to infiltration. However, exposure of the fiber coatings to air must be prevented before the infiltration process to prevent oxidation of the surface and its negative effects [42]. The Duralcan process is a successful commercial liquid infiltration method for reinforcing with particulates. This process is illustrated schematically in Fig. 2. In this process, ingot-grade aluminum and ceramic particulates are mixed and melted. A proprietary treatment is performed on the ceramic particles. The melt is stirred between 600 ˚C and 700 ˚C, a few degrees higher than its melting temperature. The prepared melt is transformed into a rolling ingot, rolling bloom, foundry ingot, or extrusion blank. The particle size of the reinforcement in the Duralcan process is 8–12 mm and very small particles lead to the formation of a very large interface region and the increase in the viscosity of the melt. SiC and Al_2O_3 particles are typically utilized in the wrought aluminum alloys and foundry alloys, respectively [43, 44].

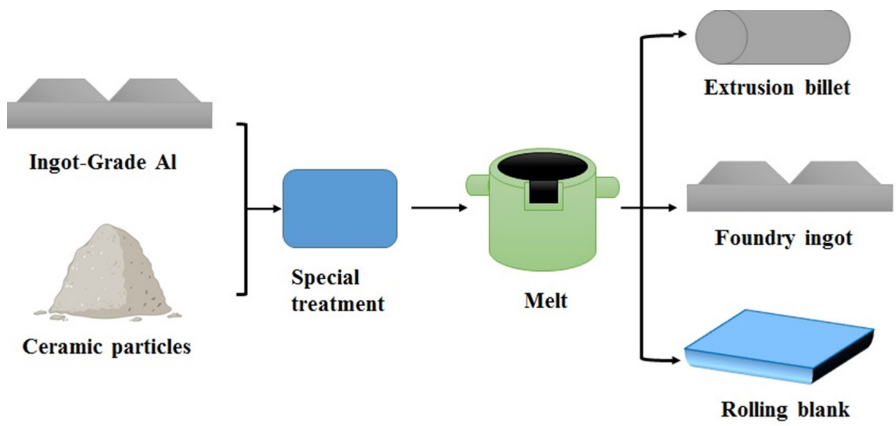

Fig. 2. Schematic illustration of Duralcan process.

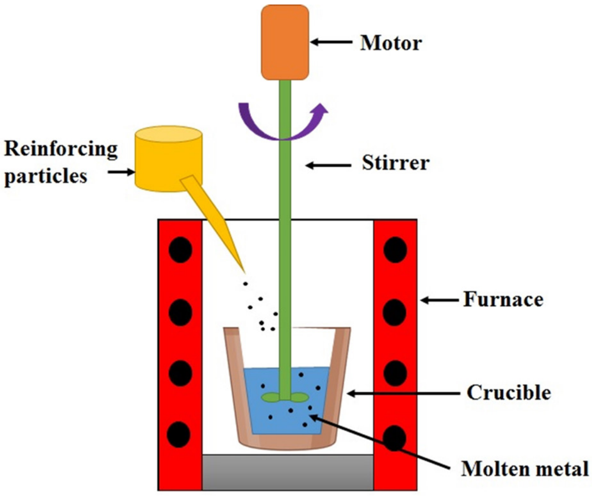

Fig. 3. Stir casting process.

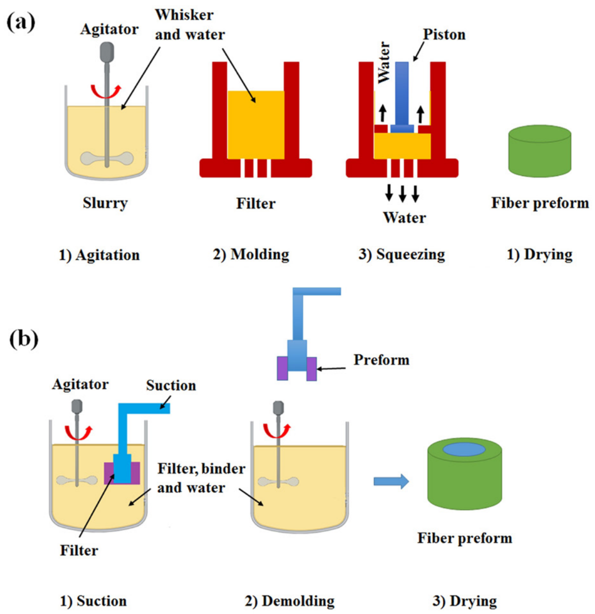

Fig. 4. Schematic illustration of fibrous preform fabrication.

4.1.2. Stir casting

The stir casting involves the introduction of the reinforcing agent into the molten metal with the help of stirring. Fig. 3 depicts the schematic of the stir casting process. This fabrication method is considered as one of the most cost-effective methods to produce large near-net-shape parts made from MMCs by conventional stirring followed by casting. The most commercially used and the simplest one among other stir casting methods is the vortex technique, in which the pre-treated ceramic particles are introduced in the vortex of molten alloy with the rotating impeller [45, 46].

Bauri et al. [47] fabricated 8090 Al alloy/SiCp composites using the stir casting process. The average size of SiC particles was 40 µm, various contents of SiC were introduced in the composite, and the cast billets were undergone hot extrusion. According to the results, the composites exhibited higher damping capacity compared to the unreinforced alloy. This was reported to be related to the higher interface damping, grain boundary, and dislocation density. Moreover, the moduli of both composites and alloy reduced with the increment of the temperature.

In other research, Bauri et al. [48] prepared Al-Li-SiC_p composites using a modified stir casting technique. The incorporation of the SiC particulates improved the elastic modulus, ultimate tensile strength, hardness, and 0.2% proof stress of the composites with 8% and 12% of SiC. It was proposed that the reduction of the strength of the composite containing 18% of SiC was due to the clustering of the SiC particles.

4.1.3. Pressure infiltration/squeeze casting

In the squeeze casting process, which is a pressure infiltration method, the infiltration of a fibrous preform by the molten metal is carried out by applying a force. Fig. 4 depicts two processes used for the fabrication of fibrous preforms. In the press forming method, fibers are well agitated in an aqueous slurry and then poured into a mold followed by squeezing out the water by applied pressure, and finally the preform is dried (Fig. 4 (a)). In the second method, the preform is fabricated by applying suction to an agitated mixture of water, binder, and whisker. The preform then is ejected from the mold and is dried (Fig. 4 (b)) [49]. The squeeze casting technique is schematically presented in Fig. 5. The pressure application continues until the complete solidification of the composite. In this method, good wettability of the preform by the melt is provided using the pressure to force the liquid metal into small pores in the fibrous preform. The advantages of this technique include the absence of prevalent casting defects including shrinkage cavities and porosity and having minimum reaction between the molten metal and reinforcement due to short dwell time at elevated temperature. Squeeze casting as an old method, was developed to produce aluminum alloy components with no pores and fine grains, which have superior properties in comparison with conventional mold casting. This casting method has been employed for the production of aluminum alloys such as silicon-free alloys in pistons of the diesel engine. Obtaining these alloys by conventional methods is difficult [50, 51].

For the fabrication of composites with selective reinforcements, this method of casting has been quite popular. In squeeze casting, a porous fiber preform is firstly located in the die, the melt then is poured into the preheated die. The penetration of molten metal into the preform and bonding with the fibers occur by applying pressure about 70–100 MPa. Another liquid metal infiltration method involves the infiltration of the preform by a pressurized inert gas under the controlled pressure. Complex-shaped structures and higher fractions of fiber volume are achievable by this technique. In this type of molten metal infiltration, the fibrous preform is heated in the die and melting of the matrix alloy is carried out in a crucible in a vacuum. Subsequently, the molten metal, which its temperature is about 100 ˚C higher than its melting temperature, is poured onto the fibrous preform and infiltrates the preform by introducing Ar gas pressure. Generally, some additives are added in the molten metal to assist wetting the fibers [52].

Dong et al. [53] fabricated a composite of SiC_w and Al-Li-Cu-Mg-Zr alloy using the squeeze casting technique and investigated its age-hardening behavior. According to the results, the prepared composite showed an accelerated hardening response in comparison with pure matrix alloy at 130, 160, 190, and 220 °C. The hardening behavior of the composite was greatly influenced by the aging temperature. They exhibited that the incorporation of SiC whiskers to the alloy could accelerate the growth rate of δ´ (Al_3Li) phase, which resulted in the nucleation of S´ (Al_2CuMg) phase in earlier stages. They proposed that the enhanced age hardening of the composite was due to accelerated precipitation of S´ and δ´.

In other research conducted by Dong et al. [54] incorporated SiC_w in Al-Li and Al-Li-Cu-Mg-Zr alloys by squeeze casting method and studied their tensile deformation microstructure. Based on the results, a considerable suppression of planar slip was observed by the addition of SiC whisker to Al-Li alloys. This is a general phenomenon observed

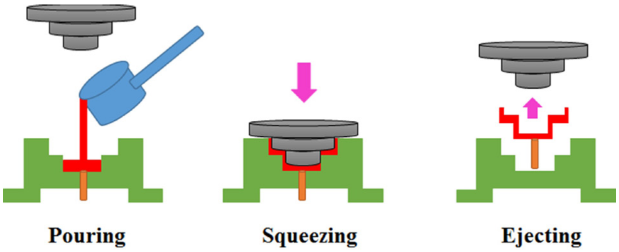

Fig. 5. A schematic of squeeze casting process.

in Al-Li based alloys, which happens by the interaction between dislocations and δ phase.

4.1.4. Spray forming

Spray methods that have been used for the production of monolithic alloys, can be utilized for spray forming of particulate-reinforced MMCs [55]. In this process, a molten aluminum alloy is atomized by a spray gun and ceramic particulates, such as SiC_p, are injected into the atomized alloy stream. The ceramic particulates are usually preheated to remove the moisture. Fig. 6 exhibits a schematic of this technique. For an efficient transfer in this process, the particle should be in the optimum size range. For instance, whiskers are very fine for being transferred. The produced preform in this process has generally a porous structure; therefore, the cosprayed MMCs are subjected to secondary finishing processes to make a wrought material [56]. This process falls under the category of liquid metallurgy processes, is totally controlled by the computer, and is conducted quite fast. Due to the short time of flight, detrimental reaction products are not formed. By this method, the incorporation of SiC_p into Al alloys with volume fractions up to 20% and an aspect ratio between 3 and 4 has been possible. The capability of fabricating different types of composites is a significant advantage of this technique. For instance, selective reinforcement is possible and in situ laminates can be produced by two sprayers. However, the spray forming method is relatively expensive due to the expensive capital equipment [57].

Gomez et al. [58] added 15 vol.% of SiC particles to the 8090 Al alloy using spray codeposition of the SiC_p and matrix on a substrate; then, the composite was extruded into rectangular bars at 420 ˚C. The results revealed that the reinforcement enhanced the wear behavior of the alloy and delayed the transition to higher sliding velocities, temperatures, and normal loads. However, wear rates of the synthesized composite were higher than those of the pure alloy in the mild wear regime. This was proposed to be a result of the abrasive role of SiC_p detached from the composite surface during the wear test.

Gonzalez et al. [59] also developed 8090 Al alloy composite by adding 15 vol.% of SiC_p using spray co-deposition of the particles and the matrix on a substrate and subsequent extrusion at 420 ˚C. Within the whole temperature range, damage in the composite was initiated by the fracture of particles. By increasing the temperature, the mechanisms associated with the final matrix fracture changed from intergranular fracture to ductile void growth. Furthermore, the elongation to failure of the composite was less affected by temperature compared to the alloy. However, the onset of plastic instability dictated the fracture strain of the prepared composites rather than the physical fracture mechanism.

4.2. Solid-state processes

Solid-state processing (SSP) is one of the various production techniques for AMCs preparation. In the SSP method, the matrix and the reinforcement are in solid state and are categorized as powder metallurgy (PM) and diffusion bonding processing [60].

4.2.1. Powder metallurgy

Powder metallurgy involves mixing of ceramic fibers, platelets, or

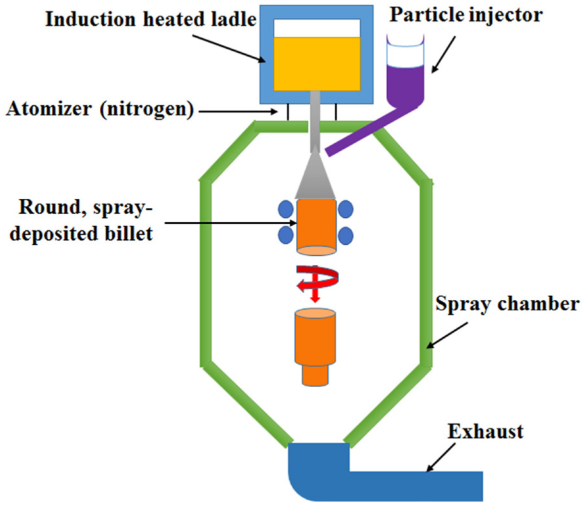

Fig. 6. Spray forming process schematic.

dispersion powders with matrix powders followed by cold pressing, sintering, and plastic working (extrusion or forging) [61]. Hot plastic working is performed when only a green part is produced by cold pressing and cold plastic working is performed when the green part is preliminary sintered [62]. The schematic illustration of this technique is shown in Fig. 7. Because of simplicity, PM is widely used for producing composite materials based on copper matrices [63, 64], aluminum alloys matrix [65, 66], and magnesium alloys matrix [67].

Nowadays, mechanical alloying has become a widely employed technique for producing particle-reinforced composite materials. In this process, hard dispersion particles are introduced into a metal matrix by a high-energy ball mill [68-70]. The prepared composite powders are then cold-pressed, sintered, and undergone cold plastic working or cold-pressed and undergone hot plastic working such as hot isostatic pressing, forging, or extrusion. The mechanical alloying process is used to produce composite materials, magnetic materials, amorphous materials, and materials with very fine grains [71].

Tan et al. [72] used PM technology to produce MMC materials based on AA2196 (Al-Li Alloy) and TiB_2 dispersion particles. They reported a homogeneous dispersion of the reinforcements in the main matrix using the PM process. It was observed that by adding TiB_2 reinforcement, the hardness of the composite increased, and with the increment of TiB_2 content, more porosities were formed in the composite. TiB_2 particles resulted in the formation of porosities in the grains as well as the grain boundaries of the matrix. The coarse particle size of the matrix was affected by sintering parameters, as the sinterability decreased by the increase in grain size.

4.2.2. Diffusion bonding

Diffusion bonding method is a solid-state process to weld similar or dissimilar metal pieces together. Welding is the result of atomic interdiffusion from the surfaces of clean metals in contact at high temperatures. The basic diffusion bonding technique has many variants; however, applying high temperature and pressure simultaneously is common among all of them. In this process, monolayer laminae, matrix alloy foil and composite wire, or fiber arrays are stacked in the desired order [73]. In Fig. 8, depicts a diffusion bonding technique schematically, which is also known as the foil-fiber-foil method. In this case, panels and filaments are stacked and hot pressed. For metal matrix composites, vacuum hot pressing should be carefully examined in the diffusion bonding techniques. The remarkable advantages of the diffusion bonding process include the ability to control fiber volume fraction and orientation as well as the capability of processing various metal matrices [74]. On the other

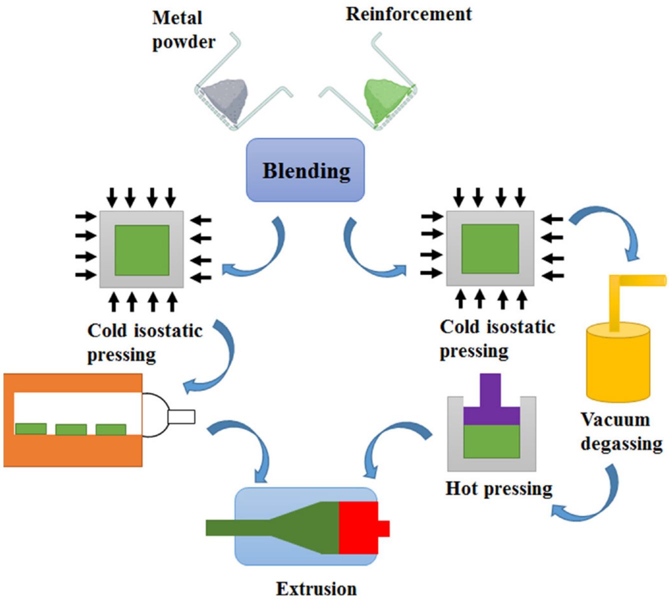

Fig. 7. Powder metallurgy process.

hand, high processing pressures and temperatures and long processing times make this technique quite expensive. Additionally, the produced objects are of limited size. Instead of uniaxial pressing, hot isostatic pressing (HIP) could also be employed, in which the consolidation of the composite is carried out by gas pressure against a die containing the composite. Variable geometries can be obtained by HIP due to the relatively easy application of high pressures at high temperatures [75].

Wang et al. [76] used accumulative roll bonding (ARB) to fabricate Al-Li/B_4C composite at room temperature. The investigations showed that by the increment of the number of cycles, the B_4C agglomerates in the interfaces of Al-Li layers were transformed into the uniform dispersed particles and small clusters in the matrix. After 8 cycles of ARB, a few nano-grains were observed, which indicates that near nanostructure was successfully prepared. It was reported that the simultaneous improvement of ductility and strength was obtained with the increment of ARB cycles. In addition, after 8 cycles, high Young's modulus and excellent mechanical properties were obtained. It was proposed that the high strength of the prepared composite was associated with dislocation strengthening and grain refinement strengthening. Furthermore, good ductility of the Al-Li/B_4C composite after 8 cycles of ARB resulted from proper wide grain size distribution and the uniform dispersion of B_4C particles.

4.3. In situ processes

The in situ process involves the in situ formation of the reinforcement phase. In contrast to typical composite processing, the production of composites is carried out in one step out of a suitable starting alloy, in which the difficulties originating from the combination of the separate components are avoided [77, 78]. The controlled unidirectional solidification of eutectic alloys is an example of this technique. Because of unidirectional solidification, one phase is dispersed in fiber or ribbon form in a eutectic alloy. Controlling the solidification rate can lead to the fine distribution of the reinforcement. However, the practical solidification rate is limited because of maintaining a stable growth front. Furthermore, a high temperature gradient is required for the stable growth front. During this process, a precast rod of a eutectic alloy is usually melted in an inert gas atmosphere or vacuum by induction and more thermal gradients could be obtained by cooling the crucible below the induction coil [79, 80].

Another in situ process is the XD™ technique, in which the third phase is obtained by an exothermic reaction between two components. Such processing methods are sometimes considered as the self-propagating high-temperature synthesis (SHS) process and are commonly used to produce ceramic particle reinforced MMCs. Using the reaction synthesis, master alloys with high contents of reinforcement are fabricated. To develop a composite with a desirable volume fraction of particle reinforcement, the master alloy is blended and remelted with the base alloy. Typical reinforcement particles include TiB_2, SiC, etc. in Ni, Al, or intermetallic matrix [42, 81, 82].

Wu et al. [83] studied mechanical properties and microstructural evolution of cast Al-Li-Cu/TiB_2 composite during heat treatment. In this research, the salt-metal reaction technique was used to synthesize an in-situ Al-Li-Cu/TiB_2 composite. The as-cast composite showed clusters of larger reinforcement particulates, mixed with coarse secondary phases along the alloy grain boundaries. It was reported that most of these phases dissolved into the α-aluminum phase by two-stage solution heat treatment. The grain boundaries are pinned by the stable particulates at high temperatures leading to the thermal stability of the composite grain size. Therefore, no remarkable increase was observed after solution treatment. A significant age-hardening response was shown in the composite with the peak-hardness at 175 °C in 160 h.

Zhao et al. [84] fabricated the in-situ Al-Cu-Li/TiB_2 composite by hot extrusion and evaluated the influence of nano TiB_2 particulates on mechanical properties and microstructural of the composite after T6 heat treatment. The results indicated that the majority of TiB_2 particles were aggregated together and particle bands were formed. The matrix developed weak < 113 > and < 111 > textures, while the prepared composite developed the typical fiber textures with < 100 > and < 111 > parallel to extruded direction. It was demonstrated that the addition of TiB_2 nanoparticles could increase the volume fraction and intensity of major texture components. S and T1 phases were smaller and possessed higher number density resulted from the incorporation of TiB_2 particles. Additionally, the T1 phases could form a continuous network by connecting with each other. In contrast to the matrix alloy, the θ′ phase was rarely appeared in the composite. In comparison with the matrix alloy, the yield and ultimate tensile strength of the composite enhanced by 152 MPa and 248 MPa, respectively.

5. Conclusions and future insights

In the review of the aluminum-Lithium alloy matrix composite rein-

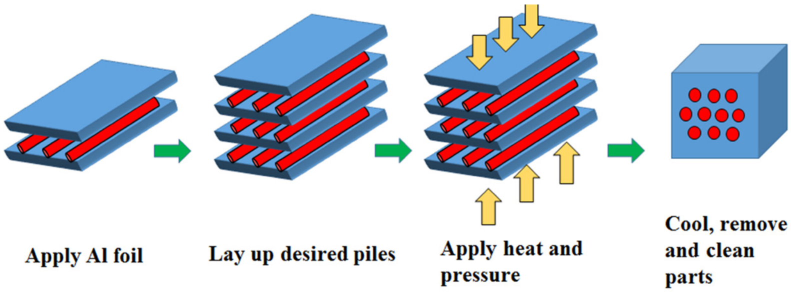

Fig. 8. A schematic of diffusion bonding process.

forced with ceramics, it was concluded that ceramic-reinforced Al and its alloys show noticeable improvement in their mechanical properties including tensile strength, yield strength, and hardness, at the expense of ductility. The preparation methods could also result in different properties in these composites. It has been revealed that the alloy composition affects the route employed for processing, the corrosion behavior, mechanical properties, and heat-treatment of the composites. Regarding the properties of low-density Al-Li composites, they will be considered as promising materials for aerospace industry applications. It is expected that more research works would be performed on tailoring the microstructure and properties of these alloys by the careful control of the processing parameters and developing new production routes.

Conflict of Interest

All authors declare no conflicts of interest in this paper.

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