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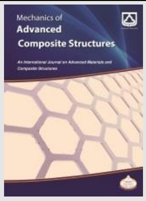

A Review of Research Outcomes on Fabrication Methods and Investigations for Evaluating Fracture Behavior of Aluminum Metal Matrix Composites with its Applications

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KEYWORDS

Aluminum metal matrix composites (AMMC), Fabrication methods, Specimens and fixtures used for fracture tests

ABSTRACT

Metal matrix composites are widely used in engineering applications because of their better mechanical properties. This review focuses on fabrication methods and fracture behaviors of aluminum metal matrix composites (AMMCs). This paper also discusses its applications. Based on the review study, it is observed that the properties of AMMC vary depending on the reinforcement used, fabrication techniques, and reinforcement disbursement in the matrix material. It is also found that the place where the composite materials are used and the difficulties behind the manufacturing processes decide the selection of reinforcements and the types of fabrication method. It is noticed that the reinforcement of AMMCs is in the form of continuous fibers, short fibers, whiskers, and particulates. The objective of this review study is to summarize the details about the techniques used for fabricating aluminum metal matrix composites, the effects of processing parameters on the mechanical behaviors of composites, the different types of test specimens, and the fixtures used to apply load for fractures experimentations of AMMC with the applications of AMMCs in various fields.

1. Introduction

Compared to other metals, aluminum is a lightweight metal; hence it is more popular in the applications of automobile sectors in reducing fuel consumption. Also, it is especially used largely in aerospace applications because of the same reason. Aluminum is used as metal matrix composites with various reinforcement materials in ceramics such as SiO_2, SiC, B, B_4C, etc., to enhance better mechanical properties [1]. The mechanical, thermal, and other properties of AMMCs vary based on the reinforcement used. The interaction between the metal and reinforcement particle decides the properties of composites majorly [2]. Aluminum is used as a matrix material in MMCs because of its strength, specific modulus and wear resistance, and low thermal expansion coefficient [3],[4]. Reinforcement in a sense, Al_2O_3 is used widely in AMMCs. In some AMMCs, Al_2O_3 is used as nano particulates [5],[6].

Aluminum alloys are also used as matrix materials for their lightweight properties. Bandil et al. [7] studied the effect of SiC reinforcement on Al-Si alloy. The increment of SiC decreases the density and increases the hardness. The wear rate decreases with an increase in SiC because of the reduction of co-efficient of friction by forming the lubricating film on the surface. Corrosion prevention rate is improved by the SiC particles with corrosion prevention efficiency of 56.58% at 20% weight of SiC.

A356 alloy RHA- Fly ash reinforced MMC was fabricated by Vinod et al. [8]. The composites were fabricated employing a double stir casting process. In this work, physical and mechanical properties were studied. It is reported that there was an improvement in the mechanical properties due to the addition of organic and inorganic particles as reinforcement. Fly ash particles form more porosity in the composites.

Jamwal et al. [9] manufactured the Al/Al_2O_3 and TiC composites using the stir casting process.

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The tensile strength of composites was improved up to 149.3 MPa because of the strong bonding between the matrix and reinforcement particles. The wear rate decreases with the increment of reinforcement.

Yan Li et al. [10] investigated the fracture behavior of 6092 Al/SiC particulate metal matrix composites through mode I loading conditions and reported that interface debonding is the unique mechanism for increasing the toughness of MMCs. This debonding also promotes plastic deformation in the ductile matrix.

Doddamani et al. [11] investigated the Al6061-9% graphite particulate metal matrix composites and presented the composite fractured specimens' fracture toughness and micro fractography. Here, the CT specimens were fabricated through stir casting techniques, and the fractured surfaces were analyzed using scanning electron microscopic images.

In this review, the fabricating techniques, the effects of processing parameters on the mechanical behaviors of AMMCs, the test specimens and fixtures used for loading in the experimentations on fracture, and the different fields of applications are investigated using inputs from various researches.

2. Fabrication methods of AMMCs

The method of fabrication plays an important role in determining the properties of composites [12]. The following are the primary techniques to fabricate the AMMCs.

a. Solid State Processes

b. Liquid State Processes

c. Deposition Processes

This review study is confined to the methods of fabrication based on extensive applications by many researchers. Figure 1 shows the fabrication techniques investigated.

2.1. Solid-State Processes

2.1.1. Powder metallurgy (PM Process)

These are mostly used processes to make AMMCs. Although it is a traditional metallurgy process, it is later taken to manufacture the metal matrix composites [12]. It is a desirable process because even at a lower temperature, the metal matrix composites can produce. The kinetic interfaces can be controlled easily by this process. Alloy compositions of the matrix also can be varied easily in this process. The following figure illustrates a step-by-step procedure of powder metallurgical process (Figure 2).

Step 1. Weighing the composition (Metal powder, reinforcement, additives, if any)

Step 2. Mixing the above composition.

Step 3. The blended powder is compacted through a uni-axial press tool. The resultant is called a green body. The density of the green body should be approximately 85% of the composite.

Step4. The green body is then sintered by applying heat at a desirable temperature [13].

Then the resultant is called a sintered body. Its density should be the same as the composite.

PM Process made a sintered body of Al-Al2O3 composites [12]. Here the composite powder of 160-380 μm particle size is produced using a vibration rotary mill. Then the sintering process is carried out inside a graphite container maintained at a vacuum of 2.67 Pa. The sintered body is made under a pressure of 15MPa, 910K temperature for 15min. The microstructure of the composite powder is analyzed through a microscope, and the micrograph is given. In the micrograph, as shown in Figure 3, Al_2O_3 particles are surrounded by the matrix particles. Moreover, the coarser particles are distributed uniformly than, the finer particles. P. S. Bains et al. [14] produced a β-phase titanium alloy by employing mechanical alloying with spark plasma sintering process (SPS) and reported that the fabricated titanium alloy has the best microhardness.

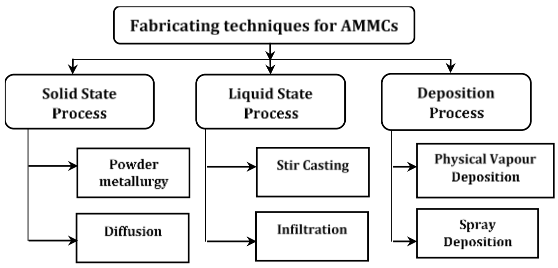


Fig. 1. Fabrication techniques for making AMMCs

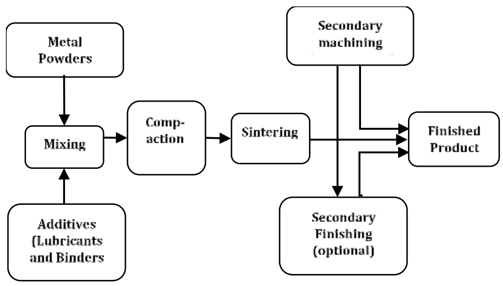
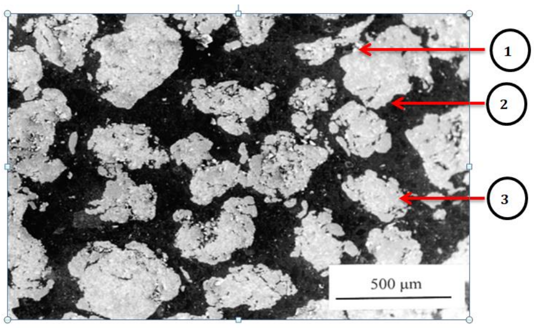


Fig. 2. Powder metallurgy Process



1. Coarse Al_2O_3 Particle, 2. Matrix Material, 3. Finer Al_2O_3 Particle

Fig. 3. The micrograph of Al-Al_2O_3composite powder [12]

Preetkanwal Singh Bains et al. [15] reported the analysis and research findings based on the fabrication techniques and various machining on the MMCs. It is found that the PM method is a versatile route of MMC's fabrication because of the homogeneous microstructure of the fabricated MMCs. But the presence of impurities is the main limitation of this method.

2.1.2. Diffusion bonding

It is the process mainly for materials having high heat sensitivity and persistent oxide layers. This process is also used for making composites that are hard to join with the reinforcement particles [16].

Diffusion bonding is like a pressure welding process in which the interatomic bonding will be done by applying pressure and temperature. The materials which are subjected to the diffusion bonding process have rough surfaces. In the first stage, the boding is done by using pressure that deforms the substrate roughness and disrupts and disperses the above-mentioned surface layers. In the second stage, diffusion and grain growth takes place to form a new material. Figure. 4. illustrates the diffusion bonding process.

Alumina (Al_2O_3/Al_2O_3) joints and alumina/aluminum MMC (Al_2O_3/Al–MMC) joints were fabricated using an Al_2O_3–Al composite as an interlayer [17]. The joints' microstructures, phase compositions, and mechanical properties were examined using Scanning electron microscopy (SEM), X-Ray Diffraction analysis, and shear testing, respectively. The SEM image is shown in Figure 5.

2.2. Liquid state Processes

2.2.1. Stir casting

It is the most commonly used liquid state fabrication process. The matrix material is melted in the crucible or muffle available in the stir casting setup, as shown in Figure 6. The temperature is given through the electrical filament arrangement.

Then the treated reinforcement particles are poured into the molten matrix metal for stirring. The stirring is done because of the uniform dispersion of the reinforcement particles. The casting of the desired shape follows the stirring. Stir casting is the most economical technique when compared to most of the casting techniques [17]. The vortex technique is followed for the addition of reinforcement particles. The pre-treated reinforcement particles are poured into the vortex of the molten alloy created by the stirrer[18].

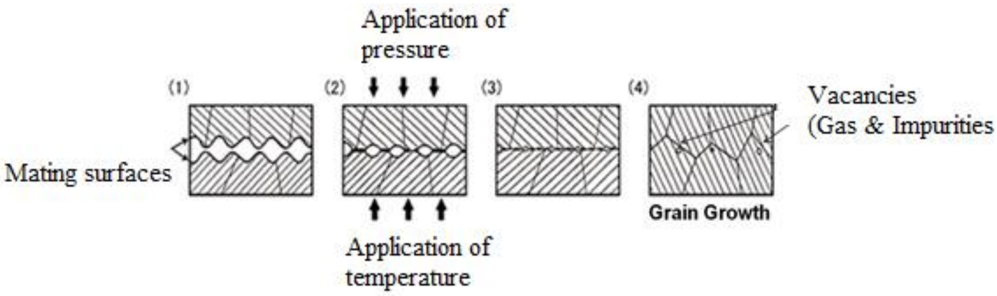


Fig. 4. Diffusion bonding process [16]

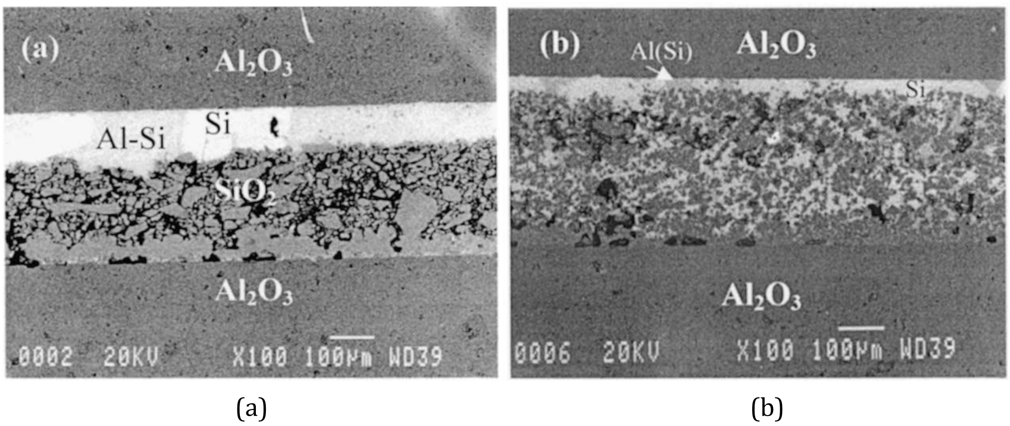


Fig. 5. SEM images of Cross-section of Al_2O_3/Al–Al_2O_3/Al_2O_3 composite; (a) at 850°C, (b) at 1000 °C [17]

The crucible size, impeller or stirrer size, the temperature of molten metal/alloy, time of stirring, stirring speed, and the rate of reinforcement pour are the controlling parameters to get the homogenous mixture to cast. The following are the two challenges in this process[19].

The molten metal does not wet some reinforcement particles. So pre-treatment is necessary.

(ii) Due to the density variation of molten metal and reinforcement particles, the reinforcement particles tend to float or sink within the molten metal, and hence the uniform dispersion is not at the desired level.

Mafi et al. [20] fabricated the aluminum alloy matrix and TiC reinforced composites differently using the stir casting technique. For fabricating the composites, 500g of aluminum alloy was taken in a furnace, and 2 Vol% of TiC metal powder was carried in an aluminum foil and added to the molten alloy during stirring. After stirring, the mixer is poured into the CI cylindrical mold.

A. Ramanathan, et al.[21] investigated all the production processes for the fabrication of MMCs. It is concluded that the Stir casting technique is the most suitable process because of its simplicity, cost of production, and mass production capability, etc. In this study, the process parameters that affect the quality of MMCs are evaluated. Some notable process parameters are discussed below.

a. Reinforcement size: The small size of reinforcement particles improves the mechanical properties of MMCs.

b. Stirring speed: The interparticle distance can be increased by the stirring speed. High stirring speed should not create high resistance of particle movement, and low stirring speed should not hold the reinforcement particle in one place of metal melt. So, the exact numerical value of stirring speed cannot be specified without matrix and reinforcement particle details.

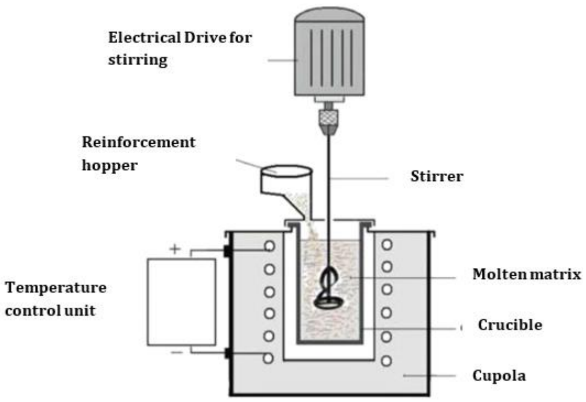


Fig. 6. Stir Casting Equipment

c. Stirring time: Higher stirring time results in inhomogeneous mixing and improved mechanical properties, but it depends on the blade profile of the stirrer.

d. Melt temperature: It should be at an optimum level because higher the melt temperature will improve the wetting ability of melt but lower the melt temperature will improve the particle agglomeration rate. So it should be at an optimum level.

e. Stirrer blade design: It is crucial for creating a vortex and achieving the proper mix. The stirrer blades are coated with Zirconia for reducing the reaction between metal melt at high temperatures.

f. Die preheating temperature: The mechanical properties of MMCs are improved with the die preheating temperature, but it reduces the life of the die.

2.2.2. Infiltration process

In the infiltration process, a preform is prepared with the use of reinforcement material with high porosity. Then the molten metal is allowed to fill the porosity of the reinforcement preform. If the molten metal wets the preform, the external force is not needed to fill the molten metal in the preform pores. The force of capillarity is enough. Otherwise, external mechanical force is applied against the drag and capillary force. Then the pressure is used on the filled preform for combining the molten metal and preform well. Figure 7 illustrates the infiltration process.

In an experimental study, an AMMC of pure Aluminum powder as matrix and continuous fibers of α – Alumina as reinforcement is made with a medium pressure infiltration process. The micrograph is given for the above AMMC [18]. Figures 8 (a) and (b) show the cross-section and in-plane section of the in-filtered AMMC.

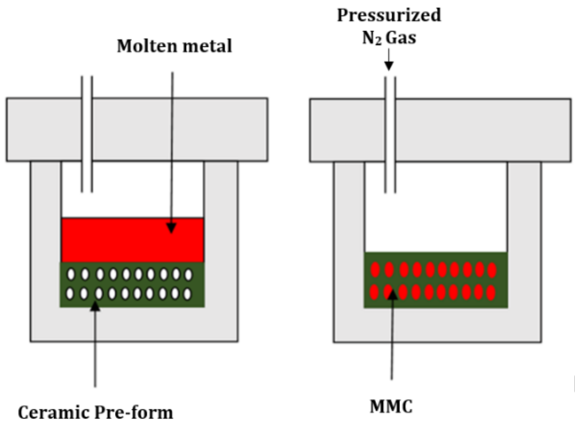
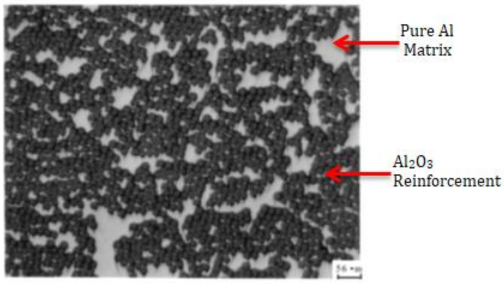
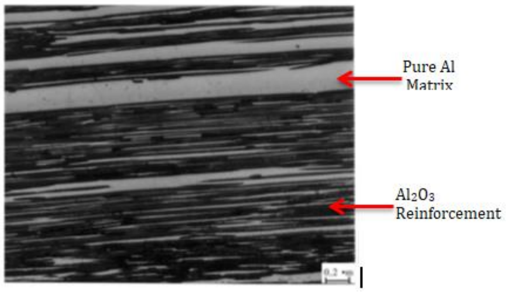


Fig. 7. Infiltration process



(a)



(b)

Fig. 8. (a) Cross Section of In-filtered AMMC. (56 μm)[18]
(b) In-plane section of In-filtered AMMC (0.2 μm)[18]

Metal matrix composites are made using the Spontaneous infiltration process and Forced infiltration process also.

2.2.3. Spontaneous infiltration process

The spontaneous Infiltration process is otherwise called a pressure-less infiltration process. The external pressure or external forces are not used here to enter liquid metal into the cavities. In a gaseous atmosphere, the temperature is controlled to bring the desired wetting conditions. The poor wettability between the matrix and reinforcement is the major limitation of this process. Ineffective wettability will delay the fabrication process. It also forms intermetallic composites such as AL3SiC4 and AL-SiC based composites. So, the wettability of preform by the molten metal is a significant parameter in this pressure-less infiltration process of making MMCs. Witting et. al.[22] manufactured Zirconia-based MMcs by this method. Active metals such as aluminum, vanadium, and titanium wet ZrO_2 but inert metals such as tin, copper, and silver do not wet ZrO_2. Ti is used as an activator here to improve the wettability of Zirconia.

2.2.4. Forced infiltration process

The Forced infiltration process is further classified into the following types.

a) Gas pressure infiltration process.
b) Squeeze casting infiltration process.
c) Vacuum infiltration process.
d) Ultrasonic infiltration process.
e) Pressure die infiltration process.
f) Lorentz force infiltration process.
g) Centrifugal infiltration process.

a. Gas pressure infiltration process

The liquid state of matrix material is implanted into the preform by applying a certain amount of pressure by a pressurized gas on the molten matrix, as shown in the figure. For avoiding air bubbles in the fabrication, a vacuum is introduced at the preform. This process fabricates the large-scale production of composite materials. The only disadvantage of this process is the higher cost of high-pressure gases. Qi et al. [23] fabricated the MMC by hydrostatic gas pressure infiltration process and reported that this process has low fabrication cost and high operational flexibility.

b. Squeeze casting infiltration process

Almost this process is similar to the squeeze casting process. The molten metal is placed above the preform in the fixed die. The movable die is used to apply pressure on the molten matrix, and hence it is penetrated to the preform. Figure 9 illustrates the schematic of the squeeze casting infiltration process. Based on Xue et al. [24], the MMCs produced by this process have exact dimensional properties, good surface characteristics, more creep strength, and higher corrosion resistance.

c. Vacuum infiltration process

In this process, a vacuum tube containing preform is surrounded by a molten metal matrix to fabricate the MMCs. A temperature control unit controls the temperature of the whole setup. The negative pressure inside the vacuum tube sucks the molten metal, and hence the molten metal is penetrated to the preform for forming composites. Here the infiltration time, temperature, and the vacuum applied are the major process parameters.

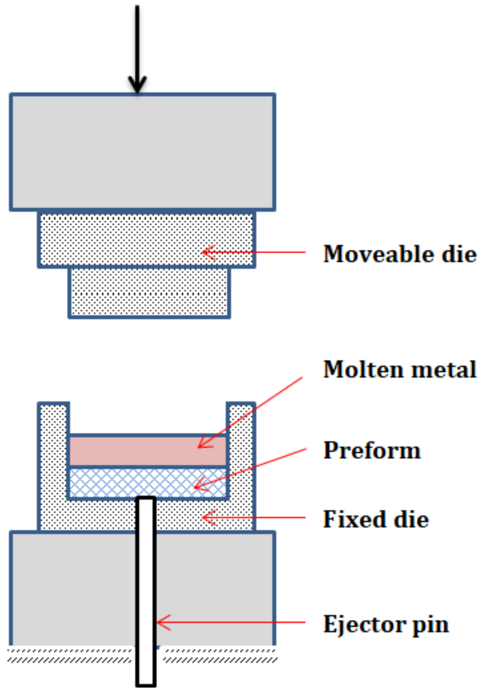


Fig.9. Squeeze casting infiltration process

Ferhat Gul et al. [25] studied the effects of the reinforcement volume fraction on the dry sliding wear behavior of Al–10Si/SiCp composites fabricated by vacuum infiltration technique. Here, an Al–10Si alloy was infiltrated into SiCp, Al, and Mg powders compact. After the parametrically controlled fabrication, optical micrographs of the composite were taken. It is found from the micrographs that the distribution of the particles is homogenous.

d. Ultrasonic infiltration process

The ultrasonic sound vibrations create pressure waves to immerse the molten metal with the reinforcement. A horn is used to actuate the ultrasonic vibration to produce the acoustic cavitation inside the molten metal. Infiltration occurs due to the collapse of bubbles created by the acoustic cavitation inside the molten metal. The air present inside the preform is entrapped by the dissolved gases produced by the collapse of bubbles. The bubble formation is decreased with the increment of the diameter of the hole available in the horn [21].

e. Pressure die infiltration process

In the pressure die infiltration process, the molten material is injected into the mould, performed by a piston arrangement. Then the molten metal in the mould is allowed to solidify by cooling. After the solidification, the moulded material is ejected using ejector pins. The schematic diagram is shown in Figure 10.

Li et al. [26] produced an Al-Cu alloy matrix with alumina fiber and aluminum particle reinforcement by a low-pressure infiltration process and evaluated the wear properties. It is found that the increment of the volume fraction of alumina fiber and the aluminum particle reduces the infiltration defects.

f. Lorentz force infiltration process

It is a unique infiltration process in which Lorentz force (the combination of electric and magnetic force) merges the molten metal with the reinforcement particles. Lorentz force is created by combining the eddy current with a magnetic pulse. This force immerses the molten metal with the reinforcement.[23]

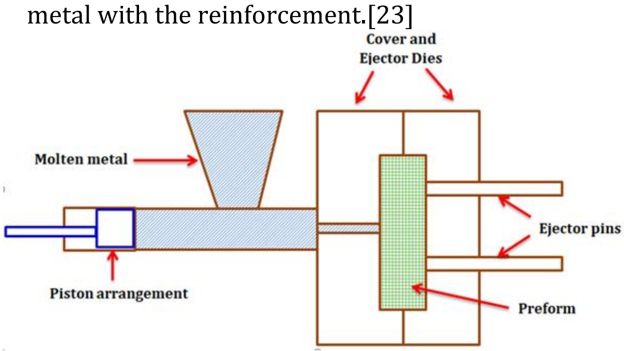


Fig. 10. The pressure die infiltration process

g. Centrifugal infiltration process

Here the centrifugal force is used to fabricate the composite. The reinforcement is placed inside a mould with an elongated runner filled with molten metal matrix init. Due to the large rotational or centrifugal velocity, the merge occurs between reinforcement and molten metal. [23].

2.3. Deposition process

2.3.1. Physical Vapour Deposition (PVD)

Metal matrix composites are made by this process also. It is a very slow process. An electron beam is used to vapourize the metal, and the fiber material is passed over the region of high partial pressure metal vapours. Metal vapours are condensed over the fiber materials, and hence thick coating is done on the fiber. Normally deposition rate is 5-10 μm. Then the coated fibers are arranged as rows and subjected to hot press operation for getting metal matrix composites [27]. The above said method is Electron beam Physical Vapour deposition. Another method is also available, namely the sputtering technique. In the sputtering technique, coating materials are sprayed with ions of the inert gas field over the metal piece. The coating material with inert gas ions broke the metal piece's atoms and coated on it.

2.3.2. Spray deposition method

In this method, the fine droplets of molten metal are formed and sprayed over the substrate to make the composite material. There are two types of spray deposition methods.

a) Osprey method
b) Thermal Spray method or plasma spray method

In the Osprey method, the fine metallic droplets are made using inert gases and sprayed over the metallic substrate. The quality of the coating depends on the following parameters.

a) Nozzle to substrate distance (flight length)
b) Type of atomizing inert gas
c) Angle of spray
d) Atomizing pressure
e) Rate of the coating.

The thermal spray or plasma spray process, as shown in Figure 11, is a different technique by which ceramics, alloys, intermetallic alloys, and functionally graded materials are coated [28],[29]. In this method, the rotating mandrel is used to spray the metallic droplets over the substrate. Computer programming is used to control the rotating mandrel to get the desired shape of composite material. Figure.10. shows the SEM image of Al-Al_2O_3 composite powders made by the plasma spraying process.

3. Consequences of processing parameters on the mechanical behavior of AMMCs

The desirable properties of AMMCs are

a) High modulus of strength
b) High Fracture strength
c) High Compressive strength.
d) Low thermal expansion coefficient
e) Wear resistance
f) Corrosion resistance

The characteristics of AMMCs fabricated using the PM method are largely influenced by the volume fraction of reinforcement particles, dispersion of reinforcement particles, and the process parameters of the PM method, such as sintering time and temperature applied. Rahimaian et al. fabricated Al-Al_2O_3 composites by PM technique and studied the effect of particle size, sintering time, and sintering temperature on various properties of AMMC [30]. Alumina of average particle size 3, 12, and 48 μm are used. Sintering temperature in the range of 500 to 600°C and sintering time of 30 to 90 min is given for the fabrication. The density is improved for the increment of sintering time from 45 to 90 min and the increment of sintering temperature. The composite density increases first up to a level and then decreases by decreasing alumina particle size. Compared to coarse particles, finer alumina particles give higher hardness, yield strength, compressive strength, and elongation at fracture.

In a research work [31], the composites were fabricated through ARB (Accumulative Roll Bonding) process. First of all, the specimens were dropped in a bath of acetone and scratched using a stainless-steel brush. Then the Fe_3O_4 nanoparticles, which are suspended in acetone, were sprayed on the scratched specimen. Then the specimen was rolled to reduce the size to half of its original size. Preetkanwal Singh Bains et al. [32] used SiC abrasive particulates mixed EDM oil as a flushing dielectric medium with the tool electrode for improving the surface finish, including the higher material removal rate and lower tool wear rate.

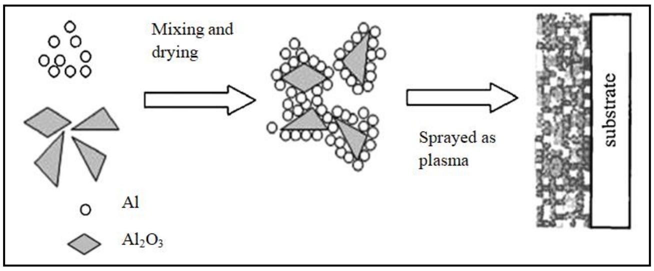


Fig. 11. Process of plasma Spray coating process [29]

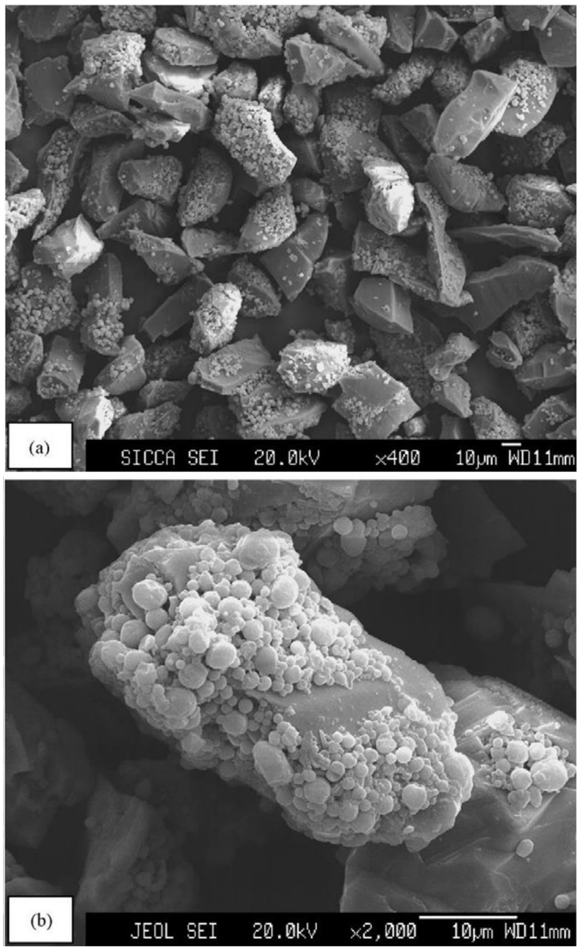


Fig. 12. SEM image of Al-Al2O3 composite powders made by the plasma spray process[29]

4. Test specimens and fixture selection for fracture studies

Since the 1970s, the control of fatigue crack propagation and damage tolerant theories have been investigated and developed. Initially, Irwin was the first scientist who studied crack behavior. Based on the direction of application loads, the fracture toughness is evaluated by three modes. The following shows the different modes of failure (Figure 13).

4.1. Various types of test specimens to evaluate fracture toughness

Laminated polymeric composites of different materials are analyzed to evaluate the delamination strength by applying loads above modes. Vishnu Prasad et al. [33] assessed the mode I and mode II inter-laminar fracture toughness of flax fiber reinforced epoxy composites through the double cantilever beam as shown in Figure 14.

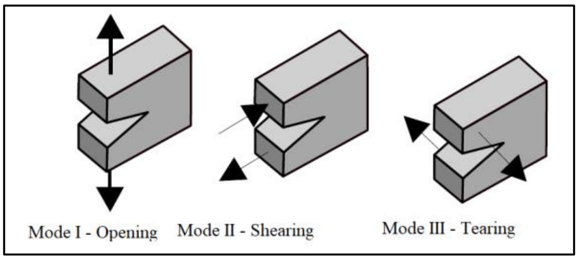


Fig.13. Modes of failure

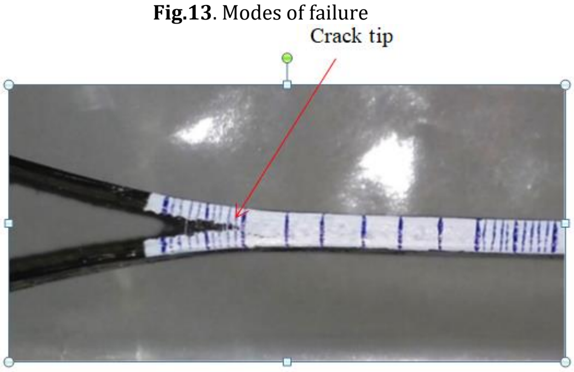


Fig.14. the double cantilever specimen for evaluating inter-laminar fracture toughness [33]

But in the case of metal matrix composites, the double cantilever beam is not suitable to find out the fracture toughness. CTS (Compact tension specimen) [34], SCB (Semi-circular bend specimen) [33], a specimen with spiral crack [35] are the notable specimens subjected to various modes of loading, i.e., mode I mode II, mode III, and mixed modes. Figure. 15 shows the test specimen subjected to multiple modes of loading.

Safari Naderi et al. [35] studied the delamination behavior of a composite structure reinforced with a carbon layer under a bending load. Finally, the procedure is used to predict the behavior of the wind turbine blade root. Three-point bending tests examined delamination. For that, an ordinary three-point bending specimen is used.

4.2. Fixtures used to evaluate fracture toughness of MMCs

The test specimen for fracture tests are loaded as mode I, mode II, or mode III, or mixed modes. The load cannot be applied directly. For the tensile test, the test specimen can be loaded directly in UTM. But in the case of different modes of loading, some types of loading fixtures are used. Mohammad Reza Hosseinia et al. determined the mode I interlaminar fracture toughness value for woven glass/epoxy laminated polymeric composites [27].

In this experiment, a double cantilever beam (DCB) specimen is used for testing. For loading, the DCB specimen door latch is used as a fixture. Figure 16 (a) shows the DCB specimens with the fixtures.

Qi et al. evaluated the fatigue crack propagation rate of mixed I-II mode crack created in the $30Cr_2Ni_4MoV$ steel [34]. In this study, the LCF (low cycle fatigue) specimen and CT specimen are used to evaluate the fracture parameter.

Here the mixed-mode I-II load is applied on the CT specimen using a different type of loading fixture called "Arcan fixture". Figure 16 (b) shows the CT specimen with the Arcan fixture for applying mixed mode type of loading.

Afshin Zeinedini fabricated a fixture for loading the CT specimen for the mixed modes of mode I/II, mode II/III, and mode I/III. The stress field around the crack tip of linear elastic material loaded with the mode mix is called a T-stress. In this study, the T-stress, three-dimensional plastic zone around the crack tip, and the stress intensity factor of a pre-cracked epoxy polymeric material are investigated using a novel fixture [35]. The novel fixture and its dimensions are shown in Figure 17.

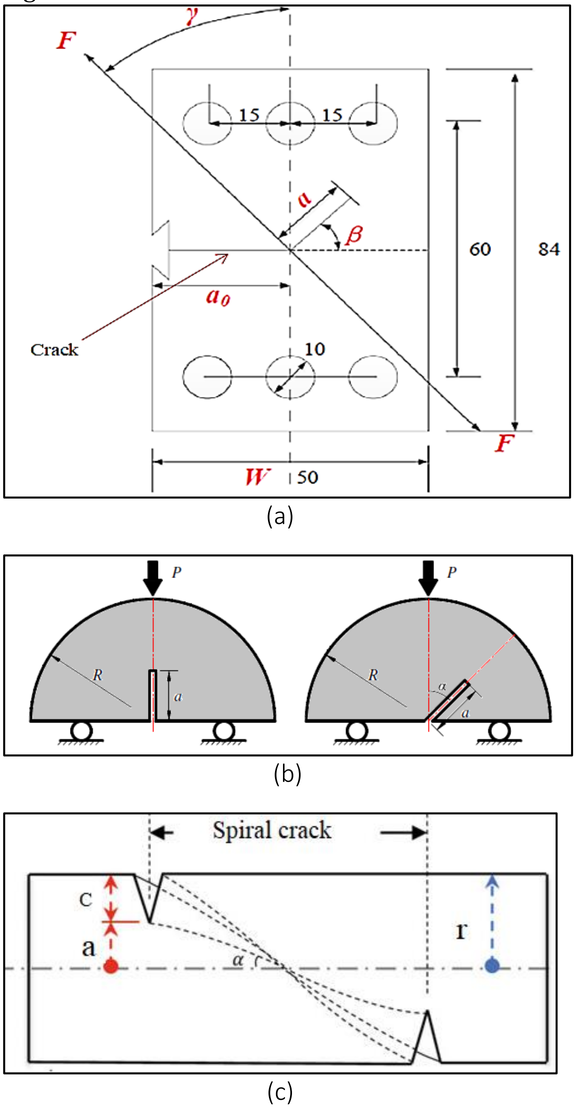
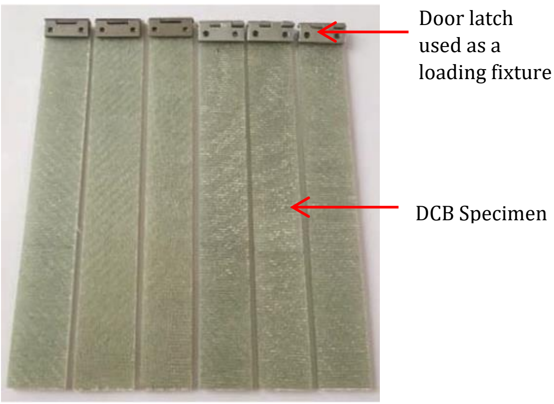
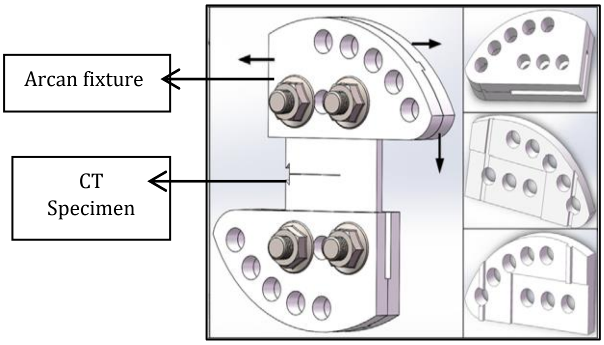


Fig. 15. Test specimen (a) CTS [25] (b) SCB [24]
(c) Dynamic specimen with spiral crack [26]



(a)



(b)

Fig. 16. (a) DCB specimen with loading fixtures [36]
(b) CT Specimen with loading fixture[34]

5. Various applications of aluminum metal matrix composites

Based on the market survey, pure aluminum, Al alloys, and aluminum matrix composites have good records because of their desirable properties such as high modulus of strength, high Fracture strength, high Compressive strength, and low thermal strength expansion coefficient, etc. The industrial applications of aluminum products are shown in Table 1 have grown tremendously for a few years. When compared to other metallic composites, the production of Al-based composites are very large.

Among the above advantages, the cost/performance ratio of aluminum products is the greatest concern. Other metal matrix composites are in the market due to their desirable properties. Even the cost/performance ratio of Aluminum-based composites is not at a desirable level, Al-based composites can compete. Ultimately very large commercialization of Al-based composites will happen soon [37],[38],[39].

Most industries are started to produce AMMCs instead of aluminum alloys and pure aluminum due to their better mechanical and electrical performance. The various applications, components made in the respective fields, and their advantages are tabulated in Table. 1.

And the comparison of various fabrication routes based on the field of applications is tabulated in Table 2.

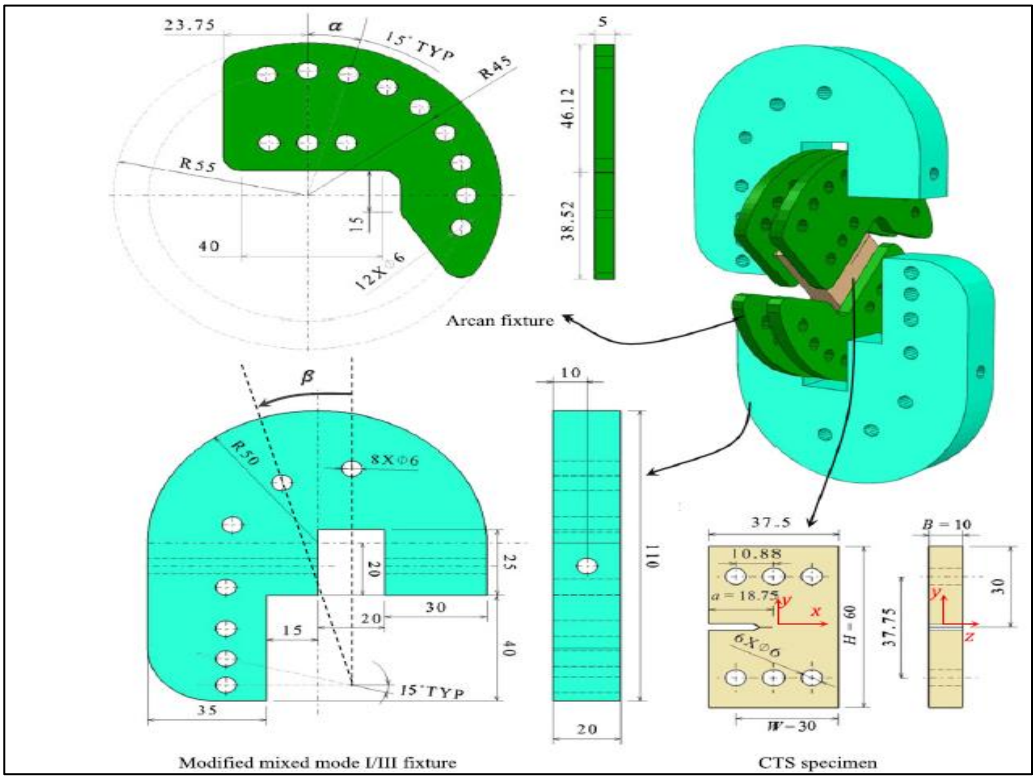


Fig. 17. The fixture used for mixed-mode I-II and mixed-mode I-III Fracture testing [35]

Table 1. Applications of AMMCs in various fields [23]

Various fields of applications	Components made by AMMCs and their advantages
Automobile field	Pistons, Connecting rods, Engine blocks, Brake rotors, Current collectors, Propeller shafts, and brake discs
Aerospace and aircrafts	Wings with its supporting structures, fuselage, military aircraft, and Cargos
Railways	Usage of AMMCs in railway wagons provides better fuel efficiency and higher load carrying capacities
Marine transports	Usage of AMMCs causes high speeds to boats, higher fuel efficiency, and reduced maintenance costs.
Off-shore applications	For making off-shore platforms and sea walls
Building and construction materials	Some supporting structures are made up of AMMCs. It gives greater strength and stiffness.
Packaging and containerization fields	Beverage bottles, food containers
Sports and recreation	Most of the sports goods for providing greater strength and lightweight (Boron and Silicon carbide reinforcements are used with aluminum here)
Electrical transmission	The properties of higher corrosion resistance, higher life, and electrical conduction of AMMCs are most wanted for electrical transmission.

Table 2. Comparison of fabrication route based on applications [23]

Fabrication route	Cost of fabrication	Field of Applications
Stir casting	Very least	It is suitable for the mass production of AMMCs and commercial products
Squeeze casting	medium	The components used in automotive industries made by this method
Spray Casting	medium	The components used for friction, such as grinding tools and cutting tools, are made by this method.
Liquid metal Infiltration	low	The building materials like rods and some other uniaxial components are produced by this method.
Powder metallurgy	medium	Small mechanical components such as bolts, valves, and pistons, etc., are produced using this fabrication technique
Diffusion bonding	High	The sheets having large areas, blades and turbine vanes, etc., are produced by this method

6. Conclusions

Various fabrication techniques to make aluminum metal matrix composites have been investigated in recent researches. All fabricating methods have their advantages and limitations. The selection of fabrication technique is based on many factors such as cost of production, process efficiency, resultant quality of composites, etc. The summary of the discussions made here is below.

- Researchers mostly selected the Powder metallurgy process in the solid-state process because of its controllable processing parameters. In the liquid state process, the stir casting technique is very attractive.
- The infiltration process is rarely used, and the deposition and spray processes are only for coating the substrate.
- In the surface morphology-based researches, the deposition and spray processes are adopted.

Experimentation methods on the determination of fracture toughness and other fracture parameters are surveyed from earlier research studies. The summary is given below

- Mode –I fracture toughness is evaluated mostly for determining the delamination strength of laminated polymeric composites using DCB specimens.
- The earlier researchers determined the single and mixed-mode fracture behaviors of metals, alloys, and metal matrix composites through the mode I/II and mode I/III and

mode II/III loading conditions using CT SCB specimens by employing its appropriate fixtures.

Based on this review study, there is a scope for exploring the research in fracture behavior determination by considering appropriate methods and experimental procedures on AMMCs in the fields like aerospace and defence sectors, etc.

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