Production Technologies of Metal Matrix Composite: A Review

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Abstract
This paper presents a study on the Metal matrix composites, production technologies related to MMCs. In this paper the recent progress in production technologies of metal matrix composites is reviewed. Composite materials are often shortened to composites are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished structure Metal Matrix Composites (MMCs) are made of a continuous metallic matrix and one or more discontinuous reinforcing phases. The reinforcing phase may be in the form of fibers, whiskers or particles. These days metal matrix composites (MMCs) are replacing conventional materials in many applications because of their superior properties such as high strength to weight ratio, hardness, stiffness and wear and corrosion resistances over conventional materials. Various processes are used for making metal matrix composites like liquid fabrication methods, solid state fabrication methods, etc. various production processes like metal injection molding ,friction stir process, mechanical alloying ,squeeze casting technology, continuous binder-powder coating etc. are used bt the researchers for manufacturing metal matrix composites. Lot of work is going on in the field of production technologies of MMC which has brought down their cost to an acceptable level compared to those processed by powder metallurgy and spray casting process.

Keywords
Composites, Metal Matrix Composites (MMC), Processes

I. Introduction

Composites materials have been utilized to solve technological problems for a long time but only in the 1960 did these materials start capturing the attention of industries with the introduction of polymeric based, metal matrix based composites. A composite material is made by combining two or more materials to give a unique combination of properties [1]. The main concept of composite is that it contains matrix materials. In composite material the reinforcements can be fibers, particulates or whiskers, and the matrix materials can be metals, plastics, or ceramics. The reinforcements can be made from polymers, ceramics and metals. In this paper we have discussed about the metal matrix composites, production technologies related to MMC and their role in manufacturing industries. Metal matrix composites (MMCs) are made of a continuous metallic matrix and one or more discontinuous reinforcing phases. The reinforcing phase may be in the form of fibers, whiskers or particles.The metal matrix composites have various advantages over other types of composites. Such as high strength, high modulus, high toughness and impact properties, Low sensitivity to changes in temperature or thermal shock, high surface durability and low sensitivity to surface flaws, high electrical conductivity. There are different types of metal matrix composites on the basis of reinforcement in MMC. such as (a) particle reinforcement; (b) short fiber reinforcement; (c) continuous fiber reinforcement; (d) laminate reinforcement as shown in fig. 1.

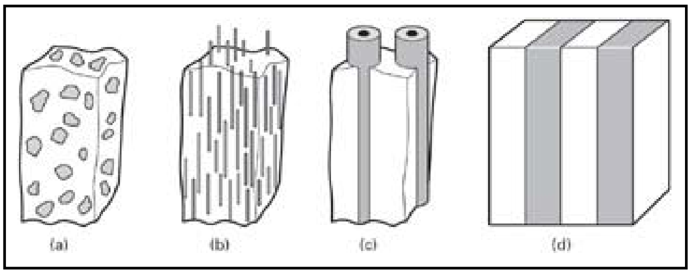

Fig. 1: Types of Metal Matrix Composites [2]

II. Techniques for Fabrication of Metal Matrix Composites

These metal matrix composites have many advantages as compared to monolithic metals as discussed above so their applications are increasing day by day in various fields. Various processes are used to manufacture MMCs which are described here. These processes are classified on the basis of temperature of the metallic matrix during processing [3] Accordingly, the processes can be classified into five categories: (1) liquid-phase processes, (2) solid–liquid processes,(3) deposition techniques and (4) in situ processes. (5) two- phase (solid–liquid) processes. In this paper we have discussed only first three types only.

A. Liquid State Fabrication of Metal Matrix Composites

It involves incorporation of dispersed phase into a molten matrix metal, followed by its solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase particles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix.
The methods of liquid state fabrication of Metal Matrix Composites: Stir casting, Infiltration like gas pressure infiltration , Squeeze casting infiltration or Pressure die infiltration.

1. Stir Casting

It is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. Stir casting as shown in fig. 2 is the simplest and the most cost effective method of liquid state fabrication. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies.

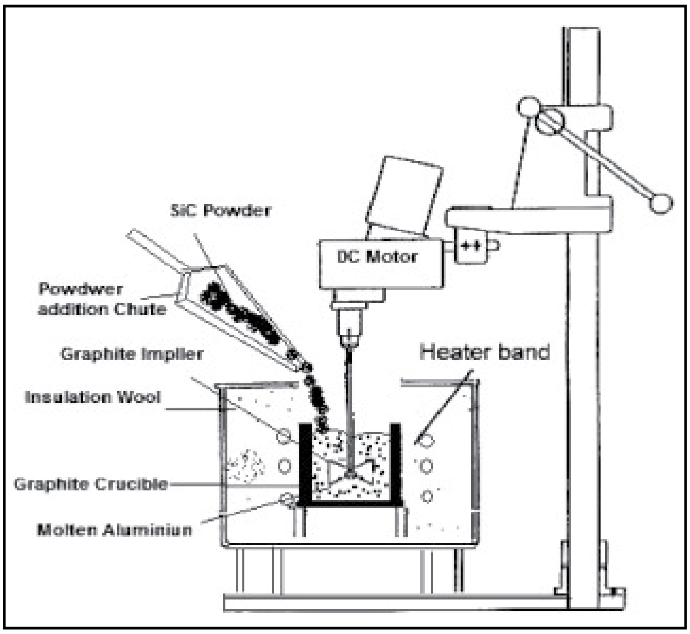

Fig. 2: Stir Casting by Vortex Method [3]

2. Infiltration

It is a liquid state method of composite materials fabrication, in which a preformed dispersed phase (ceramic particles, fibers, woven) is soaked in a molten matrix metal, which fills the space between the dispersed phase inclusions.

The motive force of an infiltration process may be either capillary force of the dispersed phase (spontaneous infiltration) or an external pressure (gaseous, mechanical, electromagnetic, centrifugal or ultrasonic) applied to the liquid matrix phase (forced infiltration).

(i). Gas Pressure Infiltration

It is a forced infiltration method of liquid phase fabrication of Metal Matrix Composites, using a pressurized gas for applying pressure on the molten metal and forcing it to penetrate into a preformed dispersed phase as shown in fig. 3. Gas Pressure Infiltration method is used for manufacturing large composite parts.

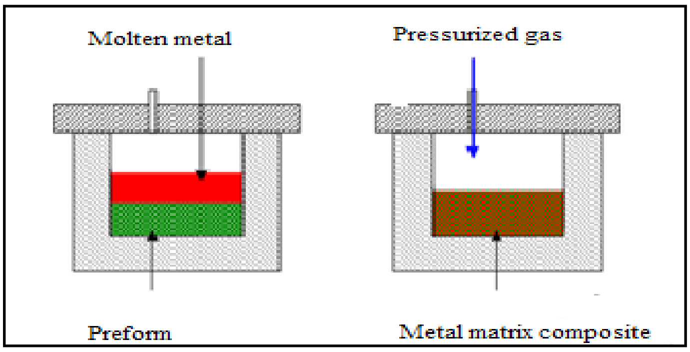

Fig. 3: Gas Pressure Infiltration [4]

Squeeze Casting Infiltration or pressure die infiltration – It is a forced infiltration method of liquid phase fabrication of Metal Matrix Composites, using a movable mold part (ram) for applying pressure on the molten metal and forcing it to penetrate into a preformed dispersed phase, placed into the lower fixed mold part as shown in fig. 4. The method is used for manufacturing simple small parts like automotive engine pistons.

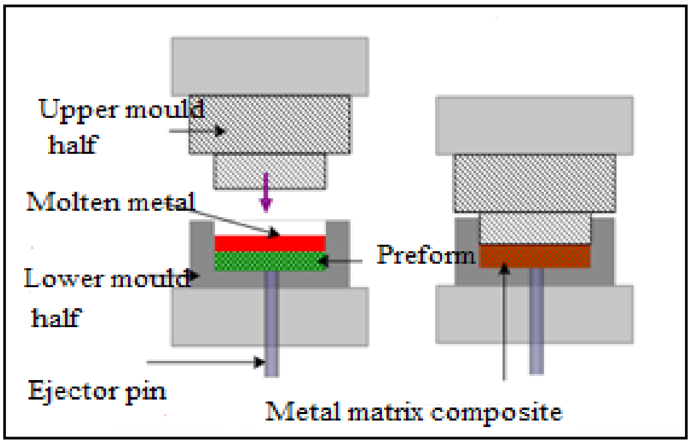

Fig. 4: Squeeze Casting [4]

B. Solid State Fabrication of Metal Matrix Composites

Solid state fabrication of metal matrix composites is the process , in which MMC are formed as a result of bonding of matrix metal and dispersed phase due to mutual diffusion occurring between them in solid state at elevated temperature and under pressure.

1. Diffusion Bonding

It is a common solid-state processing technique for joining similar or dissimilar metals. Inter diffusion of atoms between clean metallic surfaces, in contact at an elevated temperature, leads to bonding. It is also used for fabrication of MMC as shown in fig. 5.

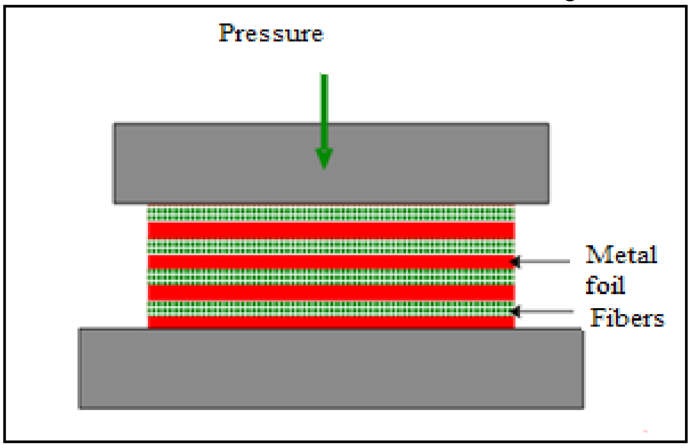

Fig. 5: Diffusion Bonding [4]

The principal advantages of this technique are the ability to process a wide variety of metal matrices and control of fiber orientation and volume fraction.

2. Powder Processing or Powder Metallurgy

These methods in conjunction with deformation processing are used to fabricate particulate or short fiber reinforced composites as shown in fig. 6. This typically involves cold pressing and sintering, or hot pressing to fabricate primarily particle- or whisker-reinforced MMCs. The matrix and the reinforcement powders are blended to produce a homogeneous distribution.

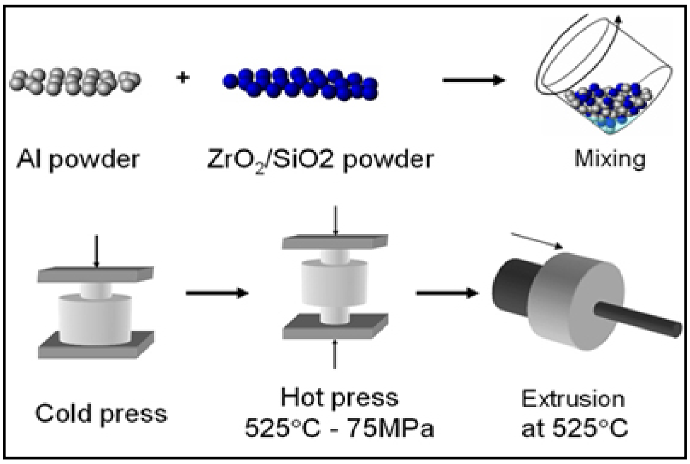

Fig. 6: Powder Metallurgy [4]

The blending stage is followed by cold pressing to produce what is called a green body, which is about 80% dense and can be easily handled. The cold pressed green body is canned in a sealed container and degassed to remove any absorbed moisture from the particle surfaces. The material is hot pressed, uniaxially or isostatically, to produce a fully dense composite and extruded.

C. Deposition Techniques

These processes for metal-matrix composite fabrication involve coating individual fibers in a tow with the matrix material needed to form the composite followed by diffusion bonding to form a consolidated composite plate or structural shape. The main disadvantage of using deposition techniques is that they are time consuming. Several deposition techniques are available: immersion plating, electroplating, spray deposition, chemical vapor deposition (CVD), and physical vapor deposition (PVD), spray forming.

1. Spray Forming

One particular example of this, a co-spray process, uses a spray gun to atomize a molten aluminum alloy matrix, into which heated silicon carbide particles are injected as shown in fig. 7.

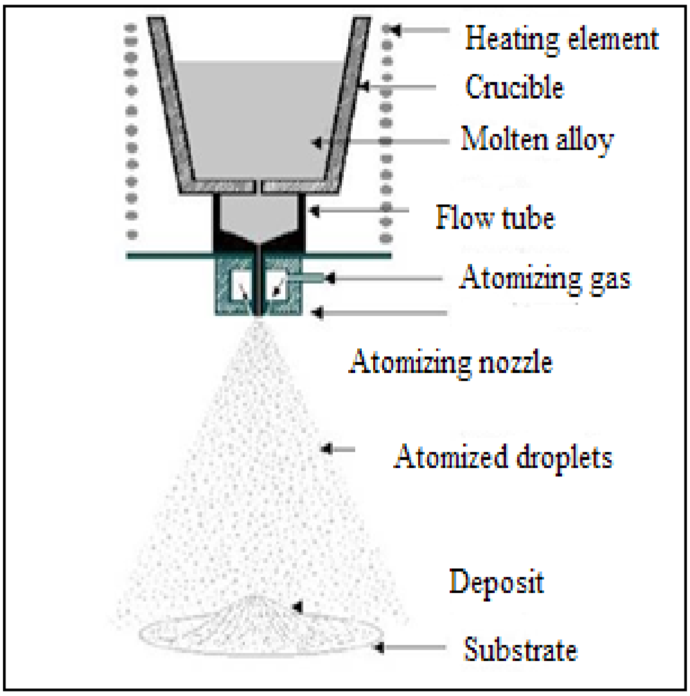

Fig. 7: Spray Forming [4]

Dipping or immersion plating is similar to infiltration casting except that fiber tows are continuously passed through baths of molten metal, slurry, sol, or organometallic precursors.

2. Electroplating

It produces a coating from a 10 μm solution containing the ion of the desired material in the presence of an electric current. Fibres are wound on a mandrel, which serves as the cathode, and placed into the plating bath with an anode of the desired matrix material.

3. Spray Deposition

This technique typically consists of winding fibers onto a foil-coated drum and spraying molten metal onto them to form a monotape. The source of molten metal may be powder or wire feedstock which is melted in a flame, arc, or plasma torch.

4. Chemical Vapour Deposition (CVD)

It is a vaporized component decomposes or reacts with another vaporized chemical on the substrate to form a coating on that substrate. The processing is generally carried out at elevated temperatures.

D. In-situ Fabrication of Metal Matrix Composites

In these techniques the reinforcement phase is formed in situ. The composite material is produced in one step from an appropriate starting alloy, thus avoiding the difficulties inherent in combining the separate components

E. Two-phase Processes

Two-phase processes like ospary deposition, compocasting, etc. involve the mixing of ceramic and matrix in a region of the phase diagram where the matrix contains both solid and liquid phases.

III. Research Work in Processing of MMCs

In this paper [5] the importance of metal matrix composites in various fields was discussed. Over the past two decades – a period coinciding with publication of Important MMC applications in the ground transportation (auto and rail), thermal management, aerospace, industrial, recreational and infrastructure industries have been enabled by functional properties that include high structural efficiency, excellent wear resistance, and attractive thermal and electrical characteristics. A suite of challenging technical issues has been overcome, including affordable primary and secondary processing, material design and development methodologies, and characterization and control of interfacial properties. This article describes the technological features that characterize the MMC industry. Matrix/reinforcement systems and primary and secondary processes of commercial significance was broadly described. The paper [6] presented a brief state of the art of advanced ceramics, metal matrix and ceramic matrix composites. The attention was focused on process technologies related to ceramic and metal matrix composites involved, applications and future of these "potential" materials. Some experimental results were included. The future of advanced materials is related to systems solutions, economical manufacturing processing, diverse markets and new technologies. The new materials will provide the opportunity for growth to a new and healthier balance, with vibrant commercial sector delivering an improved quality of life and stronger technology base. They [7] used two step-mixing method of stir casting technique to fabricate MMC and subsequent property analysis has been made. Aluminium (98.41% C.P) and SiC (320-grit) has been chosen as matrix and reinforcement material respectively. Experiments have been conducted by varying weight fraction of SiC (5%, 10%, 15%, 20%, 25%, and 30%), while keeping all other parameters constant. The results indicated that the 'developed method' is quite successful to obtain uniform dispersion of reinforcement in the matrix. An increasing trend of hardness and impact strength with increase in weight percentage of SiC has been observed. The best results (maximum hardness 45.5 BHN & maximum impact strength of 36 N-m.) have been obtained at 25% weight fraction of SiC. The results were further justified by comparing with other investigators.

Conventional stir casting process has been employed for producing discontinuous particle reinforced metal matrix composites for decades. In this paper [8], aluminium metal matrix composites were fabricated by different processing temperatures with different holding time to understand the influence of process parameters on the distribution of particle in the matrix and the resultant mechanical properties. The distribution is examined by microstructure analysis, hardness distribution and density distribution. Al-(10-15)%B4C MMCs [9]were produced using a powder injection . They have used two base matrices used: pure Al and 6063 alloy. Small amounts of Ti and Zr were added to each melt before B4C powder injection was carried out. Composite melts were poured into metallic L-shaped and rectangular book-type molds. As-cast microstructures revealed uniform distribution of B4C particulate and good wettability with the matrix. Segregation was sometimes observed when the melt was stirred at low speed.

A method for producing MMCs [10] was successfully implemented for mixing hybrid, nano and low micron sized, reinforcing particles in an aluminium alloy matrix. The hybrid SiC particles were produced by milling 3µm to 5µm SiC particles to a particle size range between 2.5µm and 150 nm. The hybrid particles were mixed with A356 aluminium alloy under combined magneto-hydrodynamic (MHD) and mechanical stirring. The composite was then transferred to a High Pressure Die Casting (HPDC) machine in the semi-solid state. Increased ultimate tensile strength, yield strength and hardness were achieved for the new cast metal matrix hybrid component (MMHC) alloy. Metal injection molding (MIM) is a near net-shape manufacturing technology [11] that is capable of mass production of complex parts cost-effectively. In this paper, the status of the research and development in fabricating metal matrix composites by MIM is reviewed, with a major focus on material systems, fabrication methods, resulting material properties and microstructures. They have discussed about refractory metal based MMC, titanium based, intermetallic based and steel based Also, limitations and needs of the technique in composite fabrication are presented in the paper. MIM is used for producing complex –shaped parts from tungsten or molybdenum based materials. The current research on titanium matrix composites through MIM is primarily focused on applications in the biomedical field. The use of MIM in ferrous composites is to improve their wear characteristics. Friction stir processing (FSP) was applied [12] to modify the microstructure of sintered Al–SiC composites with particle concentrations ranging from 4 to 16 vol%. Two SiC particle sizes (490N and 800 grades) were examined. Following FSP, the hardness of the 4 and 8 vol% of 490N grade SiC composites increased from 130 HV and 145 HV to 171 HV and 177 HV respectively. The increase was accounted for by the severe deformation occurring during FSP which uniformly distributed the SiC particles. The composites containing 16 vol% SiC could not be fully consolidated using FSP, and contained residual pores and lack of consolidation which originated from the as-received sintered microstructure. The production methods and properties of metal matrix composite materials reinforced with dispersion particles, platelets, non-continuous (short) and continuous (long) fibres are discussed in this paper [13]. The most widely applied methods for the production of composite materials and composite parts are based on casting techniques such as the squeeze casting of porous ceramic preforms with liquid metal alloys and powder metallurgy methods. On account of the excellent physical, mechanical and development properties of composite materials, they are applied widely in aircraft technology and electronic engineering, and recently in passenger-car technology.

Recently, accumulative roll bonding (ARB) has been used [14] as a novel method to produce particle reinforced metal matrix composites. In this study, aluminum matrix composite reinforced by submicron particulate alumina was successfully produced and the effects of number of ARB cycles and the amount of alumina content on the microstructure and mechanical properties of composites were investigated. According to the results of tensile tests, it is shown that the yield and tensile strengths of the composite are increased with the number of ARB cycles. Scanning electron microscopy (SEM) reveals that particles have a random and uniform distribution in the matrix by the ARB cycles and a strong mechanical bonding takes place at the interface of particle-matrix. Mechanical alloying (MA) technique [15] has been used to produce aluminium-based metal matrix composite powders. As base material, the aluminium alloy AA2014 was selected, and two different carbides (VC and TiC) were chosen as reinforcements. Elemental powders(Al, Mg, Si and Cu) and carbide powders were mixed together in a high energy horizontal ball mill .The amount of elemental powders was such that the composition of AA2014 alloy (4.4% Cu, 0.5% Mg, 0.7% Si, Al bal., all wt.%) reinforced with 5%vol carbide powders was obtained. The produced composite powders were consequently analyzed. The influence of the mechanical alloying parameters on morphology, particle size, micro hardness, and microstructure of the final powder was studied. Results show that composite powders can be obtained in an only step with improved properties by means of mechanical alloying. The use of this technique and these powders as raw materials not only eliminates problems associated to other techniques of the MMC production but allows the achievement of materials with enhanced final properties due to a better powder production. This technique eliminates the employment of ball mills for blending steps.

They have used [16] continuous binder powder coating (CBPC) to produce for titanium metal matrix composites reinforced with continuous SiC filaments.. Based on powder–cloth process, this new fabrication route is characterized, analyzed and its application viability is discussed considering the other related routes. Results have shown that the titanium matrix composites processed by continuous binder-powder coating(CBPC) present simultaneously good matrix densification and consolidation, also a weak interaction between matrix and fibers, when the hot pressing is performed under 150 MPa at temperature below b-transus. The most important characteristics of the CBPC process and its application viability are reported. In order to fabricate continuous carbon fiber-reinforced aluminum alloy matrix composites, various infiltration methods such as gas pressure infiltration, CVD-infiltration, and ultrasonic infiltration methods have been developed. Among these methods, the ultrasonic infiltration [17] method is the simplest. In this study, the effects of ultrasonic power, the diameter of the hole of the horn, fabricating speed, and magnesium content on the ease of infiltration are investigated. As the results, both an ultrasonic power of 200 W and the addition of more than 2.4 mass% Mg are indispensable to infiltrate molten aluminum alloy into a PAN-based M40J carbon fiber bundle, which has6000 filaments. Contrariwise, the tensile strength and relative strength (ROM ratio) of the obtained composites decreased from1100 MPa (0.7) at both 2.4 and 4.7 mass% Mg contents to 800 MPa (0.5) at 10 mass% Mg content. This was probably caused by an increase in the content of the Al3Mg2 intermetallic compound. Consequently, the addition of magnesium is effective in improving the infiltration; however, it causes the strength of the composites to decrease. It is found that in this process, the optimum magnesium content in aluminum from the viewpoints of ease of infiltration and strength was 4.7 mass%. This paper [18] reviews about the principles of squeeze casting technology, which can be applied to process discontinuous fiber reinforced metal. Squeeze forming process is a special casting technique that combines the advantages of traditional high pressure die casting, gravity permanent mold die casting and common forging technology. This advanced casting method is applied for processing of both ferrous and non-ferrous materials besides composites. The major advantages of this technology are elimination of porosity and shrinkage, 100% casting yield, attainment of greater part details, good surface finish, good dimensional accuracy, high strength to weight ratio, improved wear resistance, higher corrosion resistance, higher hardness, and resistance to high temperature, improved fatigue and better creep strength. The components manufactured by this casting method requires lesser post machining operation and they have improved mechanical properties like higher strength and ductility. In squeeze casting process the liquid metal is pressurized while they solidify and hence near net shapes can be produced with sound and dense quality. The micro structural refinement of squeeze cast products is desirable for many critical applications. This process is simple, economical and it can be automated easily. The process generates the highest mechanical properties attainable in a cast product. So this process has been adopted to make composite castings at an affordable cost. In this paper [19] they discussed about a new continuous processing method for the production of continuous – fiber- reinforced metal matrix composite (MMC) wires. They developed MMC wires with the diameter of 0.5-1.6 mm continuously by continuous pressure infiltration unit. Wires with various fiber- metal combinations like Nextel 440/6061 Al wire, Al 2 O 3 (F)/ 6061 Al wire, carbon/ Al wires have been produced successfully by high speed, low exposure time operations of the unit and their characteristics are discussed in this paper. It is an important step for the production of high performance MMC wires for large scale commercial applications.

IV. Conclusion

The use of metal matrix composites is increasing day by day due to their characteristics of behaviour with their high strength to weight ratio. Every industry like automobile, sports, aerospace, construction, marine, etc. utilizes the benefits of composites especially metal matrix composites. Various processes like stir casting, powder metallurgy, infiltration, etc. are used to manufacture MMCs as discussed in this paper. The main aim is to make these manufacturing processes more economical, productive and efficient, so researchers are developing new technologies like mechanical alloying, metal injection moulding(MIM), continuous binder powder coating(CBPC), etc. to manufacture these MMCs to meet the demands of various industries. Selected research is underway to improve existing MMC materials and processes and architectures are available to establish a second generation of materials and process research and development.

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