CHAPTER 2

LITERATURE REVIEW

The qualities of the weldments are assessed by different process parameters while the process of friction stir welding for metal matrix composites were used. There were reports on the effects of FSW such as tool geometry, axial force and also on the welding speed on Aluminium Metal Matrix (Al-MMC) composites which can result in better joints in the weldment areas of the composites. The literature available for the problems associated with the composites during welding process is discussed in detail in this chapter with the analysis methods and its related issues were discussed in detail in this chapter.

2.1 COMPOSITES AND ITS CLASSIFICATIONS

2.1.1 Metal Matrix Composites

The base composite materials possess somewhat good mechanical and thermal stability. To improve their mechanical, thermal and metallurgical properties, the composites were effectively added to some of the impurities to the base material known as matrix. These matrix changes the physical and chemical nature of the composites. The mixing of matrix in the parent (host) material is known as reinforcement and that when metals were mixed with the ceramic particles, the reinforcements are generally called as metal matrix composites or in short MMC’s. The required characteristics may not be obtained in pure ceramics and hence the addition of metals to form MMCs improves certain characteristic properties such as aluminium and its alloys.
which are widely used. These aluminium mixed composites are a special class of MMCs which is called as aluminium MMC or in short Al-MMCs. They significantly improves the ductility which is very poor in aluminium based alloys and this can be achieved by mixing the composites of SiC and TiB$_2$ in the aluminium matrix.

In generally, metals such as Al, Cu, Mg, Ti, Fe, Si, Ag, Sn, Pb and Zn were used as metal reinforcements in the metal matrix composites of SiC and TiB$_2$ ceramics. These reinforcements are carried out to improve the wear behaviour and to improve the environmental resistance conditions of the wear and tear parts. In some of the applications where there is a need for more thermally stable materials, the improvement of coefficient of thermal expansion is achieved by the reinforced MMCs and thereby the thermal conductivity and mechanical strength is improved. For tribological behaviour improvement, the reinforcement improves the elastic modulus, ductility and the mechanical strength of the composites. In some of the electrical applications, these reinforced Al-MMCs and MMCs are also used.

The uniform distribution of reinforcement in the matrix helps the metal matrix composites improves the corrosion resistance properties and thereby the oxidations on the surfaces are reduced. For effective fabrication, the degree of bonding between the reinforcement and the host matrix metals play an important role and this can be achieved by the uniform distribution of the fibers or ceramic particles (Ashok Kumar & Murugan 2012).

Aluminium based MMCs have its own advantage of low density due to which it results in low weight and also offers good mechanical and corrosion resistance properties in recent years. The reduction of lowering of thermal conductivity and light weight nature has opened up a new era in the avionics and in aerospace industry and thereby the common man benefits the
lower cost due to the lowered usage of fuel in flights (Toptan et al. 2010). For guided missiles and in other military applications silicon carbide (SiC) reinforced Al-MMCs were recently used due to its easy handling and fabrications (machinability). The addition of lithium in the Al-MMC improves the wettability and thereby the machinability properties (Kerti & Toptan 2008, Mazahery & Shabani 2012).

There was wide range of metal alloys that is being used in the automobile industry out of which aluminium plays a crucial role due to their numerous advantages such as low density and flexibility in handling for machining. Due to its low heat treatable nature, it’s preferred over its contemporary counter parts of magnesium based alloys due to its better elastic modulus. The aluminium alloys were primarily classified as 1xxx, 2xxx, 3xxx, 4xxx, 5xxx, 6xxx, 7xxx, and 8xxx based on their primary metal compositions. Depending on the different alloying element, the aluminium metal matrix can be classified according to ASTM standards and are given in Table 2.1. In general, both magnesium (Mg) and aluminium (Al) were used in the basic composites for wettability nature (Kubota & Cizek 2008).

For effective component development of reinforcements, many basic factors such as metal matrix and reinforcement particle nature has to be considered which can effectively improve the stability of the MMC and thereby the thermal expansion and thermal conductivity can be improved to the desired level. The formation of better composite are primarily due to the effective bonding that exist between the reinforcement and the matrix. The inefficient bonding can result in increased wear nature on the fabricated component surface and thereby the loss of material can damage the frictional parts.
Table 2.1 Designation of Wrought aluminium alloy (AA)

<table>
<thead>
<tr>
<th>Aluminium Alloy (AA) Series</th>
<th>Principal Alloying Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1xxx</td>
<td>Minimum Aluminium</td>
</tr>
<tr>
<td>2xxx</td>
<td>Copper</td>
</tr>
<tr>
<td>3xxx</td>
<td>Manganese</td>
</tr>
<tr>
<td>4xxx</td>
<td>Silicon</td>
</tr>
<tr>
<td>5xxx</td>
<td>Magnesium</td>
</tr>
<tr>
<td>6xxx</td>
<td>Silicon and Magnesium</td>
</tr>
<tr>
<td>7xxx</td>
<td>Zinc</td>
</tr>
<tr>
<td>8xxx</td>
<td>Other Elements</td>
</tr>
</tbody>
</table>

For better performance of materials in engineering applications, the traditional metals and alloys performance in terms of mechanical and tribological behaviour should be improved. To make an improved performance in the engineering components more and more composite materials are used in the areas of construction applications, ship building and in various mechanical components manufacturing. Proper selection of these composites helps the metal matrix composites ease in manufacturing as well as machining becomes easier thereby the production cost can be reduced. Thus in recent years mixed and hybrid composites were widely investigated for their day-to-day usages in many industrial and in domestic applications. Depending on the general requirement, the metal matrix composites can be broadly classified in to three categories as follows.

1. Fiber reinforced metal matrix composites,
2. Particle reinforced composites and
3. Long aligned fiber reinforced composites.
The fabrication of the Metal Matrix Composites (MMC) based components can be modified by varying various input ingredients in the matrix during the synthesize of the compounds itself. Hence careful selection of matrix and the reinforcement is to be carried out during the manufacturing of raw MMC materials itself. This could possibly reduce the cost of production thus enabling the economical viability of fabrication of MMC’s. In general, composites such as graphite, Silicon Carbide (SiC), titanium boride, boron carbide and alumina were widely used as reinforcements in the aluminium based MMC’s. To achieve better mechanical strength and to have economical viability, alumina (Al$_2$O$_3$) and silicon carbide were used as the fabricating components which can be easily machined and welded.

2.2 ALUMINIUM METAL MATRIX COMPOSITES (Al-MMC’s)

For processing of metal matrix composites, careful examination of parent compounds should be taken so that the wettability of the composites is maintained for possessing proper metallurgical and mechanical properties and hence it is imperative to choose the appropriate metal matrix (Ağaoğulları et al. 2012). During the process of reinforcement the natural dichotomy between the reactant parent compounds of metallic alloy and the matrix metal is considered for the wettability of the reinforced particulates in the matrix (Berghezan 1966). Due to this a strong interface can be obtained for the MMCs so that the load transfer characteristics remains improved for the matrix metal (Jartiz 1965, Kelly 1967).

Proper chemical bonding between the host matrix and the reinforcement particulates can be achieved by proper examination and thus the reactivity can be improved by various combinations and compositions and thereby the wettability can be improved creating a stron interface inside the matrix. As there are too many interdependent parameters involved, a simple composition replacement is not the only option. Such kind of complex
situations were described by many authors in the recent past where they have investigated the addition of silicon carbide, graphite and boron carbide reinforced Aluminium Metal Matrix Composites (Al-MMCs) (Van suchetclan 1972, Thomas et al. 1991, Sukumaran et al. 2008, Aydin et al. 2010, Yadav & Bauri 2011). Hence the chemical stability and physical suitability is an important factor while preparing the composites for better improved properties.

2.3 PARTICULATE REINFORCED CERAMIC COMPOSITES

Many physical parameters such as working temperature and mechanical strength can be improved by the reinforced of particulate in the ceramic composites. Thereby the stiffness can be improved and in addition the density of the composites can be reduced to achieve light weight composites which are the main goal for the reinforcement. Hence fabrication methods not only reduces the usage of raw material but the reinforcement bring more chemical stability to the matrix and thus the selection of compounds for metal matrix leads to economic viability to end users at lower cost with best of the quality.

While the proper choices of reinforcement are required for the effective fabrication of the raw materials for composites, the following main criteria can be considered as major contributors.

- Particle impurities such as Na, Ca and Si for reinforcement of sapphire
- Shape of the fiber in which whiskers, irregular or regular spherical shaped or chopped fibers
- Surface morphology for which rough or corrugated or smooth
• Polycrystalline or single crystalline
• Inherent natural properties of elastic modulus, density and strength
• Aspect ratio which depends on the diameter of the particulate size
• Structural defects which results in discontinuity due to voids, etc
• Surface modifications due to the addition of compounds such as C or SiO$_2$ films such as SiC or other such residual films

There were many types of particle reinforcements available for the composites, while most of them involve ceramic particulates for effective fabrication (Wert 2003, Fernandez & Murr 2004, Minak et al. 2010). Out of the above listed variables, the change in compositions may vary the chemical and physical nature due to the contradiction characteristics of the particular type of particles which acts as foreign body in the host matrix which inturn affects the processing equipments and hence care should be taken for the choice of particulates (Marzoli et al. 2002, Nakata et al. 2003).

Many mechanical frictional parts shoots to higher temperature during frictional motion and hence high degree of withstanding capacity without any physical deformation is required. For these type of exceptional high temperature requirements, graphite reinforcements were generally used in the metal matrix to improve the good damping behaviour with good mechanical properties at higher temperatures (Mahoney et al. 1964). Eventhough these types of graphite based composites can be used at higher temperatures, the wettability of aluminium is created due to the cavitation effects in the materials and thus oxidation should be avoided during the
reinforcement of composites (Taya & Arsenault 1989, Sarsilmaz & Caydas 2009). There were many reinforcements that were widely investigated by many researchers in the past of which TiC, SiC, B4C, TiB₂, Si₃N₄ and Al₂O₃ shows noticeable effects in the specific stiffness (Zedalis et al. 1991).

Apart from these types of materials, titania (TiO₂) or widely known as titanium oxide is widely used reinforcement particles in the aluminium matrix. These reinforcements significantly improve the tensile strength and hardness of the aluminium metal matrix composites (Al-MMCs). It also improves the wear resistance and thereby the loss of materials on the surface of the components is greatly reduced. The reinforcements of mica, SiC, zircon, clay and graphite were earlier reported by Deonath & Rohatgi (1980)). Reports were also there for other reinforcements of oxides, borides and carbides were to be mentioned in particular. Figure 2.1 shows the specific strength vs Specific modulus for various reinforcement materials for potential applications in aerospace industries.

![Figure 2.1 Specific strength vs Specific modulus for various reinforcement materials for potential applications in aerospace industries](image)

Figure 2.1 Specific strength vs Specific modulus for various reinforcement materials for potential applications in aerospace industries
In general the reinforcement of ceramic in the aluminium alloy was primarily to improve the mechanical and its thermal stability. These reinforcements can generally be classified into continuous and discontinuous which represents the reinforcement materials in the metal matrix. Generally the fibers reinforced are continuous and those discontinuities can further be termed as amorphous type of reinforcements. These are widely categorized again as short range fibers (also called as chopped fibers), continuous fibers, whiskers, particulate or wire type reinforcements. Ceramics such as carbides, nitrides and oxides are used as reinforcements with that of wires which gives high stiffness and strength both at room temperature as well as higher elevated temperatures (Zedalis et al. 1991).

The mechanical properties with the varied silicon carbide (SiC) reinforcements with various compositions of 5, 10 and 15 weight percentages was reported by Tamer Ozben et al. (2008). They reported on the hardness and impact toughness which is the primary requirement for mechanical testing with respect to the cutting speed and feed rate. They also reported on the surface roughness and also on the tool wear characteristics to assess the resultant factors. The increase in SiC of upto 10 % increased the hardness and impact toughness but showed a inclined tensile strength which is further reduced by the addition of SiC content to 15 %. Whereas, the wear resistance is increased by the increase in the SiC particulate reinforced aluminium metal matrix composites (Al-MMCs). These advantages proved very much helpful to the fabrication of components while the production is carried out at the very large scale (Lloyd 1990).

2.3.1 Applications of Al-MMCs

There were variety of applications that require various reinforced metal matrix composites. Some of the fiber reinforcement in the metal matrix
is given in Table 2.2. Depending on the composites, they were widely used in structural and in various mechanical applications.

Table 2.2 Various fiber reinforcement and metal matrix and their corresponding applications

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Matrix</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphite</td>
<td>Aluminium</td>
<td>Satellite, missile, and helicopter structures</td>
</tr>
<tr>
<td></td>
<td>Magnesium</td>
<td>Space and satellite structures</td>
</tr>
<tr>
<td></td>
<td>Lead</td>
<td>Storage-battery plates</td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>Electrical contacts and bearings</td>
</tr>
<tr>
<td>Boron</td>
<td>Aluminium</td>
<td>Compressor blades and structural supports</td>
</tr>
<tr>
<td></td>
<td>Magnesium</td>
<td>Antenna structures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jet-engine fan blades</td>
</tr>
<tr>
<td>Alumina</td>
<td>Aluminium</td>
<td>Superconductors restraints in fission power reactors</td>
</tr>
<tr>
<td></td>
<td>Lead</td>
<td>Storage-battery plates</td>
</tr>
<tr>
<td></td>
<td>Magnesium</td>
<td>Helicopter transmission structures</td>
</tr>
<tr>
<td>Silicon carbide</td>
<td>Aluminium, titaniu</td>
<td>High temperature structures</td>
</tr>
<tr>
<td></td>
<td>Supealloy (cobalt-base)</td>
<td>High temperature engine components</td>
</tr>
<tr>
<td>Molybdenum, tungsten</td>
<td>Superalloy</td>
<td>High temperature engine components</td>
</tr>
</tbody>
</table>
2.3.2 Manufacturing of Composite Materials

Composites are manufactured by two process widely viz., the process involving metals at the molten level and the powder metallurgy process (PM). In the molten processing of metals, they were heated to the melting point and that the ceramics such as alumina is mixed with the molten metal to form ceramic reinforcement in the metal matrix layer. Even though this process can be carried out, there is a limitation that the mixing of alumina in the presence of certain metals leads to the formation of unwanted compositions such as aluminium – magnesium reaction to form unstable $\text{Al}_2\text{MgO}_4$ compound. Hence care must be taken to avoid these unstable phases. In the molten process, the efficiency and reliability can be achieved by compatible formation mechanism and that it can be carried out even in very large scale.

The mechanical performance of the composites depends on the reinforcement particulates and also on the metal matrix constituents and hence care should be taken while mixing the reinforcement particulate with the metal matrix. The chemical properties of both these materials results in better matrix with working temperature and also reduces the processing and fabricating time. The volume fraction to achieve better strength of the composites during reinforcement can be seen with the comparison of unreinforced MMCs which in turn reduces the mechanical characteristics of Al-MMCs which was reported earlier (Friend 1987). The key factor that governs the strength the composites is the residual MMCs which decreases the volume percentage with increase in the content and this can leads to the ineffective load transfer to the reinforcement particles from the metal matrix composites.
2.3.3 Effect of Particle Size

The effect of particle sizes was reported by many researchers in the recent past of which the significant alteration in the deformation and fracture mechanism of the composites was also one (Friend 1987). The increase in the yield strength and Ultimate Tensile Strength (UTS) was reported with the reduction in the particle size by Lewandowski et al. (1991). The effect of particle size greatly influences the fracture toughness and stability of the composites failing with which results in crack behaviour on the surfaces. To obtain effective stiffness for the composite system, smaller fine reinforced particles were widely used to improve the fracture toughness.

2.3.4 Effect of Reinforced Particle Distribution in MMCs

The ductility of metal matrix composites (MMCs) and fracture toughness are influenced by the distribution of the particles which are used as reinforcements in the metal matrix and thus the mechanical properties can be controlled by these factors. The strength is also determined by the particle distribution in the matrix. Hence to have a proper load sharing capacity of the MMCs, the reinforcement is to be maintained uniformly throughout the matrix to obtain desired physical characteristics (Lewandowski et al. 1991).

There will be clusters formation due to the particulate in the processing of composites if non-homogenous distribution of the particles is done during the reinforcement which could results in undesired characteristics in the final product. This could reduce the fracture toughness, ductility and lesser strength in the resultant final composite product. MMCs finds numerous applications in automobile, aerospace, construction and in transportation industries. These applications require good thermal stability, high structural efficiency, electrical conductivity and wear resistance nature
which could be provided by the proper reinforcement of the particulate in the metal matrix (McKimpson & Scott 1989).

### 2.3.5 Economic viability

The raw materials used for the particle reinforcement should be readily available in all the required quantities and sizes for the production of various grades in various chemical combinations and compositions. This is the main aspects during the production stage which could easily reduce the cost of production during demand and supply which in turn could reduce the fabrication cost and thereby the end users can benefit from this reduced cost.

### 2.4 FABRICATION OF ALUMINIUM METAL MATRIX COMPOSITES (AL-MMCs)

The aluminium not only possesses the advantage of light weight metal matrix composites, but it has an advantage of the ability to recycle during the primary extraction process as well as production process. However, certain factors also affect the performance of the recycled raw materials for Al-MMCs such as the impurity effect affect the mechanical as well as metallurgical nature of the composites. By the proper choice of particle constituents and fabrication techniques, this problem can be avoided and thereby the undesirable secondary phases or unstable intermediate phases can be avoided (Lloyd 1990, Allison & Cole 1993, Eliasson & Sandstorm 1995).

For mechanical and automobile applications traditional metal and alloys were used in the past which in recent years has been replaced by the metal matrix composites due to its exceptional performance. There were several fabrication methods which reduces the cost of production of the MMCs which can result in the production of different composites with different dimensions. Depending on the physical and chemical nature of the
reinforcement material and the matrix, the fabrication technique can be varied. Few such methods include squeeze casting, stir casting, powder metallurgy, diffusion bonding, vapour deposition method, roll bonding and spray deposition methods to be mentioned. From the above mentioned methods, stir casting is widely used for its economical viability and also in the easiness of material handling for the production of base materials. Hence a detailed view on stir casting is focussed in this chapter to highlight the need and methods adopted in the present investigation.

2.4.1 Stir Casting

Powder metallurgy is a process in which the parent materials as taken in the solid form and mixed for longer durations and then heat treated to obtain the required compositions. The main disadvantage of this solid state fabrication process is that it takes longer time and very less efficient to obtain the raw material (Kenney & Courtois 1998). Hence the process of liquification (ie., melting) can be done and that the reinforcement can be added to the molten metals or alloys so that the effective reinforcement can be done with the ceramics. While doing so, the liquid state is stirred to obtain homogeneity and that the agitation helps us to obtain homogeneous reinforcement throughout the matrix. The wettability is achieved during the solidification process and thus the stir casting method can be used to fabricate the high tolerance band type of composites which can improve the production time for longer life of the die materials (Witulski et al. 1996).

Traditional found methods are also widely used for the fabrication of metal matrix composites (Gupta et al. 1991). Poor distribution of randomly oriented reinforcement particles leads to the sedimentation of the particle in the matrix which leads to the poor fabrication of the components (Surappa & Rohatgi 1981). For the synthesis of MMCs (Lin et al. 1995), stir casting is primarily used for its low production cost however for higher dense
composites lot of technical aspects needs to be considered before going for large scale production.

The process of external mechanical stirring which is preferably friction stir welding process can be effectively used to improve the process for MMCs. The use of such stirring can help the particles to reinforce uniformly inside the melt of the matrix. The distribution of particles, stirring speed, stirrer position and geometry and temperature of the melt can influence the homogenous distribution of particle in the matrix. Such kind of optimization process for MMCs were also reported by many authors and they are available in the literature. But there were only few reports on the reinforcement particulate distribution time for these MMCs. Due to the non transparency in the furnace, it is practically difficult for the effect of time on the tool stirring action due the high temperature of MMCs which exists as molten metal form. Hence in the present research focus, a software is used for simulating the particle flow and for the stirring action on the molten fluid and its effect.

2.5 Al-MMC’s AND THE WELDING PROCESS

2.5.1 Classification of Welding Processes

There were several methods reported in the literature for the joining of composites of aluminium metal matrix composites (Al-MMCs) and the problems associated with it. These welding processes can be divided in to the following three main groups as follows (Composite Materials Handbook 1999):

- Solid state welding processes
- Fusion welding processes
- Other welding processes
2.5.2 Fusion Processes

For the particulate reinforced MMCs, fusion welding process is most suited and the problems associated with it can be given as below:

- Chemical reactivity between reinforcement particulates and the matrix
- Molten pool shows an increased viscosity
- Evolution of gases
- Solidification effects occurs during segregation and segmentation process.

While the mixing of particulate is carried out, care should be taken that the viscosity is kept at the minimum for the uniform distribution of the particulate. Highly viscous nature could lead to improper mixing of silicon content (or in general ceramic content) inside the aluminium matrix and thereby coagulation can occur on the raw materials which could lead to mechanical failure of the fabricated components (Ellis 1996).

In aluminium metal matrix composites (Al-MMCs), during the solidification process, the segregation takes place due to the clusters reinforcements in the parent material and these unreinforced regions creates cracks during welding process. The magnesium (Mg) wires can be used as fillers in the alumina reinforced Al-Mg alloy composites which reduces the density of the Al-MMCs. The chemical reaction temperature between the reinforcement and the matrix is increased by the addition of Mg which in turn worsens the reaction temperature (Ellis 1996). The component becomes more brittle and it is prone to corrosion if the SiC content is increased beyond certain lime due to the formation of $\text{Al}_4\text{C}_3$ and silicon clusters. Hence to
control the process parameters of welding, care should be taken for the control of reinforcements of the ceramics in the MMCs.

For the aluminium based metal matrix (Al-MMCS) or in general MMCs the evolution of gases is used for the fusion welding process. The cracks in the weld joints occur due to the discontinuity which results in the entrapment of the gases in the Heat Affected Zone (HAZ) during welding process. To avoid this effect degassing technique is widely used during the welding of composites (Ellis 1996).

The welding process for aluminium based MMCs that could be carried out are listed as below:

- Laser Beam Welding (LBW) process
- Capacitor Discharge (CD) welding process
- Gas Tungsten Arc Welding (GTAW) process
- Electron Beam Welding (EBW) process
- Gas Metal Arc Welding (GMAW) process

2.5.2.1 GTAW process

In the Gas Tungsten Arc Welding (GTAW) process, the non-consumable tungsten electrode and the work specimen is maintained with an electric arc. The contamination is avoided by maintaining a shielding gas which usually protects the molten pool when the electric arc is applied. In these types of GTAW, very low voltage is required and these are generally used for welding Metal Matrix Composites (MMCs) and aluminium alloys. Silicon rich wire are used as fillers for the welding of Alumina (Al₂O₃) reinforced Al-MMCS. There is a possible formation of fragmentation and dissolution of the matrix can occur if the weldment area is not used with
fillers and this can overheat the boron particles due to which these anomalies can occur. The commercially available ER4043 is used as fillers which was reported by Kennedy & Courtois (1998). The process of Direct Current Electrode Positive (DCEP) and Direct Current Electrode Negative (DCEN) are the two configuration process which are widely used for GTAW.

There are two halves involved in the AC-GTAW process, while the first half is used to eliminate the surface contaminants and other half cycle is used to melt the base metal. The weld can be controlled by controlling three basic parameters viz., (1) welding speed, (2) welding current and (3) welding position which are discussed in detail below:

i) Welding speed

To obtain good quality weld of the MMCs, care should be taken that the welding speed is to be optimized and that while control of input heat supplied to the weldment in the weld region is to be carefully monitored. General problems like porosity, undercut and magnetic distortions can occur when the weld is supplied with excess heat and high speed. Hence deeper penetration of weld can be done with wider area when the welding speed is maintained at lower level.

ii) Welding current

In the welding by arc process the supply of welding current significantly influences the weld area. The current supplied directly influences the rate of melting of wire which is used as filler and hence excess welding current can create distortions in weld joints and hence it is necessary to maintain lower currents for effective fusion and proper penetration. As aluminium alloys possess higher thermal conductivity, the supplied welding current should be higher than this value to obtain uniform melt. The rate of
loss of heat also depends on this thermal conductivity factor for which it is faster than most of these metals.

iii) **Welding position**

For proper metal deposition on the surfaces of the weld area flat position is preferred in which solidification allows slow rate of trapping of gases on the weld pool. The porosity of the weld region is thus reduced in the flat weld position. Inclination of rods in 45°- 75° angles for vertical-horizontal positions of weld allows the weld area to possess lesser defects. Generally pure tungsten or its alloys with thoria or zirconia are used as welding electrodes for aluminium based metal matrix composites (Al-MMCs).

### 2.5.2.2 GMAW process

Gas Metal Arc Welding (GMAW) is also known as MIG (Metal Inert Gas) welding which is generally used for deposition at high rate during the welding process. GMAW is also known as a semiautomatic welding process in which the wire is supplied continuously to the spool. The automation for higher welding speed is possible for various consumable electrodes. The schematic representation of Gas Metal Arc Welding (GMAW) is shown in Figure 2.2. When compared with the gas tungsten arc welding (GTAW) process, GMAW is more adaptable and feasible method for the welding and joining of boron carbide and silicon carbide reinforced Al6061 type of MMCs. But in both the cases, the filler wires are used for B₄C reinforced Al6060 type of composites. The earlier reports suggest that GMAW is more suitable for these type of composites in which exceptional quality of welding of the products was obtained with lesser defects at the joining of the Al-MMCs (Composite Materials Handbook 1999).
2.5.2.3 EBW process

Electron Beam Welding (EBW) is a welding process in which high beam of energy electrons impinges on the weld area to heat it so that the weld joint are bonded together. Figure 2.3 shows the EBW process in which the electrons are generated by high voltage cathode grid. The produced electrons are then guided by electron stream and magnetic lens which is then deflected by the coils and thus the electrons falls on the workpiece in the vacuum chamber. Electron beam generates power density in the range 100 to 200 W/cm² and that the electrons are raised to a high energy state by accelerating them to roughly 30 to 70 percent of the speed of light due to which heat is produced at the weldment areas. In the case of SiC reinforced composites, these EBW are much effective than compared with other process also (Lienert et al. 1993).
The electron beam is always generated in a high vacuum. The use of specially designed orifices separating a series of chambers at various levels of vacuum permits welding in medium and nonvacuum conditions. Although, high vacuum welding will provide maximum purity and high depth to width ratio welds.

**EBW Benefits**

- Low distortion
- Single pass welding of thick joints
- Low contamination in vacuum
- Heat affected zone is narrow
- Hermetic seals of components retaining a vacuum
- Weld zone is narrow
- Uses no filler metal
- Dissimilar metal welds of some metals
EBW Limitations

- Rapid solidification rates can cause cracking in some materials
- Time delay when welding in vacuum
- High weld preparation costs
- Work chamber size constraints
- High equipment cost
- X-rays produced during welding

2.5.2.4 LBW process

In these types of Laser Beam Welding (LBW) process, laser beams of power density of 106 W/cm² focuses with lenses on the work piece materials. Hence the surface of the layer on which the laser falls get heated much above the melting point and thereby cooling induces welding at the joints. The intensity of laser beam required differs with material to material which mainly depends on the melting point of the composite or the corresponding alloys used. Narrow and deep grooves of weldments can be obtained by these LBW process (Wang et al. 2000). The brittle nature of SiC reinforced Al-MMC’s can effectively welded by this process in which the primary silicon and intermetallic compounds like Al-Si eutectic formation can be primarily avoided due to the excess Heat Affected Zone (HAZ). However, the intermetallic formation of Al₄C₃ cannot be avoided in some cases and this is the limitation of these laser based system where controlling of heat is very much difficult. The addition of titanium can reduce the formation of these secondary phases during welding process as titanium has more affinity towards carbide (Meinert et al. 1992).
There were literature reports on the Laser Beam Welding (LBW) process and Electron Beam Welding (EBW) process of SiC reinforced aluminium metal matrix composites which is shown in Figure 2.4(a) and Figure 2.4(b) respectively for similar powder of 3.0 kW with specification of 8.5 cm/s. The sharp focus of the image shows that for LBW, there are grains...
or needle type of morphology at the surface due to excess heating whereas in case of electrons it is homogeneous for SiC reinforced Al-MMCs (Lienert et al. 1993).

### 2.5.2.5 Capacitor discharge (CD) welding process

Figure 2.5 represents the schematic representation of Capacitor Discharge (CD) welding process in which the phenomena of resistance welding process is adopted for hybrid type of materials. In this process a series of capacitor is connected parallel to the welding system (resistance) and when the discharges of high energy pulses are supplied in short duration of time of the order of 2 – 20 ms to the weld region. The short duration supply of pulses by capacitors helps the weld areas to obtain uniform weld and thereby the unwanted secondary phases formation can be avoided. When compared with the LBW and EBW process, these CD welding process produces better weld joints and it was reported by earlier authors also (Composite Materials Handbook 1999).

![Figure 2.5 Schematic representation of Capacitor discharge (CD) welding process](image_url)
Advantages of CD welding process

- Attractive appearance with minimal burn and possess better strength in lightweight applications
- Minimal backside marking in which without damage it can be repainted
- Fast process with extremely short weld time and fewer assembly steps are involved thereby possessing the economic advantages of labour saving

2.5.3 Diffusion bonding (DB) process

In this process of Diffusion Bonding (DB), for longer durations the two work pieces are welded at higher temperatures and in particular for surface welding process of temperatures in the 400 - 650°C these process can be used for Al-based materials.

![Figure 2.6 Schematic representation of Capacitor discharge (CD) welding process](image-url)
The main criteria is that the sample work-piece should be under protective layer and that it also depends on the thickness of the sample. For thermal applications such as pipes, heat exchangers and radiators, these diffusion bonding is applied also (Composite Materials Handbook 1999). Figure 2.6 represents the diffusion bonding animation for which longer duration of time is applied for welding of joints.

Muratoglu et al. (2006) Mechanical and metallurgical properties of weldments of diffusion bonding of silicon carbide reinforced pure aluminium are investigated by The authors found that accumulation of SiC particles decreased at the interface after artificial ageing.

The major advantages of this process are that for parent material, the mechanical and physical properties are not altered.

This process produces clean joint which is free from interface discontinuity and porosity and both similar and dissimilar material can be joint by diffusion bonding process.

It provides good dimension tolerance to make precision components at low cost.

It is simple in working and it does not use filler material, flux etc. which are used in arc welding process.