Fabrication of Al7075 Metal Matrix Composite Through Stir Casting Method - A Review

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Abstract:- **Aluminium alloys are widely used in aerospace and automobile industries due to their low density and good mechanical properties, better corrosion resistance and wear, low thermal coefficient of expansion as compared to conventional metals and alloys. The excellent mechanical properties of these materials and relatively low production cost make them a very attractive candidate for a variety of applications both from scientific and technological viewpoints. The aim involved in designing metal composite materials is to combine the desirable attributes of metals and ceramics.Present work is focused on the study of behavior of Aluminium alloy (Al 7075) with SiC and TiB_2 composite produced by the stir casting technique. Al7075 alloy is taken as base material and then it is reinforced with silicon carbide (SiC) and titanium di- boride (TiB_2). Different weight % of TiB_2 reinforcement is used by keeping standard weight % of SiC. After preparation of suitable samples, tensile test and hardness test were performed and results were analyzed. At last, a comparison is made between the mechanical properties of base aluminium alloy and the prepared aluminium metal matrix composites.**

INTRODUCTION

OVERVIEW OF COMPOSITES:

People have been making composites for many thousands of years. One early example is mud bricks. Mud can be dried out into a brick shape to give a building material. It is strong if you try to squash it (it has good compressive strength) but it breaks quite easily if you try to bend it (it has poor tensile strength). Straw seems very strong if you try to stretch it, but you can crumple it up easily. By mixing mud and straw together it is possible to make bricks that are resistant to both squeezing and tearing and make excellent building blocks. Another ancient composite is concrete. Concrete is a mix of aggregate (small stones or gravel), cement and sand. It has good compressive strength (it resists squashing). In more recent times it has been found that adding metal rods or wires to the concrete can increase its tensile (bending) strength. Concrete containing such rods or wires is called reinforced concrete.

Industrial technology is growing at very rapid rate and there is increasing need of materials. Conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness and density. To overcome these shortcomings and to meet the always increasing demand of modern day technology, composites are most promising materials. Composite materials are those formed by combining two or more materials on a macroscopic scale to form useful third material that results in better properties than those of the individual components used alone. Generally a composite material can be defined as a combination of a matrix and a reinforcement, which when combined gives properties superior to the properties of the individual components. The matrix and reinforcements work together to give the composite unique properties. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties.

The first modern composite material was fibreglass. It is still widely used today for boat hulls, sports equipment, building panels and many car bodies. The matrix is a plastic and the reinforcement is glass that has been made into fine threads and often woven into a sort of cloth. On its own, the glass is very strong but brittle and it will break if bent sharply. The plastic matrix holds the glass fibres together and also protects them from damage by sharing out the forces acting on them. Some advanced composites are now made using carbon fibres instead of glass. These materials are lighter and stronger than fibreglass but more expensive to produce. They are used in aircraft structures and expensive sports equipment such as golf clubs.

The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. The industrial need of good materials with light weight, excellent properties and low cost demanded the scientists to research on composite materials.

CLASSIFICATION OF COMPOSITES:

Composites are classified based on the types of matrix and reinforcements. Matrix is the base material in the composite. Reinforcements are usually added to the matrix (base metal) to improve its properties like strength, stiffness, conductivity, wear and corrosive resistance etc. Reinforcements increase the properties of matrix by transferring the strength to the matrix constituent.

BASED ON THE TYPE OF MATRIX:

(i) Polymer matrix composites (PMCs): In PMCs, matrices are mostly cross-linked thermoset polymers (epoxy, polyester, phenolics). Glass fiber-reinforced thermoset polymers have high strength and stiffness to weight ratio, thus they are usually used in automotive components. Other matrices in PMCs include thermoplastic resins (PE, Nylon, PVC,).

(ii) Metal matrix composites (MMCs): In MMCs, light metals like aluminum, titanium and magnesium, and their alloys are usually used as matrices. Aluminum is most commonly used due to its excellent strength, toughness, and resistance to corrosion and abrasion.

(iii) Ceramics matrix composites (CMCs): In CMCs, silicon carbides are regularly used for both matrices and reinforcements. However, the silicon carbide reinforcements are of multiple forms to achieve preferred properties.

BASED ON THE TYPE OF REINFORCEMENT:

Depending on the types of reinforcements, composites are classified as (i) particle reinforced composites, (ii) short fiber composites (whisker), and (iii) continuous fiber composites (sheet). The materials for reinforcements can be organic fibers, metallic fibers, ceramic fibers, and particles.

(i) Particle reinforced composites: In particle reinforced composites, particles can be ceramics, glasses, metal, and/or amorphous materials. While the modulus of a composite is higher than that of its matrix, the permeability and ductility are lower. Therefore, particle reinforced composites can sustain higher tensile, compressive and shear stresses.

(i) Short fiber composites (whisker): Fiber reinforced composites consist of short fiber composites and continuous fiber composites. The modulus of a composite of this type is higher than that of a matrix because of the strong covalent bonds along the fiber length. The orientation of the fibers relative to one another has significant impact on the mechanical properties of the composite. These contain reinforcements with an aspect ratio of greater than 5, but are not continuous. These were produced by squeeze infiltration process. Whisker reinforced composites are produced by either by PM processing or by infiltration route. Mechanical properties of whisker reinforced composites are superior compared to particle or short fibre reinforced composites However, in the recent years usage of whiskers as reinforcements is fading due to perceived health hazards and, hence of late commercial exploitation of whisker reinforced composites has been very limited. Short fibre reinforced AMCs display characteristics in between that of continuous fibre and particle reinforced AMCs.

(ii) Continuous fiber composites (sheet): Here, the reinforcements are in the form of continuous fibres (of alumina, SiC or carbon) with a diameter less than 20 µm. The fibres can either be parallel or pre woven, braided prior to the production of the composite.

METAL MATRIX COMPOSITES (MMC):

Metal Matrix Composites is a combination of two or more components, i.e. matrix and reinforcing material. Usually, Metal matrix composites (MMCs) consist of a low-density metal, such as aluminum, magnesium, titanium, copper etc., reinforced with particulate or fibers of a ceramic material, such as silicon carbide or graphite.

The most important MMC systems are: Aluminum matrix

- ✓ Continuous fibers: boron, silicon carbide, alumina, graphite
- ✓ Discontinuous fibers: alumina, alumina-silica
- ✓ Whiskers: silicon carbide
- ✓ Particulates: silicon carbide, boron carbide Magnesium matrix
- ✓ Continuous fibers: graphite, alumina
- ✓ Whiskers: silicon carbide
- ✓ Particulates: silicon carbide, boron carbide Titanium matrix
- ✓ Continuous fibers: silicon carbide, coated boron
- ✓ Particulates: titanium carbide Copper matrix
- ✓ Continuous fibers: graphite, silicon carbide
- ✓ Wires: niobium-titanium, niobium-tin
- ✓ Particulates: silicon carbide, boron carbide, titanium carbide.

Superalloy matrices

- ✓ Wires: tungsten

Matrix is the monolithic material and continuous in nature in which diverse materials are embedded in it. Reinforcements are added to the matrix to improve its properties like hardness, strength, elongation, conductivity, corrosion resistance etc. Compared with unreinforced metals, MMCs offer higher specific strength and stiffness, higher operating temperature, and greater wear resistance, as well as the opportunity to tailor these properties for a particular application.

ALUMINIUM METAL MATRIX COMPOSITES (AMMC):

Aluminum matrix composites (AMMC) are materials in which the ductile metal matrix is reinforced by hard fibers or particulates. In Metal Matrix Composites (MMCs), aluminum and its alloys have attracted most attention as base metal because of its low density, low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity, etc. In AMMC, aluminium acts as the matrix phase and forms percolating network. These AMMCs offer a large variety of mechanical properties depending on the chemical composition of the Al-matrix.

Aluminium alloys, such as the 2000, 5000, 6000 and 7000 alloy series are the most commonly utilised materials in composite fabrication. Addition of various reinforcements such as fly ash, TiC, SiC, Al_2O_3, TiO_2, B_4C etc., to aluminum matrix will enhance the mechanical and tribological properties. In recent years, Al based composite materials have gained significance in aerospace, automotive and structural applications due to their enhanced mechanical properties and good stability at high temperature.

HYBRID METAL MATRIX COMPOSITES:

Hybrid metal matrix composites are current generation composites where more than one reinforcement of different shape and size are used to attain improved properties. Hybrid MMCs are made by dispersing two or more reinforcing materials into a metal matrix. Hybridization is commonly used for improving the properties and for lowering the cost of conventional composites. The applications of hybrid composites are in the field of aerospace industries and automobile engine parts like drive shafts, cylinders, pistons and brake rotors, consequently interests in studying structural components wear behaviour.

PROCESSING OF METAL MATRIX COMPOSITES:

Processing of metal matrix composites (MMC) can be classified into three main categories:

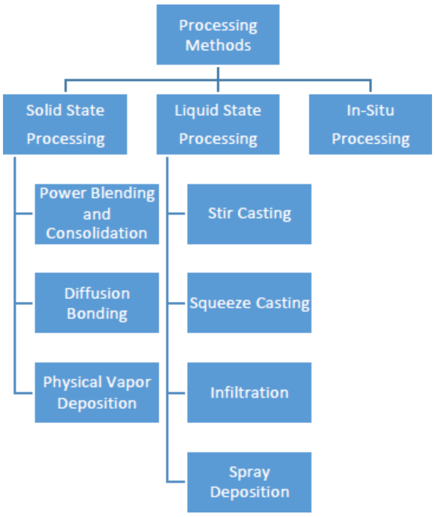

Figure MMC processing methods

1. Solid State Processing
2. Liquid State Processing
3. In-Situ Processing

1. Solid State Processing

The main fabrication methods for solid state processing of metal matrix composites are powder blending and consolidation, and physical vapor deposition.

a) Powder Blending and Consolidation:

Metal alloy powder is blended with ceramic whisker/short fiber/particles in dry condition or in liquid suspension. After blending, the mixture is further processed by cold compaction, canning, degassing, and high temperature consolidation. There are some oxide particles in volume fraction of 0.05-0.5 depending on the powder and processing conditions that help dispersion- strengthening of the metal matrix composites. This method is usually used for the processing of aluminum and magnesium metal matrix composites.

b) Diffusion Bonding:

The inter diffusion atoms at the metallic surfaces under pressure creates bonding between the metal matrix and fibers. This fabrication method is widely used for aluminum or magnesium MMCs reinforced with continuous/discontinuous fibers.

c) Physical Vapor Deposition:

Fibers are continuously passed through a region of high partial pressure of metal to be deposited. The vapor is produced and inserted in the process, then the condensation occurs at this region to produce a coating on the fiber. The rate of deposition is about 5-10 micrometer per minute. The coated fibers are then consolidated by hot pressing or hot isostatic pressing.

2. **Liquid State Processing:**

a) Stir Casting:

Particulate reinforcements are mixed with liquid metal melt and the mixture then solidifies. Specifically, the pre-treated particles are inserted into the vortex of molten alloy, which is created by a rotating impeller. A problem arises during the stir casting process as the reinforcements are not uniformly distributed and form sediments in the molten alloy. Generally, up to 30% particles in the size of 5-100 micrometer can be incorporated into the metal alloy. An example of this method is Al-(10-15%) B_4C MMCs. In another variant of the stir casting method, particles are introduced into the metal alloy in the semi-solid state.

b) Squeeze Casting:

Molten metal is introduced into an open die. The dies are then closed so that the molten metal solidifies under pressure within the dies. The heat is rapidly transferred from the molten metal to the dies under high pressure and through the contact between the metal and the die surface. As a result, a fine-grain casting with little to no pore is produced using this method.

c) Infiltration Process:

Liquid metal alloy is infiltrated into the porous forms of fibers/whiskers reinforcements. The volume fraction of the reinforcements usually ranges from 10- 70%, depending on the level of porosity. Silica and metal-based mixtures are often employed as binder to retain the integrity and shape of the porous forms.

d) Spray Deposition:

Particle/whisker/short fiber reinforcements are injected into the spray, creating a deposition layer of porosity of 5-10% on the metal surface. The depositions are then consolidated to full density by further processing. For continuous (long) fiber reinforced metal matrix composites, matrix metals are sprayed onto the fibers. The fiber spacing and fiber layer in this processing method impact the fiber volume fraction and distribution.

3. **In-Situ Processing:**

In-situ processing involves chemical reactions that result in the creation of reinforcing phase within a metal matrix.

The reinforcements can be formed from the precipitation in liquid or solid. This method provides thermodynamic compatibility at the matrix reinforcement interface. The reinforcement surfaces are also likely to be free of contamination and, therefore, a stronger matrix-dispersion bond can be achieved.

STIR CASTING ROUTE FOR FABRICATION OF MMC:

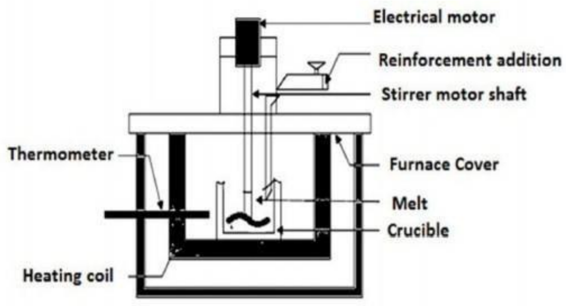

Figure: Stir casting Experimental set up

From all the processing routes, liquid metallurgy method is the most sought due to its several advantages such as cost-effective, mass production, near net shaped components can be produced. Therefore, only the casting method is to be considered as the most optimum and economical route for processing of aluminium composite materials. Among various casting process, Stir casting is considered to be most effective method. The stir casting methodology is relatively simple and low cost.

Stir casting set-up mainly consists a furnace and a stirring assembly. Stirrer is used to agitate the molten metal matrix. The stirrer is generally made up of a material which can withstand at a higher melting temperature than the matrix temperature. Generally graphite stirrer is used in stir casting. The stirrer is consisting of mainly two components cylindrical rod and impeller. The one end of rod is connected to impeller and other end is connected to shaft of the motor. The stirrer is generally held in vertical position and is rotated by a motor at various speeds.

In this method first the matrix metal is heated above its liquid temperature so that it is completely in molten state. After it is cooled down to temperature between liquid and solidus state means it is in a semi-solid state. Then preheated reinforcement particles are added to molten matrix and again heated to fully liquid state and are stirred thoroughly for a homogeneous mixture with the matrix alloy. In this method, the particles get accumulated often; the accumulated particles can be dissolved at higher temperature by vigorous stirring. The liquid composite materials is then poured into the sand/die casting mould and then allowed to solidify. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement. A major concern in associated with the stir casting is segregation of reinforcement particles due to various process parameters and material properties result in the non- homogeneous metal distribution.

STIR CASTING PROCESS PARAMETER:

Process parameters plays a vital role on properties of Al based MMC. In case of Stir casting, process parameters like stirring rate, stirring temperature, pouring temperature etc., are to be maintained for achieving better properties of MMC

- ✓ **Speed of rotation:** For successful production of casting, the control of speed is very important. Rotational speed also influences the structure; increase of speed promotes refinement and very low speed results in instability of the liquid mass. It is logical to use the highest speed to avoid tearing.
- ✓ **Stirring speed:** Stirring speed is one of the most important process parameters as wettability is promoted by stirring i.e. bonding between matrix & reinforcement. The flow pattern of the molten metal is directly controlled by the stirring speed. As solidifying rate is faster it will increase the percentage of wettability.
- ✓ **Stirring temperature:** The viscosity of Al matrix is influenced by the processing temperature. The particle distribution in the matrix is subjective to the change of viscosity. When processing temperature is increased along with increasing holding time of stirring, there is a decrease in the viscosity of liquid. There is also acceleration in the chemical reaction between matrix and reinforcement.
- ✓ **Stirring time**: Uniform distribution of the particles in the liquid and perfect interface bond between reinforcement and matrix is promoted by stirring. In the processing of composite, the stirring time between matrix and reinforcement is considered as important factor.
- ✓ **Pouring temperature:** A major role is played by the pouring temperature on the mode of solidification and determines relation partly to the required structure type. Low temperature is associated with maximum grain refinement and equiaxed structure while higher temperature promotes columnar growth in many alloys. However, the range is limited in practical scenarios. To ensure satisfactory metal flow and freedom from collapse whilst avoiding coarse structures, the pouring temperature must be sufficiently high.
- ✓ **Mould temperature**: Its principal signification lies in the degree of expansion of the die with preheating. The risk of tearing in casting is diminished by expansion. The mould temperature should neither be too low nor be too high, in non-ferrous casting. The mould should be at least 25 mm thick with the thickness increasing with size and weight of casting.
- ✓

ADVANTAGES OF ALUMINIUM BASED MMCS

The major advantages of AMCs compared to unreinforced materials are as follows:

- ✓ Greater strength
- ✓ Improved stiffness
- ✓ Reduced density(weight)

- ✓ Improved high temperature properties
- ✓ Controlled thermal expansion coefficient
- ✓ Thermal/heat management
- ✓ Enhanced and tailored electrical performance
- ✓ Improved abrasion and wear resistance
- ✓ Control of mass (especially in reciprocating applications)

LITERATURE SURVEY

This chapter presents a review of the literature data available on the effect of various reinforcement types, their size and volume fraction, ageing behaviour with AL based MMC's.

Dattatraya N et.al, presents a study on stir casing process and process parameter having Al alloy as a matrix phase and alumina (Al2O3) as a reinforcement. In their study, they have concluded the following points: (i) Stir casing process can successfully be used for manufacturing of AMMC's having low density and enhanced mechanical properties. 2) Stir casting process is cost effective and conventional route for manufacturing of composite material. 3) Material having isotropic nature can be manufactured successfully. 4) Preheating of mould reduces porosity and enhances mechanical properties. 5) Addition of Magnesium is important to increase wettability. 6) Design of stirrer decides the flow pattern of melt. 7) Stirrer speed, stirring time decides quality of casting. 8) Preheat temperature of mould, preheat temperature of reinforcement, reinforcement size, reinforcement feed rate and melt pouring rate are also the important parameters in stir casting method.

Manikandan.C, noticed in his experimental study, that the 12% of SiC and 450°C preheat temperature of the reinforcement improves the hardness and impact strength of the composite. At 6% of SiC , 200 rpm of stirrer speed and 500°C reinforcement pre heat temperature attains the improved level of tensile strength . The hardness and impact strength to values are directly proportional to the SiC composition rate. the minimal percentage of elongation is obtained in the 9% of SiC,
250 RPM and 500 °C pre heating temperature of reinforcement.

Hariharan.R et.al, carried out the research work by fabricating Al6061 – TiB_2 MMC by stir casting method. The addition of the TiB particles into Al-6061 is a good route to improve the mechanical properties of materials. The resulting composite showed the increase in tensile strength when compared to the unreinforced alloy. SEM and XRD analysis of the composite confirms the presence of TiB particle and its volume fraction. The increased volume fraction of the TiB particles contributed to increase the strength of composites. The dry sliding at room temperature shows that there is a definite increase in the wear resistance of Al6061 alloy by the addition of TiB2 particles.

Pradeep R et.al observed the study of mechanical properties of Al- Red Mud and Silicon Carbide Metal Matrix Composite (MMC) of Aluminium alloy of grade 7075 with addition of varying weight percentage composition such as SiC8%+Al7075, SiC6%+Red mud2%+ Al7075, SiC4%+Red mud 4%+Al7075,
SiC2%+Red mud 6%+Al7075, Red mud 8%+Al7075ed mud and Silicon Carbide particles by stir casting technique. The experimental result reveals that the combination of a matrix material with reinforcement such as SiC and Red mud particles, improves mechanical properties like tensile strength, compressive strength, hardness and yield strength. [4]

Ravichandran M et.al carried out the research work by fabricating aluminium metal matrix composites through liquid powder metallurgy route. The aluminium matrix composite containing TiO2 reinforcement particle was produced to study the mechanical properties such as tensile strength and hardness. The characterization studies are also carried out to evident the phase presence in the composite and the results are discussed for the reinforcement addition with the mechanical properties. Results show that, the addition of 5 weight percentage of TiO2to the pure aluminium improves the mechanical properties. [5]

H. Izadi et.al investigated through
FSP and has observed improvement in the micro hardness of Al–SiC composites produced by traditional powder metallurgy and sintering methods. The material flow in the stir zone during FSP was successful in uniformly distributing the SiC particles. However, when samples with 16% SiC (by volume) were processed, there were residual pores and lack of consolidation. An increase in hardness of all samples was observed after friction stir processing which was attributed to the improvement in particle distribution and elimination of porosity. [6]

Keshavamurthy R et.al studied about Al7075-TiB2 in-situ composite, processed by stir casting technique using commercially available Al-10%Ti and Al- 3%Br master alloys. Both matrix alloy and composite were subjected to microstructure analysis, micro hardness test, grain size studies and tensile test. Microstructure shows fairly uniform distribution of TiB2 particles in matrix alloy. Average grain size of the composite was lower than unreinforced alloy. Micro hardness, yield strength and ultimate tensile strength of Al7075-TiB2 composite, were considerably higher when compared with unreinforced alloy..

Uvaraja et.al observed that Hybridization is commonly used for improving the properties and for lowering the cost of conventional composites. Hybrid MMCs are made by dispersing two or more reinforcing materials into a metal matrix. They have received considerable research and trials by Toyota Motor Inc., in the early 1980s. Hybrid metal matrix composites are a relatively new class of materials characterized by lighter weight, greater strength, high wear resistance, good fatigue properties and dimensional stability at elevated temperatures than those of conventional composites. Due to such attractive properties coupled with the ability to operate at high temperatures, the Al matrix composite reinforced with SiC and B4C particulate are a new range of advanced materials. It was found that applications of hybrid composites in aerospace industries and automobile engine parts like drive shafts, cylinders, pistons and brake rotors, consequently interests in studying structural components wear behavior.

Anand Kumar et.al research work carried out by Addition of reinforcement such as TiC, SiC, Al2O3, TiO2, TiN, etc. to Aluminium matrix for enhancing the mechanical properties has been a well– established fact. In-situ method of reinforcement of the Aluminium matrix with ceramic phase like Titanium Carbide (TiC) is well preferred over the Ex–situ method. In the present investigation, Al- Cu alloy (series of 2014 Aluminium alloy) was used as matrix and reinforced with TiC using In-situ process. The Metal Matrix Composite (MMC) material, Al-.5%Cu/10%TiC developed exhibits higher yield strength, ultimate strength and hardness as compared to Al-4.5%Cu alloy. Percentage increase in yield and ultimate tensile strengths were reported to be about 15% and 24% respectively whereas Vickers hardness increased by about 35%. The higher values in hardness indicated that the TiC particles contributed to the increase of hardness of matrix.

CHEMICAL COMPOSITION OF AL7075

Among several series of aluminium alloys, Al7075 alloy are highly corrosion resistant, exhibits moderate strength and finds much applications in the fields of construction, automotive and marine applications. In the present work, Aluminium 7075 alloy with the theoretical density 2.81 g/cm^3 was selected as matrix materials. The chemical composition of Al 7075 alloy is given in

Typical chemical composition for Aluminium alloy 7075

Ele men ts	M n	C r	F e	C u	S i	M g	Z n	T i	Al
(wt %)	0. 3	0. 2 8	0 . 5	2 . 0	0 . 4	2 . 9	6 . 1	0 . 2	Bal anc e

Properties for aluminium alloy 7075

Density	2.81 g/cm^3
Hardness, Brinell	150 GPa
Ultimate Tensile Strength	572 MPa
Tensile Yield Strength	503MPa
Elongation at Break	11%
Modulus of Elasticity	71.7 GPa
Poisson's Ratio	0.33
Shear Strength	331 MPa
Shear Modulus	26.9 GPa
Melting Point Temperature	477 – 635^0 C

the severest conditions this property can be further enhanced by anodic treatment.

ANODISING

7075 can be anodised by any of the common processes, the resulting protective film ranging in color from grey to dark brown.

APPLICATIONS

Typical applications for aluminium alloy 7075 include: Aircraft and aerospace components, Marine fittings, Transport, Bicycle frames, Camera lenses, Drive shafts, Electrical fittings and connectors, Brake components, Valves, Couplings

MACHINABILITY

Alloys of this and similar compositions are rather difficult to machine. This is due firstly to their tendency to drag and secondly to the rapid tool wear caused by the high zinc content. Carbide tipped tools with large rake angles and relatively low cutting speeds give comparatively good results. A cutting lubricant and coolant should be employed.

CORROSION RESISTANCE

7075 exhibits excellent resistance to corrosion under both ordinary atmospheric and marine conditions. For The ductility of 7075 enables castings to be rectified easily or even modified in shape, e.g. simple components may be cast straight and later bent to the required contour.

CONCLUSION

Now a days challenges in the fabrication of metal matrix composite are growing vigorously. In this paper the method for the manufacturing of AL7075 by various research are discussed from this. It was founded, the casting of such alloys are now tp be easyer under the optimized varyig process parameter.

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