Connecting Rod Made Using Particulate Reinforced Aluminum Metal Matrix Composite - A Review

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***Abstract*: The connecting rod is bridge between the crankshaft and piston in reciprocating engine, which is used to convert linear motion into rotary motion and vice-versa. The automobile engine connecting rod is a high volume production, critical component, hence most of the work and study is carried out to redesign a connecting rod with aim to achieve for its light weight and to bear all the various forces and loads during operation and finally enhancing manufacturing feasibility and cost reduction too. In high speed engines I-section or H-section or Tabular section is used which reduces the weight and helps to achieve lightness. The Lightness of the rod help in keeping the inertia forces as small as possible, hence Aluminum is used. And reinforcement is done in order to get improved mechanical and tribological properties like strength, stiffness, abrasion, impact resistance and wear resistance using particulates of oxides or carbides or borides such as Al_2O_3, TiB_2, TiO_2,SiC,TiC, B_4C,etc are done in combination i.e, to achieve hybrid composite or any single entity as required. The stir casting process is commonly used for Aluminum Metal Matrix Composites (AMMCs) with Particulate reinforcement which has low production cost, easier and helps best in achieving uniform distribution of Particulates in the Matrix. This paper guides towards proper selection of reinforcement to be added into AMMC material, with suitable, economical and feasible manufacturing process in designing and production of connecting rods.**

***Index Terms*: Connecting Rod, Reinforcement, Particulate, Metal Matrix Composite.**

I. INTRODUCTION

Connecting rod is among large volume production component in the internal combustion engine, which connects the piston to the crankshaft and is responsible for transferring power from the piston to the crankshaft and sending it in to transmission. Hence, these rods must have lowest weight to achieve the highest possible rigidity. There are different materials and manufacturing process used in the production of connecting rods. During operation the combination of axial and bending stresses are induced in the connecting rod. The cylinder gas pressure produces the axial stresses which is compressive in nature and the inertia force arising in account of reciprocating action which includes both tensile and compressive force, whereas the centrifugal effects cause the bending stresses. The con rod consists of a long shank, a small end and a big end. The cross-section of the shank may be I-section, rectangular, circular, tubular or H-section. Generally I-section is preferred for high speed engines which provide the maximum rigidity with minimum weight and circular section is used for low speed engines. The manufacturing processes used are casting, forging, and powdered metallurgy. Now a days the particulate reinforced Aluminum matrix composite are going importance because of low processing cost, having isotropic properties and chances of secondary processing.

C. Saravanan *et.al* Studied the combined effect of reinforcements on Aluminum Metal Matrix composites with individual and multiple particulate reinforcements like Hybrid Metal matrix composites, which are finding increased applications in automobile, aerospace and transportation applications. This is mainly due to improved mechanical and tribological properties like strength, impact resistance, stiffness, abrasion and wear resistance [1].

Arun L.R *et.al* Comparative study was carried out on connecting rod by replacing the existing material with aluminum based composite material reinforced with fly ash and silicon carbide. Weight can be reduced and strength can be achieved by changing the material of the current connecting rod to hybrid composites. Finally obtaining the new optimized connecting rod which is comparatively much stiffer than the former [2].

G.M Sayeed Ahmed *et.al* Connecting rod made of forged steel is replaced with Aluminum alloys and Carbon Fiber. The materials are changed so that the weight of the connecting rod is less when aluminum alloys and carbon fiber are used by replacing Forged Steel. Analysis is done on the connecting rod using materials AA6061, AA7075, AA2014 and carbon fiber 280 GSM bidirectional. By observing the analysis results the stress obtained are very much less than their yield strength values [3].

Vivek C. Pathade *et.al* The major stress induced in the connecting rod is a combination of axial and bending stresses in operation. The axial stresses are produced due to cylinder gas pressure (compressive only) and the inertia force arising in account of reciprocating action (both tensile as well as compressive), whereas bending stresses are caused due to the centrifugal effects. The stresses induced in the small end of the connecting rod are greater than the stresses induced at the big end. Therefore, the chances of failure of the connecting rod may be at fillet section of both ends [4].

Vinithra Banu *et.al* Investigated the connecting rod made of Carbon steel. The modeling and analysis of connecting rod is carried out by replaceing Carbon steel with Aluminum reinforced Boron Silicide. A parametric model of connecting rod is modeled using CATIA V5. Analysis is carried out by using ANSYS Workbench software. When compared both materials the better results were obtained with parameters like Von misses stress and strain, deformation and weight reduction of con rod is obtained [13].

Generally there are few common materials like Aluminum, Steel alloy and Titanium which are used in manufacturing of connecting rods. Aluminum and Titanium are used in high performance engines. To reach various specifications required the manufacturing and heat treatment is done. The combination of materials like Al and Ti is done with reinforcing with hard materials like B4C, SiC, Al2O3, Graphite particulates, etc. In obtaining the performance engine, great attention should be paid on connecting rods, which is obtained by suitable cross section design, manufacturing process, material and its reinforcements.

II. REINFORCED ALUMINIUM MATRIX COMPOSITES

Aluminum Matrix Composites (AMCs) refer to the class of light weight high performance aluminum centric material systems. The reinforcement in AMCs can be done in the form of continuous/discontinuous fibers, whisker or particulates, in volume fractions ranging from a few percent to 70% which depends on the wettability of matrix material. By suitable combinations of matrix, reinforcement and processing route the properties of AMCs can be tailored to the demands of different industrial applications required. 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
- Improved abrasion and wear resistance

The advantages can be achieved by proper addition of reinforcement. It is interesting to note that research on particle-reinforced cast AMCs took root in India during the 70's, and now attained industrial maturity in the developed world and is currently in the process of joining the mainstream of materials [5]. MMC (Metal matrix composites) are metals reinforced with other metal, ceramic or organic compounds. They are made by dispersing the reinforcements in the metal matrix. Reinforcements are usually done to improve the properties as desired. The reinforcements should be stable in all the working temperature and non-reactive too. The most commonly used reinforcements are Silicon Carbide (SiC) and Aluminum Oxide (Al2O3). SiC reinforcement increases the tensile strength, hardness, density and wear resistance of Al and its alloys. Boron Carbide is one of hardest known elements next to diamond. It has high elastic modulus and fracture toughness. The addition of Boron Carbide (B4C) in Al matrix increases the hardness, but does not improve the wear resistance significantly [6-10].

III. SELECTION OF REINFORCING MATERIALS

The prime role of the reinforcement in the matrix metal is to carry and distribute the load. The reinforcement may be divided into two major groups continuous and discontinuous The MMCs produced by these are therefore named as continuously reinforced composite and discontinuously reinforced composite. In general the reinforcement increases the properties like stiffness, strength and temperature resistance capacity but lowers the density, ductility and fracture toughness of the composite. The proper selection of reinforcement type, geometry or shape and size is important in order to obtain the best combination of properties at substantially low cost. The following aspects must be considered in selecting reinforcement.

- Size - diameter and particulate size.
- Shape - continuous fiber, chopped fibers (whiskers), spherical or irregular particles or flakes.
- The density of particulates should be closer and must be less than that of matrix material.
- Surface morphology - smooth or rough.
- Structural defects – presence of voids, sharp edges etc
- Inherent properties - such as strength, moduli and density.
- Chemical stability with the matrix under various environments.

Property \ Material	Al_2O_3	SiC	Graphite	B_4C
Density(at20^{o}C) (g/cm^3)	3.97	3.22	2.23	2.65
Melting point (^{o}C)	2,228	2,973	3,915	2,763
Coefficient of thermal expansion. (um/mK)	7.1	4	6	3.2
Thermal conductivity (W/mK)	35.6	126	85	90
Young's Modulus (GPa)	370	410	10	472
Poisson's Ratio	0.21	0.14	0.23	0.21

Table.1 Properties of particulate reinforcements

In case of particulate composites, the size of the particulates plays important role. The size should be selected such that it gets properly distributed or mixed with matrix during stirring process (In stir casting). The extra fine the particle size is then there will the chance of the particulates to float on the molten matrix, which causes irregular particle distribution. The Table.1 has some details about properties on commonly used particulate reinforcements [11].

IV. HYBRID ALUMINUM METAL MATRIX COMPOSITE

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 increased [1]. Aluminum-based Metal Matrix Composites (MMCs) have received increasing attention in recent decades as engineering materials. The introduction of a ceramic material into a metal matrix produces a composite material that results in an attractive combination of physical and mechanical properties which cannot be obtained with monolithic alloys. The various reinforcements that have been tried out to develop AMCs are graphite, silicon carbide, titanium carbide, tungsten, boron, Al_2O_3, flyash, Zr, TiB_2 or there combination to produce Hybrid composites. Addition of hard reinforcements such as silicon carbide, alumina, and titanium carbide improves hardness, strength and wear resistance of the composites. Aluminum alloys are still the subjects of intense studies, as their low density gives additional advantages in several applications. These aluminum alloys have started to replace bronze and cast iron, to manufacture wear resistant parts [7].

V. PROPERTIES OF ALUMINUM AND ITS ALLOYS

The three main properties of aluminum which makes its application in many areas are its low density, the high mechanical strength achieved by suitable alloying, reinforcing and heat treatments, and the relatively high corrosion resistance of the metal in its pure state. Other valuable properties include its high electrical and thermal conductance, its high ductility, its reflectivity and low working cost. Still further valuable features are obtained by alloying, reinforcing and various treatments of the metal, based on the applications of aluminum required. In its pure state, aluminum is, however, a relatively soft metal with yield strength of only 34.5 N/mm^2 and a tensile strength of 90 N/mm^2. Through the development of a wide range of alloys and composites the required properties like strengths and ductility can be achieved, and this has led to the many applications today. Also in its pure state it has a relatively high corrosion resistance and needs less protection than most metals. On the other hand, the commercial metal and its alloys are distinctly more sensitive to corrosion, and the development of high strength light alloys, containing heavy metals such as copper, zinc or nickel, has made it must to have protective surface treatments. The nature of the heavy metal additions appreciably influences the alloy's susceptibility to corrosion, and high mechanical strength and corrosion resistance have so far proved largely incompatible [8].

Basically, two classes of alloys may be considered. The first are the 'cast alloys' which are cast directly into their desired shape and size by one of three methods (sand-casting, gravity die casting or pressure die casting), while the second class, the 'wrought alloys', which are cast in ingots and hot and cold worked mechanically into extrusions, foil, forgings, sheet, tube and wire. The main classes of alloys are 1000 series, which are pure or the one without alloying elements, the 2000 series (Al-Cu alloys), which are high-strength materials used mainly in the aircraft industry after heat treatment process, but have poor weldability, the 3000 series (Al-Mn alloys) used mainly in the canning industry,which have good formability and weldability. the 5000 series (Al-Mg alloys) which are used unprotected for structural and architectural applications as they are good corrosion resistant, the 6000 series (Al-Mg-Si alloys) which are the most common extrusion alloys and are used particularly in the building industry and corrosion resistant, and the 7000 series (Al-Zn-Mg alloys) which are again high strength alloys whose tensile strength ranges between 450-600MPa, these find application in automobiles, aircraft, military and other fields.

Series 1000, 3000, 5000, 8000 are non-heat-treatable alloys and 2000, 6000, 7000, are heat-treatable alloys. The alloy used in any particular application will depend on factors such as the mechanical and physical properties required, the material cost and the service environment involved. The great benefit of aluminum is that such a wide variety of alloys with differing mechanical properties is available, and hence make it a very versatile material.

VI. APPLICATIONS OF MMCs

Among various types of MMCs available, Aluminum based composites have found its application in various engineering components like cylinder block lines, automobile piston and connecting rods, driven shafts, etc. Breaks are made of particulate reinforced composites using ceramic and carbon particulates. Dispersion phase like B4C, SiC and Al2O3 are commonly used particulate reinforcements in composites. The successful and high volume production was Aluminum Toyota-Piston rings, which has short Saffil fibers (whiskers) as reinforcement. The other known and typical applications are bicycle frames, fishing rod, tennis rackets and balls, etc. The inherent high damping properties of MMCs is used in vibration damping during launching of space satellites.

VII. MANUFACTURING OF MMCs

Metal matrix composite materials can be produced by many different techniques. The selection of suitable manufacturing process depends on the, quantity and distribution of the reinforcement components (particles and fibers), the matrix alloy and the application. By changing the manufacturing process, as well as by the form of the reinforcement components and other parameters, it is possible to obtain different characteristic profiles, although the same composition and amounts of the components are used. For cost effective reasons, prototypes with dimensions close to the final product, and reforming procedures are used, which can minimize the mechanical finishing of the construction units.

A key challenge in the processing of composites is to homogeneously distribute the reinforcement phases to achieve a defect-free microstructure. Based on the shape of the product required, the reinforcing in the composite can be either particles or fibers. The relatively low material cost and suitability for automatic processing has made the particulate-reinforced composite preferable to the fiber-reinforced composite for automotive applications. Primary processes for manufacturing of AMCs at industrial scale can be classified into two main groups.

A. Solid state processes

Solid state process include Powder blending followed by consolidation (PM processing), high energy ball milling, friction Stir Process, diffusion bonding and vapor deposition techniques. The selection of the processing route depends on many factors including type and level of reinforcement, loading and the degree of micro structural integrity required.

B. Liquid state processes

Melting metallurgy/ Liquid state processes for the production of MMCs is at present of greater technical importance than powder metallurgy. It is more economical and has the advantage of being able to use well proven casting processes for the production of MMCs. The types of Melting metallurgy are,

1. Compo-casting or melt stirring
2. Gas pressure infiltration
3. Squeeze casting or pressure casting

Parameters / Method	Range of shape and size	Volume fraction	Reinforcement damage	Cost
Stir casting	Wide range of shapes, large size up to 500Kg	Up to 0.3	No damage	Least expensive
Squeeze casting	Limited by pre form shape up to 2cm height	Up to 0.5	Severe damage	Moderate
Powder metallurgy	Wide range, restricted size	-	Fracture	expensive
Spray casting	Limited shapes, large shape	0.3-0.7	-	expensive

Table.2 A comparative study of different technique used for fabrication.[11]

Stir Casting

Among the variety of manufacturing processes available for discontinuous metal matrix composites, stir casting is generally accepted as a particularly promising route, currently practiced commercially, which is also least expensive compared to other process. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. In a stir casting process, the reinforcing phases are distributed into molten matrix by mechanical stirring. Stir casting of metal matrix composites was initiated in 1968, when S. Ray introduced alumina particles into an aluminum melt by stirring molten aluminum alloys containing the ceramic powders. Mechanical stirring in the furnace is a key element of this process. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement. The cast composites are sometimes further extruded to reduce porosity, refine the microstructure, and homogenize the distribution of the reinforcement. A major concern associated with the stir casting process is the segregation of reinforcing particles which is caused by the surfacing or settling of the reinforcement particles during the melting and casting processes. The final distribution of the particles in the solid depends on material properties and process parameters such as the wetting condition of the particles with the melt, strength of mixing, relative density, and rate of solidification .The distribution of the particles in the molten matrix depends on the geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and the characteristics of the particles added [7]. An interesting recent development in stir casting is a two-step mixing process. The process is shown in above figure 1. In this process, the matrix material is heated to above its liquids temperature so that the metal is totally melted. The melt is then cooled down to a temperature between the liquids and solidus points and kept in a semi-solid state. At this stage, the preheated particles are added and mixed. The slurry is again heated to a fully liquid state and mixed thoroughly. This two-step mixing process has been used in the fabrication of aluminum.

In the past few years the global need for low cost, high performance and good quality materials has caused a shift in research from monolithic to composite materials. In case of MMC's, aluminum matrix composite due their high strength to weight ratio, low cost and high wear resistance are widely manufactured and used in structural applications along with aerospace and automobile industry. Also a simple and cost effective method for manufacturing of the composites is very essential for expanding their application. Reinforcements like particulate alumina, silicon carbide, graphite, fly ash etc can easily be incorporated in the melt using cheap and widely available stir casting method. The following variable parameters are to be considered, while preparing the MMC by stir casting, Speed of rotation, Stirring speed, Stirring temperature, Reinforcement pre-heat temperature, Stirring time, Pouring temperature, Mould temperature [11].

Stir Casting 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. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies. Density of the particles is one of the important factors determining the distribution of the particles in molten metal. Particles having higher density than molten metal can settle at the bottom of the bath slowly and particles of lower density can segregate at the top. During subsequent pouring of the composite melt, the particle content may vary from one casting to another or even it can vary in the same casting from one region to another. Therefore uniform distribution of the particles in the melt is a necessary condition for uniform

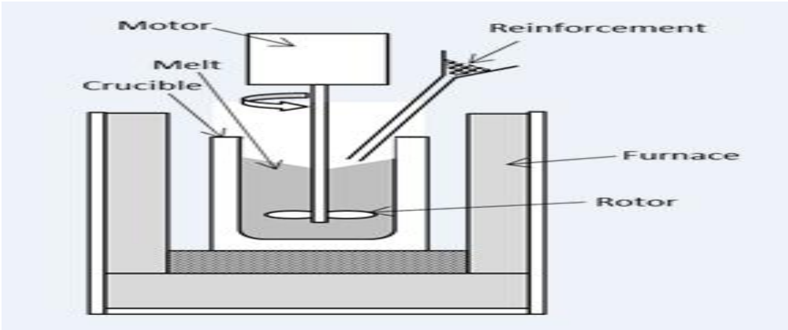

Fig.1 Stir Casting Process

distribution of particles in the castings. The properties of composites are finally dependent on the distribution of the particles. Hence the study of the distribution of the particles in the composite is of great significance.

VIII. CONCLUSION AND FUTURE SCOPE

The current literature review the can draw the following conclusions and reveals that extensive work has been reported to improve the properties of different aluminum based MMC by forming their composites being reinforced with fibers and various particulate materials such as Al_2O_3, TiB_2, TiO_2, SiC, TiC and B_4C etc., The below are the conclusions drawn from various papers by varying the material properties and comparing with former.

- It has been observed that one of the least expensive methods to fabricate MMC is stir casting.
- Using aluminum as base material is feasible to obtain desired properties by alloying or reinforcing it with suitable materials.
- The density of the composite increases with the addition of the hard ceramic reinforcement into the matrix material. And increase in hardness and increase in tensile strength that is almost twice the base aluminum alloy.
- Weight can be reduced by changing the material of the current Al360 connecting rod to hybrid Al+ Fly Ash+ Sic composites and is comparatively much stiffer than the former.
- The weight of the connecting rod is less when aluminum alloys and carbon fiber are used instead of Forged Steel.
- SiC reinforced Al MMCs have higher wear resistance than Al_2O_3 reinforced MMCs, which are suitable materials for brake.
- Weight fractions are also a considerable parameter as it effects the mechanical properties of the composites such as tensile strength. The mechanical behaviour of SiC/Gr reinforced hybrid composites showed improved results when compared with single reinforcement. The density with different weight fractions, was studied and the density increases with SiC and decreases with SiC/Gr hybrid particulates, so SiC/Gr hybrid composites can be regarded as a useful light weight Engineering Material.
- The microstructure study is evident to know the uniform distribution of reinforcing particulates in the matrix.
- Reinforcing Aluminum and its alloys with ceramics particles has shown an appreciable increase in its mechanical properties. Addition of alumina, SiC, B4C etc. particles in aluminum improves the hardness, yield strength, tensile strength while ductility is decreased.
- Addition of graphite in aluminum increases the tensile strength and elastic modulus but hardness is decreased. Also it shows a decrease in friction coefficient in case of tribological behavior.
- This process is successful in manufacturing of AMC at less cost.

Above conclusions help in knowing the better combination of material to be used in AMMCs, the manufacturing process, heat treatment, etc. Based on this data available the new combinations with different weight fractions can be used to obtain better materials with different manufacturing process and heat treatments. The usual problem in particulate reinforcement is the wettability and porosity. This can be avoided by varying the stir casting parameters. The wettability also depends on the size and density of the reinforcement.

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