International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Review Article

A Review on "Optimization of Process Parameters Al Metal Matrix Composites using Taguchi Analysis"

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Received 20 Dec 2018, Accepted 21 Feb 2019, Available online 26 Feb 2019, **Vol.9, No.1 (Jan/Feb 2019)**

Abstract

Aluminium metal matrix composites are widely used in various manufacturing sectors like automotive, aerospace, electrical etc. Aluminium metal matrix composites provide better physical and mechanical properties e.g. tensile strength, toughness, strength to weight ratio etc. as compared to its base alloy. Now a days, consumption of aluminium casting has increased from 85,000 ton in 1995 to 180,000 ton in year 2010. Among all the fabrication processes, stir casting technique is best suited for aluminum metal matrix composites because of its simplicity and less expensive. Normally, reinforcements added in aluminium metal matrix composites are SiC, B_4C, Al_2O_3, TiC etc.

Keywords: *Aluminium Metal Matrix Composite, Reinforcement, Stir Casting.*

Introduction

Metal matrix composite are widely used in industries as they offer better physical and mechanical properties than their parent metals. There are many definitions of metal matrix composite which are accepted worldwide. One of them is that a metal matrix composite is a material consists of two or more materials phase with primary base metal. The primary base metal in which others materials are added is known as matrix while those materials added to base metal to change the properties is known as reinforcements. The reinforcements added are in the form of small and nano-particles, whiskers, rods etc. They are extensively used for better properties and performance in automotive, aerospace, industrial, military, electrical etc. industries.

At present aluminium metal matrix composites are one of the best materials utilized for mechanical, aerospace, transportation and manufacturing industries in which light weight is of primary requirements. Aluminium metal matrix composite provides a wide range of popularity specially in automobile sector. As recently, it is discovered that lightweight metals will leads to decrease in fuel consumptions and environmental pollutions. So, use of aluminium metal matrix composite will leads to increase in efficiency and reduction in environmental pollution. Apart from this, aluminium metal matrix composite also provides better physical and mechanical properties like ductility, strength, excellent wear resistance, excellent corrosion resistance, low thermal expansion coefficient, high temperature creep resistance and high fatigue strength. So, various kinds of reinforcements materials like Al_2O_3, SiC, B_4C, TiC etc. are added in aluminium metal matrix composite to improve required properties. [Amol Mali *et al* , 2018; A. Thirumoorthy *et al* , 2018]

Types of Aluminium metal matrix composites

The aluminium metal matrix composites are divided depending upon the type of reinforcements added into following categories

1. *Particle Reinforced Aluminium Metal Matrix Composite*

These types of composites are manufactured by reinforcing particle fillers into aluminum metal matrix by powder metallurgy, stir casting, infiltration and in-situ processes techniques. In this type of composites, the volume fraction of reinforcements added are varies according to the requirements. For examples, when it is used for wear and structural applications, fraction of volume remains less than 30 % and for electronic packaging applications, fraction of volume can be increased up to 70 %.

2. *Continuous Fiber Reinforced Aluminium Metal Matrix Composite*

In this type of composites, reinforcements added are continuous unidirectional fibers either parallel or braided. These reinforced composites have highest

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DOI: https://doi.org/10.14741/ijcet/v.9.1.16

elastic stiffness and tensile strength. So, they are generally used in structural and heavy-duty applications. Normally, the use of metallic fibers usually fails because of high density and their affinity to react with the matrix alloy.

3. Hybrid Aluminium Metal Matrix composite

These types of composites are manufactured by reinforcing two or more particles in aluminium matrix. Here, by varying the mixture of reinforcements with different weight percentage and size, it can be used for required functions.

Types of Reinforcements

A) Alumina Reinforcements (Al_2O_3)
B) Boron Reinforcements (B_4C)
C) Silicon Carbide (SiC)
D) Titanium Carbide (TiC)

Manufacturing Process of Aluminium Metal Matrix Composite

The processing methods used in the manufacturing of Aluminium Metal Matrix Composites at industrial level are classified into three categories

1. Solid State Processes
2. Liquid State Processes
3. Deposition Processes

So, different manufacturing processes for manufacturing Aluminium Metal Matrix Composite are given below in the table no. 1 [Manish Shukla *et al* , 2017]

Table 1: Different Types of Processing Technique

Method	Range of shape and Size	Range of Vol fraction	Damage to reinforcement	Cost
Stir Casting	Wide range of shapes, larger size up to 500kg	Up to 0.3	No damage	Least expensive
Squeeze casting	Limited by perform shape up to 2cm height	Up to 0.5	Severe damage	Moderate expensive
Powder metallurgy	Wide range, restricted size		Reinforcement fracture	Expensive
Spray casting	Limited shape, large shape	0.3-0.7		Expensive

Stir Casting

As, this paper is based on stir casting, so we discussed only stir casting here. Stir casting for metal matrix composites was started to use in 1968 when S. Ray reinforced alumina particles into an aluminium alloy containing ceramic particles by stir casting process. In this furnace, mechanical stirring is very important process for making composites.

In stir casting process, reinforced particulates is mixed into the aluminium molten liquid by mechanical stirring. Mechanical stirring is the most important element of the process. After the mechanical mixing, the molten metal is directly transferred to a shaped mould prior to complete solidification. Below fig. 1 shows the schematic diagram of stir casting process.

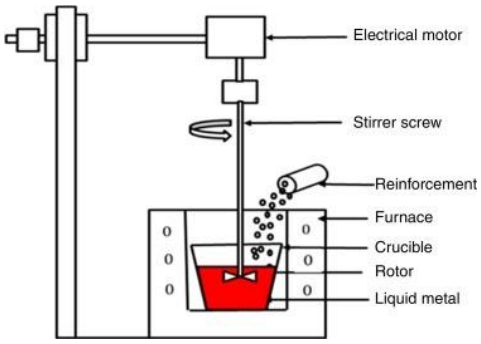

Fig.1: Schematic diagram of stir Casting [Manish Shukla *et al*, 2017]

Stir casting is best for manufacturing composites till 30% volume fractions of reinforcements. Also, distribution of reinforcement particles in metal matrix depends on different process parameters and material properties e.g. strength of mixing, wetting condition of the particles with the melt, relative density and rate of solidification.

Now a days, a two-step stir casting process is used for manufacturing metal matrix composites. In this, the matrix material is also heated till the metal matrix is completely melted. Now, melted metal matrix is cooled down to the liquids and solidus temperatures and maintained in a semi- solid state. Here, at this stage, preheated reinforcement particles are added and mixed in semi-solid metal matrix. Again, the semi-solid metal matrix mixed with preheated particles heated to a fully liquid state and mixed them completely. So, this is the two-step stir casting process which is used now a days frequently.

Commercial Applications of Aluminium Metal Matrix Composite [S.T. Mavhungu *et al* , (2017]

1. Brake rotors developed by Knorr Bremse AG made from aluminium Composites (AlSi7Mg+SiC particulates) for German high-speed train ICE-1 and ICE-2.
2. Reinforced Aluminium alloy is used to make brake systems (discs, drums, calipers or back plate) of Volkswagen.

3. Aluminium metal matrix composites with continuous fiber are used to produce pushrods by 3M for racing engines.
4. Aluminum metal matrix composite wires are manufactured by 3M used for the core of an electrical conductor.
5. Duraclan, Martin Mareitta, GKN and Lanxide are used Al- SiC particles composites for manufacturing pistons, brake rotors, liners, calipers and propeller shafts.
6. Connecting rods of Nissan manufactured by using Al-SiC whiskers composites.
7. Al-Al2O3 composites is used to manufacture piston rings of Toyota.
8. Connecting rods of DuPont and Chrysler is also manufactured by using Al-Al2O3 composites.
9. Al-TiC particle composite is used to manufactured pistons and connecting rods of Martin Maretta.
10. Engine blocks of Honda is manufactured by using Al-Al2O3 carbon fibers hybrid composites.
11. Brake rotors of Lotus Elisse, Chrysler and Volkswagen are manufactured by using Al-SiC particle composites.
12. Al-SiC particle composites is used to manufactured rear brake drum, drive shaft and engine cradle of General Motors.

Literature Review

Amol Mali *et al* (2018) aimed to study in detail the effects of hybrid reinforcements on mechanical and wear properties behavior of aluminium metal matrix composites. In this investigation, a hybrid composite material consists of aluminium 6061 as a matrix while fly ash with varying weight 3%, 6% and 9% using stir casting process is used. After fabrication of specimens, comparisons of various mechanical properties like tensile strength, compressive strength, hardness and wear is done.

Thirumoorthy *et al* (2018) analyzes that because of the unique properties like good mechanical properties, better durability, high strength to weight ratio etc. of aluminium based composites, its usage is increasing day by day in manufacturing industries. Their study is mainly based on Al6061 and Al7075 alloys because of their commercial easy availability and wide use for structural purpose in manufacturing sectors. It is also study that many researches have been done only on few carbides and oxides reinforcements particles addition in aluminium matrix but not much research is done on addition on nitrides and oxides particles reinforcements addition in aluminium matrix.

S.T. Mavhungu *et al* (2017) reviewed the advances and trends of aluminium metal matrix composites for industrial uses. Aluminium metal matrix composites have high specific stiffness and high strength which could be used in long terms applications such as robots, high speed rotating shafts, high speed machinery and automotive engine where saving weight is an important factor. In this, it also told that stir casting fabrication process should be used for future research compared to other fabrication processes because of its low cost.

Raminder Singh Bhatia *et al* (2017) aims to develop hybrid aluminium metal matrix composites by adding different reinforcements so that combination with best properties can be obtained. Here, metal base used was aluminium alloy with 12% Si and reinforced with varying percentage of alumina, graphite and boron carbide by weight using stir casting technique.

Casting formed here are used for studying microstructural behavior and subjected to mechanical testing for varying reinforcements. The analysis reveals that greater wettability of particles is produced by boron carbide interface crack and alumina and graphite particles showed perfect interface which will increase microhardness of surface with further reinforcements.

Rohit Sharma *et al* (2017) deals that addition of different reinforcements like silicon carbide, graphite, fly ash, red mud, organic material etc. in aluminium metal matrix composite improves the properties of base alloy. Addition of different reinforcements improve different property of the base alloy.

Anja Schmidt *et al* (2017) studied that a material like aluminium metal matrix with particle reinforcements will show a successful innovation if this material gives better advantages both in technological as well as economic point of view. For that, the concept of an integrated technology, market analysis, user and forecast has been developed for finding out the technological and commercial potential of a new material in early life cycle stages in the Collaborative research Centre SFB 692. So, result showed that particle reinforced aluminium metal matrix provides not only technological advances but also considerable economic potential.

Girija Moona *et al* (2017) analysis that aluminium metal matrix composites should be known as new generation potential material for most of the engineering applications. The characteristics and properties of aluminium metal matrix composite is mostly depends upon types of reinforcement, interface bonding and processing parameters. In aluminium metal matrix, different types of reinforcements are added to improve various properties like hardness, stiffness, toughness, fatigue properties, wear resistance, thermal stability, electrical properties etc.

Manish Shukla *et al* (2017) focus on the manufacturing processes, mechanical properties and surface texture of aluminium metal matrix composites reinforced with silicon carbide with varying weight percentage of 0, 5, 10, 20 fabricated with the help of stir casting process. In this aluminium metal matrix composites, reinforcing of silicon carbide increases tensile strength and hardness and maximum tensile strength is occurred at 20 wt. %. Also, with increase in the silicon carbide into aluminium matrix, increases the porosity and decreases the ductility of aluminium metal matrix composite.

Bangarappa. L *et al* (2017) carried out the experimental study to investigate the mechanical properties i.e. tensile strength, hardness, impact test, shear test etc. of aluminium metal matrix composite. In this, experimental study, silicon carbide- graphite Al6061 alloy composite with 10 to 20% of silicon carbide and 5 to 10% graphite fibers are fabricated by stir casting process. AS a result, with increase in the percentage of graphite, hardness as well as tensile strength reduces.

P. B. Pawar *et al* (2017) reviewed the present development in aluminium metal matrix composite manufacturing, fabrication methods, mechanical properties and challenges in the developments. Presently aluminium matrix is reinforced with some reinforcements like TiB_2, Al_2O_3, B_4C, SiC etc. It offers improved and better mechanical and tribological properties compared to conventional metals and now a days, considered as potential material for light weight metals.

Yashpal *et al* (2016) represents an overview of work done on aluminium metal matrix composites with different reinforcement particles. Because of light weight, high strength to weight ratio, workability, corrosion resistance of aluminium metal matrix composites, it is widely used in aerospace, automotive and other industries. Stir casting method is the best fabrication technique available for the aluminium metal matrix composites because of its cost effectiveness and convenience. It also reveals that increase in percentage of reinforcements and reduction in particle size increases tensile strength and hardness of the composites.

Sallahauddin Attar *et al* (2015) studied that aluminum metal matrix composite have been used as advance material which is best suited in automotive, defense, aircraft, space, and other engineering sectors. Utilization of aluminum is increased from just 6% in 1950 to 28% in 2010 in transport sectors. Also, aluminium casting consumption has increased from 85,000 ton in 1995 to 180,000 ton in 2010. So, reinforced aluminium metal matrix provides a better wide range of properties over conventional materials i.e. high specific modulus, improved resistance to high cycle fatigue, improved resistance to wear, higher stiffness to weight ratio, high thermal conductivity, low coefficient of thermal expansion.

Dinesh Kumar Koli *et al* (2015) analyzed that applications of aluminium metal matrix composite is increasing continuously in the automotive and aerospace sectors since it has better physical, mechanical and tribological properties as compared to its base alloy. They are used in manufacturing of various parts e.g. pistons, engine blocks, brakes, cylinders etc. in automotive industries. When reinforced with different reinforcements like SiC, Al_2O_3, B_4C, ZrO_2, TiB_2, graphite particles etc., aluminium matrix provides better microstructural characteristics that develops better physical and mechanical properties in space and automotive industries.

B. Vijaya Ramnath *et al* (2013) studied that aluminium metal matrix composite are best material for several applications because of their good physical and mechanical properties. Also, it presents the overviews of the effects of addition of different reinforcements in aluminium matrix as addition of different reinforcements improves various properties like stiffness, specific strength, wear, creep and fatigue strength etc.

Various Process variables used in Aluminium Metal Matrix Composites-

Various process variables used in aluminium metal matrix composites are [Dinesh Kumar Koli *et al* , 2015]

1) Speed of rotation

Rotational speed of stirrer should be kept around 10 m/sec. After initial vortex is formed in metal and reinforcement has been added, then, it stirred for about 10 minutes in such a way that there is proper mixing with molten metal.

2) Pouring temperature

Reinforcement before poured into the molten metal are preheated and for strong bond formation between reinforcements and matrix, pouring temperature should be high. If pouring temperature is less, then, molten metal will start to solidify which leads to improper mixing with reinforcements.

3) Pouring speed

The main problem generally occur with stir casting process is segregation of reinforcements on the surface of molten metal. For proper mixing of reinforcement and molten metal, pouring speed should be controlled as slow speed is normally used for proper mixing.

4) Cooling medium

In the manufacturing of aluminium metal matrix composite, cooling medium is also an important parameter. Cooling mediums like air cooling, water cooling etc. helps in settling of reinforcements in aluminium metal matrix.

5) Cooling time

Cooling time is also a important parameter used in aluminium metal matrix composites. It helps to maintain the required time for fabrication of aluminium metal matrix composites.

Methods for optimization of process variables- Taguchi Method

Taguchi method is used to optimize different process parameters utilized in manufacturing of aluminum

metal matrix composites by using stir casting process. In taguchi method, it involves identification of proper control factors so that optimum results should be obtained. Here, it involves a large no of experiments to be conducted. But, if no of factors increases, then, it becomes complex. So, to avoid this, taguchi used a specially designed method called as orthogonal array method which is used to study entire parameters with less no of experiments. In taguchi method, taguchi loss function is used to measure the performance characteristics which are deviating from the desired target value. Generally, value obtained from taguchi loss function are converted into signal to noise ratio. Normally, three categories of performance characteristics are used to analyze signal to noise ratio which are nominal to best, larger the best and smaller the better. There is no. of steps involved which are below

1) Identify the main function and its side effects.
2) Identify the noise factor, testing condition and quality characteristics.
3) Identify the objective function to be optimized.
4) Identify the control factors and their levels.
5) Select a suitable orthogonal array and construct the matrix.
6) Conduct the matrix experiments.
7) Examine the data, predict the optimum control factor levels and its performance.
8) Conduct the verification experiments.

So, a series of experiments are to be conducted according to the no. of steps involved in taguchi method. So, here are some conclusions from different research papers used taguchi method for optimization of process parameters-

M. Kathiresan *et al* (2017) is deal with the machining parameters for aluminium metal matrix reinforced with 5 wt% boron carbide and 6 wt% flyash in electric discharge machining through taguchi method. From considering all the control parameters i.e. current, pulse on time and pulse off time in taguchi method, current is the most important parameter which is mostly involved in all machining processes like metal removal rate and surface roughness.

M. D. Selvam *et al* (2017) optimized the percentage composition of aluminium alloy Al6061 reinforced with fly ash, copper and graphite by using taguchi orthogonal array. Here, by using regression analysis with the help of Minitab software, a mathematical model representing the tensile strength is developed which helps in the optimization.

Vijayanad Dharanikota *et al* (2014) selected different loads, sliding speed, sliding distance and varying percentage of silicon carbide as control factor for the analysis of aluminium hybrid metal matrix composite by using grey relational analysis in the taguchi method. Here, result showed that four test parameters have much greater role in controlling the friction and wear behavior of composites. But, % volume is the most influential parameter followed with load for specific rate and load for coefficient of friction on aluminium hybrid metal matrix composites.

Lakhvir Singh *et al* (2013) is used three parameters i.e. particle size of alumina, wt % of reinforcements, stirring time to manufacture different samples of aluminium metal matrix composites by using stir casing technique. Here, Analysis of variance (ANOVA) is used to find out the effect of these input parameters on output. The result showed that wt % of alumina, stirring time and particle size of alumina have a great effect on the hardness, impact strength and tensile strength.

Raviraj Shetty *et al* (2009) concluded that steam pressure is the most significant parameters among others parameters like speed, feed, depth of cut, nozzle diameter and steam pressure from analysis of taguchi method. Here, a no. of experiments is conducted by using PSG A141 lathe to relate cutting parameters on surface roughness, tool wear, cutting force, feed and thrust force.

Conclusion

From the review papers, following conclusions have been drawn

1) The major advantage of aluminium metal matrix composites is high strength to weight ratio, high tensile strength, high toughness, high wear resistance etc. Because of these reasons, it used in manufacturing sectors e.g. automotive, space, electrical etc.
2) The best process for the fabrication of aluminium metal matrix composites is stir casting technique compared to others as it is simple and inexpensive. Also, stir casting does not damage the reinforcement particles.
3) The characteristics and properties of aluminium metal matrix composites is basically depends upon the types and wt.% of reinforcements, interface bonding and process parameters.
4) It is clearly analyzing that almost all the research has been done on carbides and oxides reinforcements addition in aluminium matrix. But not much research has been done on nitrides addition in aluminium matrix. So, there is huge potential to develop aluminium metal matrix composite more economically and better properties.

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