

## Porosity in aluminium matrix composites: cause, effect and defence

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### ABSTRACT

The popularity of Aluminium matrix composites is drawn from the properties they possess; however, these mechanical properties are adversely affected by the presence of porosity. This paper provides a comprehensive insight into the concept of porosity, the major factors leading to occurrence of porosity in a cast composite and the effects that the porosity content has on the mechanical properties of the cast composites which ultimately affect the life and performance of the composite. Further it discusses the methods that can be adopted to minimize the occurrence of porosity. These methods are to be adopted in different stages of the casting process and each of the method has proved beneficial in the task of reducing the overall percentage of porosity in a cast aluminium matrix composite. These include variation in the casting techniques and processing parameters, alteration in the composition of the ingredient materials, the timing of the ingredient incorporation and the mode of ingredient incorporation. © 2016 Trade Science Inc. - INDIA

### KEYWORDS

Aluminium matrix composites;  
Stir casting;  
Defects;  
Porosity;  
Mechanical properties.

### INTRODUCTION

The demand for production and development of metal matrix composites (MMC's) has been increasing rapidly owing to special combination of properties achievable by the joint action of metals and ceramics. Pai and Rohatgi<sup>[1]</sup> stated that among all of the MMC's Aluminium matrix composites (AMC's) have captured a major portion of interest of designers and engineers because of their easy castability, low melting point, higher thermal conductivity, lighter weight, high specific strength, high specific stiffness, low coefficient of thermal expansion, im-

proved abrasion and wear resistance, improved damping capabilities etc. Rohatgi<sup>[2]</sup> has opined that, because of their excellent properties AMC's have found their place in defence, mining, aerospace, automobile, thermal management and other related sectors of the industry. This fact was further substantiated and reiterated by Surrappa<sup>[3]</sup>.

According to Ray<sup>[4]</sup>, Stir casting is one of the methods used for the fabrication of Aluminium matrix composite castings. It was first used in 1968 by the author wherein the reinforcing phases of alumina (usually in powder form) were distributed into molten Aluminium by mechanical stirring. Luo<sup>[5]</sup> found

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that, 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 mould casting, or even sand casting. Saravanan and Surrappa<sup>[6]</sup> established that, Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement.

Hashim et al.<sup>[7]</sup> associated Stir casting technique with a lot of limitations as far as the quality of the composite is concerned. The volume percentage of porosity, dimensions and distribution in a cast Aluminium matrix composite is a primary factor for controlling the mechanical properties.

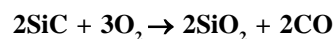
### POROSITY

According to Ghosh and Ray<sup>[8]</sup>, Porosity is a casting defect and is undesirable as far as Aluminium matrix composite castings are concerned. In general porosity arises from three causes: (a) Gas entrapment during mixing (b) Hydrogen evolution (c) shrinkage during solidification. However the process parameters of holding times, stirring speed and size, and the position of the impeller influence the development of porosity. It has also been opined by Samuel et al.<sup>[9]</sup>, that the structural defects during casting like porosity are a result of unsatisfactory casting technology. Hashim et al.<sup>[7]</sup> reported that the occurrence of porosity cannot be ruled out however, it can definitely be minimised.

### CAUSES OF POROSITY

Christian et al.<sup>[10]</sup> has shown that casting parameters are the core reason that causes porosity formation. The casting parameters are: casting route applied, stirring speed and position of the impeller, volume fraction of the reinforcement material, and process parameters that consists of holding time. Ray<sup>[11]</sup> has explained that in cast composites porosity can be classified into two types. (a) At the interface of the matrix phase and the reinforcement, (b) Away from the ceramic particles in the matrix alloy. The first one is more undesirable as it increases the debonding of the ceramic particles from the metal alloy under low stress. In composites gas porosity

generally nucleates unevenly on the surface of the composite reinforcements during solidification and helps them to float to the surface of the melt. The suction of particles and bubbles together at the vortex may also result in bubble particle combination floating freely in the slurry. The particle in certain cases may also become attached to the bubbles, during their movement inside the molten alloy. All these mechanisms are primarily responsible for the occurrence of porosity. Lajoie and Surey<sup>[12]</sup> have considered both oxygen and hydrogen as sources of difficulty in the fabrication of light alloy composites. The affinity of aluminium for oxygen instigates the reduction of surrounding water vapour and the formation of hydrogen, which in turn readily dissolves in molten aluminium. In spite of a substantial drop in solubility of hydrogen during solidification, it remains in the form of a solid solution of super saturated nature. This leads to creation of pores and voids. Zyska and Braszczyński<sup>[13]</sup> further substantiated the fact that, Oxygen and hydrogen are the sources of water vapours present on the surface of reinforcing ceramic particles. In addition to water vapours the SiC particles are covered with SiO<sub>2</sub> layer.



This layer obtains its existence during the production of SiC. SiC undergoes passive oxidation in which SiO<sub>2</sub> film forms on the surface leaving CO gas, which later becomes the reason for porosity. Brondyke and Hess<sup>[14]</sup> have observed that the amount of gas porosity in a casting depends more on the volume fraction of the inclusions than any of the other factors. Experimental observations have proved that the occurrence of porosity in cast composites increases almost linearly with particle content. According to Ghosh and Ray<sup>[15]</sup>, the porosity of a composite is primarily a result of air bubbles entering the slurry either on their own or in the form of an envelope containing the reinforcement particle. Most of the gaseous content on a particle surface is H<sub>2</sub>O which increases with decreasing the size of the particle. Akhlaghi et al.<sup>[16]</sup> conducted experiments and have revealed that the increase in the content of fixed size of SiC particles resulted in an increase of porosity content. Bindumadhavan et al.<sup>[17]</sup> have found

that there is an increase in volume percentage of porosity corresponding to an increase in volume percentage of the reinforcing ceramic particles of SiC. The possibility of this was attributed to the fact that the composites with higher percentage of reinforcements which were stirred for relatively longer time during their processing, have an increased amount of air bubbles sucked into the molten metal vortex. It was found that there is a positive correlation between the particle volume percentage incorporated in a composite and the porosity content of that composite. According to Surrappa<sup>[18]</sup>, in cast Metal matrix composites the occurrence of porosity can be attributed invariably to the amount of  $H_2$  gas present in the melt, oxide film on the surface of the ceramic particle, which is drawn into the molten metal at the time of stirring. Vigorously stirred melt or vortex tends to entrap gas into the molten mixture. Nripjit et al.<sup>[19]</sup> also found that the porosity of the reinforced composite is more as compared to unreinforced alloys and goes on increasing with the increase in the volume fraction of the reinforcements in aluminium alloy matrices. Hishombor et al.<sup>[20]</sup> have found similar results with  $TiB_2$ . Kok<sup>[21]</sup> conducted a study of aluminium reinforced with  $TiB_2$  particles, it was established that the amount of porosity and density in the composite increased with the increase in volume content of  $TiB_2$  particles.  $Al_2O_3$  has been extensively used as a reinforcement medium for Al alloy composites. As far as the occurrence of porosity is concerned, aluminium oxide is no different to the other types of reinforcements. A study on  $Al_2O_3$  with Al alloy matrix also revealed an increase in porosity levels with increase in volume percentage of  $Al_2O_3$ . The porosity level of the composite went upto 4 %. Another analysis of the course of formation of the composite castings with saturated reinforcement done by Szweycer and Jackowski<sup>[22]</sup>, has shown that in some areas considered as isolated regions, the pressure was much lesser than actually acting on the casting. In consequences, the blisters of occluded gas may grow in these regions and moreover, the blisters of hydrogen entrapped in the metal may get released from there. This may initiate occurrence of gas pores in the composite castings.

Depending on the processing parameters, the

presence of the pores was higher in volume at higher level in the castings than at lower level or bottom of the castings. This result is because of the fact that there is faster cooling rate of the melt at the bottom of the casting where the melt comes in contact with the mould surface, and therefore decreases the possibility of pore formation. A faster cooling rate hinders the clustering of the ceramic particles and hence results in low porosity, Allison and James<sup>[23]</sup>. Skibo et al.<sup>[24]</sup> proved that vigorously stirring in the melt so as to mix the reinforcement particles incorporated in the melt introduces a greater proportion of gas into the slurry. High velocity of slurry, due to higher stirring speeds forms a vortex on the surface of the slurry. The formation of a vortex on the surface was quite helpful in the movement of ceramic particles into the slurry of alloy and reinforcements. This was attributed to the pressure difference created between the inner and the outer surface of melt, which pulls the ceramic particles into the melt. This has been reiterated by Ghosh and Ray<sup>[8]</sup> that the extent of porosity in a cast composite depends on the state of agitation and it can be reduced by the control of certain process variables. Studies have shown that there is a variation in percentage porosity by the variation in the stirring speed and the position of the stirrer. In another research Hashim et al.<sup>[25]</sup> found that, without the application of stirring, particle clustering is definite to occur causing porosity in the melt due to non wetting of the particles. Mechanical stirring was applied to the Al-SiC slurry. Although manual stirring mixed the particles in the melt, but as soon as the stirring stopped the particles tended to return to the free surface. The particles were also attracted towards each other to form clusters and moreover the single particles also tended to return to the surface strongly indicating the presence of surrounding surface gas layer. This gas layer is a significant factor in poor wettability leading to porosity. Jahangir and Suh<sup>[26]</sup> showed that for microstructures having second phase particles like ceramic reinforcements, the crack nucleation was favoured at these particles. This was due to the presence of pores and voids on the surfaces of these ceramic particles. This was primarily attributed to plastic flow of matrix melt around the surface of these hard

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particles. Void formation was related to the hydrostatic pressures which existed directly at the contact region/interface. Wettability has also been a driving factor for porosity. According to Sajjadi<sup>[27]</sup> poor wettability means that the molten matrix of alloy cannot wet the surface of ceramic reinforcing particles and as a result they simply float on the surface owing to surface tension, larger surface area, high interfacial energy and presence of an oxide film on the surface. Aggarwal and Dixit<sup>[28]</sup> have considered the presence of a ceramic oxide layer on the surface of ceramic reinforcement, which acts as a barrier to good interfacial bond between the particles and the molten alloy and the poor interfacial results in the occurrence of voids and pores.

On the basis of the above presentation of research findings the following factors seem to affect the conditions attained during interfacial reactions between the ceramic particles and the molten alloy matrix.

- Shape and size of reinforcements
- Melt viscosity
- Free energy at the interface
- Clustering or aggregation of particles
- Convection properties
- Density of melt and particles
- Shape of interface boundary
- Volume fraction of ceramic particles.
- Temperature gradient leading to solidification

### EFFECTS OF POROSITY

The effect of porosity is mainly focussed on tensile and fatigue properties of the cast composites. Skolianos<sup>[29]</sup> and Whitehouse<sup>[30]</sup> reported that the porosity affects adversely the ductility, yield strength, poisons ratio and Ultimate Tensile strength.

Winand<sup>[31]</sup> conducted longer duration test (creep test) on the specimens of composites having relatively considerable value of porosity, it lead to coalescence of the pores and finally the failure of the specimen due to attainment of the critical phase by the necked portion of the specimen. Ghosh and Ray<sup>[32]</sup> have found that the mechanical properties of the composites are adversely affected by porosity. At low levels of porosity, one may consider each pore as an independent entity of other pores as inhomoge-

neous stress distributions around pores are not overlapping each other. But the total probability of damage is additive due to each pore and it was found that the Ultimate Tensile Strength is a linear function of the volume percent of porosity.

Ghosh and Ray<sup>[33]</sup> concluded that composites are more prone to failure due to porosity than other metals and alloys. This has been attributed to screening of the inhomogeneous stress filled around each pore by harder particles of reinforcements embedded in the matrix, and thus restricts its spatial range. Ling et al.<sup>[34]</sup> studied the effect of fabrication techniques on the mechanical properties of the composites. The mechanical properties especially ductility were found to depend strongly on the variation of resulting porosity and interfacial reactions/conditions produced. Interfacial failure and cracking of reinforced particles were found to be dominant failure modes in composites with higher than 20 volume percent of SiC loading. Chawla<sup>[35]</sup> opined that, any composite draws its strength from the strength of bond between the matrix alloy and reinforcement particles at the interfacial boundary. A good bond is only resulted if the atoms of the matrix and the reinforcement are in direct contact with each other. The presence of porosity and reduction of wettability reduces the strength of the bond and as a result the strength of the composite decreases.

The formation and nucleation of porosity results in lowering of fatigue strength, yield strength of the composite and total life time. In many discontinuously reinforced metal matrix composites, the composite failure occurs from the development and growth of voids at the matrix reinforcement interface. Ductility of discontinuously reinforced metal matrix composites depend on the strain at which the damage nucleates and growth rate of the damage that causes failure. The porous cavities form high hydrostatic stress areas that will work together by a ductile tearing mechanism. Even in case of a creep failure it was observed that, the necked region has more void content than other deformed region. It has also been established by Christian et al.<sup>[10]</sup> that in highly stressed regions of component, fatigue cracks initiate from surface discontinuities. The authors found that in this case, porosity is the discontinuity

which leads to failure of the composite. Moreover, if the component is under elevated temperature and tensile stress, voids will be formed on the interface of the particle and matrix that significantly reduces the fatigue life of the material.

### METHODS TO MINIMIZE POROSITY

Although stir casting and compocasting have been widely used to incorporate ceramic reinforcements into molten alloys of Aluminium, still they face a very important factor affecting the uniform distribution of the ceramic particles in the melt which is called Wettability and is the ability of the liquid alloy to wet the surface of the solid particle inclusion and attaining an intimate contact with the particles by spreading uniformly over the entire surface. Khedar<sup>[36]</sup> reported that the Wettability develops a good bond at the interface and reduces the chances of porosity due to surface contamination of the particles. Different researchers have adopted several methodologies to enhance the wettability of the ceramic reinforcements with a molten aluminium alloy matrix. These generally include two techniques (a) Addition of an alloying element in Al matrix, (b) Addition of a layer of coating on ceramics. Tefto et al.<sup>[37]</sup> and Himbeault et al.<sup>[38]</sup> have studied such effects for (a) and (b) above respectively. Mitra and Mahajan,<sup>[39]</sup> also found that the processing variable can easily be altered to improve the wetting between the reinforcement particles and the metal matrix composites. These include (i) Addition of alloying elements, (ii) Pre treatment of the dispersoids, (iii) Increase in temperature of molten metal, (iv) Hot pressing the blended combination above the solidus temperature, and (v) Aging of the matrix with higher solid solubility.

On the basis of studies performed by various researchers in the last three decades, the solutions to reduce the problem of porosity can be further subdivided into five broad categories. They are:

- Modification in casting equipment.
- Pre-treatment of the ingredient materials.
- Addition of alloying elements into original Al alloys.
- Modification of processing parameters.

- Technique of reinforcement incorporation.

### MODIFICATION IN THE CASTING EQUIPMENT(S)

To control porosity, creation of vacuum and inert gas atmosphere has been successfully tried while mixing the particles with molten alloy by Cornie et al.<sup>[40]</sup>. The porosity gets significantly reduced as compared to conventional methods of composite casting. Girot et al.<sup>[41]</sup> considered degassing as a process of removal of dissolved gases from the melt. The authors have developed a procedure for gas removal whereas; degassing is carried out in a vacuum chamber. The application of vacuum to the melt during mixing reduces the availability of atmospheric gases and also tends to suck out the dissolved and entrapped gases out of the melt. Bharath et al.<sup>[42]</sup> adopted another modification is a three stage mixing of the ceramic particles into molten aluminium alloy. Each incorporation was aided with stirring before and after the introduction of particles for about 10 minutes. The stirrer was also preheated before its immersion into the slurry. The stirrer was placed at about 2/3<sup>rd</sup> of the height of the melt in the crucible. The stirring of the melt before and after the inclusion of the ceramic particles results in the breakage of dendrite shaped structures and their conversion into equiaxed shapes. It improves the wettability, particle dispersion more uniformly thereby reducing the occurrence of pores. Sahin<sup>[43]</sup> developed a new setup for stir casting which has a bottom pouring and tapping facility. This modification achieved full and homogeneous distribution of the particles in the melt. However his set up did not have the option of changing the placement of the stirrer inside the melt which could have further improved the reduction in porosity due to air bubble entrapment.

Another modification to the above mentioned conventional stirring was tried by Hashim et al.<sup>[44]</sup> to improve the wettability of SiC particles by Al alloy. The stirring was carried out by the authors in a semi solid state. The mechanical agitation in semi solid slurry applies larger forces on SiC particles through abrasion and collision between Al-Nuclei and ceramic particles. This process helps to break

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the gas layer and also the oxide layer to some extent enhancing the spreading of the liquid metal on the particle surface. This helps to achieve good wettability and uniform distribution of particles. This semi solid slurry agitation also prevents the migration of ceramic particles to the free surface under the action of buoyant forces. According to Parker<sup>[45]</sup> the type and placement of the stirrer also plays a vital role. On the basis of experiments, it has been recommended that a turbine stirrer be used so as to place it in such a way in the melt that 65% of liquid remains above that stirrer and 35% of the liquid remains below the stirrer during stirring operation. It has further been observed by Samuel et al.<sup>[9]</sup> that increasing the mould temperature improve the uniformity and soundness of the casting resulting in a significant decrease in the porosity levels. The porosity content decreased with the increase of size of the reinforcing particles. It was also observed by Akhlaghi et al.<sup>[16]</sup> that the increase of the mould temperature resulted in a decrease in porosity level. Clarity<sup>[46]</sup> used a fluted stirrer designed by Duralcan USA and it is claimed on the basis of their conducted experiments that their designs were aimed at keeping the top of the melt relatively quiet as compared to the epicentre of stirring. This helped in the exposure of alternative liquid of the molten alloy and thereby avoiding the excess dissolution of atmospheric gases into the melt,

Ghosh and Ray<sup>[47]</sup> have established the occurrence of porosity corresponding to a particular size, speed and the position of the stirrer for a particular set of operations. But the maximum incorporation of the ceramic particles is also attained at same combination set of operation parameters. This puts a limitation to the changing of process variables. Installation of ceramic baffles has also been tried by Mohan et al.<sup>[48]</sup> on the upper portion of the stirrer which comes in contact with the top layer of the melt during the stirring operation. The main aim of this design was to suppress the movement of melt on the top so as to put a restriction on the formation of a vortex and at the same time increase the turbulence during the stirring operation. This resulted in decrease of the gas being sucked into the melt at the open surface than the conventional vortex formation.

It was also discovered by the authors that the particle segregation in cast composites could either be over a microscopic range or macroscopic range. The micro level segregation of reinforcement particles is usually a result of uneven distribution of particles of ceramics in the slurry. In stir casting the stirrer imparts motion in the form of a vortex, which creates eddies, however the eddies have to be created at a micro level and smaller enough to break the particle clusters, failing which the porosity occurs.

## PRE-TREATMENT OF THE INGREDIENT MATERIALS

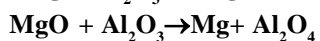
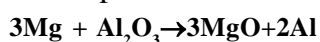
With a view to lessen the chances of porosity the ceramic reinforcements combined with preheating, were introduced at three different instances in equal proportions by Bharath et al.<sup>[42]</sup>. The results of these authors showed a significant improvement in the microstructure of the cast composite. In a different analysis of the reinforcement particles carried out by Mitra and Mahajan<sup>[39]</sup> revealed that the ones having a metallic character exhibit a strong and better interfacial bond leading to a greater improvement in Young's Modulus, yield, Ultimate Tensile Strength as well as improved ductility. According to Sajjadi<sup>[27]</sup>, improvement in wettability can be achieved significantly by preheating the reinforcement particles so as to remove absorbed gases from the surface of the particles. Zhiquiang<sup>[49]</sup> tried the use of surface coatings on the surface of the ceramic particles has also been tried. The coatings used were Yttria and the experimental set up was same as used in the conventional stir casting. It was observed by the author that the coatings of the ceramic particles enhanced the wettability of the particles, improved upon the uniform particle distribution and resulted in low level of percentage porosity. Aggarwal and Dixit<sup>[28]</sup> have used the technique of preheating the reinforcement particles before the incorporation into the molten alloy. Graphite powder particles tend to retain on the surface of the melt after incorporation. However, preheating the graphite particles led to zero retention of the particles. In a research conducted by Ribes et al.<sup>[50]</sup>, SiC particles also exhibited better processability after preheating to around

900 degree Celcius. The results were better owing to removal of surface impurities, desorption of entrapped gases and removal of the oxide layer from the free surfaces. This ultimately leads to reduction of pores. Similarly in another study conducted by Namai et al.<sup>[51]</sup>, the preheating of  $\text{Al}_2\text{O}_3$  has also resulted in significant improvement in wettability of the particles. This resulted in better interfacial strength and uniform distribution of particles with minimum porosity.

### ADDITION OF ALLOYING ELEMENTS INTO ORIGINAL ALLOYS.

Calderson et al.<sup>[52]</sup> reported that alloying elements have always played a detrimental role in governing the formation of precipitate at the interfaces of metal alloy composites. Fine et al.<sup>[53]</sup> suggested that segregation of the alloying element added to metal matrix at the interface between melt and solid particle results in reduction of interfacial energy due to Gibbs absorption phenomenon. But at the same time results in increase of the ionic or covalent character of the interfacial bond which in turn can prove a factor affecting toughness of the interface.

According to Levi et al.<sup>[54]</sup>, the type of interfacial bond can be improved by addition of magnesium to the Al alloy –  $\text{Al}_2\text{O}_3$  composites. The inclusion of Mg to matrix initiates the formation of  $\text{MgO}$  and  $\text{MgAl}_2\text{O}_4$  at the interface. This chemical reaction improves the wettability.



When it comes to the addition of magnesium in an Al alloy and SiC composites the results are similar in nature. Mg content reduces the strength of  $\text{SiO}_2$  layer on the surface of the SiC which enhances the wettability of the particles.



In a similar study Sritharan et al.<sup>[55]</sup> reported that the maximum strengthening effect has been shown with high Mg content as it increases the precipitation of Mg to Si. Sukumaran et al.<sup>[56]</sup> have considered Mg to be a very powerful surfactant. Mg also has a very low value of surface tension with com-

parison to Al or Al alloys. The addition of Mg to Al improves wetting as a result of drastic drop in surface energy of Al alloy. It has been found that for obtaining maximum benefit of Mg in an Al alloy composite, the optimum value of Mg content must be around 1 % by weight. Lower content of Mg results in agglomerates of reinforcements.

Levi et al.<sup>[54]</sup> established that any element which can interact chemically with the dispersoids and results in the formation of a new phase at the interface enhances the wetting and bonding of the reinforcement. It was found that in case of Al-Mg alloy, the formation of  $\text{Mg-Al}_2\text{O}_4$  layer resulted in good bond as a result of reaction between the reinforcing ceramic particles and the Mg content in molten alloy matrix.

It has been proved by Mondolfo<sup>[57]</sup> that addition of Mg in molten alloy scavenges the oxygen by reacting with it on the surface of particles and thereby reducing the thickness of the gas layer resulting in improvement of wettability and reduction in agglomeration. This was established with Al alloy matrix and SiC crystal particles as reinforcements.

In addition to Mg, other elements have also been extensively added to Al alloy matrix so as to improve the wettability and reducing the tendency of occurrence of porosity. Lithium is one element which has been studied in this context by Dhingra<sup>[58]</sup>. Li also results in reduction of severity of oxide layer at the boundary/surface of the ceramic particle which otherwise prohibits the contact of Al and  $\text{Al}_2\text{O}_3$ .

Webster<sup>[59]</sup>, conducted similar experiments with SiC in place of  $\text{Al}_2\text{O}_3$ . According to his findings the Li increases the reactive power of Al and as a result promotes the interaction between SiC and alloy at the interface. The Li addition also enhanced the matrix reinforcement bond strength.

The Molebdenum presence in the alloy also helps in good interfacial characteristics. As per the research of Calderson et al.<sup>[52]</sup>, it has been found that the segregation of Mo at the interface boundary relaxes the strains resulting from the elastic misfits or the change of interfacial energies.

Aluminium with controlled properties of other metals like Indium, Lead, Thallium have been found successful in reducing surface tension of the alloys

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by Kimura et al.<sup>[60]</sup>. Some other elements have also been tried over the past few years but not with very encouraging results. These include: Cerium by Ramani et al.<sup>[61]</sup>, Lanthanum, Zirconium and Titanium by Kobash and choh<sup>[62]</sup>, Bismuth, zinc by Aggarwal and Dixit<sup>[28]</sup>.

Copper has also shown significant impact on the interfacial strength. The studies of Torralba et al.<sup>[63]</sup> on the interfaces of composites with Cu show the interface to be harder, however, there has been no significant effect on the tensile properties.

### MODIFICATION OF PROCESSING PARAMETERS

Experiments conducted by Ghosh and Ray<sup>[64]</sup> have proved that there is decrease in porosity level with increase in holding temperature. Miwa and Ohashi<sup>[65]</sup> found that the evolution process of H<sub>2</sub> gas relying on temperature is mostly finished at temperatures between 200 and 600 degree Celcius. Thus the authors suggested the liberation of H<sub>2</sub>O gas by treating the particles with isothermal heating at 600 degree Celcius.

The effect of processing temperature has been found to affect the uniform distribution of particles restricting the clustering, which enhances porosity. The processing temperature mainly affects the change in viscosity of Al matrix and also it accelerates the chemical reaction at the interface. At higher viscosity with lower temperature the geometric contact of the particle is restricted by the vortex of the molten metal and thus the uniform particle distribution is achieved. It was also observed by Sozhamannan et al.<sup>[66]</sup> that the holding time helps in two ways: (a) To distribute the particles evenly, (b) To create a perfect interfacial bond between the reinforcement and the matrix. But at temperatures above 800 degree Celcius the vortex can suck air bubbles into the slurry which can create pores into the composite.

### TECHNIQUE OF REINFORCEMENT INCORPORATION

An alternative has been tested by Caron and Masonave<sup>[67]</sup> wherein the bed of the crucible is ini-

tially filled with the reinforcement particles and then the liquid metal is poured over it with intent to exclude the possibility of interfacial porosity resulting from air bubble attachment to the ceramic particles during conventional incorporation. However this process requires enhanced agitation to lift the particle from the bed of the crucible, which in turn creates a higher speed of the vortex and thus pulls up the rate of suction of air bubbles through the vortex. Still if an effective baffling arrangement is adopted, it can eliminate the chances of porosity due to this specific reason.

Rajan et al.<sup>[68]</sup>, conducted experiments to study solidification and casting/mould interfacial heat transfer characteristics of composites formed from Al alloy matrix. They showed that the addition of ceramic particles along with the Al alloy reduces the overall solidification time. This enhances the cooling rate of the castings and thereby limits the chances of clustering of the particles due to free movement of the particles. Thus this results in a decrease in the level of porosity in the final casting. Arda and Kalkanli<sup>[69]</sup>, studied the effect of solidification rate on the spatial distribution of SiC particles in A356 alloy composites. It was concluded that the distribution of ceramic particles is highly dependent on secondary arm spacing. With reduced arm spacing, the dispersoid particles exhibit fewer tendencies towards clustering, thus reducing the probability of porosity.

A new approach to fabricating cast Al matrix composites by using stir casting technique has been proved successful. Hashim et al.<sup>[70]</sup> found that placing all the ingredients together in a crucible, and then heating to melt excludes any chances of bubble entrapment and other atmospheric inclusions. This type of technique also removes moisture content from the surface of the ceramic particles during initial heating prior to the melting of the alloy matrix. This improves the particle distribution and limits the chances of occurrence of porosity. In a separate study by Olszowska-Myalska et al.<sup>[71]</sup>, one another modification to particle introduction was tried wherein Aluminium powder was mixed with reinforcement particles and then the mixture was incorporated into the molten Al alloy just like conventional stir cast-

ing methodologies. The cast composite samples were however found to have inhomogeneous microstructure and the distribution of ceramic particles in any of the samples could not have been described by Poisson's distribution. Suresh and Mishra,<sup>[72]</sup> developed yet another technique based on stir casting. They mixed micro and nano particles of  $Al_2O_3$  and incorporated them in the melt after preheating. Uniform distribution of particles was achieved for both micro as well as nano particles of ceramic reinforcements. Both the samples were found to have low levels of porosity and much better strength. In another work by Veruzan et al.<sup>[73]</sup> chemically assisted immersion of SiC,  $Si_3N_4$  and  $Mg_3N_2$  particles into an Al alloy matrix was experimentally investigated at a temperature between 1100 degree Celsius and 1500 degree Celsius using mixing times between 10 minutes to 1 hour. Before the incorporation of SiC particles their surface chemical composition was changed in order to promote the exergonic interfacial reactions. The results suggested that the volume fraction of successfully immersed particles increases linearly by time of immersion and exponentially by the temperature of the melt. It was concluded that the volume fraction of ceramic reinforcements can be increased with lowering of the activation energy at the interface. Kok<sup>[21]</sup> studied the microstructural changes of Al alloy composites by different sizes of  $Al_2O_3$  particles upto 30 wt %. It was observed that, larger the size of the particles, greater is the distribution uniformity, whereas the finer particles resulted in segregation and agglomeration resulting in increased porosity. It was also observed that porosity of composite increased with decreasing size and increasing wt% of particles. The porosity was also decreased by applying pressure, which enhanced the bonding force and resulted in increased porosity.

## CONCLUSIONS

The porosity is an undesirable defect in the composite which hinders the performance of the composites for which they came into existence. The porosity in a cast aluminium matrix composite affects the mechanical properties in an adverse manner. It reduces tensile strength, ductility, creep strength as

well as the fatigue life of the cast composites. Various reasons have been found to affect the creation of porosity in the composites and certain modifications to the casting technique like bottom pouring, motorised stirring, controlled incorporation of particle reinforcements, improved designs of casting equipment like fluted stirrer, turbine shaped stirrer, preheated moulds, treatments to the casting ingredients like preheating the ceramic particles, covering the outer layer with chemicals, addition of some alloying elements and variations in casting processing parameters like stirring time, stirring temperature, cooling time/solidification time, timing of particle incorporation have resulted in significant reduction in the porosity content of the cast composites.

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