

# Processing effect of Powder-chip based reinforcement in AA6061 Semi solid cast composite

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**Abstract.** Powder-chip based reinforcement and pouring temperature are the two factors for the internal cooling and shrinkage. The objective of this work was to experimental study to the effect of casting factors for aluminum based cast material inoculates with solid chips. The casting factors such as pouring temperature and reinforcement made by a combination of powder and waste chips for the processing in the semi-solid stage were investigated. The results indicate that these factors affect the behavior of microstructure properties of the cast composite in semi-solid stage. Pouring temperature is the factor that has the main influence on the behavior of the slurry with a marginal effect of reinforcement to most satisfactory results from a microstructural view point. Microstructures of the cast surfaces at various locations showed the incorporation of solid particles in un-melted conditions. Whereas, a parameter RIF (Reinforcement Incorporation Factor) value also confirms the potential of the processing in which this value reaches to 0.96 closer to 1. Fine microstructure of the cast composite inside the cavities also confirms the dendrites of about 200nm due to effect of powder.

## 1. Introduction

The general processing routes for metal matrix composites (MMCs) are casting technique and powder metallurgical technique [1-6]. There are several types of processing factors for the ceramic based aluminum composites. These processing can be divided into two categories as a liquid phase in which no force is implemented during the processing and second is a high force processing method for converting solid phase into a desired shape. In between these two techniques a semi-solid phase is in trend on these days due to excellent features especially in casting due to faster cooling rate, minimum solidification shrinkage and time reduced thermal fatigue etc [7]. Further aluminum is the most important metal and most widely used in the engineering and commercial application, fabricated by the various casting methods. Furthermore, during the processing, more than 20% of aluminum waste out due to the higher surface area to volume and these defects are not avoidable. This waste is increasing up to 20% in case of tiny chips without any proper utilization and processing technique [8].



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To reduce the wastage and production cost a new process is proposed to recycling the chips as reinforcement also with the advantage of nano size powder during casting using phenomena of a combined property of solid particles and semi-solid casting [9]. In this research work study of powder-chip based consolidated with low pouring temperature have been made for the effect of both parameters according to the microstructural point of view. Further, direct recycling of AA6061 aluminum alloy scrap composed with powder and chill bricks have been used in casting process in semi-solid stage and without any use of ceramics.

## 2. Materials and Methods

### 2.1 Preparation of Reinforcement

In this research, waste aluminum chip (60% by weight) shown in figure 1(a) and powder (40% by weight) of AA6061 alloy as shown in table 1, which were pre-mixed in between 180°C-200°C. After cooling to room temperature, reinforcement was prepared by the use of ball milling machine, in which powder particles were conjugated with the chips (shown in figure 1 (b)). The main purpose of the used powder is to form solid chip conjugate bunches which results in a faster drop of the melt temperature. As the surface area of the addable reinforcement have been increased with the use of the powder with waste chips also along with multiple small numbers formed of solid bunches. Further due to this a partial melt of chips was appears initially during the processing.

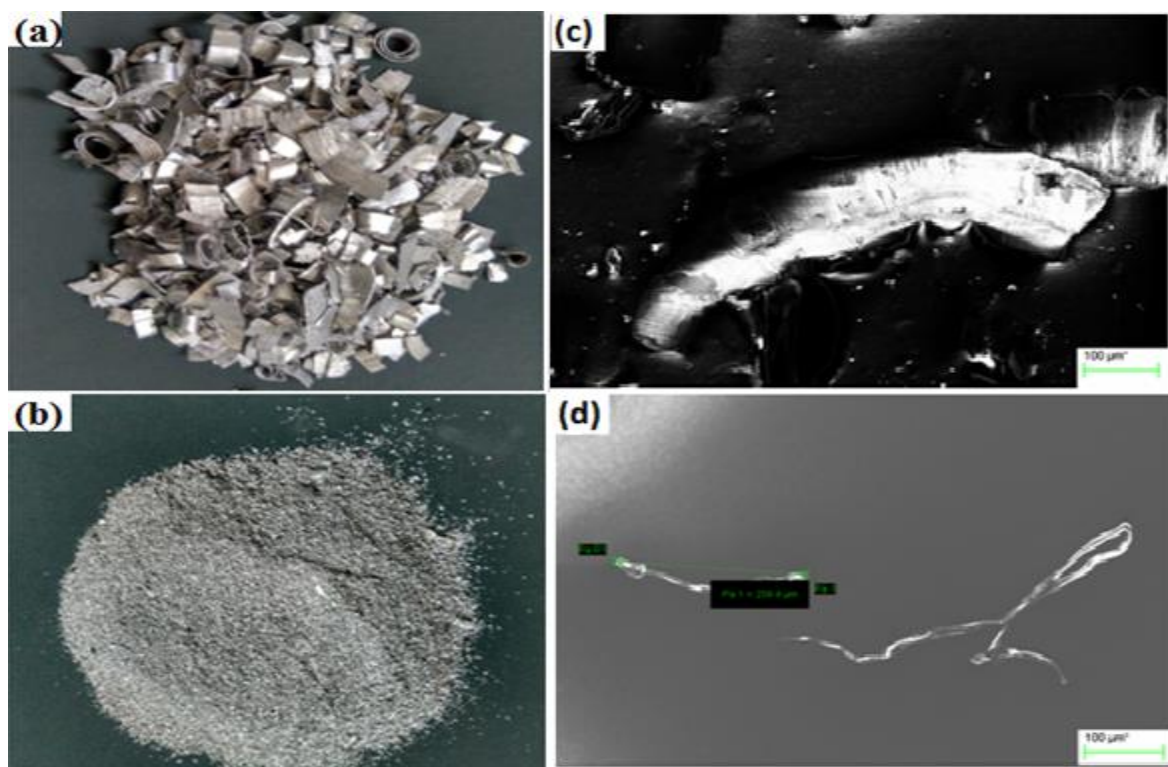


Figure 1 (a) Scraped chips used in processing (b) Fabricated Reinforcement (c) Microstructure of reinforcement particle (d) Un-melted chips inside the cast after processing

As powder particles are soft as comparison to micro size chips, particles mixed and imposed along the length of chips, results in the formation of larger spherical particulates after the milling process. During the mixing for a particular volume fraction of initial phase, enlarging and flattening the particle

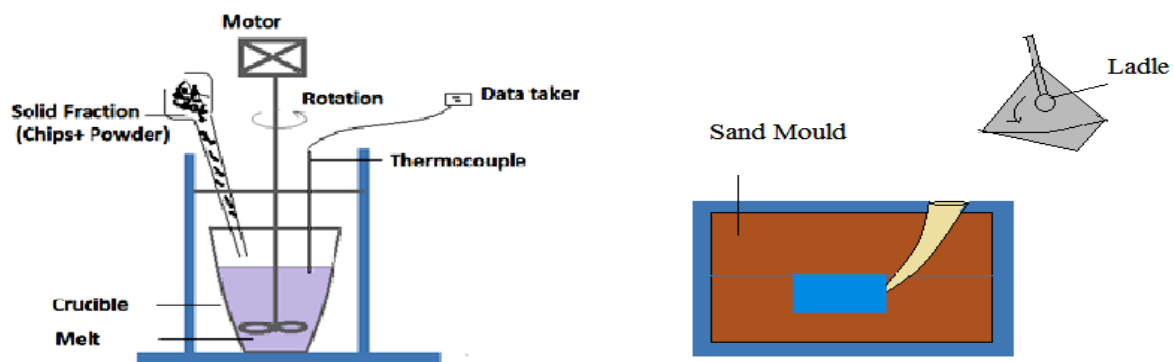
size increase in the average the joining between the nano particles and micro particles. Further, if plastic deformation promotes in between these particles and a finer dispersion is generated during the nucleation of particles on the dislocation in the matrix, so during the preparation of reinforcement extensive plastic deformation of alloys strong particles (chips), dispersed particles (fine powder along the length of the chips) results to joining in better way also like similar to cold worked fabricated parts. Microstructure of the fabricated reinforcement is shown in figure 1(c). Further, due to low melting temperature partially un-melted chips are left (variable size more than 200 $\mu\text{m}$ ) which can be clearly seen from the figure 1 (d).

**Table 1** Chemical composition of AA6061 aluminum alloy (Mass fraction %)

Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Tn	Ti	Cr	Al
0.42	0.693	0.404	0.529	0.021	0.004	0.097	0.058	0.020	0.037	0.017	97.97

## 2.2 Composite Fabrication

Fabricated reinforcements were added inside the melt by the ratio of 1:5 for two combinations under the stirring process of 120 rev min<sup>-1</sup>. The melt temperature reduces to 580°C - 680°C after 3 minutes stirring from 900°C-920°C initial temperature. The slurry formation process is shown in figure 2. After slurry preparation, it was cast into a sand mould with faster-cooling rate to fabricated AA6061/powder-chip cast composite brick. The process was employed at pouring temperature at 580°C. All the thermal measurement has been done with the help of K-Type thermocouple with digital data taker of accuracy  $\pm 10^\circ\text{C}$ . A ZEISS EVO MA 15 scanning electron microscopy setup was used to study of the microstructural behavior of the produced casting. After grinding and polishing the samples with proper etched (Keller solution) to microstructural study.



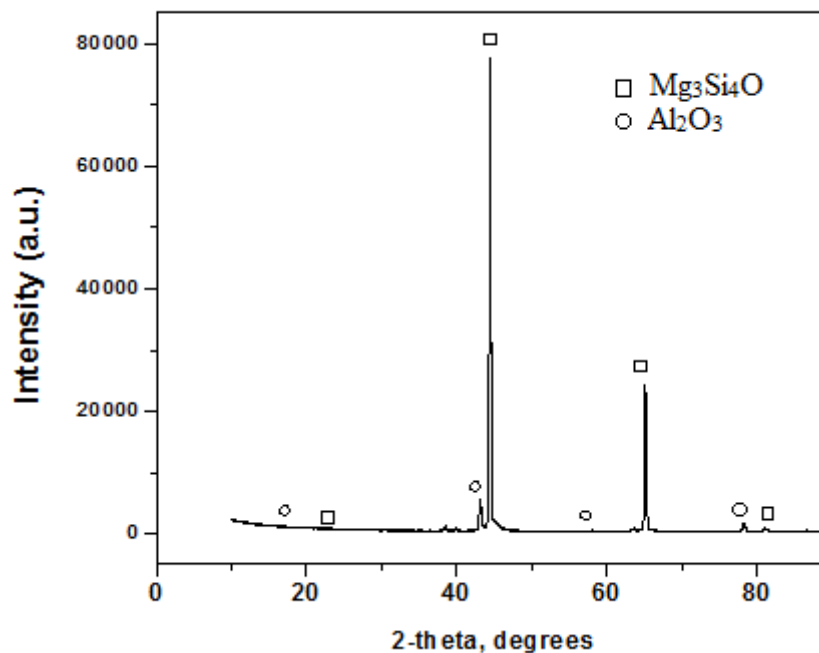
**Figure 2.** Schematic diagram of slurry formation and semi-solid casting process

To determine the effect of processing factors and shrinkage behavior on the cast microstructure by the addition of reinforcement was conducted with the help of microstructure. Furthermore, shrinkage behavior of the reinforcement bunches during the slurry processing has been discussed also with the effect of oxide formation on the surface of the cast composite. For contrast, phase constituents were analyzed by the X-ray Diffraction (Make: XRD, PAN Alytical Xpert) for the oxide formation. During the XRD, scanning rate was maintained at and below 0.2° per sec step size and scan range was 10° to 90°.

## 3. Results and Discussion

Effect on the cast surface due to oxide formation has been estimated is shown in figure 3. Oxide layer development on the cast surface is directly influenced by the effect of the precipitate solidification and

this mainly depends on the temperature gradient between the melt and reinforcement. These oxide layers over the cast surface behave like a thin transparent metallic layer enriched by the  $\text{Al}_2\text{O}_3$  and  $\text{Mg}_3\text{Si}_4\text{O}$ . Majorly,  $\text{Al}_2\text{O}_3$  penetrated to a lower depth of the cast surface and worked as a thermal insulator. The increase in thickness of oxide layer depends on the cooling rate and solidification of metal which was expected.



**Figure 3.** XRD pattern of the cast composite for oxide formation on the surface

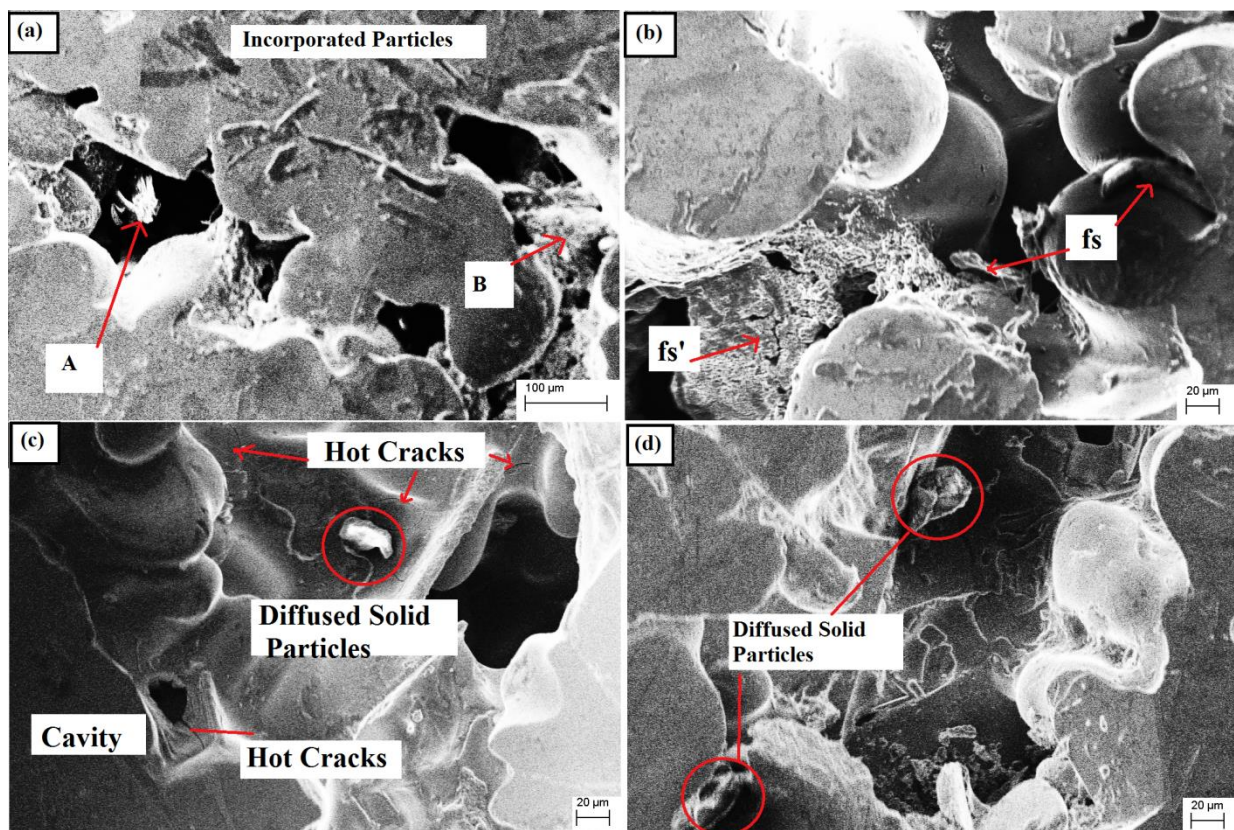
The microstructure images of semi-solid low pouring temperature cast are shown in figure 4. There are a number of large rosettes as  $\alpha$ -Al grains and un-melted reinforcement particles appear inside the cavities as shown in SEM image 4 (a). Several incorporated particles can be found in figure 4 (a) and (b). Maximum melting of the reinforcement participates due to very fine solid powder particles which can be observed by these incorporated solid particles. Since surface and contact area of solid powder particles was higher than the solid chips then these particles melt and accumulate on the nearby chips particles. Further weight to volume ratio of the reinforcement was lower than the primary melt, it takes place inside the cavities due to sudden contraction can be observed from figure 4 (a) as marked by 'A'. Processing increased in incomplete recrystallization due to the sudden and faster cooling of the melt during the solidification. It was also observed that during the processing when slurry reached to mould cavity, large reinforcement particles conjugated and generates some big bunches of the reinforcement which finally settled inside the bubbles formed by the entrapped air due effect of gravity which finally increase in the relative density [9]. Furthermore, some amount of bunches of reinforcement diffused inside the cavity can be found in figure 4 (a) as marked by 'B'. It has been observed that this diffusion is quite different from the un-melted reinforcement in the way that density of solid grains is quite finer. After being poured at  $580^\circ\text{C}$  almost every primary  $\alpha$ -Al grains are spherical and uniformly distributed clearly traced in figure 4 (b). Many investigations showed that microstructure of aluminum alloy during the semi-solid processing is sensitive due to low superheat and prompt in the formation of  $\alpha$ -Al grains which converts rosette to spherical grains [10, 11]. From figure 4 (b), it is clearly observed that some amount of un-melted chip particles mixed and solidifies with these spherical grains (marked by 'fs'). Further diffused solid grains takes place inside the cavity due to higher cooling rate and settled inside the cavity marked as 'fs'. The process shows an



excellent level of reinforcement addition and mixing in the melt with Reinforcement Incorporation Factor (RIF) about 0.96. This value may be increase with the higher pouring temperature and stirring speed. RIF calculation has been done by the help of following equation:

$$RIF = (1 - \frac{R_r}{R_i}) \times 100\% \dots\dots\dots \text{Equation (1)}$$

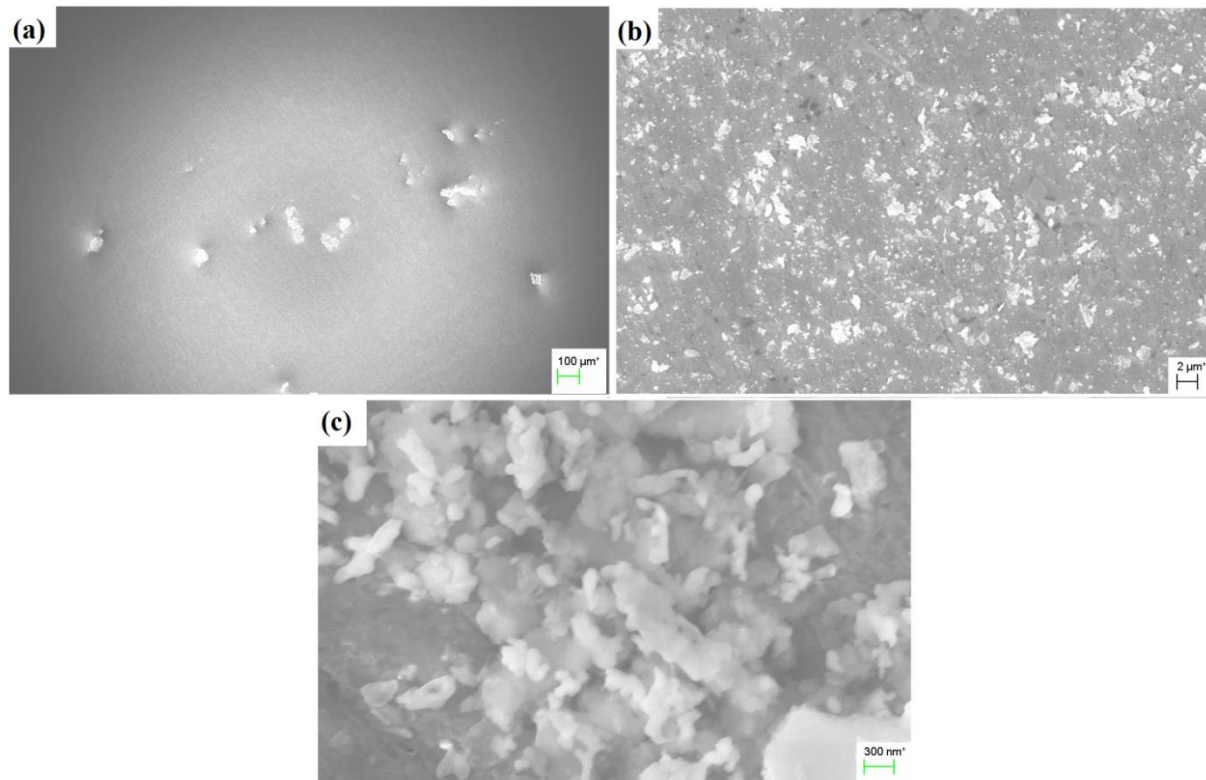
Here,  $R_r$  is the mass of un-incorporated particles and  $R_i$  is the incorporated particles. Values of  $R_r$  and  $R_i$  have been an approximate evaluation data before processing and after the casting.  $R_r$  values show un-incorporated particles which was collected by the cast surfaces and crucible. This value provides a rough approximation for the solid fraction component inside the melt. If this value reaches to zero, results in 100% RIF value.



**Figure 4.** SEM micrograph for semi-solid low pouring temperature cast surfaces at various locations

The microstructure images of the lateral surface of solid fraction cast at low pouring temperature are shown in figure 4 (c and d) to examine for better understanding the effect of pouring temperature. The pouring temperature has an obvious effect on the microstructure of the cast in semi-solid stage, whereas a continuous increase in the pouring temperature results in the increases the diffusion rate [9]. In particular, higher amount of solid particles were added and due to higher consumption of heat by these solid fraction components primary  $\alpha$ -Al grain formed in form of spherical grains as shown in figure 4 (c). Further, due to sudden heat consumption, shrinkage of the solid grains enhanced and hot cracks appear on the cast surface can be seen in the image 4 (c). Furthermore, at some places diffusion rate is higher, results in blank cavities with less amount of diffused solid fraction at some places [11]. Hot deformation causes the less softening which is mainly assign dynamic recovery, which organizes normal grains to a more stable structure [7, 10]. According

to the density, smaller particles concentrated at the bottom of the melt after when static equilibrium takes place whereas larger particles are better and uniformly distribute because these particles are rises on the top of the melt [ 5, 7, 11 -13]. Further in this case low pouring casting, powder particle immersed in the upper layer of the chips during the processing and better segregated as appears in the closer SEM images 4 (b and d).



**Figure 5.** Microstructure image of (a) distribution of reinforcement along the cavity (b) distribution of fine particles along the surface (c) closer grain observation

Effect of the powder-chip based reinforcement can be seen from the figure 5 (a). At several places, white concentration along the cavities showed in microstructure and indicates that small fine bunches and un-melted reinforcements effectively settled inside the cavities which further improve the density of the component. From figure 5 (b) and (c) a dense distribution of the particles along the surfaces can be observed clearly due to which reinforcement incorporation during the solidification process and time. Majorly, melt slurry contains three different phases as primary  $\alpha$ -Al phase particles, liquid aluminum alloy, and un-melted solid micro chips. The flow phenomenon is very complicated in this case due to the semi-solid metal slurry and solid particles mixed in the slurry. Finally, an observation depicts that un-melted chip particles incorporated along the surface as well as along the cavities settled which results in the reduction in the size and number of pores. Accordingly, figure 5 (c), it is clear, maximum dendrites of size about 300nm are richer as a comparison to bigger grains. This shows fine microstructure as well as confirms the easy incorporation of grains inside the cavities.

#### 4. Conclusions

Both pouring temperature and powder-chip based reinforcement are the important influencing factors for the microstructural and mechanical properties of an alloy. Pouring of the slurry at temperature just above liquidus line increases the incomplete recrystallization, spherical and small grains. The addition of waste aluminum chips in a specific quantity has noticeably increased the relative density and

homogeneous grain growth by the sudden internal cooling due to increasing in surface area during the processing. This sudden cooling with powder-chip based reinforcement via stirring proves the enhancement in the formation of globular structure. The microstructural images conclude that semi-solid casting processed cast by the similar metal reinforcement has been effectively improving the metallurgical properties by the refining in the microstructure of the cast composite.

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