Microstructure and Chip formation of LM2-Al_2O_3 Metal Matrix Composite fabricated by Squeeze Casting Method

Madki Santosh Jaykumar, Dr. Vishaldatt V.Kohir

Abstract— Squeeze casting is a process by which molten metal is solidified under applied pressure that is maintained until the end of solidification. There are various parameters which affect the mechanical property of the casting manufactured by squeeze casting. The major parameters considered in this paper are squeeze pressure, reinforcement and die temperature. The higher the squeeze pressure, the higher the tensile strength and lesser the porosity and shrinkage was observed. The optimum pressure focusing tensile strength was observed to be 100 Mpa. But for better machining of metal matrix composites (MMCs) , review shows low squeeze pressure (quantity) is to be preferred as it yields into coarse grain structure, which in turn enhances machining. In this research work, LM2 is used as matrix and alumina (Al_2O_3) powder is used as reinforcement. The result of lower pressure was observed in shortening the length of chips enabling the machining easier. On the other hand when the alumina powder is poured in the liquid matrix in the furnace and stirred, the uniform distribution of the reinforcement was observed.

Index Terms— Aluminium alloy Metal Matrix Composite, Squeeze Casting, Microstructure, grain size, Chips

INTRODUCTION

Aluminium metal matrix composites (AMC) are used for various engineering applications like aerospace, marine, automobile and mineral processing due to their light weight properties along with remarkable specific strength and thermal properties. In aluminium composites, the properties like high toughness and ductility associated with aluminium matrix are combined with superior properties of ceramics such as high strength and elastic modulus by adding ceramic reinforcements in the base matrix. Alumina (Al_2O_3), silicon carbide (SiC) and graphite (Gr) are the most common reinforcing materials which are used in the base aluminium matrix in the form of whiskers or particles. However particle reinforced composites are simpler from manufacturing point of view. In this research work, alumina in the form of fine particles is used as reinforcement and LM2 is used as matrix.

I. SQUEEZE CASTING

There are various methods of fabrication of MMCs. Stir casting method is broadly used in manufacturing MMCs, in which the reinforcement is added into molten matrix and stirred thoroughly and poured into the moulds by gravity casting method. The MMCs prepared by stir casting methods are found to have porosity and shrinkage defects. To overcome these defects, squeeze casting method is used. In squeeze casting process, after adding the reinforcement in the molten matrix, the pressure is applied on the mixture while solidifying. This pressure is applied between liquidus and solidus line with reference to its phase diagram. The squeeze casting process enhance the mechanical properties also along with removing shrinkage and porosity defects.

Major investigations are made on the machinability of stir casted specimens and a very little study on machinability of squeeze casted specimen is conducted. In this work macro examination of chips is made after turning operation along with its study of microstructure and hardness.

II. LITERATURE SURVEY

Machining Metal Matrix Composites (MMCs) is notoriously difficult due to the existence of two or more distinct phases, one of which is extremely abrasive, as well as the significant variations between the two constituents: the ductile metal matrix and the hard ceramic reinforcement. As a result, several attempts to manufacture metal matrix composite components in nearnet-shape forms have been made. However, such parts must always be machined to meet the final design specifications.

Major investigations on machinability are made on stir casted specimens and a very little study on machinability of squeeze casted specimen is conducted. There are many factors which affect the squeeze casting of metal matrix composites like melt (matrix) pouring temperature, die temperature, squeeze pressure, squeeze time duration, amount of reinforcement, type and size of reinforcement, type of matrix used and rate of cooling. Many parameters are interdependent. These parameters affect the mechanical properties of the casting. In aluminium metal matrix composites, many experiments are carried out to study the properties by varying the above parameters.

Ibrahim Ciftci et al [1] Three SiC/Al metal matrix composite specimens (MMCs) with SiC particles of 30, 45, and 110 m in mean size were developed using a melt stirring-squeeze casting route in this experimental study. Machining tests on MMCs were performed with cubic boron nitride (CBN) cutting tools at different cutting speeds while maintaining a constant feed rate and depth of cut. In the machining of MMCs containing SiC particles with sizes of 30 and 45 m, flank wear was found to be the most common wear mode of

Madki Santosh Jaykumar, Research Scholar Khaja Banda Nawaz College of Engineering, Kalaburgi (Karnataka), India.

Dr. Vishaldatt V. Kohir, Professor Department of Mechanical Engineering, Khaja Banda Nawaz College of Engineering, Kalaburgi (Karnataka), India

the CBN cutting tool, with abrasion and adhesion as the most common wear mechanisms. The MMC with SiC particles of 110 m in mean size caused very high tool wear. At a lower cutting speed of 150 rpm, tool wear is noted as minimum. In another experiment authors prepared the MMCs containing two levels of SiC particles (8 and 16 wt%) of different mean particle
sizes 30, 45 and 110 μm [2]. Machining tests were carried out on the composites using uncoated and triple-layer coated carbide cutting tools at various cutting speeds under a constant feed rate and depth of cut. The cutting speed, as well as the size and weight fraction of the reinforcement particles, were found to be the most important factors affecting tool life. While edge chipping was observed at higher cutting speeds, abrasion was the main tool mechanism. Coated cutting tools performed better than uncoated cutting tools in terms of tool wear for all the materials machined. Uncoated cutting tools produced a better surface finish in the majority of cases, particularly at lower cutting speeds.

C. Kannan et al [3] conducted the Machinability studies on Al 7075/BN/Al2O3 squeeze cast hybrid nano-composite under different machining environments. They found that the small percentage reinforcement of alumina and BN is found to have higher Brinell hardness and ultimate tensile strength of the nano composite. Under both dry and MQL condition, the hybrid nanocomposite is able to produce lower surface roughness than the unreinforced aluminum alloy due to the reinforced BN particles. During the machining of hybrid nanocomposite under MQL (Minimum Quantity Lubrication) conditions, lower cutting forces are produced. This is due to a combination of secondary processing techniques i.e. squeeze casting, and reinforced BN particles' self-lubricating properties. Higher flank wear is observed with the hybrid nano-composite under high feed rates

Parakh Agarwal et al [4] made the investigation on fabrication and machinability analysis of squeeze cast Al 7075/h-BN/Graphene hybrid nanocomposite (HNC), which has been fabricated by reinforcing hexagonal boron nitride (0.5 wt% h-BN) and graphene nanoparticles (1 wt% GNPs). They found that , under both the conditions dry as well as MQL surface profile of the machined surface were found smoother at the lower feed rates. Further, as the feed rate increases, the roughness of the machined surface also increases. As the cutting speed increases, decrement in the surface roughness has been observed though feed rate has prominent effect as compared to cutting speed. During machining, hybrid nano-composites have a cleaner surface finish than Al 7075 alloy, owing to the self-lubricating properties of h-BN and GNPs. As a result of the reduced cutting forces, tool wear and chip length are also reduced.

The machinability study on squeeze cast metal matrix composites is available to very little extent. The major study of squeeze cast MMC was based on improving mechanical properties of the MMC. All pressure studies were carried out keeping tensile strength and density of MMC in focus but from machining point of view, the low squeeze pressure makes the grains coarser and the number of grain boundaries exposing to the cutting tool reduce and the MMC cutting may become easier [5]. Grain boundary play important role in machinability as it exposes first to the tool while machining. The phase comes next to the boundary. Denser the boundaries or more the number of boundaries, difficult is the machining [6]. Finer grain size, more the number of boundaries and it becomes difficult in machining. Therefore high pressures are not recommended in case, when machining is at focus. On the other hand finer the grain size, more the surface finish. A compromise in pressure for sufficient level of surface finish is found to be the mean way. The research work in this paper attempts to examine the machinability of the squeeze cast aluminium metal matrix composite and surface macroscopically. This work also confirms about the method by which the distribution of reinforcement Al_2O_3 in the matrix LM2 is uniform.

III. FABRICATION OF SPECIMENS

The Aluminium Metal Matrix Composites (AMMCs) are fabricated by various processes. Liquid state fabrication methods like stir casting, compo-casting, squeeze casting, spray forming, liquid metal infiltration are implemented. Among these methods, it is found that stir casting is simplest and most economical method. But in this experiment the specimens are prepared with squeeze casting process.

In this work the aluminium alloy metal matrix LM2 is taken and aluminium oxide (Al_2O_3) also referred as alumina is used in particulate form (average particle size 40μ). The chemical composition of LM2 matrix used is shown in Table.1

Table 1: **The properties of LM2 [7]**

Sr No.	Property	Quantification
1	Specific gravity:	2.74 g/cm^3
2	Melting Range:	525-570^0
3	Coefficient of liner thermal expansion:	20 x 10^{-6} K^{-1}
4	Thermal Conductivity:	1000WMK
5	Electrical Conductivity:	26% IACS
6	Modulus of Elasticity:	71 GPa

Aluminium oxide powder average particle size 40μ is identified as reinforcement. The properties of aluminium oxide powder also referred as alumina powder is shown in Tale.2

Table 2: **Properties of Aluminium Oxide [8]**

Sr No.	Property	Quantification
1	Density:	3950kg/m^3
2	Tensile Strength:	2.1 GPa
3	Modulus of Elasticity:	379
4	Melting Temperature:	2015^{0}C
5	Specific Modulus:	98.6 x 10^7 cm
6	Specific Strength:	5.3 x 10^6 cm

LM2 is melted in a conventional coal fired furnace, Fig.1 (a) and pressure is applied by hydraulic press Fig.2(a) . The squeeze die Fig.1 (b) is heated by air heating gun and temperature of the die is maintained at 180^{0}C. Reinforcement

(Al_2O_3 Powder) added is 5% by weight i.e. 15 gm. Pressure applied for both specimens 100 kg/cm^2

Table 3: Chemical analysis by Spectro method conforms to BS1490:1988: LM2 (AlSi10Cu2)

Sr.No.	Element	Observed Value
1	% Mn (Mangenese)	0.16
2	% Si (Silicon)	9.64
3	% Cr (Chromiun)	0.030
4	%Ni (Nickel)	0.070
5	%Cu (Copper)	1.34
6	%Sn (Tin)	< 0.010
7	%Pb (Lead)	0.30
8	% Al (Aluminium)	Remainder
9	%Fe (Iron)	0.80
10	%Zn (Zinc)	0.89
11	%Mg (Magnesium)	< 0.030
12	Ti (Titanum)	0.045
13	Total other elements	< 0.50

Fig.1 (a) Coal fired furnace (b) Squeeze casting Split Die

The two specimens fig 2(b) are prepared as follows

Specimen-1: Reinforcement alumina powder (Al_2O_3) is added in the stream of liquid metal LM2 while pouring in the die (inoculation) and squeezing is made. Squeezing process is nothing but applying the specific pressure on the melt between its liquid and solid state.

Specimen-2: Reinforcement alumina powder (Al_2O_3) is added in the crucible when it was in the furnace itself, stirred properly and then poured in the squeezing die followed by squeezing.

Fig.2 (a) Hydraulic Press (b) Specimens Prepared

IV. MICROSTRUCTURE

Small pieces of thickness 8 mm are cut from each specimen for microstructure study. Both specimens were mirror polished and etched with NH_4OH. Olympus GX series Inverted Metallurgical Microscope with X400 is used for the microstructure study. The images were captured by using attached webcam. Refer Fig.3 (a) and (b)

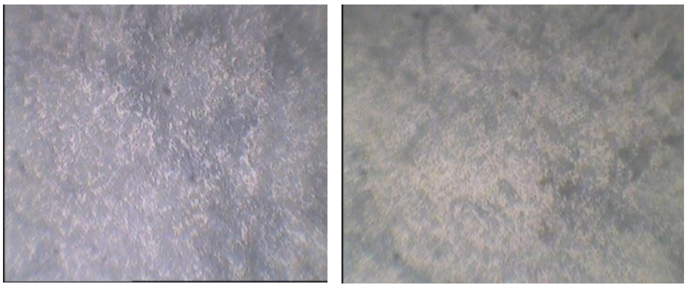

Fig.3 (a) Microstructure Specimen-1 (b) Microstructure: Specimen-2

Specimen-1

Identification: Alumina Powder added in molten metal stream (inoculation) and squeezing.

Microstructure- It shows coarse aluminium and alumina mixture with clear grain boundaries. Reinforcement is not uniform and found segregated

Specimen-2

Identification: Alumina Powder added in the melt in crucible and stirred followed by pouring in the die and squeezing. *Microstructure*-It shows very fine mixture of aluminium alloy and alumina. Distribution of alumina is uniform and very fine. No grain boundaries are visible. It indicatesSpecimen-2 shows compact grain structure with fine grain size

V. CHIP MORPHOLOGY

Both specimens are turned on light duty conventional lathe with speed 300 rpm, feed 1mm/rev and depth of cut 0.5 mm. The chips were collected and examined.

Fig. 4 Turning of Specimen on Lathe

The average chip length in specimen-1 is found 12 mm and in specimen-2 is found as 8 mm. Average width of chip in specimen-2 is found more than specimen-1.Refer fIg. 5 (a), (b)

Fig.5 (a) Chip Morphology Specimen-1 (b) Chip Morphology Specimen-2

VI. CONCLUSION

In the present study, an investigation is performed on two specimens with LM2 as metal matrix and alumina powder (Al_2O_3) as reinforcement. The specimens were prepared by squeeze casting method. In one specimen, the reinforcement powder is added in the molten matrix stream (inoculation) while pouring in the squeeze casting die and then pressure is applied. In the other specimen, the reinforcement is added in the molten matrix when the crucible was in furnace. Then it is properly stirred and then poured in the die followed by pressure application. Major findings of the experimental investigation are presented below.

1. In microstructure of specimen-2, uniform and fine distribution of alumina particles in LM2 matrix is observed. Very less grain boundaries are visible.

2. In machining, the specimen 2 is observed to have more machinability as average chip length is 8 mm and hip width is 1 mm.
3. Low squeeze pressure makes the grains coarser and the number of grain boundaries exposing to the cutting tool reduce and the MMC cutting becomes easier.

4. By macroscopic study, surface finish of machined surface of specimen 2 is more than specimen-1. The surface of specimen -1 has more waviness, with all the cutting conditions kept same.

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Madki Santosh Jaykumar, Research Scholar Khaja Banda Nawaz College of Engineering, Kalaburgi (Karnataka), India.

Dr. Vishaldatt V. Kohir, Professor Department of Mechanical Engineering, Khaja Banda Nawaz College of Engineering, Kalaburgi (Karnataka), India.