

Manufacturing of Aluminum Composite Material Using Stir Casting Process

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ABSTRACT

Manufacturing of aluminum alloy based casting composite materials via stir casting is one of the prominent and economical route for development and processing of metal matrix composites materials. Properties of these materials depend upon many processing parameters and selection of matrix and reinforcements. Literature reveals that most of the researchers are using 2, 6 and 7xxx aluminum matrix reinforced with SiC particles for high strength properties whereas, insufficient information is available on reinforcement of " Al_2O_3 " particles in 7xxx aluminum matrix. The 7xxx series aluminum matrix usually contains Cu-Zn-Mg. Therefore, the present research was conducted to investigate the effect of elemental metal such as Cu-Zn-Mg in aluminum matrix on mechanical properties of stir casting of aluminum composite materials reinforced with alpha " Al_2O_3 " particles using simple foundry melting alloying and casting route.

The age hardening treatments were also applied to study the aging response of the aluminum matrix on strength, ductility and hardness. The experimental results indicate that aluminum matrix cast composite can be manufactured via conventional foundry method giving very good responses to the strength and ductility up to 10% " Al_2O_3 " particles reinforced in aluminum matrix.

Key Words: Stir Casting, 7000 Series Aluminum Alloys; Aluminum Cast Composites, Effect of Composition on Mechanical Properties of Cast Composites, " Al_2O_3 " Particulates

1. INTRODUCTION

The modern development in the field of science and technology demands the developments of advanced engineering materials for various engineering applications, especially in the field of transportation, aerospace and military engineering related areas. These area demands light weight high strength

having good tribological properties. Such demands can only be met by development and processing of aluminum metal matrix composite materials.

The main challenge in the development and processing of engineering materials is to control the microstructure,

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mechanical properties and cost of the product through optimizing the chemical composition, processing method and heat treatment. This requires the sound theoretical and practical knowledge of the materials engineers.

The aluminum metal matrix composite materials is the combination of two or more constituents in which one is matrix and other is filler materials (reinforcements). Aluminum metal matrix may be laminated, fibers or particulates composites. These materials are usually processed through powder metallurgy route, liquid cast metal technology or by using special manufacturing process. The processing of discontinuous particulate metal matrix material involves two major processes (1) powder metallurgy route (2) liquid cast metal technology. The powder metallurgy process has its own limitation such as processing cost and size of the components. Therefore only the casting method is to be considered as the most optimum and economical route for processing of aluminum composite materials [1-25].

Literature reveals that most of the previous work was done to reinforce SiCp in various aluminum matrix composites [6,9,13,15-1, 21-24]. However, some information is available regarding Al_2O_3 particulates reinforced in various aluminum matrix [3,7-8,14,19-20, 22].

The effects of SiCp in Al-4.5% Cu-1.5% Mg alloy on mechanical properties of materials were investigated by Stefanos [19]. He prepared composite material using stir casting route and concludes positive response on fatigue and tensile strength in heat treated condition with addition of SiCp. The stir cast aluminum alloy matrix and process parameters were thoroughly investigated by Pai, et. al. [18]. They conclude from literature that stir casting process is relatively simple and less expansive as compared to other processing methods. They also emphasize that properties of cast composite materials depend upon uniformity of dispersoids, wetting of ceramic particles and containing low casting defects. Balasivanandha [16] investigated stirring speed and stirring time on distribution of ceramics particles in cast metal matrix composites using

SiCp reinforced in A348 aluminum matrix. They recommended that 600 rpm stirring speed and 10 minutes stirring time gave best results on properties of cast aluminum composites.

A 7075 aluminum alloy matrix reinforced with 15 volume percent of SiCp were prepared by using liquid metallurgy route by Rupa and Meenia [15]. The properties comparisons were made with parent metal. They found the improvements in mechanical properties and sliding wear resistance in aluminum cast composite materials. But they did not investigate the effect of " Al_2O_3 " particles reinforced with cast aluminum composites with the same material.

A low cost AMMCs product having cost \$2.20 per kg using rapid mixing process technique was developed by Darrel, et. al. [13], using SiCp in 359 aluminum matrix.

A10% and 20% SiCp reinforced in A535 and A 6061 aluminum matrix using stir casting method was investigated by Zhou and Xu [10]. They had recommended two step mixing method and preheat treatment for achieving better mechanical properties.

The processing -microstructure- mechanical properties of aluminum base metal matrix composite materials synthesized using casting route were investigated by Gupta and Surappa [9]. They had used SiC reinforced in 6061 aluminum matrix and reported the improvements in the mechanical properties up to 15% SiCp.

Das [6] has reported up to date information regarding SiCp reinforced in aluminum metal matrix composites for engineering applications.

A similar effect of " Al_2O_3 " particles reinforced with various aluminum matrix composites was observed by numbers of investigators [14,21-23]. They had investigated abrasive wear, mechanical properties and microstructure, using casting route and reported similar effect of " Al_2O_3 " particles on properties of composites materials.

Literature reveals that some previous work has been conducted to investigate the effect of Cu-Zn-Mg in

aluminum matrix alloy reinforced with " Al_2O_3 " particulate using stir casting route.

Therefore, the present work was planned to investigate the effect of Cu-Zn-Mg in aluminum matrix reinforced with " Al_2O_3 " particles using simple foundry conventional casting, for economical development of aluminum casting composite materials for engineering applications. The details of the research work are given in the subsequent sections.

2. EXPERIMENTAL WORK

For alloy development pure aluminum ingot, copper, magnesium and aluminum oxide average particles size $46\mu\text{m}$ were purchased from local market. The aluminum ingot was melted in a graphite crucible and alloyed with required quantity of Cu-Zn-Mg metals. The details of the theoretically selected alloy composition (design composition) and manufacturing processing are given Table 1 and Figs. 1-3.

TABLE 1. SELECTED COMPOSITIONS OF MASTER ALLOYS IN GRAMS FOR MANUFACTURING OF COMPOSITE MATERIALS

Alloy No.	Cu (gm)	Mg (gm)	Zn (gm)	Al (gm)
1.	0.00	122	150	4728
2.	100	140	300	4460
3.	400	50	300	4250
4.	250	50	0.00	4700
5.	150	120	300	4430



FIG. 1. MELTING OF ALLOYS

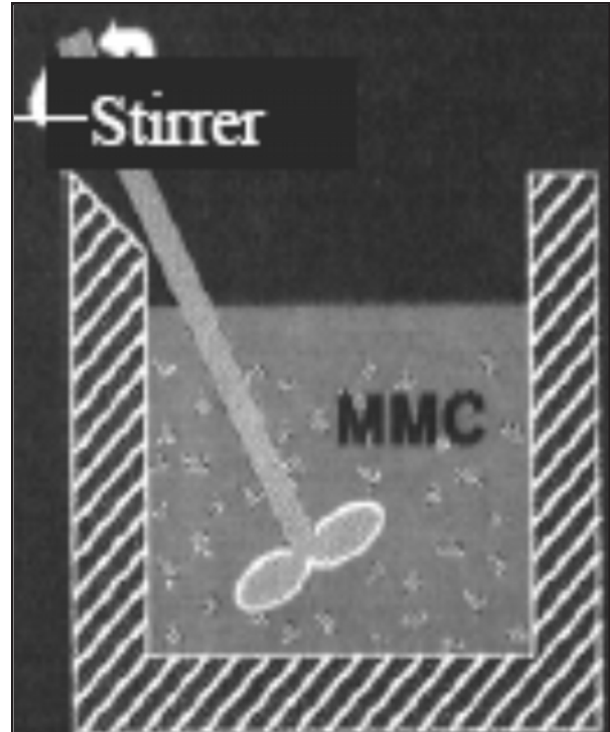


FIG. 2. STIR CASTING PROCESS (REFERENCE FROM 25, THE SAME PROCEDURE IS USED IN PRESENT WORK)

The developed alloys were purged with N_2 gas for few seconds. The required quantities of " Al_2O_3 " particles were added in 2.5, 5, 10 and 15% weight percents. The ceramics particles were mixed in a designed mixer by stirring for few minutes and cast in a steel mold consist 25 mm dia and 130mm length (Fig. 4). The casting temperature was maintained at 750°C.

The cast samples were machined to prepare standard samples. 40 standard samples were prepared using lathe machine as shown at Figs. 5-6.



FIG. 3. CASTING OF AMMC

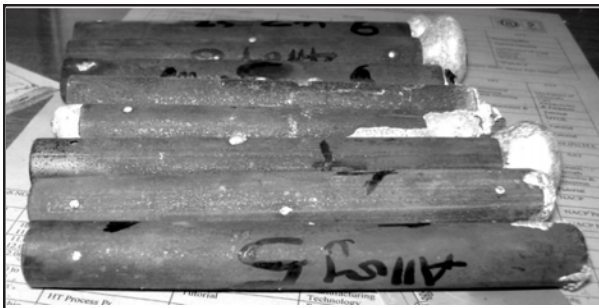


FIG. 4. CASTING OF SAMPLES IN METAL MOLD



FIG. 5. PREPARATIONS OF SAMPLES ON LATHE



FIG. 6. PREPARED STANDARD SPECIMENS FOR TENSILE TEST

20 samples were solution heat treated at 580°C for 1 hour and age hardened at 120°C for 24 hours in a muffle furnace. Tensile strength, elongation was determined using universal tensile testing machine at Dawood College of Engineering & Technology, Karachi, Pakistan. The details of the tensile test parameters are given in Table 2.

Chemical analysis of the raw material and samples were conducted using SEM and Spectrometer analysis method as shown at Figs. 7-12 and Table 3.

The Vickers hardness tests and metallographic investigations were conducted at the Department of Metallurgy & Materials Engineering, Mehran University of Engineering & Technology, Jamshoro, Pakistan, using Vickers hardness testing machine. The Vickers hardness was converted to HRB scale. The metallographic investigations of aluminum were conducted using Scanning Electron Microscope to determine micro structural porosity Fig. 13. The Optical Metallurgical Microscope was also used to investigate aluminum matrix and ceramic particles at 100X and 200X magnification as shown in Fig. 14(a-d). Fig. 14(d) clearly showing uniformly distribution of ceramic particles.

The details of the mechanical properties such as tensile strength, hardness and elongation are given in Figs. 15-19

3. RESULTS AND DISCUSSION

Keeping in view of the various limitations as reported in literature review present research work was plan to develop

aluminum alloy containing Cu-Zn-Mg in aluminum as a 7000 series at Mehran University Jamshoro. The alloys were developed using conventional casting foundry method Figs. 1-3. The alloys were reinforced with various %ages of " Al_2O_3 " particles. The alloy composition and properties were investigated using simple foundry melting alloying and conventional stir casting method.

The results mentioned in Tables 1-2 and Figs. 7-19 shows that the composition has significant effect properties of aluminum cast composites especially containing Cu-Zn-Mg in aluminum with different %age of " Al_2O_3 " particles. The mechanical properties including tensile strength, hardness and elongation were thoroughly investigated because the literature reveals very little information on the developments of 7000 series of aluminum alloy matrix reinforced with " Al_2O_3 " particles from elemental method using simple foundry conventional casting method. However, most of the previous work was done in this regard is discussed as under:

Venkatraman and Suundararajan [24], conducted research on 7075 aluminum alloy and AMMCs reinforced with SiCp using powder metallurgy method. They correlate mechanically mixed layer and wear behavior with 7075 aluminum alloy and AMMCs. They observed that precipitation hardening of AMMCs gave positive response in improving in mechanical properties. However, they did not investigated the effect of " Al_2O_3 " particles in 7075 aluminum alloy using simple conventional stir casting method.

TABLE 2. PRAMETERS OF TENSILE TESTING MACHINE

Order Number	1 2.5 Cast Sample
Charge	Rs 300
Test Standard	ASTM
Customer	M. H JOKHIO
Material	Aluminium Cast Composte Material
Extensometer	
Load Cell	Maximum 250 KN
Pre-Load	2 N/mm ²
Pre-Load Speed	10 mm/min
Test Speed	50 mm/min

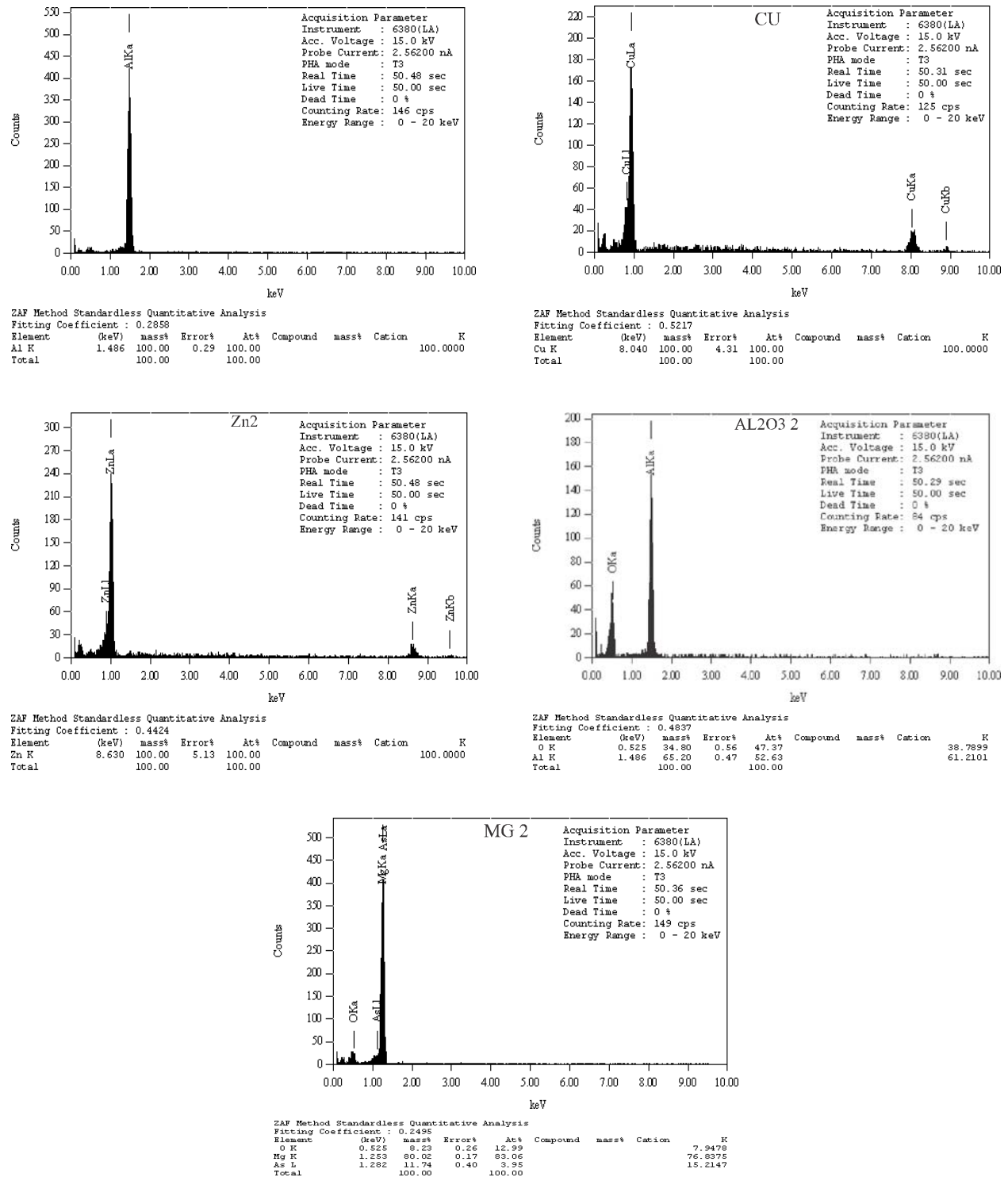


FIG. 7. ANALYSIS OF RAW MATERIAL Al, Cu, Zn, Mg AND Al_2O_3

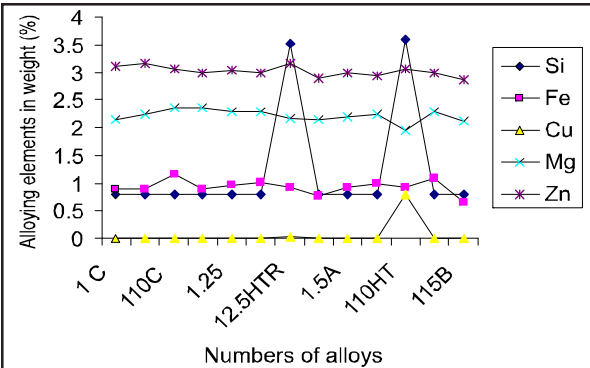


FIG. 8. ANALYSIS OF ALLOY 1

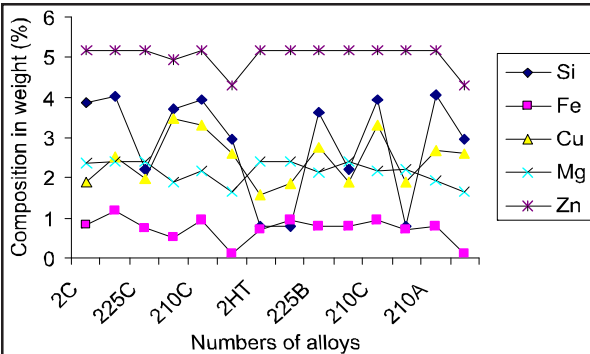


FIG. 9. ANALYSIS OF ALLOY 2

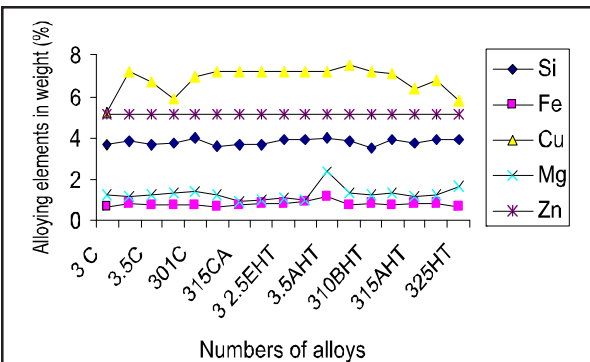


FIG. 10. ANALYSIS OF ALLOY 3

Aluminum alloy matrix containing Cu-Zn-Mg were developed by Rupa Dasgupa and Humarira Meena [15]. They developed aluminum alloy matrix from elemental metals using stir casting method and reinforced with SiCp. The properties of 7075 aluminum alloy matrix were compared with parent metal after casting and heat treatment of the same matrix the research report concluded the improvements in mechanical properties of and sliding wear resistance of cast aluminum alloy. However they did not investigated the effect of " Al_2O_3 " particulates in 7075 aluminum matrix.

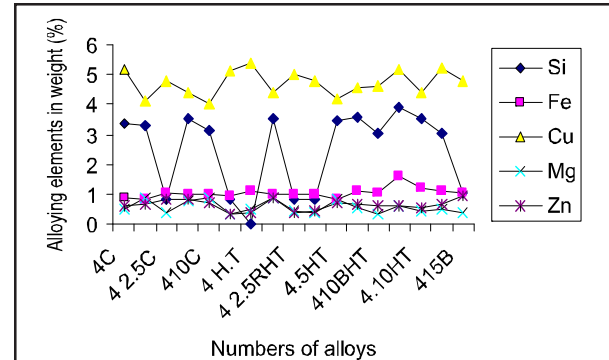


FIG. 11. ANALYSIS OF ALLOY 4

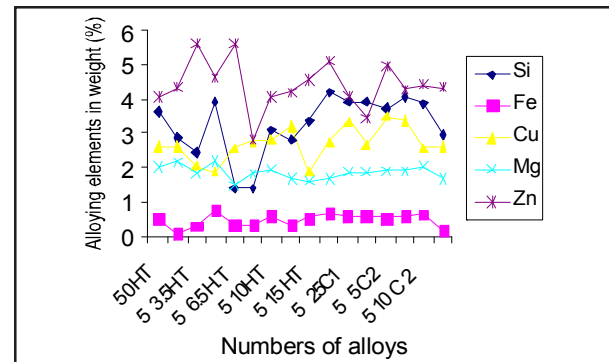


FIG. 12. ANALYSIS OF ALLOY 5

TABLE 3. THEORETICAL COMPOSITION & ACTUAL AVERAGE COMPOSITION IN WEIGHT PERCENT AS DETERMINED BY X-RAY AND SPECTROMETER TEST RESULTS.

Alloy No.	Theoretical Composition of Cu (%)	Actual Composition of Cu (%)	Theoretical Composition of Mg (%)	Actual Composition of Mg (%)	Theoretical Composition of Zn (%)	Actual Composition of Zn (%)
1.	0.00	0.066	2.50	2.20	3.10	3.00
2.	2.00	2.45	2.77	2.15	5.50	5.00
3.	8.00	7.00	1.00	1.28	6.00	5.16
4.	5.00	4.70	0.50	0.60	0.00	0.60
5.	3.00	2.70	2.00	1.80	5.00	4.40

The experimental results indicate that porosity defects were the most common factors in stir casting method Fig

18. The similar effects of porosity in stir casting were also found by numbers of investigators [1-12,14-29].

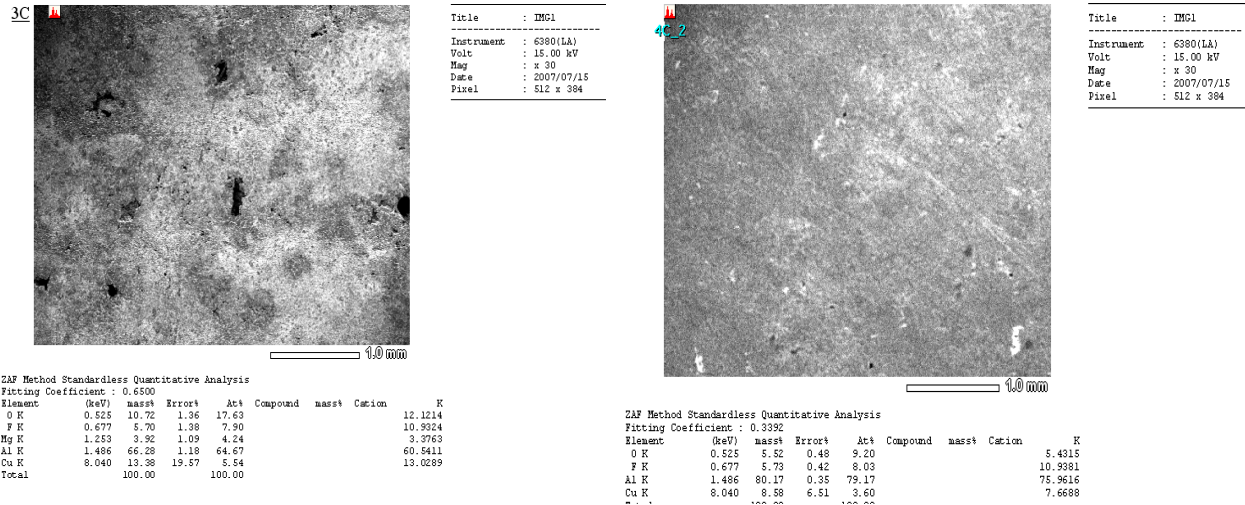


FIG. 13 SEM MICROGRAPH FOR INVESTIGATION OF POROSITY IN STIR CAST COMPOSITES ALLOY-3 AND ALLOY-4

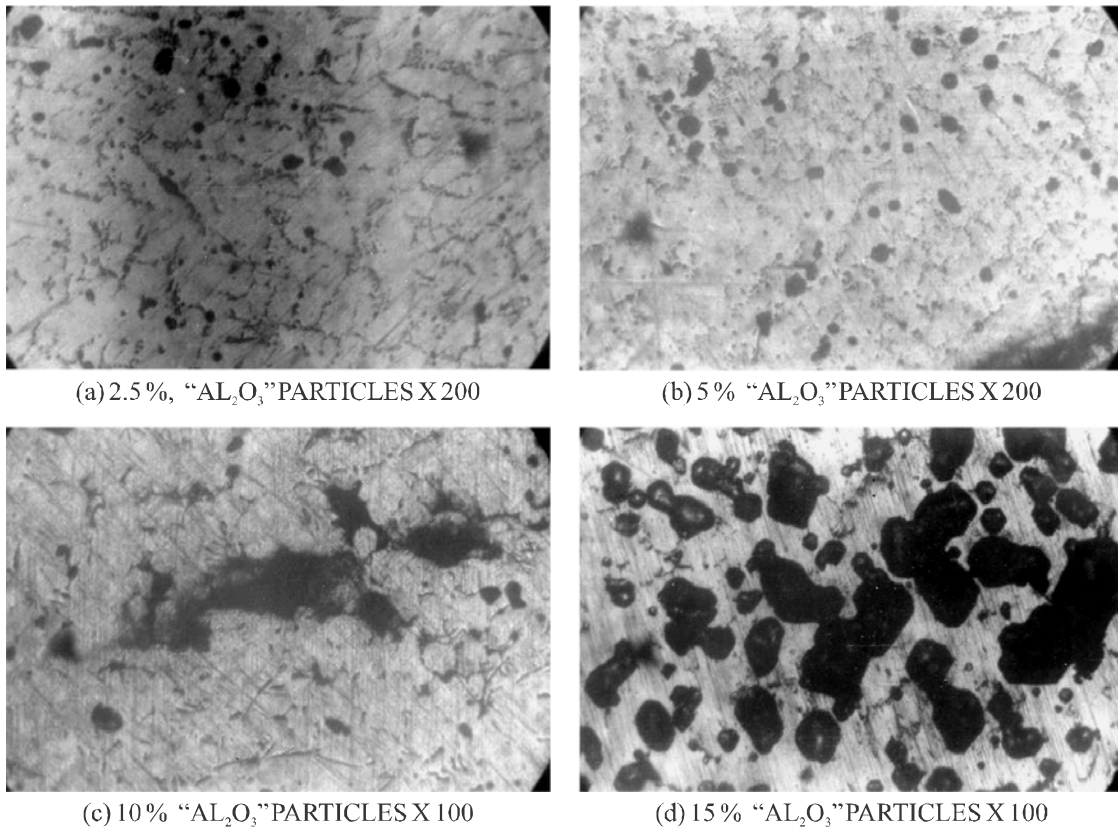


FIG. 14 A-B SHOWS THE MICROSTRUCTURE OF "AL₂O₃" PARTICLES REINFORCED IN ALUMINUM MATRIX COMPOSITES

Comparing mechanical properties alloys contains less percentage of " Al_2O_3 " as compared with alloy which contain the higher percentage " Al_2O_3 " which shows some higher strength and ductility. The high percentage of " Al_2O_3 " up to 15% in alloy 2 and 5 decreases the tensile strength. The decrease in strength of alloys is due to increase the higher percentage of " Al_2O_3 " in alloys. Literature reveals that high " Al_2O_3 " particles in matrix requires the higher melting, alloying treatments temperature and longer holding time is also required for homogenizing the alloy chemistry. The similar effect of the processing parameters and causes of

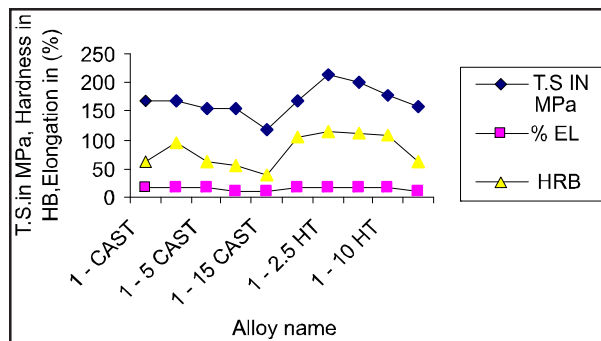


FIG. 15. MECHANICAL PROPERTIES OF ALLY-1.

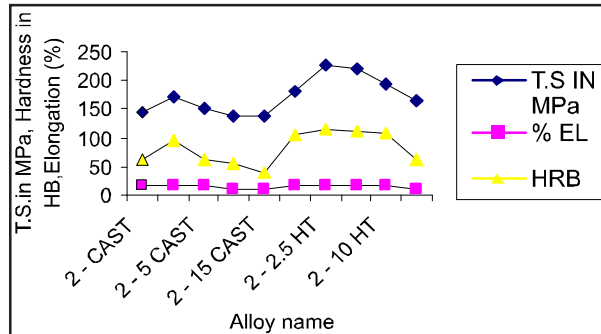


FIG. 16. MECHANICAL PROPERTIES OF ALLY-2

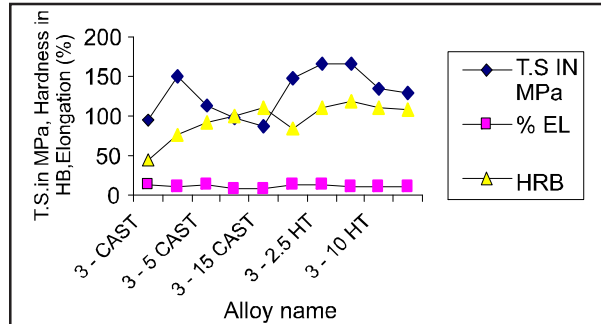


FIG. 17. MECHANICAL PROPERTIES OF ALLY-3

porosity in stir cast aluminum composites were found by number of other investigators [6,7,14].

For examples Porosity decreases the mechanical properties when particle size accedes up $50\mu\text{m}$ in stir casting as reported by Taha [6].

Hashim, et. al. [5,12], reported that porosity in stir castings is produced as a result of gases entrapped in melting and during stirring/mixing, which form gas bubbles, causes large porosity. However the causes of porosity and their control are well documented in literature [6-12].

Considering the experimental results of alloy 5 which show highest tensile strength 297 MPa was due to proper wetting and uniform distribution of ceramics particles in aluminum matrix. Similar effect of distribution of ceramic particles and their proper wetting with matrix was reported by Kok [7]. They observed that large particles dispersed more uniformly than fine particles leads to agglomerations of particles and creates porosity in vertex method in production of 2024 aluminum matrix casting composite

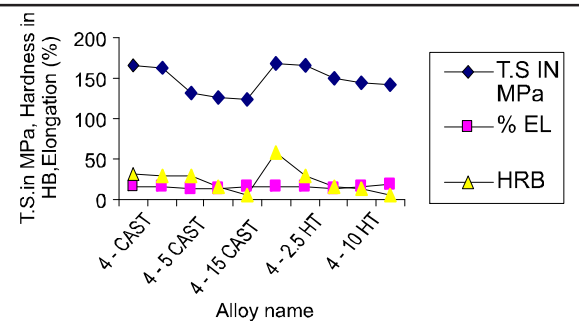


FIG. 18. MECHANICAL PROPERTIES OF ALLY-4

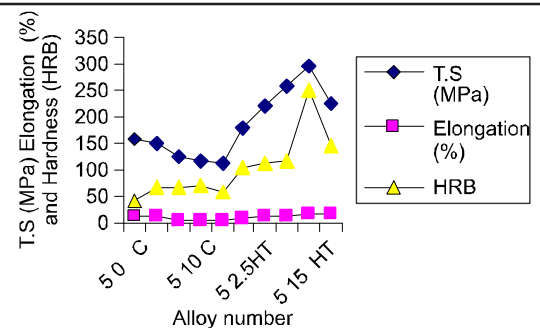


FIG. 19. MECHANICAL PROPERTIES OF ALLY-5

material reinforced with " Al_2O_3 " particles. The stir casting aluminum composite material usually inherent porosity and the degree of porosity depend on the processing parameters such as pouring temperature types of matrix and volume fraction of reinforcements [6,7,14].

It has been observed from the experimental work that Mg content up to 2.77% increases the wetting ability of the ceramics particles as compared to alloys which contains less or no Mg. The similar effect of Mg has been found by other investigators [3,5,11,12,15,17,22].

It is also observed that the tensile strength increases as the percentage of " Al_2O_3 " particle increase in as cast aluminum alloys up to 2.5% " Al_2O_3 " particles in as cast conditions. This increases is due to the presence of " Al_2O_3 " Particles which act to refine the grain size of aluminum casting composites by nucleating fine grains size during the solidification process in as cast conditions. The decrease in tensile strength and ductility with increase the volume fraction of " Al_2O_3 " particles up to 15% in as cast condition have been observed in aluminum alloy matrix. This is due to increase in porosity in stir casting aluminum matrix [6,7,14].

The experimental results especially in alloy 1, 2 and 5 showing good aging response on mechanical properties of aluminum alloy matrix cast composite is also yields very good response after solution treatment and ageing at 120°C for 24 hour shows increase in properties. The effect of Cu-Zn-Mg metals in aluminum matrix using SiCp were investigated by number of investigators [10-11,15,21-22]. But they did not investigate the effect of " Al_2O_3 " particles in same aluminum matrix.

Comparing mechanical properties of present investigation with the previous work conducted by other investigators using stir casting method (Table 4), giving superior responses to strength increases up to 300 MPa and ductility up to 17 % with addition of 10% " Al_2O_3 " particles reinforced in aluminum matrix.

4. CONCLUSIONS

- (i) Aluminum alloy matrix can be developed successfully with the addition of Cu-Zn-Mg metals and reinforced with " Al_2O_3 " using simple foundry melting alloying and casting route.
- (ii) Results show that " Al_2O_3 " particles up to 10% increase the tensile strength 297 MPa and elongation 17% in aluminum alloy matrix containing Cu-Zn-Mg in aluminum.

TABLE 4. COMPARISONS OF TENSILE STRENGTH AND ELONGATION RESULTS WITH THE RESULTS OF OTHER INVESTIGATORS

Author Name	Country	Reference	Matrix Composition	Reinforcement	Process Used	Strength	El
Jokhio	Jamshoro Pakistan	[28, 29]	Al-Cu-Zn-Mg	Particulate " Al_2O_3 " 48 μm	Stir Casting	297MPa	17%
Kok	Turkey	[7]	Al-Cu 2024	10% " Al_2O_3 " Max	Vortex	112 MPa	Not Determined
Yilmaza	Turkey	[14]	Si.46 MM .17	" Al_2O_3 " 20 μm 15 Val%	Stir casting	195 MPa	Not Determined
Srapppa and Rohatgi	India	[8]	Al- 11.8% Si 1-4% " Al_2O_3 "	" Al_2O_3 " 53-63 μm	Vertex	157Mpa with 1% " Al_2O_3 "	6%
						118 Mp with 4% " Al_2O_3 "	2.5%
Stefanos Skolianos	Greece	[19]	4.5% Cu, 1.5% Mg	" Al_2O_3 " 50 μm 20 24 .2%	Stir casting	194 MPa	Not determined
Azim, et all	Egypt	[21]	2024 4.12 Cu and 1.94 Mg	" Al_2O_3 " 50-150 μm 10% " Al_2O_3 "	Vertex	132 MPa	3.2%
Rupa Das Gupta and Humaira Meenai	India	[15]	7075 Al-Cu-Mg-Zn Cu 1.6, Mg 2.5, Zn 5.6	Si Cp 40 μm 15 wt%	Stir casting	As cast alloy 63 MPa T6 100 MPa	1.13 1.56%

- (iii) The results also suggest that Cu contents in small quantity less than 2.7% Cu increases the strength and ductility along with Mg and Zn contents in aluminum matrix as in case of alloy 1
- (iv) Porosity generally found in stir casting of aluminum composites increases with increase in " Al_2O_3 " particles contents in aluminum matrix especially containing high %age of alloy addition .
- (v) The higher tensile strength in stir cast aluminum composites reinforced with 2.5% " Al_2O_3 " particles in all alloy samples do not decrease the overall mechanical properties in aluminum stir casting composites is due to refining of grain size of composite.
- (vi) Mg has pronounced effect on aluminum cast composites up to 2.77% Mg contents which increases wetability, reduces porosity and develops very good bonding with " Al_2O_3 " particles, and aluminum matrix 1 and 5 yields superior properties as compared with other aluminum matrix 3 and 4.
- (vii) 2-3% Mg in combination with 4.5% Zn in aluminum matrix reinforced with 10% of " Al_2O_3 " alloy number 1 and 5 particles yields best combination of strength and ductility in case of a heat treated conditions.
- (viii) The over all mechanical properties can be improved by precipitation hardening process in aluminum matrix as well as in aluminum cast composites reinforced with " Al_2O_3 " particles.

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