Journal of Materials and Metallurgical Engineering
Volume 3, Issue 1, ISSN: 2231 - 3818

A Novel Technique for Improved Recovery of Mg-Analysis of the Microstructure and Physical Properties

B.P. Samal[1]*, A.K. Misra[2], S.C. Panigrahi[3], S.C. Mishra[4]
[1]Department of Mechanical Engineering, Maharaja Institute of Technology, Taraboi, Khurda, Odisha, India
[2]Krutika Institute of Technical Education, Bhubaneswar, Odisha, India
[3]Rajadhani Engineering College, PO. Mancheswar, Railway Colony, Bhubaneswar, Odisha, India
[4]Department of Metallurgical and Materials Engineering, NIT Rourkela, Odisha, India

Abstract
Aluminium-Magnesium alloys are used widely in industrial applications as well as for the preparation of metal matrix composite because of their low density and high specific strength. Magnesium has a low boiling point and the recovery of magnesium is poor when it is added in pure form particularly as cheaply available turnings to the liquid metal. Magnesium is added to aluminium for increasing its wettability and thus helping in uniformly distributing ceramic particles used as reinforcement. There have been very few attempts to use the magnesium turnings to produce cast Al-Mg alloys in the range of 3-15% magnesium. A modified stir casting technique was developed using a plunger for making alloy addition by the casting route utilising cheap magnesium turnings. The recovery of Mg was close to 90% and even higher, when added in the form of turnings. In this paper, the density of Al-Mg alloy is predicted with a quadratic model. Also, the percentage of decrease in density for the magnesium alloys increased with increase in magnesium addition and the relation can be represented by a quadratic equation. This technique will be effective on improving the recovery of alloy additions with low density high volatility.

Keywords: *alloying, stir casting, hollow shaft, plunger rod, volatile alloy additions*

****Author for correspondence*** E-mail: b_p_samalrx100@yahoo.co.in

INTRODUCTION
Aluminium and its alloys particularly with magnesium are used as a possible replacement for steel due to high corrosion resistance, high specific strength and possibility of heat treatment. Aluminium-Magnesium alloy exhibit attractive properties such as low density, good manufacturability and high specific strength. Over 40% of total Mg is used to manufacture Al-Mg alloys. Magnesium as an alloy addition improves strength and reduces the density of aluminium. It makes Aluminium alloys age hardenable. It also helps in improving the wettability thus making it easier to produce ceramic particle metal matrix composites. However, as magnesium has a lower density and high volatility there is a significant loss of magnesium if added to the liquid aluminium the pure form particularly as magnesium turnings. A modified stir casting technique is presented in this paper for preparation of Al-Mg alloy utilising low cost scrap magnesium. Magnesium turnings have been used to produce Al-Mg alloys through the powder metallurgy route [1, 4]. Mg content in the commercial aluminium alloys are usually 0.5% to 13%. The low magnesium alloys provide best formability and the high magnesium alloys have good castability and high strength. Magnesium is often added to aluminium matrix ceramic reinforced composites to improve the wettabilty so as to get better distribution of the reinforcement particles melt [2].

A plunger was used for introducing magnesium turnings into the aluminium melt along with a stir casting setup commonly used for metal matrix composite preparation. The process is a modification of the stir casting technique used for obtaining a uniform distribution of ceramic particles in a liquid melt [3]. In the normal practice of stir casting cast metal matrix composite is produced by melting the matrix material then, introducing the reinforcement particles. Increased recovery of magnesium reduces the consumption of costly magnesium simultaneously reducing the magnesium vapour in the atmosphere as well as the density of the Al-Mg alloy decrease considerably [4–8].

EXPERIMENTAL PROCEDURE

Equipment

A common laboratory model stir casting apparatus was improved upon to suit the present work; where, the usual impeller solid shaft was substituted by a hallow mild steel tube as the spindle. Figure 1 shows the basic arrangements of the modified stir casting assembly unit which has been utilised for Al-Mg alloy preparation.

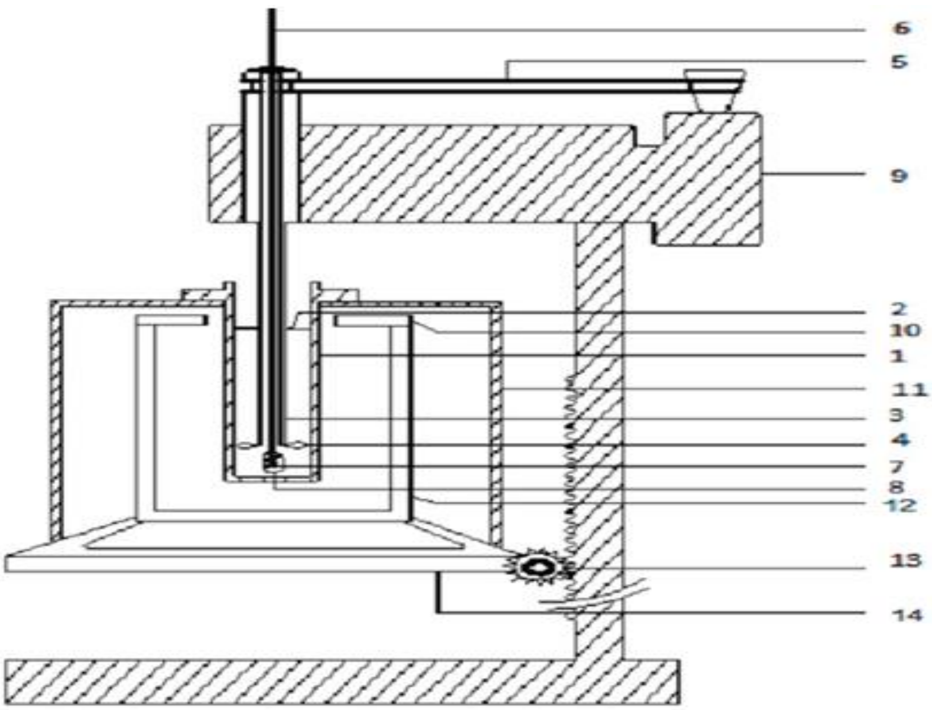

Fig. 1: *Schematic Diagram of Modified Stir Casting Apparatus for Preparation of Al-Mg Alloy*
(1)Crucible,(2)Melt Level,(3)Hollow Spindle,(4)Impeller Blade ,(5)V belt drive, (6)Plunger Rod ,(7)Capsule, (8)Mg Particle ,(9)A.C Motor and Gear Assembly ,(10)Split Cover,(11)Crucible Holder ,(12)Furnace,(13)Rack and Pinion Arrangement,(14)Base Plate.

In Figure 1a, mild steel cylindrical container 1(coated with alumina cement) is used to hold the Al melt 2. The assembly consists of a hollow spindle 3 with stirrer blades 4 attached at the bottom and a motor and V-belt arrangement 5 for rotating the spindle to effect agitation (stirring) in the aluminium melt so that homogeneous dispersion of Mg can take place. The plunger rod 6 attached with perforated capsule 8 is used to hold magnesium turnings. Magnesium (metal) turnings were packed into a perforated mild steel capsule and wrapped with an aluminium foil as shown in Figure 2 for alloy making. 7 grams of magnesium was packed in each capsule.

Fig. 2: Photograph of Capsule Welded to Plunger Rod.

MATERIALS

The Al-Mg alloy was prepared from commercially pure Al supplied by NALCO, India in the form of 20 kg ingot. The chemical composition of the aluminium used is given in Table 1.

Table 1: Chemical Composition of Aluminium Ingot Used.

Al	Si	Fe	V	Mn	Cu
99.76	0.08	0.15	0.006	0.003	0.001

Table 2: Chemical Composition of Magnesium Turning Used for Alloying.

Mg	Al	cu	Fe	Pb	Mn	Ni	Si	Zn
99.68	0.05	0.005	0.05	0.005	0.1	0.005	0.1	0.005

Magnesium metal turning was used for preparation of Al-Mg alloy. The composition Mg turning is given in Table 2

PROCEDURE

To start with the technique 700 gm of small Al blocks were cut from Al-ingot and was melted in a cylindrical crucible (made up cast iron coated with alumina cement) in a resistance furnace. The temperature was maintained at 800 ºC (well above liquidus temp of Al). Then, the impeller assembly was lowered into the crucible leaving a clearance of 2cm from the bottom of crucible. This clearance helps to accommodate the capsules. A split semi-circular cover was used to reduce heat loss from the hot metal. Then the stirrer was turned. The rpm of the stirrer was 500. Magnesium turnings in the capsule were dropped one after the other through the hollow spindle. Each capsule was packed with 7 gm of magnesium turnings. The release of magnesium started after the melting of the aluminium foil. Liquid aluminium enters into the capsule and magnesium starts to dissolve. It took about 15 seconds to complete dissolution of magnesium in the aluminium melt. The number of capsules charged depended on the composition aimed at. The process was smooth and effective. The alloy melt was stirred for 2-minutes for adequate homogenization. Then crucible was lifted manually from the furnace and the melt was poured into previously readied mould made of fire bricks joined by fire clay. The mould size was (18×8×5) cm^3. The surface appearance of cast was smooth, clean and shinning. The samples for density measurement and microstructure analysis were collected from each ingot.

RESULTS AND DISCUSSION

Samples for density measurement were collected from each casting. The density of the each alloy samples was measured using Archimedes principle. The samples were weighed in an electronic balance and volume of samples were measured by water displacement using measuring flask. The density was calculated by the formula Density=Mass/Volume. The results are given in Table 3. The density of Al-Mg alloys was calculated as percentage of magnesium added. The percentage decrease in alloy density is tabulated in Table 4.The variation in % of magnesium added and density were recorded. The data were fitted with linear and quadratic model as given in equation 1a, 1b and 2a, 2b.

Figure 3(a) and 3(b) shows the experimental data and the predicted values from the models for the density from the linear and quadratic model respectively. It is observed that the quadratic model can predict the density of alloy with very good accuracy. The % of decrease in Alloy Density vs. % of Magnesium added plot is shown in Figure 4(a) and 4(b) along with data form linear and quadratic model. The variation of % of decrease in alloy Density with magnesium content also can be predicted accurately with the quadratic model.

Table 3: *Variation of Alloy Density with Magnesium Addition.*

% of Mg added	1	3	5	7	10	14
Alloy Density(gram/c.c.)	2.696	2.668	2.641	2.621	2.585	2.545

Linear Model
Equation is- Y= –0.01154*x + 2.703 Eqn-1a
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = –0.01154 (–0.01255, –0.01053)
p2 = 2.703 (2.695, 2.711)

Goodness of fit:
SSE: 6.014e-005
R-square: 0.996
Adjusted R-square: 0.995
RMSE: 0.003878

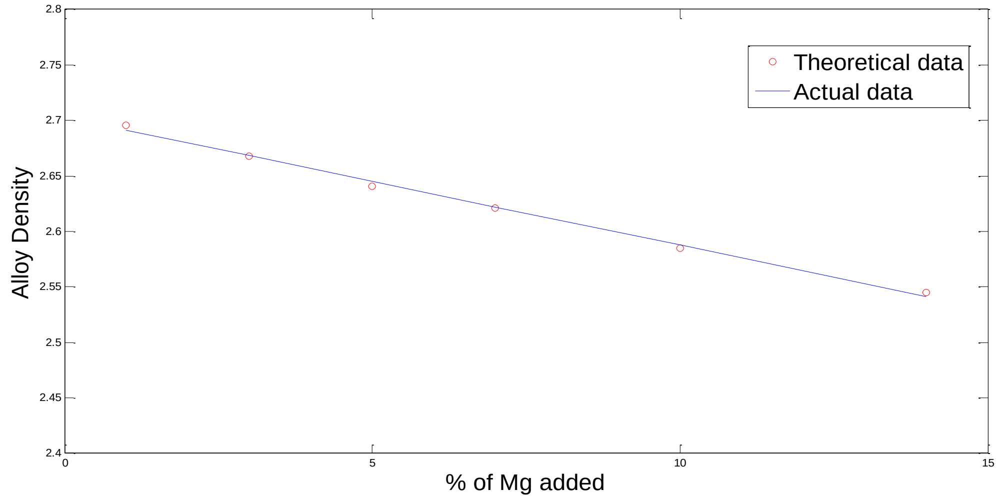

Fig. 3(a): *Linear Model Curve for % of Magnesium Added vs. Alloy Density.*

Quadratic Model
Equation is- Y= (0.0001701 $*X^2$) – (0.0141 X)+0.04107 Eqn-1b
f(x) = p1*x^2 + p2*x + p3
Coefficients (with 95% confidence bounds):
p1= 0.0001701 (3.664e–005, 0.0003037)
p2 = –0.0141 (–0.01618, –0.01203)
p3 = 2.709 (2.703, 2.716)

Goodness of fit:
SSE: 9.277e-006
R-square: 0.9994
Adjusted R-square: 0.999
RMSE: 0.001758

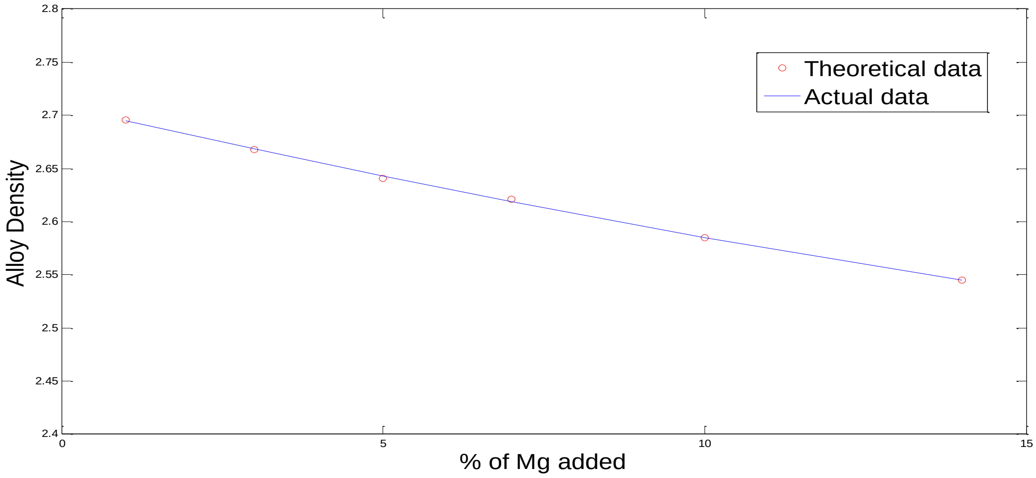

Fig. 3(b): *Quadratic Model Curve for % of Magnesium Added vs. Alloy Density.*

Table 4: *Variation of % of Decrease in Alloy Density with Magnesium Addition.*

% of Mg added	1	3	5	7	10	14
% of Decrease in Alloy Density	1.4	4.2	6.9	8.9	12.5	16.5

Linear Model
Equation is- Y= 1.154*x + 0.7059 Eqn-2a
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 1.154 (1.053, 1.255)
p2 = 0.7059 (–0.09891, 1.511)

Goodness of fit:
SSE: 0.6014
R-square: 0.996
Adjusted R-square: 0.995
RMSE: 0.3878

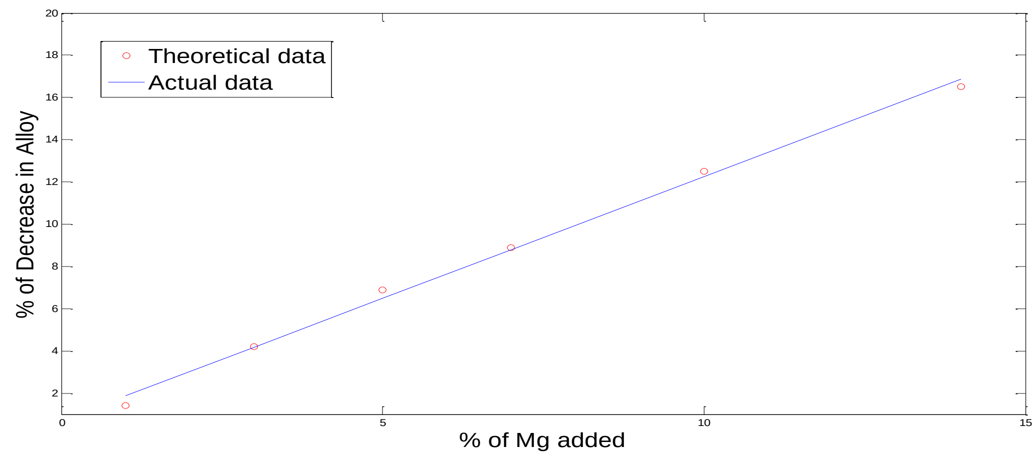

Fig. 4(a): *Linear Model Curve for % of Magnesium Added vs. % of Decrease in Alloy Density.*

Quadratic Model
Eqution is- Y= – (0.01701 $*X^2$) + (1.41 X)+0.07533 Eqn-2b
f(x) = p1*x^2 + p2*x + p3
Coefficients (with 95% confidence bounds):
p1 =–0.01701 (–0.03037, –0.003664)
p2 =1.41 (1.203, 1.618)
p3 =0.07533 (–0.5726, 0.7233)

Goodness of fit:
SSE: 0.09277
R-square: 0.9994
Adjusted R-square: 0.999
RMSE: 0.1758

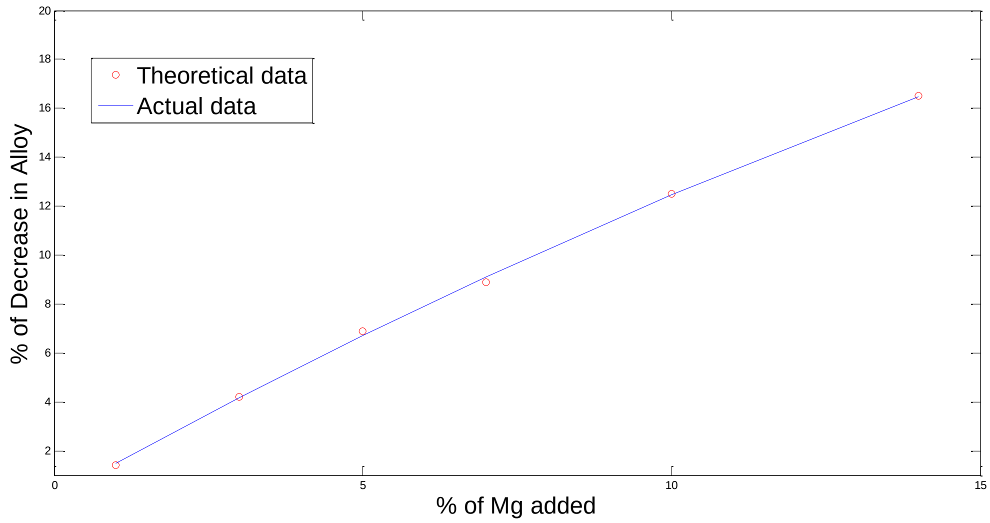

Fig. 4(b): *Quadratic Model Curve for % of Magnesium Added vs. % of Decrease in Alloy Density.*

Microstructure Analysis

The samples from each ingot of Al-Mg alloy are collected for microstructure analysis. The microstructures were conducted with OLYMPUS BX51 optical microscope. From the micrographs (Figure 5–10), it is evident that the reference Al-Mg cast ingot shows no visible porosity or blow holes, which means that our cast product in this process is very sound.

Fig. 5: *The Microstructure of Al-1wt%Mg Alloy.*

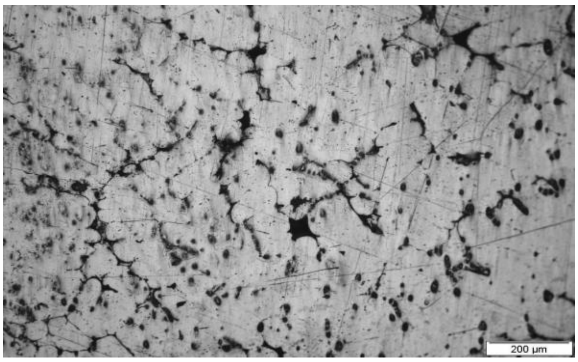

Fig. 6: *The Microstructure of Al-3wt%Mg Alloy.*

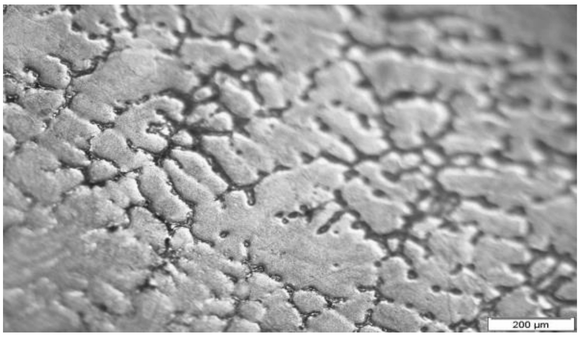

Fig. 7: *The Microstructure of Al-5 wt% Mg Alloy.*

Fig. 8: *The Microstructure of Al-7 wt% Mg Alloy.*

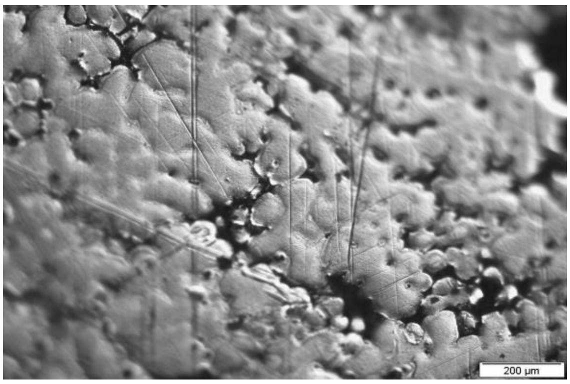

Fig. 9: *The Microstructure of Al-10 wt% Mg Alloy.*

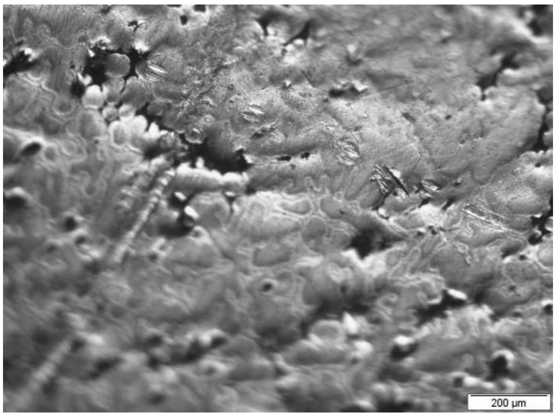

Fig. 10: *The Microstructure of Al-14 wt% Mg Alloy.*

CONCLUSION

The modified stir casting method with plunger rod can be used to reduce drastically the loss of magnesium on melting even with the use of magnesium turnings. The density can be decreased in cast Al-Mg alloys. The decrease in density data can be fitted with a quadratic model with a high accuracy. The technique can also be used to better the uniformity of distribution of the alloy addition to the melt as compared to simple stir casting. There is an increase in percentage of decrease in alloy density with increase in Magnesium addition and the data can be fitted with a quadratic model.

REFRENCES

1. Hanumanth, G.S., G.A Irons. Particle incorporation by melt stirring for the production of metal matrix composite. *Journal of Material Science*.1993; 28: 2459–2465p.
2. Hashim, J. The production of cast metal matrix composite by a modified stir casting Method. *Journal Teknologi*. 2001; 35(A), 9–20p.
3. Hashim J., l. looney, M.S.J.Hashmi. Metal matrix composites: Production by the stir Casting Method. *Journal of Materials Processing Tech*. 1999; 92-93, 1–7p.
4. Hibono, A.H. Iwatsubo, H. kawajiri. Compaction Forming and Melting Experiment in Molten Aluminium of Mg Machine Waste Chips by mixing of Mg chips, Al chips and Aluminium Melting Flux. *J. Jpn. Soc. Powder Powder Metallurgy*. 2008; 55(12):
5. Rohatgi P. Cast Metal Matrix Composites: Past, Present And Future. *AFS Trans* 2001; 01–133p.
6. Suryanarayana, C., E.Ivanov, V.V.Boldyrev. The Science and Technology of Mechanical Alloying Material Science and Engineering 2001; A304-306,151–158p.
7. Wahab M. N, A. R. Daud and M. J. Ghazali. Preparation and characterization of stircastAluminum nitride reinforced aluminum metal matrix composites. *International Journal Of Mechanical and Materials Engineering* (IJMME). 2009; 4(2): 115–117p.
8. Hashim.J, L.Looney, M.S.J.Hashmi. The Wettability of SiC Particles by Molten Aluminium Alloy. *Journal of Materials Processing Tech*. 2001; 119: 324–328p.