

INFLUENCE OF ZINC AND MAGNESIUM ADDITION ON THE FLUIDITY OF Al-Zn-Mg ALLOY

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Abstract

The goal of this research was to investigate the influence of zinc and magnesium on the fluidity of Al-Zn-Mg alloy. The fluidity test was carried out using a serpentine-shape sand mould. The length of the serpentine-shape pattern was 180 cm. The experiment was designed by varying the compositions of zinc from 1 to 5 wt%, and magnesium from 0.5 wt% to 2.5 wt%. Variation in compositions of the two elements was done separately, and later a combined variation in compositions of zinc and magnesium was investigated. The superheat temperature was placed at 70°C above the liquidus temperature. From the results obtained, it was observed that there was general increase in fluidity when the percentage weight composition of magnesium was increased. Alloy with 2.3 wt% Mg was found to have the highest fluidity, followed by alloy with 2.85 wt % Mg. When the percentage weight compositions of zinc were increased, there was a general decrease in fluidity of the Al-Zn-Mg alloy, in which alloy with 5.14 wt % zinc recorded the lowest fluidity of 57.1 cm as compared to the as-cast alloy. Also for the combined variation in compositions of zinc and magnesium, it was discovered that there was decrease in the flow length of the alloy, where alloy with 5.14 wt% Zn and 2.85 wt% Mg combined has flow length of 59.8 cm. But the reduction in fluidity length when the composition of zinc was varied was more drastic as compared to that of the combined alloying elements.

Keywords: fluidity, serpentine- shape sand mould, pattern, liquidus

1 Introduction

The increasing demand of light weight, high strength cast alloys has triggered a substantial increase in the world production of aluminium alloy castings in the past two decades [1]. The industrial demand of thin-wall castings in aluminum alloys is of great importance in order to produce light components. The production of thin wall castings is limited by the fluidity of the molten metal. Metal flow during mould filling is undoubtedly an important process in foundry. The castability/fluidity is an important feature since it limits the wall thickness that can be successfully filled [2].

In addition to properties and part performance, castability has become an important parameter in the development of aluminium cast alloys. Melt fluidity is one of the critical properties influencing castability of an alloy and is affected by many variables [3]. Aluminium producers

have increased research activity in the area of advanced aluminium alloys to provide improved performance characteristics [4].

One of the important factors considered in foundry technology is the fluidity of the alloy used. Castability is frequently considered to be synonymous with fluidity, but actually castability embraces such factors as high fluidity and freedom from microporosity and hot tears [5]. Fluidity can be defined as a material's ability to flow into and fill a given cavity, as measured by the dimensions of that cavity under specified experimental conditions before it is been stop by solidification [6]. Fluidity, in the casting sense, refers to the property of a metal, which allows it to flow when it is been poured into a standard fluidity test channel. This channel may be straight or it may be in the form of a spiral, the cross-section may be round, half round, trapezoidal, or rectangular [5]. A primary requirement for all casting processes is for the metal alloy to fill the mould cavity and to replicate the details in the mould (or die) cavity walls [7]. Generally, the distance that an alloy flows into a specifically designed cavity is taken as a measure of the alloy's fluidity.

The majority of fluidity investigations in the last 25 years have focused on maximizing fluidity with respect to precise alloy chemistry. Many methods have been developed to measure the fluidity of molten alloys. All these methods can be categorized into three. The first is based on measuring the distance to which the metal runs in a special fluidity-testing mould. The second is based on measuring the volume of flow through a given section before flow stops. The third is based on measuring the pressure loss between two points placed a given distance apart in the alloy's flow path. The flow length measurement is the traditional method and several types of apparatuses have been developed for this measurement. Fluidity tests have been developed and are used commercially as quality checks to determine the flowing qualities of metals [8-11]. From the casting engineering point of view, poor fluidity characteristics are a major factor leading to the occurrence of misrun defects in thin wall casting.

Fluidity of molten metal is of significant importance in producing sound castings, particularly thin-walled castings. To meet the industrial demands of complex shaped castings, the knowledge of the parameters affecting fluidity is required in order to have a better control of the production processes. Since fluidity is one of the measures by which the castability of metals can be quantified, a definition and a description of castability are presented in this study. A definition of fluidity follows. Fluidity depends on many factors and this study reports the influence of one of the main factors: alloy composition. Particle size has a strong influence on flow length [12-13].

The objective of this work is to produce Al-Zn-Mg alloy with different compositions via casting and to determine the influence of Zinc and Magnesium addition on the fluidity of the alloy. To accomplish this, a Serpentine –shape fluidity test was used to determine the fluidity of the alloys.

2 Experimental procedure

The materials used in this study are Al-Zn-Mg alloy, Pure Magnesium and Zinc which were sourced from Nigeria foundry Lagos, Nigeria. The following equipment were used in this experiment: gas-fired lift out crucible furnace, crucible, serpentine- shape pattern (made of mild steel) with a diameter of 14 mm and length 180 cm, moulding boxes with dimensions 59 cm length, 32 cm breadth and 6 cm height , meter rule, pouring cup having a volume of 104 cm³ and weight of 281.6Kg, K-type thermocouple, electronic digital weighing balance, hack saw and mass spectrometer.

A 180 cm long, 14 mm in diameter serpentine-shape pattern made of mild steel was used to prepare the mould. Green sand mould was prepared using 80 % Silica sand mixed with 10 %

bentonite as binder to give the moulding sand strength and plasticity, 2 % coal dust as carbonaceous material to enhance permeability and 8 % water was added to activate the clay properties and also to enhance mouldability and flowability of the sand. The sand mixture was prepared using a sand mixer. The moulds were then prepared using moulding boxes of dimensions 59 cm length, 32 cm breadth and 6 cm height. The moulds were allowed to dry in air for two days to remove moisture.

Sample A was used as the control sample which contains the composition shown in **Table 1**. The experiment was divided into three groups with each sample containing 500 g of aluminium-Zn-Mg alloy. Sample A was used as the control for the experiment. Group 1 contains samples tagged B1, B2, B3, B4 and B5 respectively with varied percentage weight of zinc (1.0, 2.0, 3.0, 4.0 and 5.0) respectively. Group 2 contains samples tagged C1, C2, C3, C4 and C5 respectively with varied weight percent of magnesium (0.5, 1.0, 1.5, 2.0 and 2.5) respectively. Group 3 contain samples labeled D1, D2, D3, D4 and D5 with varied weight percent of zinc and magnesium combined.

Table 1 Chemical Compositions of Al-Zn-Mg Alloys in [wt %]

Samples S/N	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	V	Al
A	0.3014	0.0961	0.0081	<0.005	0.6801	0.0022	0.0019	1.5423	0.0064	Bal.
B1	0.3211	0.0980	0.0079	<0.005	0.6834	0.0027	0.0021	2.8512	0.0099	Bal.
B2	0.3142	0.0962	0.0072	<0.005	0.6841	0.0025	0.0021	3.6252	0.0089	Bal.
B3	0.3387	0.0961	0.0072	<0.005	0.6839	0.0022	0.0025	4.2173	0.0120	Bal.
B4	0.3388	0.2186	0.0049	0.0411	0.6584	0.0028	0.0015	4.6232	0.0063	Bal.
B5	0.3397	0.2231	0.0049	0.0431	0.6715	0.0028	0.0010	5.1433	0.0075	Bal.
C1	0.3427	0.0952	0.0074	<0.005	1.0412	0.0022	0.0024	1.5379	0.0950	Bal.
C2	0.2941	0.0940	0.0072	<0.005	1.5253	0.0017	0.0024	1.4846	0.0920	Bal.
C3	0.2861	0.0872	0.0070	<0.005	1.9881	0.0017	0.0025	1.5163	0.0092	Bal.
C4	0.3493	0.2410	0.0054	0.0401	2.3673	0.0028	0.0015	1.4631	0.0053	Bal.
C5	0.3480	0.2337	0.0047	0.0421	2.8532	0.0030	0.0015	1.4956	0.0058	Bal.
D1	0.3113	0.0881	0.0069	<0.005	1.0412	0.0027	0.0023	2.8512	0.0099	Bal.
D2	0.3241	0.0954	0.0072	<0.005	1.5172	0.0021	0.0019	3.6415	0.0089	Bal.
D3	0.3381	0.0964	0.0068	<0.005	1.8573	0.0022	0.0021	4.2417	0.0990	Bal.
D4	0.2743	0.0901	0.0050	0.0426	2.3673	0.0028	0.0015	4.6232	0.0063	Bal.
D5	0.2172	0.0899	0.0049	0.0431	2.6921	0.0028	0.0010	5.0257	0.0053	Bal.

Five hundred grams (500 g) of Al-Zinc alloy was charged into the crucible, weighing 1.8 Kg and put into a gas-fired lift out crucible furnace. The charge was allowed to melt on firing. The molten alloy was quickly poured into a preheated pouring cup of volume 104 cm³ and immediately poured into the prepared mould. The temperature of the melt before pouring into the various prepared sand mould was maintained at 730°C for all samples using a temperature probe (thermocouple). The process was repeated for sample B1. At this time, 5.1 g of zinc was added to the molten metal and stirred vigorously to give a homogenous mixture for 10 minutes. The temperature was also maintained at 730°C. The hot liquid alloy was immediately poured into the preheated pouring cup and quickly into the mould. After each casting the crucible was cleaned thoroughly to avoid contamination. The experiment was repeated for samples B2 to B5,

C1 to C5, D1 to D5 with variations in weight of zinc and magnesium accordingly and a constant melt superheat was maintained. The experiment was repeated twice and the average fluidity measurement was taken.

3 Results and discussion

3.1 Effect of Zinc on the Fluidity of Al-Zn-Mg Alloy

The result in **Fig. 1(a)** shows the percentage variation of the weight of Zinc from 1.54 wt% to 2.85 wt% Zn in the Al-Zn-Mg alloy and it was observed to have a flow length of 62.8 cm, which indicates a decrease in fluidity length by 3.2 % as compared to sample A (1.54 wt % Zn) which has a fluidity length of 64.9 cm. The fluidity in sample B2 (3.62 % Zn) was observed to be 59.2 cm, which also shows a further reduction in fluidity by 8.7 %. This decrease in fluidity when the percentage weight of zinc was increased could be as a result of change in solidification mode that occurred in the Al-Zn- Mg alloy. The flow length of 4.22 wt% Zn was measured to be 61.0 cm. This value indicates a decrease in fluidity as compared to the control sample A which has a fluidity length of 64.9 cm. But the flow length of sample B3 was discovered to be higher than that of sample B2 (3.62 wt% Zn). This could be as a result of the slight increase in the percentage weight composition of silicon present in the alloy. Silicon has been found to increase fluidity of aluminium alloy as stated by Adefuye, [14], Di sabatino, [6]. Presented in **Fig. 1(a)** is also the flow length of sample B4 which has weight percent of zinc to be 4.62 wt % in the Al-Zn-Mg alloy to be 60.6 cm. This value of fluidity length shows a further decrease in fluidity of the A-Zn-Mg alloy in comparison to other alloy modifications of lower weight percentages of zinc in the alloy. It was also observed that there was a drastic reduction in fluidity as indicated in **Fig. 1(a)** when the compositions of zinc was increased from 4.62 wt% to 5.14 wt% (Sample B5). This decrease in fluidity when the percentage weight of zinc was varied in Al-Zn-Mg alloy is in conformity with the result obtained by Gowri and Samuel [15] , who studied effect of alloying elements on the solidification characteristics and microstructure of Al-Si-Cu-Mg-Fe 380 alloy and it was observed that there was a decrease in fluidity .

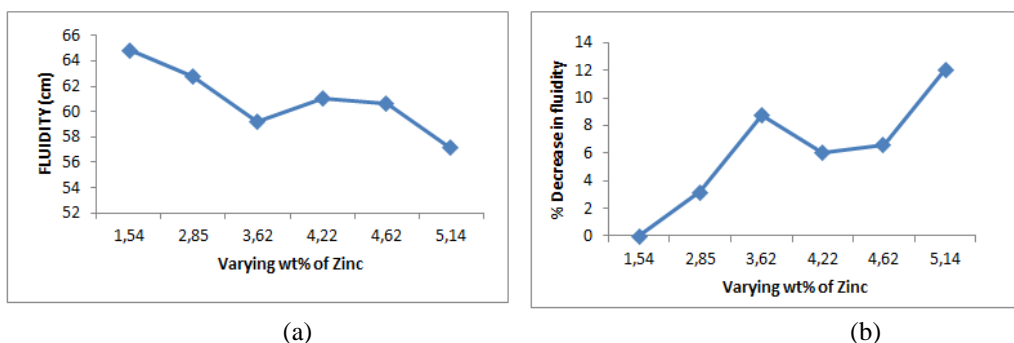


Fig. 1 Variation in Percentage Weight Composition of Zn on (a) Fluidity and (b) Percentage Decrease in Fluidity of Al-Zn-Mg Alloy with varying wt% of Zinc.

Presented in **Fig. 1(b)** is the % decrease in fluidity of Al-Zn-Mg alloy when the percentage weight of zinc was varied. In **Fig. 1(b)** the percentage decrease in fluidity of Sample B1 (2.85 wt% Zn) was calculated to be 3.2 %, which is the lowest amongst other weight percentages of zinc that was varied in the alloy. Sample B2 (3.62 wt% Zn) has a percentage decrease in fluidity of 8.7 % while 4.22 wt% Zn represented by sample B3 has percentage decrease in fluidity of 6.0

%. There was further increase in the percentage decrease in fluidity of samples B4 (4.62 wt% Zn) which was calculated to be 6.6 %. Furthermore, varying the weight percent of zinc in the Al-Zn-Mg alloy, it was discovered that there was a percentage decrease of 12% in fluidity. This drastic decrease in fluidity was recorded as the highest, when compared to other weight percentage compositions of Zinc in the alloy that was investigated. This decrease in flow length may also be attributed to the fact that the freezing range in the alloy increases as the weight percent of zinc was continuously increased, thereby causing the solidification morphology to be mushy and dendrites which obstructs the flow [16].

3.2 Effect of Magnesium on Fluidity of Al-Zn-Mg alloy

The result in **Fig. 2(a)** shows the effect of magnesium on the fluidity of Al-Zn-Mg alloy by variation in the percentage weight composition of Magnesium. Sample A (0.68 wt% Mg) which serves as the control for the experiment, has a fluidity length of 64.9 cm. When the percentage weight of magnesium in the alloy was increased to 1.04 wt% as represented by Sample C1, it was observed that the fluidity length of was 66.5 cm which shows an increase in fluidity. The result also shows that 1.53 wt % of magnesium present in the Al-Zn-Mg alloy was observed to have a flow length of 67.9 cm, while the fluidity length of sample C3 with 1.9 % Mg was measured to be 67.9 cm which also shows a further increase in fluidity when compared to Sample A. This increase in fluidity could be as a result of magnesium forming a phases, which have high heat of fusion and hence delaying the solidification of the alloy and also its ability to act as modifying agent [17]. This is in line with the work of Sahoo and Sivaramakrishnan [18], who studied the effect of modification of magnesium on the fluidity of Al-8.3Fe-0.8V-0.9Si alloy for near net casting. Sample C4 (2.37 wt% Mg) was measured and its fluidity length was observed to be 70.0 cm. This has the highest fluidity length as observed in the experiment. Sample C5 with 3.85 wt% of Magnesium has a fluidity length of 68.4 cm.

From **Fig. 2(b)** (which shows the percentage increase in fluidity of the Al-Zn-Mg alloy on varied percentage of Magnesium), it was observed that the percentage increase in fluidity of sample C1 was 3.1 %, that of sample C2 was 3.4 %. Comparing sample C1 with C2 it was observed that there was only 0.4 % difference in their fluidity. 1.99 wt% Mg has a percentage increase in fluidity of 4.6 %. Sample C4 has a percentage increase of 7.8 % as shown in **Fig. 2(b)**. 3.85 wt% Mg been represented by sample C5 has a percentage increase of 5.4%.

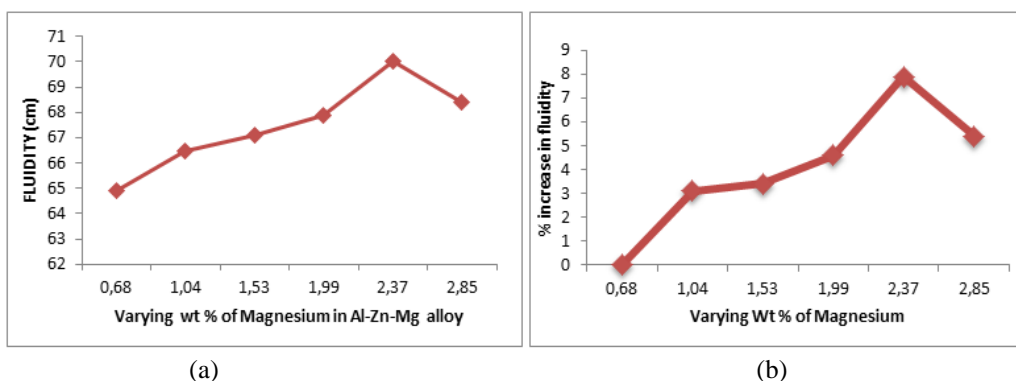


Fig. 2 Variation in Percentage Weight Composition of Mg on (a) Fluidity and (b) Percentage Increase in Fluidity of Al-Zn-Mg Alloy with varying wt% of Magnesium.

3.3 Effect of combined variation in percentage composition of zinc and magnesium on the fluidity of Al-Zn-Mg alloy

The combined percentage variation of zinc and magnesium on the fluidity of Al-Zn-Mg alloy is shown in **Fig. 3(a)**. By increasing the percentage zinc and magnesium from 1.54 wt% to 2.85 wt% and 0.68 wt% to 1.04 wt% respectively, the fluidity length of the cast alloy was measured to be 64.1 cm. Sample D2 with percentage weight of 3.62 wt% Zn, 1.53 wt% Mg, when measured has a flow length of 62.6 cm, indicating a reduction in fluidity length. Also it was observed that when the percentage composition of Zinc and Magnesium were varied (sample D3) to 4.22 wt% and 1.99 wt%, the fluidity length was found to be 63.3 cm. This reduction in fluidity could be as a result of interaction between zinc and magnesium present in the alloy and since it was observed that Magnesium tends to increase fluidity while zinc reduces flow length, there tends to be counteractions of the two alloying elements [19], [20]. The fluidity length of sample D3 was found to be higher than that of sample D2. The fluidity length of sample D4 (4.62 wt% Zn, 2.37 wt% Mg) was measured to be 63.7 cm. Sample D5 (5.14 wt% Zn, 3.85 wt% Mg) has a fluidity length of 59.8 cm. Sample D5 has the lowest fluidity length when compared with other samples.

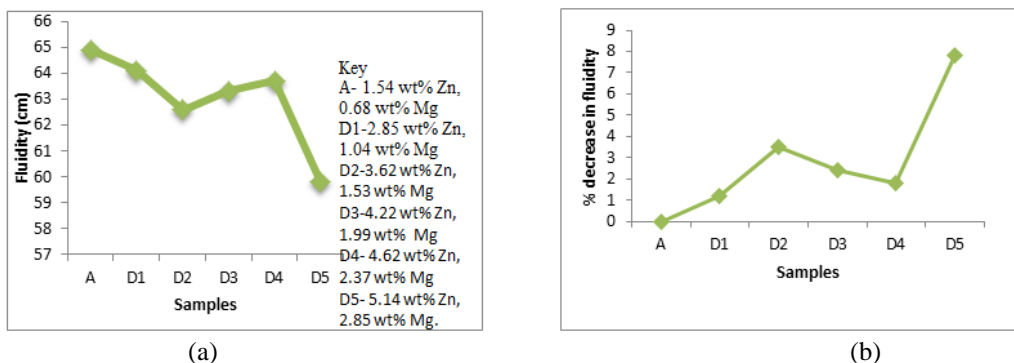


Fig. 3 Variation in Percentage Weight Composition of Mg and Zinc on (a) Fluidity and (b) Percentage decrease in Fluidity of Al-Zn-Mg Alloy with varying wt% of Magnesium and Zinc

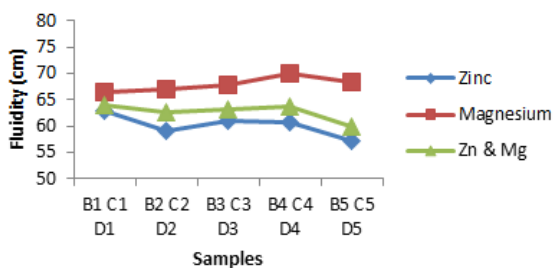


Fig. 4 Comparison of Variation in Percentage Weights of Zinc, Magnesium and Combination of both on Fluidity of Al-Zn-Mg alloy

The percentage decrease in fluidity of varying the percentage weights of zinc and magnesium is shown in **Fig. 3(b)**. The percentage decrease in fluidity of sample D1 was calculated to be 1.2

%, while that of sample D2 has percentage decrease in fluidity of 3.5 %. Sample D3 with 4.22 wt% Zn, 1.99 wt% Mg has percentage decrease in fluidity of 2.4 %. Samples D4 and D5 have percentage decrease in fluidity of 1.8 % and 7.8 % respectively.

Fig. 4 clearly shows that fluidity is highest when the percentage weight of magnesium was varied independently in the Al-Zn-Mg alloy. Fluidity value was also high when the percentage weights of zinc and magnesium were varied. But in this case fluidity measurement was lower than that of variation of magnesium and higher than the variation of percentage weight of zinc independently.

4 Conclusion

In this investigation, the following conclusions are drawn:

- I. The study revealed that by increasing the zinc content independently in Al-Zn-Mg alloy, there was decrease in fluidity of the alloy.
- II. When the percentage weight of magnesium was increased independently in Al-Zn-Mg alloy, there was increase in fluidity.
- III. It is also worthy of note that as the percentage weight of both zinc and magnesium were varied, there was decrease in fluidity, but this decrease in flow length was not as drastic as that of variation in weight percent of zinc of the alloy.
- IV. The influence of variation of both zinc and magnesium, shows a better fluidity properties as compared to the variation of weight percent of zinc independently.

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