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A COMPARATIVE ANALYSIS OF MOULD FILLING TIME, SOLIDIFICATION TIME,VOLUME FLOW RATE AND MASS FLOW RATE IN MULTI-MATERIAL CASTING OF Al-Zn ALLOYS

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Abstract-Casting is a suitable economical manufacturing process for various components. The lightweight construction is based on the principle of making the best possible use of the material. Whenever a single material does not satisfy the needs according to the property required. Especially in light weight construction, a multi-material-mix can provide ideal specific properties that are suitable for the conditions to which a part is subjected. Typically such combinations of dissimilar materials provide desired properties in various areas of the single part. The mould filling time is the parameter that have not yet been studied for Zn-Al alloy. The length of the time from which the molten metal starts entering into the mold cavity to fill it completely is known as mould filling time or it may be also called as pouring time. The purpose of this paper is to introduce the mould filling time , solidification time, volume flow rate and mass flow rate in multi-material casting.

***Keywords*- Mould filling time, Multi-material casting, Aluminium-Zinc alloys , Mass flow rate, Volume flow rate**

I. INTRODUCTION

Casting is one of the oldest manufacturing processes, and even today is the first step in manufacturing most products in industries. Nowadays, in industries it is very important to save time and money in manufacturing product, because there is lots

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of competition in industrial world. Vehicle construction and aerospace in particular demand solutions which save as much weight as possible while fulfilling identical or even greater requirements with regard to component properties, and which can be produced at low cost. Mould and pouring temperature is calculated by analysis of variance technique, this work shows that the selected technique is an effective tool for analyzing sand casting process [1]. To optimize performance, a combination of materials is the most efficient method, because one material is often insufficient to fill the complete requirement. The compound casting is the process which meets a wide range of requirements within one component by combining different materials. In addition to saving weight, it has the added advantage of reducing bonding processes. From above explanation we can identify the following needs of the multi-material casting:

- Light weight construction of the equipments.
- To satisfy more than single demand for any kind of application.
- To produce different mechanical properties in a single part of a machine.

The mould filling time is one of the important factors that play an important role in the casting process. If the mould filling time will be predefined by some specific formulae then it will become easier to make calculation for the total time that may take to complete the process of casting. That may lead to find the manpower required. This can also be implemented in the automation if the specific formula is defined.

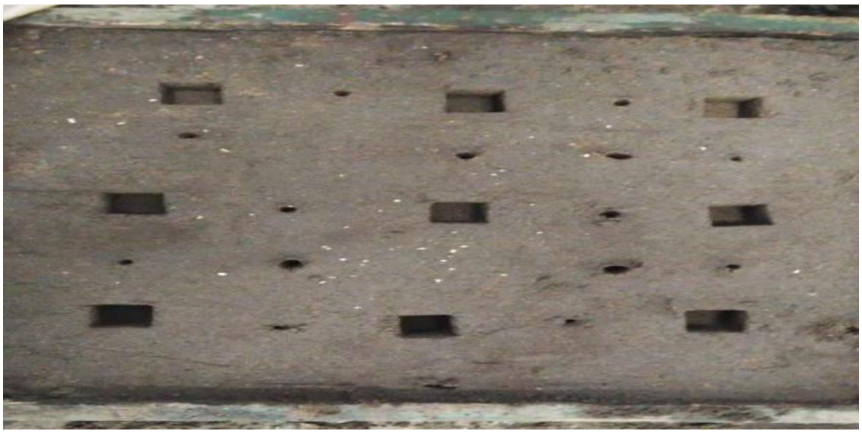

Figure 1 Sand mould cavity

II. Methodology

The process involved in the multi-material casting is described that gives the complete steps that needs to accomplish the above process. Before applying this method we need to take a great care of the material that we are going to use for any of the specific purpose. The properties of the materials play a vital role in to produce a desired effect in the application defined.

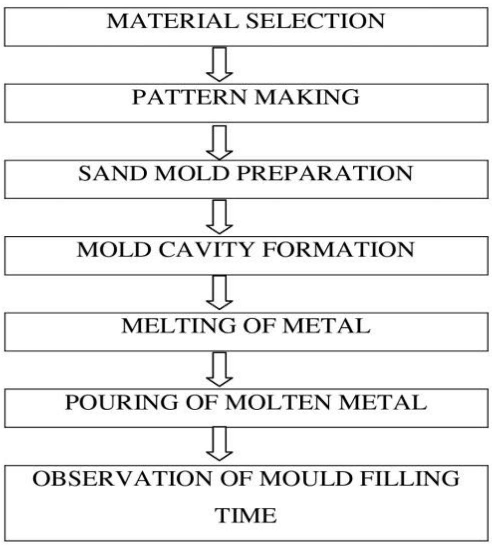

Figure 2 Multi-material casting process.

A. Material selection

Material selection is a one of the challenging task in the multi-material casting process. It arises numbers of question in the actual practice. Because the combination of any of two or more material need a deep study for its physical , chemical and mechanical properties.

The material used here by studying the properties is given in table 1 and 2 for Al and Zn respectively. Aluminium is the most common element in the earth crust and exists as aluminium oxide. It possesses some peculiar properties such as high resistance to corrosion, ease of fabrication, high thermal and electrical conductivity, low weight and bright colour. Aluminum alloy casting has melting temperature of 660°C and its pouring temperature range is between 649°C to -750°C. The knowledge of melting temperature of metals and alloys is necessary to estimate their corresponding pouring temperature.

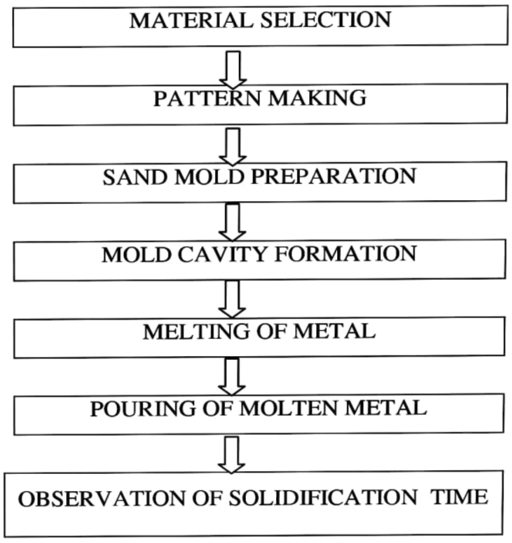

Table I Properties and Specification of Aluminium

Sr. No.	Properties of Material	Material Specification
1	Density	2700 kg/m^3
2	Strength	310 MPa
3	Corrosion Resistance	High Resistance
4	Thermal Conductivity	237 W/Mk
5	Melting Point	660^{0}C

Table II Properties and Specification of Zinc

S.No.	Properties of Material	Material Specification
1	Density	7100 Kg/m^3

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2	Strength	200 MPa
3	Corrosion Resistance	High Resistance
4	Thermal Conductivity	115 W/mK
5	Melting Point	419.58^{0}C

B. Pattern making

The pattern is the principal tool during the casting process. It is the replica of the object to be made by the casting process. The figure shows the replica of the casting to be produced.

Figure 4 Pattern

C. Preparation of sand moulding

First of all moulding sand was produced when the sand of known specification is mixed with water to foundry. Mould boxes were produced using wood as shown in figure 5. The drag was placed on a flat wooden board and then a cylindrical pattern placed on the board. The moulding sand was added to the pattern and rammed, properly. When properly rammed, the mould box containing the pattern was turned upside down and the parting sand was applied. The cope was place on the drag and care was taken to ensure proper alignment.

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Figure 5 Mould box

1) Green sand mould

Green sand is also known as tempered or natural sand which is a just prepared mixture of silica sand with 18 to 30 percent clay, having moisture content from 6 to 8%. The clay and water furnish the bond for green sand. It is fine, soft, light, and porous. Green sand is damp, when squeezed in the hand and it retains the shape and the impression to give to it under pressure as shown in figure 6. Molds prepared by this sand are not requiring backing and hence are known as green sand molds.

Figure 6 Green sand mould

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D. Mould cavity formation

Green sand mixture is filled into the mould box then it is pressed using mechanical tools . Thereafter when it becomes very smooth surface ,the pattern is pressed into the mould then the replica of the pattern is formed . The same process is being repeated and the small holes are produced to create vents into the mould to keep the smooth surface inside the mould cavity as shown in figure 1.

E. Melting of metal

The various combination of the metals in the specific proportion by weight is taken into a crucible and it is placed in the furnace The furnace gives the higher temperature as required by burning the cokes inside. The process includes melting the charge, refining the melt, adjusting the melt chemistry and tapping into a transport vessel.

Figure 7 Furnace

Figure 8 Melting of metal

F. Pouring of molten metal

When the metal is melted completely it comes into the liquid state .The molten metal from the crucible is put into the vessel having circular cross section so that constant flow rate can be maintained. Pouring can be accomplished with gravity, or it may be assisted with a vacuum or pressurized gas.

Figure 9 Pouring of molten metal

G. Observation of the mould filling time

The mould filling time is the time taken to fill the mould cavity from the constant cross –section provided in the discharge vessel. The mould filling time can also be termed as the pouring time. The stop watch is used to count the time .This time is being noted down for getting mass flow rate and volume flow rate etc.

H. Observation of the solidification time

The mould filling time is the time taken to fill the mould cavity from the constant cross –section provided in the discharge vessel. The time taken to solidify the molten metal is determined by using the stop watch.

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III. CALCULATIONS

The calculation for the desired parameters is made by using the 21 samples of different composition of aluminium and zinc in their alloy. Starting from 100% Al & 0% Zn , 95% Al & 5% Zn ……till 0% Al & 100% Zn. The mould filling time has been studied carefully and is described by tables ,figures, curves etc. Then final conclusion is analysed to obtain a unique output.

Table III Mould filling time for Al-Zn Alloy

S. No.	Percentage Amount (in %)		Mould Filling Time (T_1) in Sec	Mould Filling Time(T_2) in Sec	Mould Filling Time(T_3) in sec	Average Mould Filling Time, (T_f)avg (in sec)
	Al	Zn				
1	100	0	4.8 sec	4.8 sec	4.7 sec	4.76
2	95	5	4.6 sec	4.7 sec	4.7 sec	4.66
3	90	10	4.5 sec	4.5 sec	4.4 sec	4.46
4	85	15	4.3 sec	4.6 sec	4.4 sec	4.43
5	80	20	4.2 sec	4.3 sec	4.3 sec	4.26
6	75	25	4.1 sec	4.0 sec	4.0 sec	4.03
7	70	30	3.8 sec	3.9sec	4.0 sec	3.9
8	65	35	3.8 sec	3.8 sec	3.8 sec	3.8
9	60	40	3.7 sec	3.65 sec	3.6 sec	3.65
10	55	45	3.55 sec	3.4 sec	3.4 sec	3.45
11	50	50	3.4 sec	3.2 sec	3.2 sec	3.26
12	45	55	3.0 sec	3.0 sec	3.1 sec	3.03
13	40	60	2.8 sec	2.85 sec	2.85 sec	2.81
14	35	65	2.85 sec	2.8 sec	2.8 sec	2.81
15	30	70	2.72 sec	2.78 sec	2.76 sec	2.75
16	25	75	2.6 sec	2.55 sec	2.5 sec	2.55
17	20	80	2.5 sec	2.5 sec	2.48 sec	2.49

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18	15	85	2.4 sec	2.46 sec	2.38 sec	2.41
19	10	90	2.35 sec	2.2 sec	2.28 sec	2.28
20	5	95	2.22 sec	2.0 sec	2.0 sec	2.07
21	0	100	1.8 sec	1.9 sec	1.86 sec	1.85

Table IV Solidification time for Al-Zn Alloy

S. No.	**Percentage Amount (in %)**		**Solidification Time (T_1) in Sec**	**Solidification Time(T_2) in Sec**	**Solidification Time(T_3) in sec**	**Average Solidification Time, (T_f)avg (in sec)**
	Al	Zn				
1	100	0	2min. 41 sec	2min. 40 sec	2min. 41 sec	2min. 40.6 sec
2	95	5	2min. 42 sec	2min. 42 sec	2min. 42 sec	2min. 42 sec
3	90	10	2min. 43 sec	2min. 42 sec	2min. 40 sec	2min. 41.6 sec
4	85	15	2min. 43 sec	2min. 41 sec	2min. 43 sec	2min. 42.3 sec
5	80	20	2min. 47 sec	2min. 43 sec	2min. 43 sec	2min. 44.3 sec
6	75	25	2min. 48 sec	2min. 46 sec	2min. 49 sec	2min. 47.6 sec
7	70	30	2min. 52 sec	2min. 49 sec	2min. 46 sec	2min. 49 sec
8	65	35	2min. 57 sec	2min. 53 sec	2min. 46 sec	2min. 52 sec
9	60	40	2min. 46 sec	3min. 0 sec.	2min. 59 sec	2min. 55 sec
10	55	45	3min. 5 sec	3min. 7 sec	3min. 2 sec	3min. 4.6 sec
11	50	50	3min. 4 sec	3min. 7 sec	3min. 4 sec	3min. 5 sec
12	45	55	3min. 4 sec	3min. 6 sec	3min. 7 sec	3min. 5.6 sec
13	40	60	3min. 4 sec	3min. 7 sec	3min. 9 sec	3min. 6.6 sec
14	35	65	3min. 5 sec	3min. 7 sec	3min. 10 sec	3min. 7.3 sec
15	30	70	3min. 5 sec	3min. 9 sec	3min. 9 sec	3min. 7.6 sec
16	25	75	3min. 7 sec	3min. 9 sec	3min. 9 sec	3min. 8.3 sec
17	20	80	3min. 7 sec	3min. 11 sec	3min. 9 sec	3min. 9 sec

18	15	85	3min. 9 sec	3min. 10 sec	3min. 9 sec	3min. 9.3 sec
19	10	90	3min. 9 sec	3min. 10 sec	3min. 10 sec	3min. 9.6 sec
20	5	95	3min. 10 sec	3min. 11 sec	3min. 11 sec	3min. 10.6 sec
21	0	100	3min. 12 sec	3min. 11 sec	3min. 12 sec	3min. 11.6 sec

Table V Volume flow rate and mass flow rate of Al-Zn alloy

S. No.	Percentage Amount (in %)		Average Mould Filling Time (T_{avg}) in Sec	Volume of the mould cavity in cm^3	Volume Flow Rate of molten metal in cm^3/s	Weight of the product (in gm)	Mass Flow rate Of molten metal (in gm/sec)
	Al	Zn					
1	100	0	4.76	15.625	45	3.282	0.689
2	95	5	4.66	15.625	46	3.353	0.719
3	90	10	4.46	15.625	48	3.503	0.785
4	85	15	4.43	15.625	50	3.527	0.796
5	80	20	4.26	15.625	51	3.667	0.860
6	75	25	4.03	15.625	53	3.877	0.962
7	70	30	3.9	15.625	55	4.006	1.027
8	65	35	3.8	15.625	56	4.111	1.081
9	60	40	3.65	15.625	58	4.280	1.172
10	55	45	3.45	15.625	60	4.528	1.312
11	50	50	3.26	15.625	63	4.792	1.469
12	45	55	3.03	15.625	65	5.156	1.701
13	40	60	2.81	15.625	69	5.560	1.978
14	35	65	2.81	15.625	72	5.560	1.978
15	30	70	2.75	15.625	76	6.681	2.429
16	25	75	2.55	15.625	86	6.127	2.402

17	20	80	2.49	15.625	89	6.275	2.520
18	15	85	2.41	15.625	93	6.483	2.690
19	10	90	2.28	15.625	99	6.853	3.005
20	5	95	2.07	15.625	104	7.548	3.646
21	0	100	1.85	15.625	110	8.446	4.565

IV. RESULTS AND DISCUSSIONS

The table 3 indicates the mould filling time of the mixture of Zn and Al by varying percentage .From the above data we observe that the average pouring time is decreasing with increase in % of Zn in Al-Zn alloy. The curve is drawn below by using the above data of pouring time.

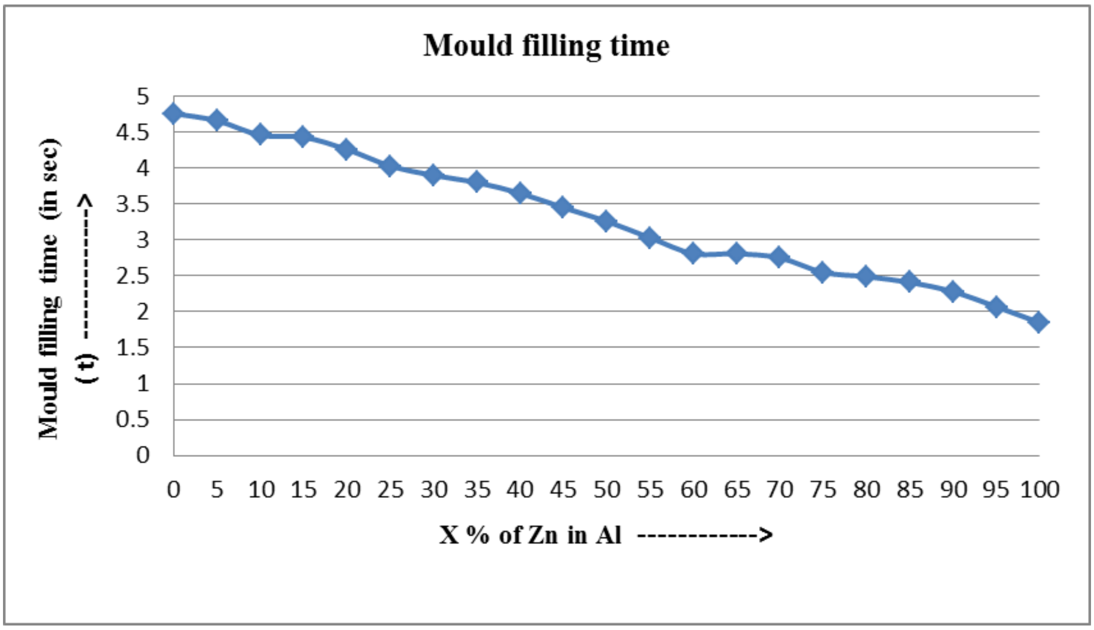

Figure 10 Mould filling time curve

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The curve drawn above here the curve is drawn between the mould filling time denoted by (t) which is indicated in vertical axis and percentage of Zn in Al-Zn alloy

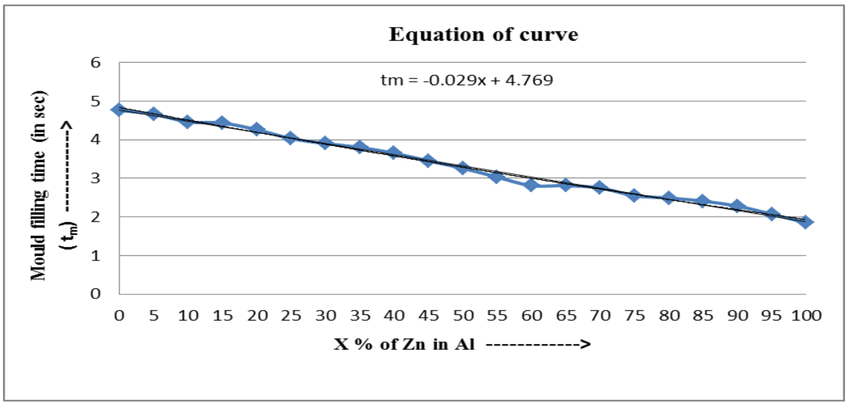

Figure 11 Mould filling time curve equation

The graph obtained by using the data in table III gives the following equation-

Mould filling time (t_m) = -0.029x + 4.769

This is the polynomial equation of order 1 where x is the percentage of Zn in Al –Zn alloys .By using this equation the mould filling time for any percentage of Zn in Al-Zn alloy can be calculated.

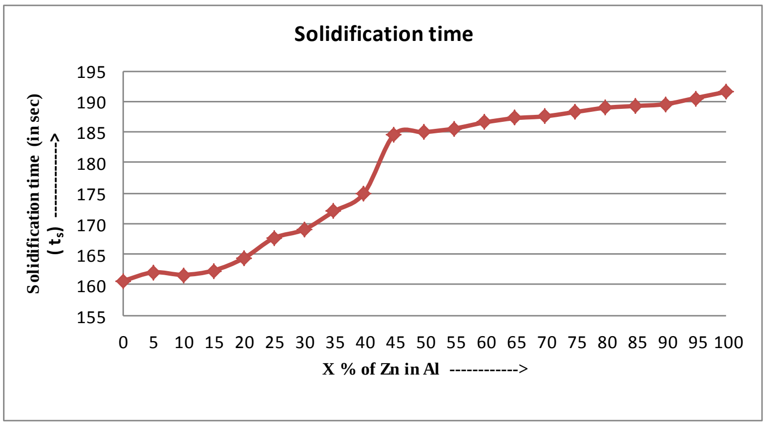

Figure 12 Solidification time curve

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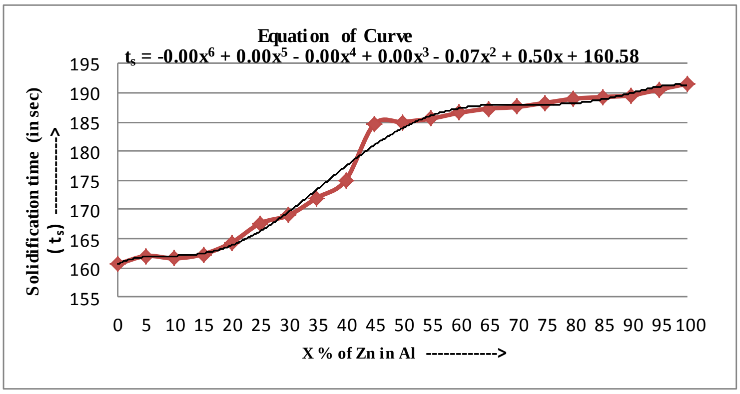

Figure 13 Solidification time curve equation

The graph obtained by using the data in table III gives the following equation

Solidification time, $t_s = -0.00x^6 + 0.00x^5 - 0.00x^4 + 0.00x^3 - 0.07x^2 + 0.50x + 160.58$

This equation can be written also be written as-

Solidification time, $t_s = -0.07x^2 + 0.50x + 160.58$

This is the polynomial equation of order 2 where x is the percentage of Zn in Al –Zn alloys .By using this equation the time for any percentage of Zn in Al-Zn alloy can be calculated.

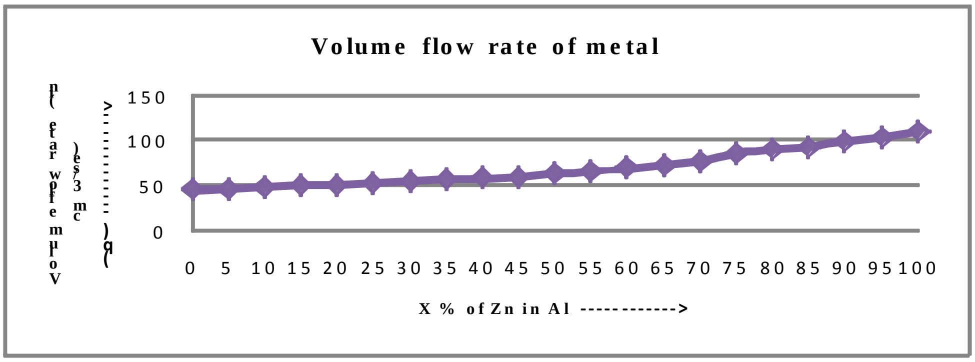

Figure 14 Volume flow rate of the material

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The equation of curve is obtained by the graph traced in the figure 14 This equation can be used to obtain the volume flow rate for each sample of Zn and Al alloy. The same process can be used to establish the equation for other combination of material

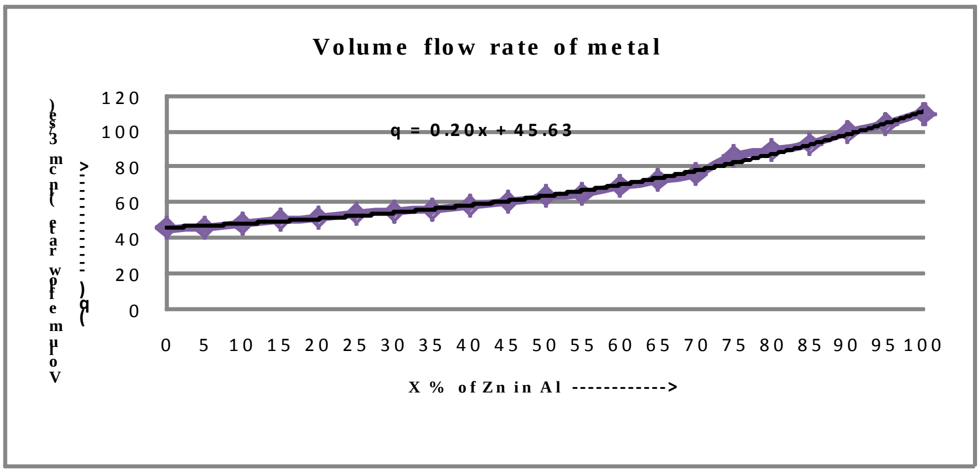

Figure 15 Equation of curve for volume flow rate of the material

The curve drawn above here the curve is drawn between the mould filling time denoted by (t) which is indicated in vertical axis and percentage of Zn in Al-Zn alloy

Volume flow rate q = 0.20x + 45.63

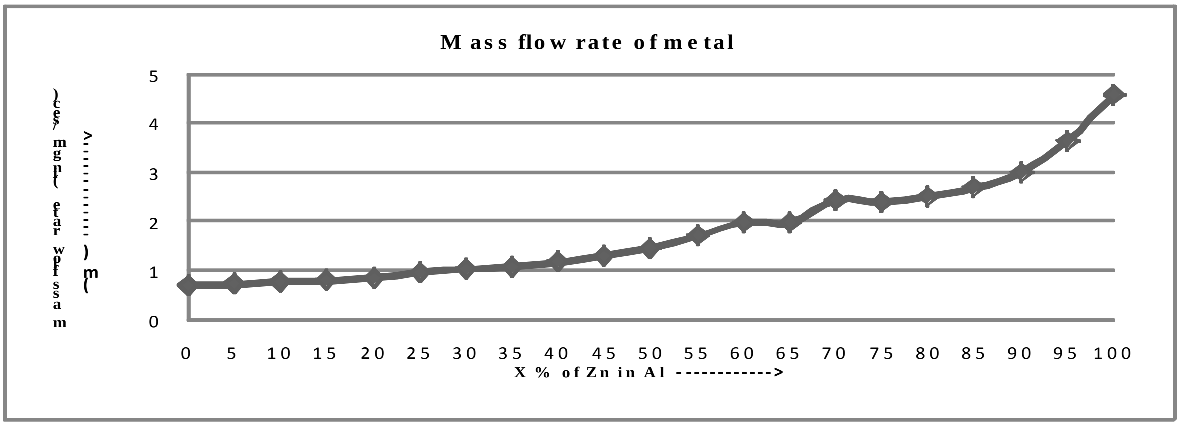

Figure 16 Mass flow rate of the material

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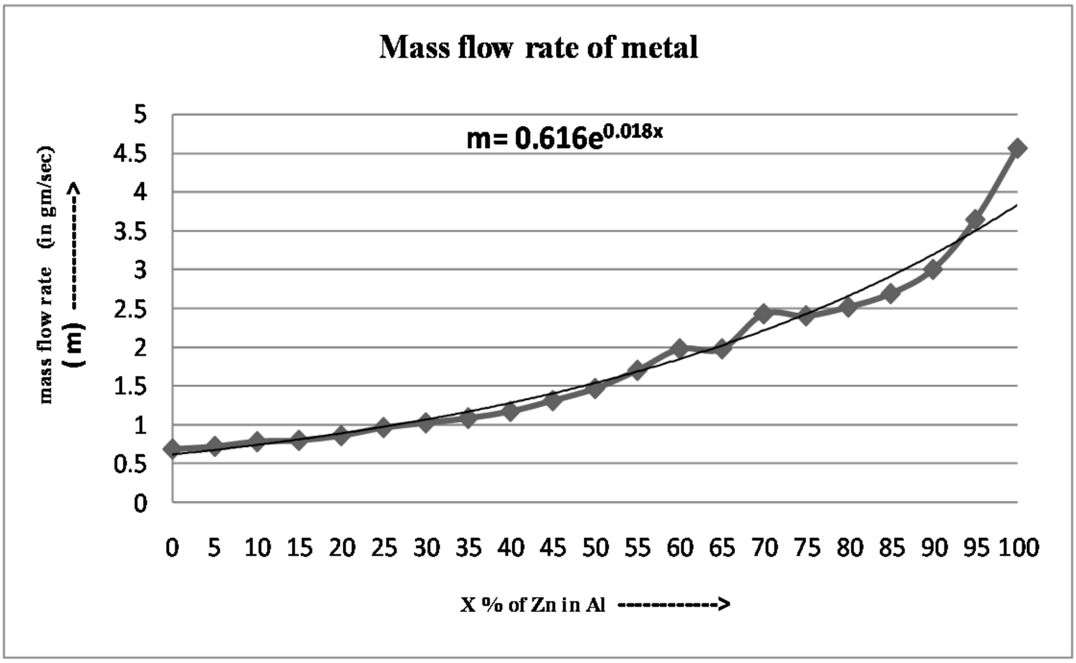

Figure 17 Equation for mass flow rate of the material

The equation generated from the graph is given below and this equation will help to estimate the mass flow rate for any sample for any percentage of zinc in Al –Zn alloy.

Mass flow rate of the material (m) = $0.616e^{0.018x}$
Where x is the percentage of zn in Al alloy

This kind of equation can be generated for other combination of material.

V. CONCLUSION AND FUTURE WORK

It is performed the experimental analysis on casting of Al-Zn alloy .By varying the percentage of Zn in alloy the following parameters have been studied and reached to the conclusion that may lead to enhance the properties of material to fulfill the desired requirement .

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Mould filling time - It is observed that when the percentage of Zn is increased in Al-Zn alloy the mould filling time decreases. Direct calculation of the mould filling time can be followed for various composition may be obtained by the following equation.

Mould filling time (t_m) = -0.029x + 4.769

Solidification time –It is found that When the percentage of Zn is increased in Al-Zn alloy the solidification time increases. Direct calculation of the solidification time can be obtained for all composition by the given equation below.

Solidification time (t_s) = - $0.07x^2$ + 0.50x + 160.5

- Volume flow rate – When the amount of Zinc in the aluminium-zinc alloy increases then the volume flow rate of the material also increases. The following equation can be used to find the volume flow rate for any sample.

Volume flow rate q = 0.20x + 45.63

- Mass flow rate – When the amount of Zinc in the aluminium-zinc alloy increases then the mass flow rate of the material also increases. The following equation can be used to find the volume flow rate for any sample.

Mass flow rate of the material **m = $0.616e^{0.018x}$**

Future work- The Desired property can be produced as per design requirement in multi- material casting by using two or more material that the single material can not produce which may fulfill exact need. So further the numbers of materials can be taken to get the specific desirable properties in a single object. Other materials can be used for obtaining the basic parameters such as mould filling time , solidification time , volume flow rate , mass flow rate etc. in multi-material casting.

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