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Prediction Of Fluidity Parameter In Thixoforming Process For Aluminum Alloy Using Fuzzy Logic Approach

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ABSTRACT
Thixoforming or semisolid metal processing is an upcoming technology to obtain near net shaped components. The material is processed in between the solidus and liquidus temperatures. This process is also known as thixoforging or thixocasting depending on the initial condition of the billet and process adopted. Fluidity is an important process parameter which determines the quality of the end product. Simulation studies are carried out to determine the fluidity parameter using Taguchi's design of experiments. An attempt is made to develop a mathematical model using fuzzy logic approach to predict the fluidity parameter. Some of the process conditions that are used to study the process are billet temperature, ram speed and die temperature. The model is validated by experimental study.
Keywords: Thixoforming,A356, Fuzzy logic,Fluidity

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INTRODUCTION

Thixoforming or Semisolid metal processing (SSMP) is a technology employed for production of near net shaped components. This process is carried out at a temperature range between its liquidus and solidus temperature [1]. The origin of SSMP can be traced to the experiments conducted by David Spencer at MIT in 1971 as part of his doctoral thesis under the supervision of Martin Flemings [2].The process combines a number of advantages of traditional casting and forging processes. Compared to casting, Thixoforming provides a more stable filling front places lower thermal loads on the metal dies and less shrinkage.

Some of the alloys which are suitable for carrying out the semisolid metal processing are alloys of aluminum, copper and magnesium. Aluminum alloy A356.0 and 356.0 are a 7% Si, 0.3% Mg alloy with 0.2 Fe (max) and 0.10 Zn. The alloys have very good casting and machining characteristics [3]. They are used in the heat-treated condition. The three important steps in thixoforming process are billet production, reheating to semi-solid condition and forming operation [4].

Typical composition of A356 alloy is given in Table 1. Alloy composition influences the properties and microstructure of the cast product. The fluidity and filling characteristics are largely influenced by the alloy composition.

Table 1: Chemical composition of A356 alloy (%wt)

Component	Si	Cu	Mg	Ti	Fe	Mn	Zn	Al
Wt %	6.5-7.5	Max. 0.2	0.25-0.45	Max 0.2	Max. 0.2	Max. 0.1	Max. 0.1	93

Fluidity is the ability of the material to flow before it completely solidifies [5]. The present study comprises of evaluating an important parameter known as mold filling ability – a measure for fluidity. Simulation studies were carried out to optimize the process parameters such as temperature, billet size and ram speed. Experiments were carried out to determine the mould filling ability and validate the simulation results.

The term fluidity is normally used in foundry to designate the casting materials ability to fill the mould cavity. The properties of casting materials which affect the fluidity to a great extent are viscosity and heat content of the melt, freezing range, specific weight and surface tension of the liquid metal [5]. The lower the coefficient of viscosity of molten metal, the higher would be the fluidity. In general, the alloys, which have a narrow freezing range, have a higher fluidity compared to the wide freezing range ones. The mould properties that affect the fluidity are thermal characteristics, permeability and the mould cavity surface.

MOULD FILLING ABILITY

Mould filling ability is influencing considerably the heat transfer and solidification of the metal. Mould filling is a critical parameter in the production of quality castings, especially in the case of complex shaped castings where section thickness varies considerably [6]. The die used for the present study was modeled based on Engler and Ellerbrok design [7]. One of the methods for evaluating fluidity is by measuring the distance to which the metal runs in a special fluidity-testing mold. The second method is based on measuring the volume of flow through a given section before flow stops. The present study comprises of evaluating an important parameter known as mold filling ability – a measure for fluidity. This is a mathematical model developed to measure fluidity by utilizing the equation 2.

METHODOLOGY ADOPTED FOR CALCULATING MOULD FILLING ABILITY

The hot metal poured into the die fills the curved cavity between the two cylindrical cores having a line contact at the center, but solidifies before filling up the complete casting. The inverse of the diameter of curvature of the edge tip of the fin gives the value of the mould filling ability. The diameter at the tip of the fin gives the meniscus diameter of the liquid metal at the time of solidification as represented in the Fig. 1. It is difficult to measure the diameter of the tip of the edge and hence an indirect way of calculation has been used which is presented below.

From Figure 1

$R^2 + (r+x)^2 = (r+R)^2$ ……………………Equation (1)

By solving Equation (1) we get,

$1 / 2r = (R-x) / x^2$ (since $2r = d$)

So, $1 / d = (R-x) / x^2$ ………………… Equation (2)

Where R = Radius of the sand core in mm,

r = Radius of the meniscus ($2r = d$) in mm,

2x = Distance between edges in mm,

1 / d = Mould filling ability, 1 / mm or mm^{-1}

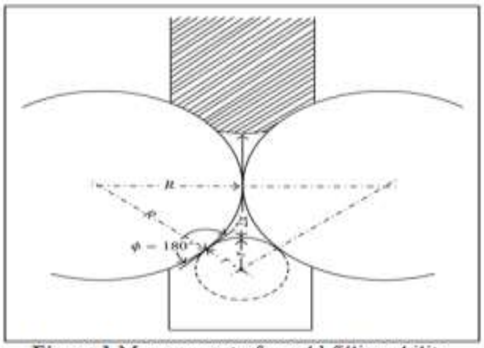

Figure 1 Measurement of mould filling ability

SIMULATION STUDIES

The following simulations are carried out in process simulation software for Aluminum alloy A356 to determine the effect of temperature of the billet on the final shape of the billet. The simulations are carried out at different temperatures between the solidus and liquidus temperature range of the alloy. The top die, bottom die and the work piece are modeled in Solid Works and exported into the process simulation software Deform 3D in .stl format. Mould filling ability value can be calculated by measuring the values of radius of core and distance between two edges. After substituting all the measured values in below equation mould filling ability (1 / d) is obtained.The mould filling ability values at various initial billet temperatures and for the L27[8] simulation runs are tabulated at Table 2. Fig 2 shows the 2D model of die and the deformed component at the end of simulation.

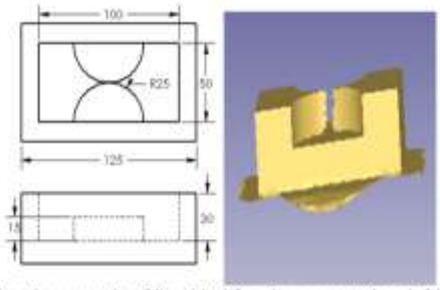

Fig. 2 Schematic representation of die and the deformed componenet at the end of similation

FUZZY MODEL

Based on the results obtained from the above study a fuzzy logic model [9] is developed based on Mamdani approach. For this study Billet temperature, Die temperature and Ram speed are chosen as input parameters each with three levels as shown in the following table. The output parameter Mould filling ability value is defined for three levels. The design part for the fuzzy interval is shown in Table 1.

Table 1. Fuzzy intervals for input and output parameters

SNO	Input Parameter	Linguistic Values	Fuzzy Intervals
1	Billet Temperature Range [580 – 620]	Low	580-590-600
		Med	590-600-610
		High	600-610-620
2	Ram Speed Range [10 – 20]	Low	10 – 12.5 – 15
		Med	12.5 – 15 – 17.5
		High	15 – 17.5 – 20
3	Die Temperature Range [30 – 250]	Low	30 – 77.5 - 125
		Med	77.5 – 125 – 187.5
		High	125 – 187.5 – 250

SNO	Output Parameter	Linguistic Values	Fuzzy Intervals
1	Mould Filling Ability Value	Poor	1.5 - 2.0 - 2.5
		Good	2.0 - 2.5 – 3.0
		Excellent	2.5 – 3.0 – 3.5

Based on the input parameters chosen a L27 orthogonal array is designed to develop the fuzzy logic model. The following table 2 presents the predicted values of Mould filling ability using the fuzzy logic model. The values are close to the values generated by carrying out the simulations. Fig 3 represents the comparative graph of MFA for the simulation trials and values generated using Fuzzy LogicApproach

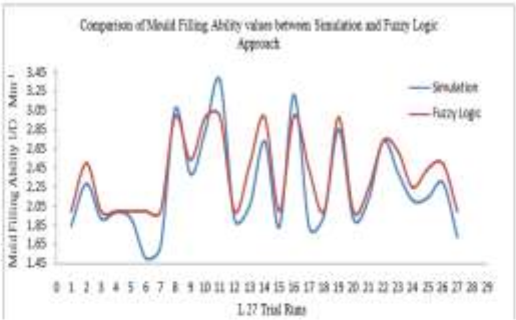

Fig. 3 MFA values for simulation and Fuzzy Logic Predicted values

Table 2.L 27 Orthogonal array used in the simulation trials and fuzzy predicted values

Run No	Temp Of Billet °c	Ram Speed Mm/Sec	Die Temp °c	Mold Filling Ability 1/D = (R-X) / X**2 1/Mm	Fuzzy Predicted Values 1/Mm
1	620	15	250	1.84	2.0
2	580	15	30	2.29	2.5
3	580	10	250	1.93	2.0
4	580	10	30	1.99	2.0
5	620	20	250	1.92	2.0
6	620	10	30	1.51	2.0
7	600	10	250	1.63	2.0
8	580	20	250	3.08	3.0
9	600	15	30	2.39	2.54
10	580	20	30	2.84	2.99
11	600	20	30	3.37	3.0
12	620	10	250	1.91	2.0
13	600	20	250	2.07	2.50
14	620	20	30	2.73	2.99
15	620	15	30	1.83	2.0
16	580	15	250	3.22	3.0
17	600	15	250	1.82	2.43
18	600	10	30	1.96	2.0
19	580	20	125	2.86	2.99
20	620	15	125	1.92	2.0
21	620	20	125	2.13	2.25
22	600	20	125	2.74	2.74
23	580	15	125	2.40	2.63
24	600	10	125	2.12	2.25
25	580	10	125	2.14	2.45
26	600	15	125	2.30	2.50
27	620	10	125	1.73	2.0

CONCLUSIONS

The present work focused on developing a mathematical model using fuzzy logic approach to understand the effect of process parameters on fluidity of aluminum alloys in semisolid metal forming. Simulation studies are conducted to determine the Mould filling ability values. The fuzzy logic model developed in MATLAB showed a satisfactory prediction to study the MFA within a range for process parameters. Experiments need to be conducted to validate the results. This model helps the industry to manufacture components using thixoforming process where controlling the process parameters is a big challenge.

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