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Applying DOE for Determining the Relative Importance of Some Gating System Design Parameters

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Abstract

Gating system is a pathway of ladle to mould cavity. This gating system affects the part quality. Gating system is design according to part dimensions, volume and weight. Gating system controls the velocity of molten metal that influences turbulence and fluidity of casting. In this work three important parameters: Ingates location, Ingate cross section and No. of ingates are considered for analysis. These parameters are taking as input and output is velocity. Analysis is done with DOE (Taguchi) method. Results shows that No. of ingates have maximum contribution (68%) followed by Ingate cross section affects (28%), however the influence of location of ingates is least significant. ANOVA is also used for verifying results.

Keywords: Sand casting, gating system, Taguchi method, Finite element method.

1. Introduction

Filling related defects are mainly classified into three categories: incomplete filling, gaseous entrapment, sand and slag inclusion. Filling related defects in casting are mainly due to uncontrolled velocity of molten metal. If velocity of molten metal is in control, filling related defects can be minimized in most of the cast parts. Velocity of molten metal can be controlled by proper designing of gating system. The objective of this work was to determine the relative influence of main gating system parameters such as (i) No. of in-gates (ii) Gating cross-section, and (iii) Gate location on velocity. In last few years, CAD (computer aided design) and simulation tools are widely using for improving casting quality and yield. It takes lesser time compare to shop floor trials. Various software packages are available for casting analysis like: Procast, MAGMA, Solid cast, Nova flow etc; these software packages simulate filling phenomena and solidification phenomena. Casting simulation experiments, are however computationally intensive. Savings in the number of simulations would translate in reduction in the length of time spent in setting up and post-processing simulation results would allow the labor resources to be used more efficiently Therefore, in order to keep the number of simulations to a minimum, experiments were designed based on the design of experiments (DOE) method.

2. Literature Review

2.1 Casting Simulation

Casting simulation is widely used by various industries and researchers for predict defects in casting. Simulation software's are based on various mathematical models like: FEM (Finite Element Analysis) and FDM (Finite Difference Method) etc. These models are simulating casting process. Once it is simulated with proper Boundary conditions we can use these results to predict defects locations. For calculation of flowing characteristics of molten metal using both the equations which are given below: (Reis et. al, 2008, Sun et. al, 2011, Wang et. al, 2012)

$$\rho = \left(\frac{du}{dt} + u\frac{du}{dx} + v\frac{du}{dv} + w\frac{du}{dz}\right) = -\frac{dp}{dx} + \rho g_x + \mu\nabla^2 u \quad (1)$$

$$\rho = \left(\frac{dv}{dt} + u\frac{dv}{dx} + v\frac{dv}{dy} + w\frac{dv}{dz}\right) = -\frac{dp}{dy} + \rho g_y + \mu\nabla^2 v \quad (2)$$

$$\rho = \left(\frac{dw}{dt} + u\frac{dw}{dx} + v\frac{dw}{dy} + w\frac{dw}{dz}\right) = -\frac{dp}{dz} + \rho g_z + \mu\nabla^2 w \quad (3)$$

Where ρ is density u, v, w are velocity in x, y, z direction, μ is kinematic viscosity and p= represent pressure.

For solidification calculation energy equations and Niyama criterion are used.(Wang et al. 2012)

Energy equation

$$\rho c\frac{dT}{dt} = \frac{d}{dx}\left(k\frac{dT}{dx}\right) + \frac{d}{dy}\left(k\frac{dT}{dy}\right) + \frac{d}{dz}\left(k\frac{dT}{dz}\right) + S \quad (4)$$

Niyama criterion (Carlson and Beckermann, 2008)

$$\frac{G}{\sqrt{R}} < Constant \quad (5)$$

Where T is temperature, c is heat capacity of material, k is thermal conductivity, S is internal energy, G is temperature gradient, and R is cooling rate. Over the years various researchers have applied simulation for casting analysis. Xuan et, al. (2012) validated filling simulation by CFD. Sun et. al (2011) eliminates defects in rear axle of truck by modifications of gating system. Tiedje and Larsen (2010) analyzed the effects of gating system on molten metal velocity. Kermanpur et.al, (2007) simulated flywheel and brake disc in CFD code flow-3D®. Gunasegaram et. al, (2008) takes 5 parameters and analyse these parameters effects on the two defects cold shut and microporosity. In this work simulation is applied for evaluating the effect of gating design parameters on velocity distribution in the benchmark part.

2.2Taguchi method

Dr Genich Taguchi develops *Taguchi method* in 1950's.Taguchi's was the first to suggest that statistically planned experiments should be used in the product development stage to detect factors that affect the variability of the output term dispersion effects of the factors. By controlling these factors we can optimize the output parameters.Taguchi classified various parameters which are: control factors, noise factors, signal factor and scaling factor. *(Krishnaiah and Shahabudeen 2012)*

Taguchi extended the audio concepts of the signal to noise ratio to multi-factor experiments. The signal to noise ratio (S/N ratio) is a statics that combines the mean and variance. The objective in taguchi method is to minimize the sensitivity of a quality characteristic to noise factors. These S/N ratios are depending on the quality characteristics. Often we deal with the following three types of quality characteristics: (Ross 1988)

Smaller is better

$$\eta = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right] \quad (6)$$

Nominal is best

$$\eta = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}(Y_i - Y)^2\right] \quad (7)$$

Larger is better.

$$\eta = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right] \quad (8)$$

Where η is S/N ratio, Y_i is respective no. of experiment, n is no. of experiments, Y is target value. Savaş et. al, 2007 investigated the factors affecting microporosity. This investigation was done by Taguchi method. They concluded that filling time and dissolved hydrogen level affects the microporosity to a larger extent. In 2008, Sun et. al, investigated multiple parameters such as casting yield, shrinkage porosity and filling time using Taguchi method. In the present study important gating design parameters are considered and these analyzed using Taguchi method.

3. Numerical Simulation and DOE

In these paper the use of CAD/CAE software to systematically simulate the design process of sand casting process and to analyse the gating system. This simulation uses (i) CAD (i.e. Pro-engineer wildfire 4.0) software to create parts (ii) NX 7.0 to generate the a mold cavity , and (iii) Pro-cast 2009.1 (FE based software) for simulation. Hollow cylinder as shown in the figure is used as benchmark part and LM 6–Al alloy material is taken as casting material.

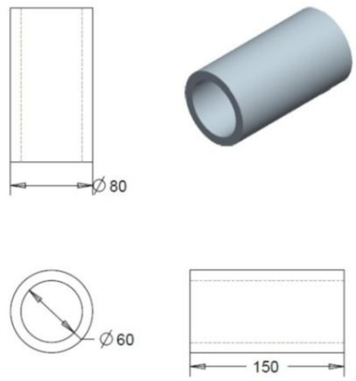


Fig. 1: Bench mark part.

Many factors influence the gating system; however in the present study we consider the following three factors:

- Gate location
- Gating cross-section
- No. of ingates.

Each of above factors are treated at three levels. These levels are shown in below table: 1. Other factors are same in all levels. These factors are presented in table: 2

Table 1 - Process parameters and their values at different levels

Process Parameter Design	**Process Parameter**	**Level 1**	**Level 2**	**Level 3**
A	Gating location	Top	Side	bottom
B	No. of ingates	2	4	6
C	Cross section	Rectangular	Circular	Square

Table 2: Other gating parameter description.

Description	**Top**	**Side**	**Bottom**
Sprue dimension in mm (top dia.*bottom dia.)	10*7	10*7	10*7
Sprue height(mm)	150	150	150
Gating ratio	1:4:4(2 and 4) and 1:4:8(6)	1:4:4(2 and4) and 1:4:8(6)	1:4:4(2 and4) and 1:4:8(6)

These three input factors and their level are arranged by Taguchi's orthogonal array (OA). Orthogonal array is selected based on no. of factors and their levels. To limit the study, it was decided not to study interaction effect among the factors. Each three level factor have 2 degree of freedom (DOF) (number of level-1). The total degree of freedom required for three parameter each at three levels is 8. As per Taguchi method the total DOF is selected is greater than or equal to the total DOF required in experiment. So an L_9OA (a three level OA) having degree of freedom was selected to present analysis. This OA has three columns and 9 experiment. Table 3 shows OA arrangements and response value.

Table 3: L9 OA with response.

S. No	A	B	C	Velocity(m/sec)
1	1	1	1	0.54
2	1	2	2	0.52
3	1	3	3	0.39
4	2	1	2	0.88
5	2	2	3	0.41
6	2	3	1	0.45
7	3	1	3	0.76
8	3	2	1	0.50
9	3	3	2	0.45

Simulations are performed for the above experimental designs considering typical sand casting process using Procast are presented in figure 2.

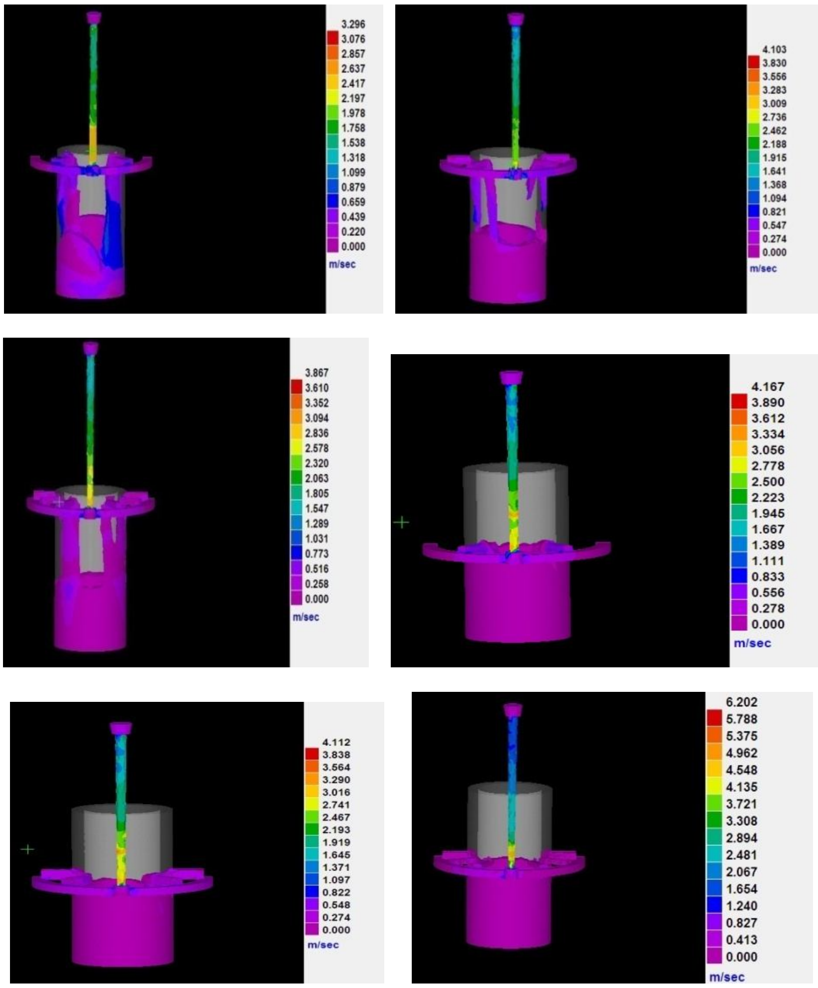
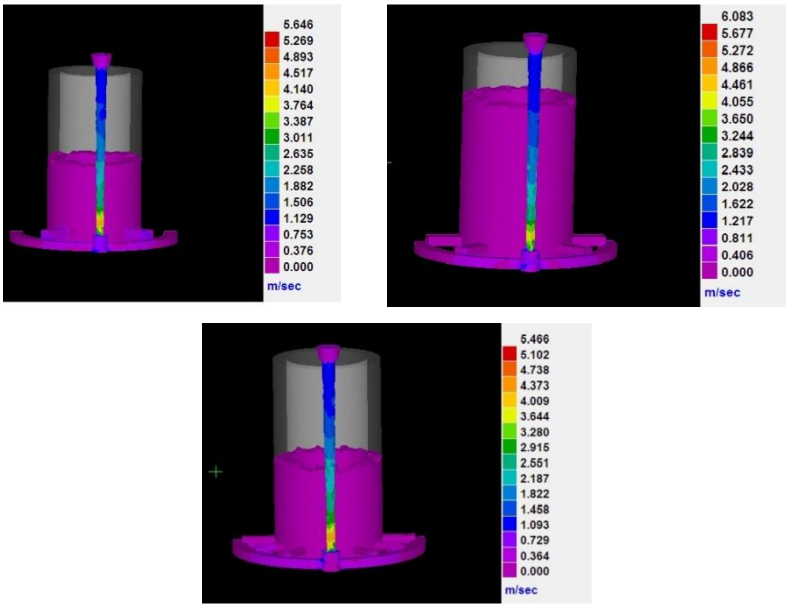


Fig. 2: Simulation of casting(9 experiments).



These S/N ratio is calculated based on 'smaller is better' characteristics.

Table 4: S/N ratio table.

S. No.	Response	S/N Ratio
1	0.54	5.35
2	0.52	5.68
3	0.39	8.18
4	0.88	1.11
5	0.41	7.74
6	0.45	6.94
7	0.76	2.39
8	0.50	6.02
9	0.45	6.94

Fig. 3 shows the mean S/N ratio of velocity in mould cavity.

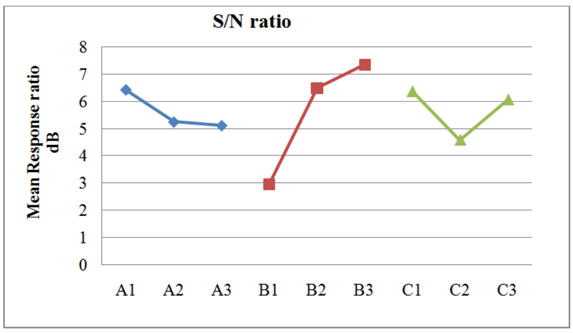


Fig. 3: Signal to Noise Ratio.

Results of Taguchi method are verified by ANOVA (Analysis of Variance). Table 6 shows the results of Taguchi method. Table shows the most influencing factor is “no. of ingates”, followed by “gating cross section” and the least significant factor is “gating location”. ANOVA (table-7) analysis the data and give same results as shown in Taguchi method.

Table-6 Rank of factors

Factors/Level	**A**	**B**	**C**
1	19.2	8.8	19.1
2	15.7	19.4	13.7
3	15.3	22.0	18.2
Max-Min	3	1	2

Table 7: ANOVA analysis.

Factor	**Sum of Squares**	**DOF**	**Mean square**	**F -Value**	**Contribution %**
A	1.51	2	0.755	11.65	3.33
B	31.04	2	15.52	238.7	68.10
C	13.02	2	6.51	100.1	28.57
Error	0.13	2	0.065	-	-
Total		8	22.785	350.5	100

ANOVA show most significant factor is no. of ingates(B) and Ingate cross section(C).Contribution% is no. of ingates> Ingate cross section > gating location.

4. Conclusion

The present study has applied Taguchi method to investigate the well known three factors, which have been proposed to affect the velocity in sand cast LM6 aluminum alloy. The conclusion of study can be summarized as follows:

1. Figure3 shows best combinations of gating system are Bottom 2 circular.
2. A LM6 alloy was sand cast under three different factor designs with three level variations to see affecting factors on velocity within cast part sections. Results show that velocity is over-whelming due to no. of ingates. The contribution effect is 68.10%.
3. The Taguchi method design method revealed that no. of ingates was that most influencing factor on velocity of molten metal. After that gating cross section is mostly affect the velocity of molten metal.
4. The ANOVA results are indicates the very less affect of gating location on velocity of molten metal.

The above results provide valuable insights to casting engineers, for the relative importance of gating system parameters. It is suggested that this study be extended considering other important parameters of gating design for assessment of its overall effect on casting quality and economy.

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