Optimization Of Hot Spot Area In Typical 'L' Casting Junction Using Response Surface Methodology

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Abstract

Response Surface Methodology (RSM) is a powerful and efficient mathematical approach widely applied in casting junctions. In this paper optimization of hot spot area in typical 'L' casting junction is done by using RSM. Casting defects can be attributed to poor part design which often leads to rejection and ultimately results in loss of productivity for a foundry. One common defect is Shrinkage Porosity occurring at casting junctions. A casting junction is an abrupt increase in local thickness caused by two or more elements meeting together resulting in high thermal concentration. Molten metal cools slowly at junctions leading to shrinkage porosity defects. The approach adopted to reduce the shrinkage porosity defect in 'L' junction is using 3D modelling & analysis through minor changes in the parameters like inner & outer radius, thickness and angle in the design. The design contains a total of 31 experimental trials with a full factorial design fashion & replication of central points. Data obtained on RSM on hot spot area were subjected to the analysis of variance (ANOVA) & analysed using 2nd order polynomial equation resulted in optimized geometric parameters. CATIA V5 is used for modelling purpose while Auto-Cast and Auto-CAD are used for solidification and statistical simulation. A 2^4 Central Composition Design was used to develop a statistical model for analysing process variables.

Keywords: *Response Surface Methodology, shrinkage porosity, Central Composite Design, Hot Spot, Simulation, Optimization.*

1. INTRODUCTION

Most castings can be viewed as an assembly of junctions. A casting junction is an abrupt increase in local thickness caused by two or more elements (walls) meeting together, resulting in regions of high thermal concentration. Molten metal cools slowly at junctions, leading to shrinkage porosity defects. The size and extent of the defect regions depend on the thickness and number of elements involved and the angle between them, all of which affect the rate of heat transfer from the casting. The defects can be avoided by casting process design changes, such as placing a riser above the junction or a chill below it, but these add to the cost of production and may not always be feasible. An alternative is to modify the junctions to minimize such problems before solidification using 3-D modeling and analysis.

General design for manufacturability guidelines have been established to reduce porosity defects in "L" junction through minor changes in the design, such as adding fillets, reducing thicknesses or adding a central cored hole to reduce stress concentrations. These guidelines apply to castings with simple junctions, but castings with complex shapes require numerical simulation of solidification to predict the location and extent of shrinkage porosity defects.

One approach to improving junction designs in complex castings involves the vector element method (VEM), which traces feed metal paths in reverse to pinpoint the location of hot spots. It is based on the principle that the direction of the highest temperature gradient at any point inside a casting is given by the vector sum of individual thermal flux vectors in all directions around the point. Multiple hot spots are detected by starting from several seed points.

Response surface methods are used to examine the relationship between one or more response variables and a set of quantitative experimental variables or factors. These methods are often employed after you have identified a "vital few" controllable factors and you want to find the factor settings that optimize the response. Designs of this type are usually chosen when you suspect curvature in the response surface.

Response surface methods may be employed to:
- Find factor settings (operating conditions) that produce the "best" response.
- Find factor settings that satisfy operating or process specifications.
- Identify new operating conditions that produce demonstrated improvement in product quality over the quality achieved by current conditions.
- Model a relationship between the quantitative factors and the response.

2. RESEARCH METHODOLOGY

The technology CAD tools played a key role in the development of new technology generations. For the

deep sub-micrometer devices, these tools provide a better insight than any measurement techniques and have become indispensable in the new device creation. Technology development, however, requires substantially more than a fundamental simulation capability: tools and methods to assist in exploration of design trade-offs and to optimize a design are becoming increasingly important. Computer aided design and manufacturing CAD / CAM packages have enabled faster design and better quality assurance of castings. However, a steep increase in the number of software developers, sophistication of programs and the changing needs of users have brought into view several hidden problems and bottle neck. Design and model the sand casting junctions, for these purpose firstly we design the parts of different complexities in Pro-E Wildfire 4.0.

2.1 Modeling of typical 'L' junction in 3D using CAD

The part model of a cast product is the backbone for a various software programs that help in improving the consistency and speed of different tasks in casting development. The various geometric features of casting and different techniques for creating a part model, including the graphical user interface of modeling programs. Casting information involves a large number of geometric, material, process and quality parameters and complex inter-relationships between them. The complete information related to a cast product is unlikely to reside in a single location. Product, tool and foundry engineers will share only a part of the information available with them, with others. The part model of a cast product is the backbone for a various software programs that help in improving the consistency and speed of different tasks in casting development. The various geometric features of casting and different techniques for creating a part model, including the graphical user interface of modeling programs.

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The solid model information regarding the overall shape of casting, base features, local features and tooling is stored in geometry objects using the symmetric data structure for boundary representation. This involves storing the bounding faces, edges and vertices of the corresponding solid model, along with the relevant topological relationships (such as adjacent faces for an edge) and geometric parameters

(plane coefficients, direction cosines and Cartesian coordinates) The solid model information regarding the overall shape of casting, base features, local features and tooling is stored in geometry objects using the symmetric data structure for boundary representation. This involves storing the bounding faces, edges and vertices of the corresponding solid model, along with the relevant topological relationships (such as adjacent faces for an edge) and geometric parameters (inner radius, outer radius, thickness, angle etc.)
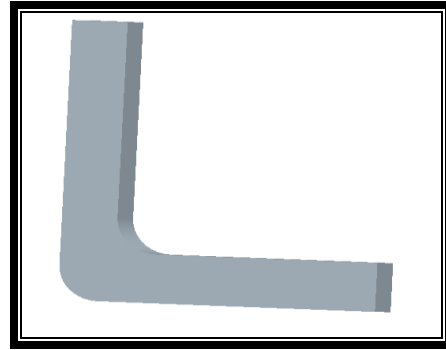

Fig.1.1 'L' Junction solid model with CATIA V5

There are following steps is used for design the part model in CATIA V5:

Step 1: First design the solid model with the help of 2D drawing. 3D CAD model is depend upon 2D drawing, because of 2D drawing shows all dimension as required to design 3D CAD model. Using Part Modeling, you can start with the creation of simple geometric features and progress to the creation of complex features and parts.

Step 2: In Part modeling you can create a part from a conceptual sketch through solid feature-based modeling, as well as build and modify parts through direct and intuitive graphical manipulation.

Step 3: The Part Modeling Help introduces you to the terminology, basic design concepts, and procedures that you must know before you start building a part. Part Modeling shows you how to draft a 2D conceptual layout, create precise geometry using basic geometric entities, and dimension and constrain your geometry. You can learn how to build a 3D parametric part from a 2D sketch by combining basic and advanced features, such as extrusions, sweeps, cuts, holes, slots, and rounds. Finally, Part Modeling Help provides procedures for modifying part features and resolving failures.

Step 4: CATIA Part enables you to design models as solids in a progressive three-dimensional solid modeling environment. Solid models are geometric models that offer mass properties such as volume, surface area, and inertia. If you manipulate any model, the 3-D model remains solid.

2.2 Solidification Simulation using Auto-CAST

Auto CAST is the world's most intuitive, incredibly fast, and truly integrated casting software for methods design, simulation and optimization Auto CAST is fast and easy to use, even if you are new to computers. It is also the most economical casting methods software available today, and is supported by a network of highly qualified and helpful consultants.
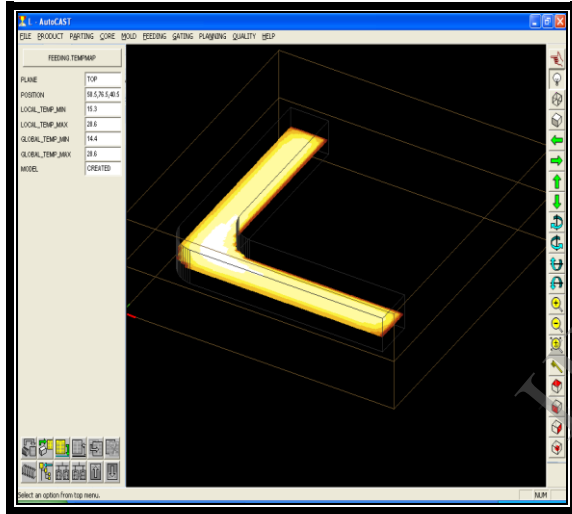

Fig1.2 Simulation of 'L' junction in Auto CAST

2.3 Measurement of Hot Spot area on Auto CAD

Table 1.1. Coded and actual levels of the independent variables for design of experiments for L junction

Independent Variables	Symbols	Coded levels				
		-2	-1	0	1	2
Inner Radius	r_1	0	15	30	45	60
Outer radius	r_2	0	15	30	45	60
Thickness	t	30	36	42	48	54
Angle	θ	30	60	90	120	150

Table: 1.1 Various parameters of L Junction

Length of junction 'L'=240mm

Height of junction 'L'=30mm
r_1 (Inner radius, mm) is calculated as $r_1=30+(15)x_1$
r_2 (Outer Radius, mm) is calculated as $r_2=30+(15)x_2$
t (Thickness, mm) is calculated as $T=42+(6)x_3$
θ (Angle°) is calculated as $\theta=90+(30)x_4$

After solidification and simulation of typical casting junction measuring the defected area for measurement of defected area in typical casting junction we use AutoCAD2008. The process of measuring area simulated casting part is in the image format use the insert command than raster image for inserting the image. Then find the actual length of object by list command, scaling the image, use spline command for show the defected area in junction. Use the area command to find out the hot spot area in typical casting junction.
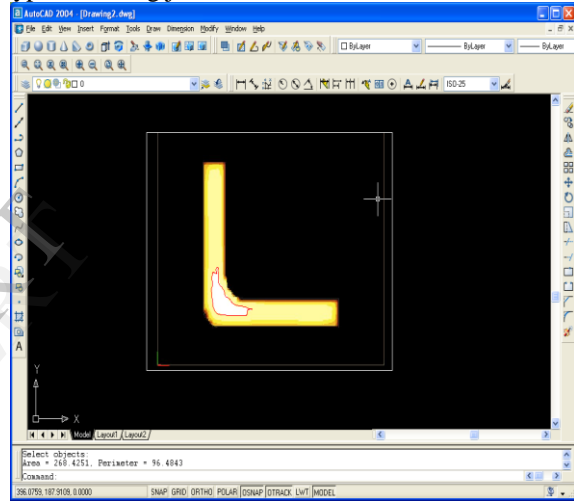

Fig 1.3 Measurement of hot spot area in Auto CAD

2.4 Analysis of data using Response Surface Methodology in MINITAB 15

➢ Create Response Surface Design
Response surface methods are used to examine the relationship between a response and a set of quantitative experimental variables or factors. These methods are often employed after you have identified a "vital few" controllable factors and you want to find the factor settings that optimize the response. Designs of this type are usually chosen when you suspect curvature in the response surface.

➢ Analyze Response Surface Design
Use Analyze Response Surface Design to fit a model to data collected using a compositor custom response surface design. We can choose to fit models with the following terms

- linear terms
- squared terms

- interaction terms

An uniform-precision 24 ($k = 4$) factorial central composite experimental design with eight star points ($F = 8$), six axial points and six replicates at the center point ($n0 = 6$), resulting in a total of 31 experiments ($\alpha = 2$) which covers the entire range of spectrum of combinations of variables were used to optimize the chosen key variables for the ethanol production from waste cashew apple juice in an aerobic batch bioreactor. The experiments were conducted in a fixed fashion. The dependent variable selected for this study was hot spot area yield. The independent variables chosen were inner radius, outer radius, thickness and angle for 'L' junction.

Source	DF	Seq-SS	Adj-SS	Adj-MS	F	P
Regression	14	186291	186290.7	13306.5	5.19	0.001
Linear	4	137348	84813.9	21203.5	8.27	0.001
Square	4	21632	21632.3	5408.1	2.11	0.127
Interaction	6	27310	27310.2	4551.7	1.78	0.168
Residual Error	16	40998	40997.8	2562.4	*	*
Lack-of-Fit	9	40976	40976.2	4552.9	1481.23	0.000
Pure Error	7	22	21.5	3.1	*	*
Total	30	227288	*	*	*	*

3. RESULTS AND DISCUSSION

As an important subject in the statistical design of experiments, the *Response Surface Methodology* (*RSM*) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response.

Response surface methods are used to examine the relationship between a response and a set of quantitative experimental variables or factors. These methods are often employed after we have identified a "vital few" controllable factors and you want to find the factor settings that optimize the response.

3.1 Analysis of L junction by Response surface Methodology in MINITAB 15.

The analysis was done using coded units.

Term	Coef	SE-Coef	T	P
Constant	153.70	18.68	8.227	0.000
r_1	11.31	24.23	0.467	0.647
r_2	-28.18	17.74	-1.588	0.132
t	120.86	24.23	4.988	0.001
θ	-56.74	24.23	-2.342	0.032
$r_1 * r_1$	-16.11	38.08	-0.423	0.678
$r_2 * r_2$	-22.00	24.16	-0.911	0.376
t*t	81.01	38.08	2.127	0.049
$\theta*\theta$	64.98	38.08	1.706	0.107
$r_1 * r_2$	80.58	37.96	2.122	0.050
r_1*t	84.18	50.62	1.663	0.116
$r_1*\theta$	64.45	50.62	1.273	0.221
r_2*t	34.23	37.96	0.902	0.381
$r_2*\theta$	19.05	37.96	0.502	0.623
t*θ	-42.43	50.62	-0.838	0.414

Table; 1.2 Estimated Regression Coefficients for Yield

S = 50.6198   PRESS = 250054 R-Sq = 81.96% R-Sq(pred) = 0.00%   R-Sq(adj) = 66.18% R^2 and adjusted R^2 represent the proportion of variation in the response .R^2 (R-Sq) describes the amount of variation in the observed responses.

Table 1.3 Analysis of variance for yield

Use the p-values (P) in the analysis of variance table to determine which of the effects in the model are statistically significant. Typically we look at the interaction effects in the model first because a significant interaction will influence how we interpret the main effects.

Obs	Std Order	Y	Fit	SE Fit	Residual	St Resid
6	6	180.410	287.162	36.608	-106.752	-3.26 R
11	11	90.6360	9.204	39.864	81.156	2.60R
22	22	420.430	355.151	38.873	65.279	2.01R

Table: 1.4 Unusual Observation For Yield

R denotes an observation with a large standardized residual.

3.2 Interpretation of RSM application on L junction

Using designed experimental data presented in Table , the polynomial proposed model for hot spot area yield is regressed by only considering the significant terms.

$$Y=153.70+11.31x_1+120.86x_3-16.11x_1^2-22\ x_2^2+81.01\ x_3^2+64.9x_4^2+80.58x_1x_2+84.18\ x_1x_3+64.45\ x_1x_4+34.23\ x_2x_3+19.05\ x_2x_4-42.43\ x_3x_4$$

In this equation put the coded factor values and calculate the predicted response. Because the coefficients are estimated using coded units, putting uncoded factor values into this equation would generate incorrect predictions about reaction yield. If the value of r_1 and t increases its hot spot area will be affected such as the value of r_2 and θ decreases the hot spot area decreases. The P-values used as a tool to check the significance of each of the coefficients, which in turn indicate the pattern of the interactions between the variables. Smaller value of P then it was more significant to the corresponding coefficient. The ANOVA result of the regression model for hot spot area yield demonstrated that the model was significance due to an F-value of 1.78 (interaction effect) and a very low probability value (P model >F – 0.005). F- Value several times greater than the tabulated F-value showed that the model predicted the experimental results well and the estimated factors effects were real. ANOVA (F-test) for the model explained the response of the dependent variable Y. The high F value and non-significant lack of fit indicate that the obtained experimental data is a good fit with the model. The experimental yields fitted the second order polynomial equation well as indicated by high R2 (coefficient of determination) value is 81.96 (a value > 0.75 indicates fitness of the model).The contour areas represent constant responses, which correspond to yields of 0, 50, 100, 150, and 200.

The contour with the darkest green color in the lower left corner indicates the contour where Yield is the highest (200).Observe that yield increases as you move from the lower right to the upper left corner of the plot. That is, yield increases as you simultaneously reduce inner radius and increase outer radius.

Use a surface plot to help us visualize the response surface. Surface plots are useful for establishing desirable response values and operating conditions. The surface plot, a three-dimensional wire frame

graph, represents the functional relationship between the response and the experimental factors. The response surface helps us to visualize how the response reacts to changes in the experimental factors.

We can maximize the Yield by setting inner radius near the minimum setting and outer radius near the maximum setting. From these settings, Yield decreases rapidly if you increase inner radius while hold outer radius constant. Yield also decreases rapidly if you hold inner radius constant as you decrease outer radius.
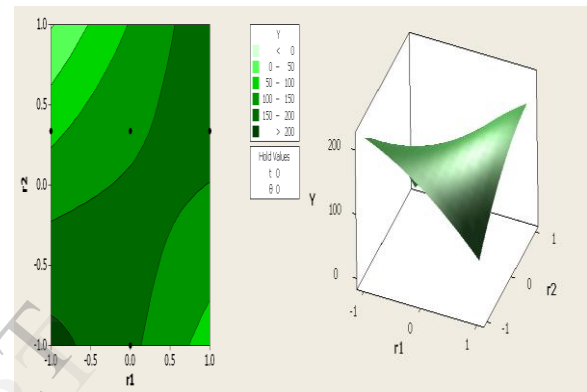

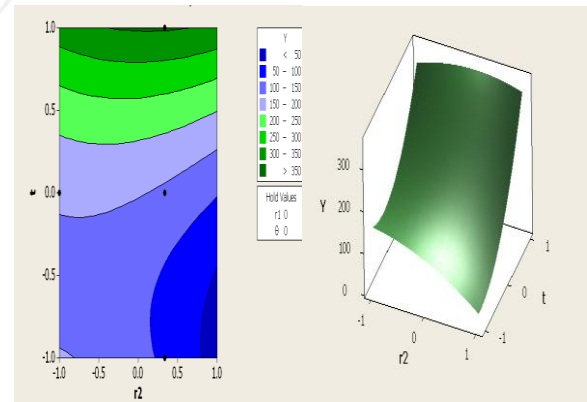**Fig. 1.4 Contour Plot & Surface Plot of Y vs. r2, r1**

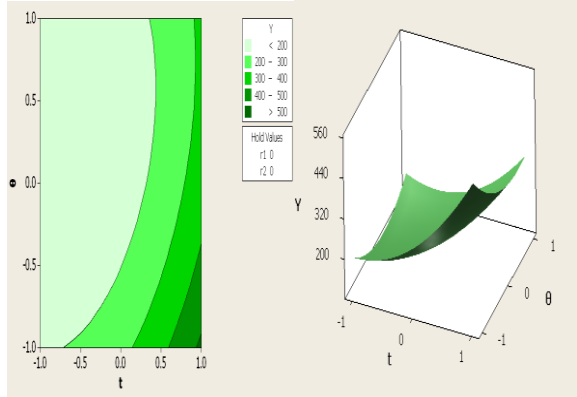**Fig 1.5 Contour Plot & Surface Plot of Y vs. t, r2**

Fig.1.6 Contour Plot & Surface Plot of Y vs. θ, t

4. CONCLUSION

Most of the casting can be viewed as an assemblage of junctions. 3D modeling and analysis of junctions helps in solving feeding problems in casting. Knowledge derived from the analysis of influence of geometrical parameters on hot spot area has been employed to RSM for junction.

Conventional optimization studies are time consuming and expensive. To overcome these problems, a Central Composite Design (CCD) was used for the optimization of process conditions. From the present study, it is evident that the use of statistical process condition optimization approach, response surface methodology has helped to locate the most significant conditions with minimum effort and time. In addition, it has also proved to be useful for predict less shrinkage defect hot spot area. Only 31 experiments were necessary and the obtained model was adequate (P < 0.001). By solving regression equation, the optimum process condition was determined. The value of R^2 and adjusted R^2 represent the proportion of variation in the response. In this study the value or R^2 is 81.96% for 'L' junction which describes the amount of variation in the observed responses and it is more significant.

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