Computer Aided Casting Simulation, Analysis and Pattern Cost Estimation

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Abstract - Casting is a major manufacturing process, which requires an understanding of a wide range of geometrical, material and process parameters. In today's market of intense competition, where the need of the hour is to develop quality products at low cost and short lead time, innovative and cost effective designs are the means to success. Early cost estimation, necessary for design-to-cost philosophy, serves as a decision making tool for the designer when a choice is to be made from a range of alternatives. In casting industry pattern cost estimation is very complex job, because there are not much tools available to estimate the exact pattern cost for the part, and in most of the industries pattern costs are estimated by experience of pattern maker, and this cost may vary from industry to industry and person to person. In addition, experience based cost is suitable only for simple patterns, as pattern complexity increases it becomes more difficult to determine the pattern cost. Through this work, an attempt has been made to cost estimation methodology, which is based on Pro-Engineering and AutoCAST software. This involves parting design and method design to arrive to one of the possible pattern design and geometrical parameters as volume ratio, thickness ratio, convex surface area ratio, concave surface area ratio, number of control dimension and quality level are calculated from the pattern design. It is perform on twenty cast part and then regression analysis is done on the data of twenty parts to obtain the equation for pattern cost estimation.

Keywords - Sand Casting, Tooling Cost, Feeder and Gating Optimization, Regression Analysis.

I. INTRODUCTION AND OVERVIEW

Casting is a manufacturing process by which a molten material such as metal or plastic is introduced into a mould, allowed to solidify within the mould, and then ejected or broken out to make a fabricated part. Casting used for making parts of complex shape that would be difficult or uneconomical to make by other methods, such as cutting from solid material. [Campbell, 2003] In sand casting, the mould cavity formed by means of a pattern, which is usually made of wood, metal, plastic or other material and has the shape of the part to be cast. The pattern usually made oversized to allow for shrinkage of the metal as it solidifies and cools. Internal surfaces are determined by means of a core, a form placed inside the mould cavity to define the interior geometry of the part. To create the cores a core box needs to built, which is the negative of the core itself. Tooling features includes different elements of tooling and their features: pattern, mould, core box, undercut, parting line, core with its support (or print), pouring basis, sprue, runner, ingate, feeder, feeder connection (or neck) and various feedaids such as chill, insulation and exothermic. Many of these, including pattern, mould, core and core box derived from the part geometry, followed by modification to incorporate various allowances.

With the help of Pro ENGINEER Wildfire 3.0, firstly modeled castable parts of different complexities and different sizes. After that these models where imported in AutoCAST, and their parting line, feeder and gating system where designed. Feeders design is performed so as shrinkage porosity defect accommodate inside the feeders. Then patterns and core boxes were modeled for all the parts using Pro-E 3.0. After these geometrical parameters like volume ratio, thickness ratio, convex surfaces area ratio, concave surface area ratio etc. which influence the cost of pattern were calculated. After calculating these parameters cost of each wood pattern is collected which are estimated by different experts in the field of pattern making. Then average of these cost are taken. After this, values of regression coefficients are calculated with the help of Minitab 15 Statistical Software. Finally general, equation for pattern cost is determined.

Figure 1: Pattern, core and core boxes

The tooling cost has two main components - the pattern and the core-boxes as shown in Fig.1. Pattern and core box making requires a high level of skill to achieve the close tolerances and accuracy. This step is critical in the casting process since the castings produced can be no better than the patterns used to make them. The pattern cost primarily controlled by the size of the part (both the envelope and the projected area), number of holes and
undercut in part, material for making pattern, required accuracy and finally part complexity. Similarly, cost of the core-boxes depends on their size, material and complexity of core. Much like the pattern, the complexity of the cores will affect the time to manufacture this part of the tooling and hence the cost. [Ravi B., 2005]

II. PREVIOUS WORKS

A number of cost estimation approaches are available today for estimating product-manufacturing cost at design stage [Camargo and Rabenasolo, 2003]. These include intuitive, analogical, analytical, feature based and parametric. The intuitive method based on the experience of the estimator, especially with similar parts and interpretation. The analogical method involves comparison of a new product with similar existing products. Case based reasoning applied to improve the results of the analogical method. The analytical method involves decomposition into elementary parts and tasks for each part, and empirical equations are used for estimating the cost of various tasks [Feng and Zhang 1999]. The feature based method uses geometric features (such as slot, hole and rib) of the product and tooling as the basis for cost estimation [Feng et al. 1996]. The parametric cost estimation methods involve formulating relations between product characteristics and its cost using available data. Since it gives quick estimates without detailed data related to downstream activities, it is gaining application in manufacturing domain. Examples include estimation of the cost of injection moulds [Fagade and Kazmer, 2000].

A few researchers have focused on cost estimation of a particular operation or domain such as sheet metal working [Rimasauskas and Bargelis, 2005], welding cost estimation [Masmoudi et al. 2007], die and mould cost estimation [Nagahanumaiah, 2005], and for Injection Moulding Cost estimation [Wang, et al. 2003]. Qing, 2007 used Artificial Neural Network (ANN) technique to estimate the manufacturing cost, ANN are ‘model-free estimators’ which is a key advantage over traditional approaches to cost estimation such as parametric methods and multiple regression analysis, i.e. ANN estimate a function without requiring a mathematical description of how the output functionally depends on the input. In common with regression analysis, neural networks learn from input–output data samples.

III. TRADITIONAL METHOD DESIGN

Traditional methods of casting design based on the experience of workers, means where to use the feeder what will be the feeder and gating size but this is not guarantee casting will free of defects. The flow of molten metal in the mould and subsequent solidification affect casting quality. This can be control by appropriate design of the mould, essentially the cavities corresponding to the casting, gating channels and feeders. After inspecting trial castings, the tooling design modified until the desired quality and yield achieved. Even then, defects may appear during regular production. A comprehensive understanding of the relation between geometric, material and process parameters involved, with respect to casting quality, is therefore essential to minimize casting defects.

IV. COMPUTER AIDED SIMULATION AND METHOD DESIGN

Today, a number of casting simulation programs commercially available. In general, Finite Element based programs are more complex to develop and use, but give better results because they can model the casting shape more accurately than finite difference methods. Some of these programs perform coupled simulation of mould filling and solidification, which gives better results. The widespread availability of powerful yet low cost computers has opened the possibility of creating, analyzing and optimizing virtual castings so that real castings can be produced ‘right first time and every time’. Computer-aided design and computer-aided manufacturing (CAD/CAM) is now being widely used in general purpose manufacturing, especially for machined parts. In casting domain, software applications are still nascent and expensive, limiting their penetration to mainly large foundries.

V. METHOD DESIGN WITH SIMULATION AND EXAMPLE

The method layout of a casting is an important aspect of tooling development. It involves decisions regarding part orientation in mould, parting line, cores, cavity layout, feeders, feedaids and gating system. An improper method layout leads to either poor quality or low yield, affecting manufacturing costs and productivity. Computer simulation provides a clear insight regarding the location and extent of internal effects, ensuring castings are right first time and every time. The AutoCAST software integrates and automates the above tasks, and provides an extremely easy to use graphical user interface suitable for even first time computer users. The mould cavities, feeders and gating system are automatically optimized, driven by the criteria and constraints specified by the user. This reduces the total time for method design and optimization of a typical casting to about one hour (AutoCAST software).

A. Part orientation mould and core design

Part Orientation decide the parting surface and parting line, the orientation of part in mould like that it
should minimize the complexity of parting line means parting line must be flat because it is easy to manufacturing tooling of cast part having flat parting line. Also part orientation governs the core complexity and core orientation apart from this part orientation decides the mould size (Fig.2).

Figure 2: Part orientation mould and core design

B. Feeding design

Shrinkage porosity defect eliminated by designing the optimal feeder at appropriate location means at hot spot. Apart from supplying metal to compensate for shrinkage during solidification, the function of a feeder is to set up thermal gradients for controlled progressive directional solidification, with shrinkage occurring in the feeder region, in order to design the feeder it is essential to determine the location of hot spot in the casting. The parting surface chosen to locate the hot spots in the casting to have easy access to feeder generally placed at the top of the mould. The feed metal flow part designed as feeder- hot spot- thin sections remote from the feeder (Fig.3).

Gating design: Gating Design in AutoCAST, suggests the connection points for ingates and ingates are automatically located on the parting line: near a side feeder or a thick section where free fall height and obstructions are less. Then design the gating system, the ideal pouring time estimated based on metal, casting weight, average section thickness and pouring parameters.

Then the dimensions of sprue, runners, and ingates, pouring basin and sprue well are calculated, based on pouring time, choke velocity and gating ratio. As per the requirement, changing of location, number of ingates, runner, and the dimension of gating system elements is possible. After that mould filling simulation is performed to determine the actual filling time, and to identify gating related defects

Figure 3: Feeder Design and cooling map position

Figure 4: Gating design and mould filling simulation

Based on this analysis in AutoCAST for this component design data obtained, which formatted in the table 1.

Table 1: Part design, parting design and method design data

<table>
<thead>
<tr>
<th>Cast Metal</th>
<th>PART DESIGN</th>
<th>PARTING DESIGN</th>
<th>FEEDER DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey Iron</td>
<td>Surface Area (mm²)</td>
<td>Volume (mm³)</td>
<td>Weight (Kg)</td>
</tr>
<tr>
<td>173674</td>
<td>125629</td>
<td>52611.95</td>
<td>300<em>300</em>250</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PART DESIGN</th>
<th>GATING DESIGN</th>
<th>POURING PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Ingates</td>
<td>Gating Weight (Kg)</td>
<td>Gating Yield (%)</td>
</tr>
<tr>
<td>1</td>
<td>1.6</td>
<td>95.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gating Ratio</th>
<th>Choke Area (mm²)</th>
<th>Ingate Cross Section</th>
<th>Runner Cross Section</th>
<th>Fill Time (sec.)</th>
<th>Max. Velocity (m/s)</th>
<th>Pouring Time (sec.)</th>
<th>Pouring Rate (Kg/sec.)</th>
<th>Pouring Temp. (°C)</th>
<th>Match Plate Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.98:1.98:1.00</td>
<td>40</td>
<td>8:6</td>
<td>7:9</td>
<td>51.9</td>
<td>1.2</td>
<td>20.3</td>
<td>0.65</td>
<td>1324</td>
<td>300*300</td>
</tr>
</tbody>
</table>
VI. GEOMETRICAL ATTRIBUTES FOR COST ESTIMATION

Pattern cost is mainly depend on pattern complexity and size but these two parameters are not sufficient to calculate the exact pattern cost estimation. Therefore, to find out the precisely cost of patterns, more influencing parameters, which directly affect the tooling cost are considered.

A. Volume Ratio

It is the ratio of total volume of copes or drag pattern to its total bounding box volume. Maximum value of volume ratio is one for a solid cube.

B. Thickness Ratio

The ratio of minimum thickness and maximum thickness for a pattern is known as thickness ratio. These minimum and maximum thicknesses of pattern are considered in all direction for that pattern. Complete pattern on match plate with feeder, core and gating design is considered to calculate minimum and maximum thicknesses according to the design.

C. Convex Surface Area Ratio

Convex surfaces are those surfaces, which extruded above the match plate. Most of the patterns consists convex surfaces more than concave surfaces. The ratio of convex surface area to total surface area known as convex surface area ratio.
D. Concave Surface Area Ratio

Concave surface area ratio is the ratio of concave surface area to total surface area. Concave surfaces are those surfaces, which are below the top face of match plate or below the parting surfaces (in core box). For making this material is removed from the solid part. These cavities and cuts are generally appeared in core boxes.

E. Number of Control Dimensions

Control Dimensions are the major dimension which need extreme accuracy during manufacturing because if these dimensions suffer minor change will affect the entire part geometry drastically. Therefore toolings with these dimensions are manufactured more accurately if control dimensions are more it increase the machining cost.

F. Quality Level

Quality directly related to accuracy, which further depends upon the tooling material and the material, which cast by these toolings. In this paper, three quality levels considered; quality level one, quality level two and quality level three. Quality level one is the highest level of quality, quality level two is moderate level and quality level three is the poorest quality. As the quality level increase tooling cost increases.

VII. REGRESSION ANALYSIS

On the data of all the parts, which are driven from method design values regression coefficients $\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5,$ and $\alpha_6$ are calculated by Minitab 15 software. Final equation for tooling cost estimation for wood given by equation 7.1.

$$Cost_{tooling(wood)} = 1952 -1717 \left( \frac{V}{V_h} \right) + 256 \left( \frac{T_{min}}{T_{max}} \right) - 2759 \left( \frac{A_{concave}}{A_s} \right) - 2768 \left( \frac{A_{concave}}{A_s} \right) + 51.3 \times N_{CD} + 20.4 \times QL \quad \ldots \ldots \ldots \ldots (7.1)$$

VIII. CONCLUSION

Pattern and core box manufacturing procedure varies from part to part and it is not very well documented. Previous cost estimation methods depend on the experience of the toolmaker and may not yield realistic estimates, especially when pattern complexity is high, and no specific method is available especially for pattern cost estimation. Therefore, this equation gives a hybrid model of cost estimation for patterns of sand casting, which based on the geometrical parameters. These parameter directly affect the cost of pattern, this formula is based on the pattern complexity not on the part complexity because part complexity is differ from the pattern complexity therefore these cost equations gives more accurate estimation of costs.

REFERENCES
