Transient Thermal Analysis for Optimized L Shaped Cross section of Casting Junctions

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Abstract

Intersection of sections is known as junctions. A casting can be viewed as an assemblage of sections and junctions. Molten metal at the junction does not possess sufficient surface area for cooling as compared to the sections; hence junctions solidify at the end and this inevitably leads to different casing defects like porosity & hot spot defects if the junctions are not designed for feedability. This paper deals with application of FEA to two-dimensional transient thermal analysis of casting junctions employing ANSYS. Determining the solidification sequence of junctions and design of L-junction has been discussed in this paper.

Keywords: Casting junction, Finite Element Analysis, Numerical Modeling, Feedability.

Introduction

Intersection of sections results in junctions. A casting can be viewed as an assemblage of sections and junctions. Junction in a casting design is an abrupt or discontinuous increase in cross-section caused by meeting of two or more sections resulting in regions of high thermal concentration. Molten metal at the junction does not possess sufficient surface area for cooling as compared to the sections; hence junctions solidify at the end and this inevitably leads to porosity defects if the junctions are not designed for feedability. As the number of sections meeting at junction increase, surface area for cooling further decreases resulting in more severity of hot spots and hence porosity defects. Numerical modeling of casting solidification involves transient thermal analysis as temperature and material properties vary with time. Transient thermal analysis using ANSYS for constructing solidification sequence charts for common junction types L, V and T junctions is presented in the forthcoming sections. Design of L-junction is reviewed with the purpose of optimization of its design is also presented.

Literature Review

A Junction of two sections of dissimilar size is a potential point of stress concentration and service failure in fatigue. Caine (1963) established relationship between fillet radius stress concentration and thermal gradients. In his book “Design of Ferrous Castings” he derived fourteen rules for minimum stress concentration and maximum castability for casting shapes varying from a straight junction to complex junctions as ‘X-T’ junctions. Design of thermally neutral T-Junction and thermally neutral bosses is also discussed in this reference [1]. ASM (1962) illustrates the potential of shrinkage porosity defect in L, T, V, +, and Y junctions. Minor changes to junction geometry as adding of fillets, changes in geometry of section and use of core are presented for their effect to reduce the area of defect [2]. Determination of sequence of solidification is important for feeder placement close to the last solidifying region. Loper and Kotshi (1976) extended the Chvorinov’s modulus approach for determining the sequence of solidification. They generated plot depicting solidification sequence for L-junction, T-junction and Plus junctions. They also constructed these charts for varying fillet radius and considering the effect of chills. Experimental analysis of solidification wave front conducted by Kim, et al., (1985). They produced a series of castings with V-junctions by decanting the liquid at various stages of solidification. The study shows that higher the outside and inside angle of V-junction greater is the progress in solidification front. Also higher the inner and outside fillet radius, greater is the progress in solidification front [4]. Application of numerical modeling and FEA using ANSYS has also been reported to be used for casting...
solidification analysis. Majchrzak, and Mendakiewicz, (1995) proposed a numerical algorithm with a composition of the Finite Element Method for nonlinear energy equation considering enthalpy with thermal diffusivities for the solid, eutectic, mushy zone and liquid sub-domains of casting and Boundary Element Method for linear energy equation written in temperature for mold. They presented isotherms for time 1, 3, 5 and 10secs [5]. Lewis et al., (2000) employed numerical modeling for optimization of feeder shape and volume for hub casting. They used objective function that included both thermal and volume components. They investigated several geometric variants within allowable constraints using FEM and finalized the design with considerable reduction in size of feeder [6]. Venkatesan, et al., (2005) in their study, developed a program for finite element modelling of casting solidification, the salient features of their program are: facility to incorporate latent heat through enthalpy method, incorporation of air gap by coincident node technique, ability to handle non-linear transient heat conduction through temperature dependent material properties, and object oriented programming. Using this program, solidification of infinite slab of water was simulated and the results were compared with the reported literature and ANSYS and were found to be in good agreement. Also, solidification of Al–6 wt. %Si alloy in sand and metal mould was simulated and compared with the experimental findings and simulation results reported in the literature and ANSYS [7].

Kotshi, 1975 applied modulus principle for generating the various solidification sequence charts it seems logical to apply ANSYS for the same, also the guidelines for design of junctions are based on specific experiments limiting their application for general use. L - junction design for minimizing the possibility of shrinkage porosity by application of ANSYS is presented in this work. The generic method proposed can be applied other junctions as well for any material process combination.

**FEM Model of Junctions**

The temperature of a location inside the casting with respect to neighboring locations governs the formation of shrinkage cavity as well as the macrostructure. This is difficult to determine even for a simple shape, since all modes of heat transfer are involved during casting solidification by convection within the molten metal, by conduction in solidified portion of the casting, by convection and radiation at the metal mold interface, and by conduction in the mould material. Also the release of latent heat has to be addressed, it increases the casting temperature at that instant and location, and has the effect of delaying the solidification [8]. For FEM modeling of junction we consider convection within the molten metal, conduction in solidified portion of the casting, conduction in the mould material and convection at the outer surface of mold box (fig 1.1). The decantation tests on pure Aluminum were conducted by Kim, et al., (1985)[4]. With pouring temperature of 1300 °F for T section casting the solidification front is shown in figure 1.2. Modeling the T section with same dimensions thermal analysis is performed using ANSYS with initial sand temperature at 80 °F and Cast Steel with pouring temperature at 2875 °F. The material properties are mentioned in table 1. The results of temperature distribution after a time period of 4 seconds are shown in figure 1.3.

![Figure 1.1 Boundary Condition](image)

**Table 1. Material property for Cast Steel and Sand**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Conductivity (KXX)</th>
<th>Enthalpy for Steel</th>
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</thead>
<tbody>
<tr>
<td>at 0°F</td>
<td>1.44 Btu/(hr-in-°F)</td>
<td>0.0 Btu/in³</td>
</tr>
<tr>
<td>at 2643°F</td>
<td>1.54</td>
<td>128.1</td>
</tr>
<tr>
<td>at 2750°F</td>
<td>1.22</td>
<td>163.8</td>
</tr>
<tr>
<td>at 2875°F</td>
<td>1.22</td>
<td>174.2</td>
</tr>
</tbody>
</table>

**Material Properties of Sand**

- Conductivity: 0.025 Btu/(hr-in-°F)
- Density: 0.054 lb/in³
- Specific heat (C): 0.28 Btu/(lb-°F)
Development of Solidification Sequence Chart

The above model employing ANSYS is now used for developing solidification sequence charts (SSC) of various junctions (fig. 1.4). First we present the SSC for T and PLUS junctions and compare them with the results of Kotshi (1976)[3] considering zero fillet radius (fig. 1.5). Three-junction parameters t, T, J (Junction) are considered for all these junctions. The order of solidification sequence is shown as T-J-t, T-t-J, t-T-J and t-J-T. The boundaries represent the areas for particular solidification sequence.

Fig. 1.2: The decantation test for T junction by Kim et, al. [4].

Fig. 1.3: Isotherms Curve by ANSYS for T junctions.

Fig. 1.4: Casting Junction represent by J

Fig. 1.5: Solidification Sequence without Fillet

Fig. 1.6: Solidification Sequence Chart of L Shape of Casting Junction with Various Dimensions
Optimization of Fillet for L Junction

Considering a L-junction of uniform thickness ‘t’ with length of sections forming junction to be 5t, choosing the proper fillet radius that minimizes the possibilities of porosity defects is reviewed in this section by applying transient thermal analysis. Using ANSYS simulation for L-junction with varying fillet radii (0.25t to 2.5t for both inner and outer corners) areas of various temperature contours are obtained for the comparison of various alternatives of fillet radius. The temperature range used for this analysis is 800 to 966 °F at time equal to 4 seconds after pouring. The temperature range is further divided into smaller temperature ranges (800 to 900, 900 to 931, 931 to 950, 950 to 960, 960 to 963, 963 to 966 and above 966 °F). For the selected metal process combination the temperature range of 900-931 °F was found to be most critical and the design of junction should minimize this area. The area of region with temperature 900-931 °F decreased from 19.34 to 2.8 sq inch on introduction of outer fillet radius equal to t (thickness of section). On providing inner and outer fillet radius of 0.5t the hot spot areas with temperature region 900-931 °F increased to 24.3 sq inch. By increasing the outer fillet radius to 2t and inner equal to t a small area (3.819 sq inch) in temperature region 900-931 °F was observed. With inner fillet radius equal to t and outer fillet radius of 2.5t area with temperature 900-931 diminished to zero, however this design is weak as compared to previous alternative of inner fillet radius of 0.5t and outer radius equal to t. Hence it can be concluded that the design of L-junction with fillet radius of 0.5t inner and outer radius equal to t can be considered to be the best design among all alternatives (fig. 1.7).

Conclusions

The solidification sequence charts developed on the basis of this model closely matched with that generated by previous researchers. This has been applied for generation of solidification sequence chart for V and X junctions that were not attempted by previous researchers. FEA of L-junction reveals that a L-junction with inner fillet radius of 0.5 times the thickness of section and outer radius equal to section thickness is the best design alternative for minimizing the possibilities of hotspots. This approach can also be extended to optimize the design of T, V, Plus and X junctions.

References:

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