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Minimization of Corner Shrinkage Defect by Analysis of Junctions in Hydrant Valve Body

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Abstract-*In investment casting process, many casting defects are occurred due to poor design of part with respect to manufacturability. Some defects cannot be eliminated by changes to tooling and process parameters. Now a day casting defects can be predicted by casting simulation and corrected by modification to part design using casting DFM (design for manufacture) guidelines. The importance of DFM and casting simulation in casting design is well established in casting industry. Sometimes Casting part design is analyse with respect to junctions and corner in casting part. Casing junctions, intersections of two or more sections leading to mass concentration, are potential location of Corner Shrinkage.*

Keyword-*Casting; Casting Junction; Corner Shrinkage Defect; Solidification Simulation; DFM (Design for Manufacturing)*

I. INTRODUCTION

Junction in a casting design is an abrupt or discontinuous increase in cross-section caused by meeting of two or more elements 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 typically leads to porosity defects if the junctions are not fed properly for volumetric contraction from liquidus to solidus temperature. 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.[3]

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 applied to reduce the area of defect. Caine (1963) established relationship between fillet radius, stress concentration and thermal gradients and derived fourteen rules for minimum stress concentration and maximum cast ability for casting shapes varying from a straight junction (abrupt change in cross-section area) to complex junctions as 'X-T' junctions. Loper (1976) extended Chvorinov's modulus approach for determining the sequence of solidification, important for feeder placement close to the last solidifying region. 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 (ASM 1980). [1]

A. Classification of casting junctions

A general characterization of junctions with N number of elements (or walls) is proposed here, based on section attributes, section orientation, additional geometric features, and feed ability properties (Figure 2). These are described here. [3]

(a) Section attributes (for each element)

(1) L - Length of element (2) t - Thickness of element

(3) h – Height (4) r - Fillet radius

(b) Section orientation (for each element)

(1) Θ, Φ - Angular references

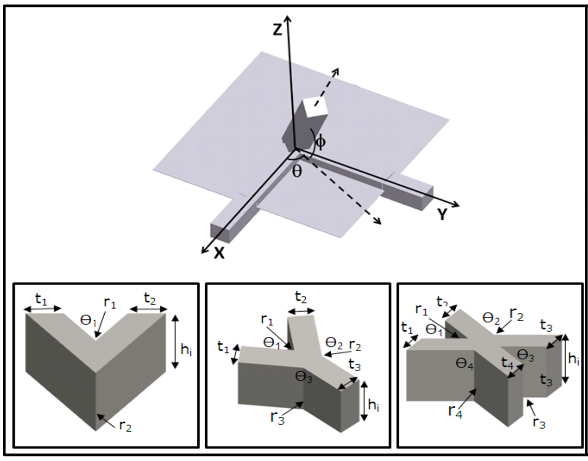
(c) Additional geometric features

(1) A - Cross-section area

(2)H/t - Extent of contact between adjacent elements:

(3) Cross-section type: (R) rectangular, (C) circular

(4)Central hole (if present): shape, surface area



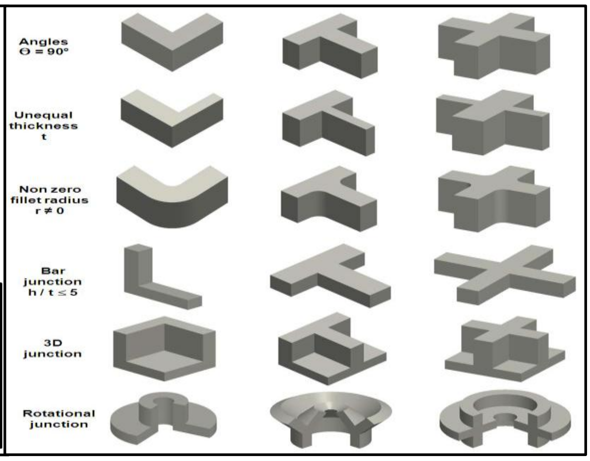


Figure 1.Junction parameters and types [3] ***Figure 2.Junction classification [3]***

From the above definition, junctions of two sections ('V' or 'L'), three sections ('Y' or 'T'), and four sections ('X' or 'K') can be derived. Further, two dimensional variations with unequal thickness, unequal and non-orthogonal angles, fillet radius, and bar elements, as well as three dimensional variations with an additional element or with rotational geometry can be derived as shown in Figure 2. [3]

B. VECTOR ELEMENT METHOD

Casting simulation is carried out using the Vector Element Method, which traces the feed metal paths in reverse to pinpoint the location of hot spots (Figure 3). It is based on the principle that the direction of the highest temperature gradient (feed metal path) at any point inside the casting is given by the vector sum of individual thermal flux vectors in all directions around the point. Multiple hot spots, if present, are detected by starting from several seed points . [2]

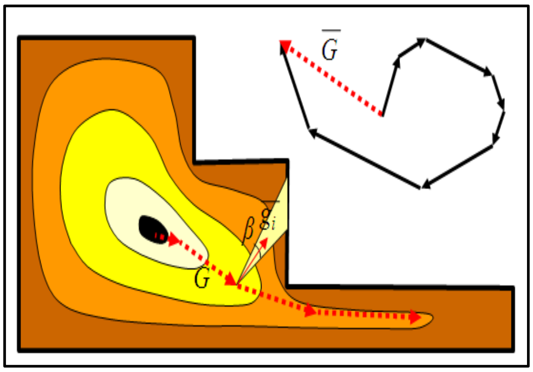


Figure 3.VEM applied to L-junction [2]

The method is based on determining the feed path passing through any point inside the casting and following the path back to the local hot spot. The feed path is assumed to lie along the maximum thermal gradient. The gradient can be determined from Fourier's law of heat conduction as follows:

$$q = -K\, A\, \Delta T\, \Delta s \qquad \text{and} \qquad G = (-1\, K)\, w$$

Where, $G = \Delta T / \Delta s$ is the thermal gradient and, $w = q / A$ is the heat flux at given point inside the casting, in given direction. The gradient (as well as the heat flux) is zero in a tangential direction to the isotherm passing through the point, and the maximum in perpendicular direction. The magnitude and direction of the maximum thermal gradient at any point inside the casting is proportional to the vector resultant of thermal flux vectors in all directions originating from that point. [2]

II. LITERATURE REVIEW

Investment casting process is one of the most oldest method to produce metal component of complicated shape and size, in previous days foundry uses the trial and error method to reduce internal shrinkage defect but current scenario is about virtual foundry concept for producing robust component without shop floor trail. [5]

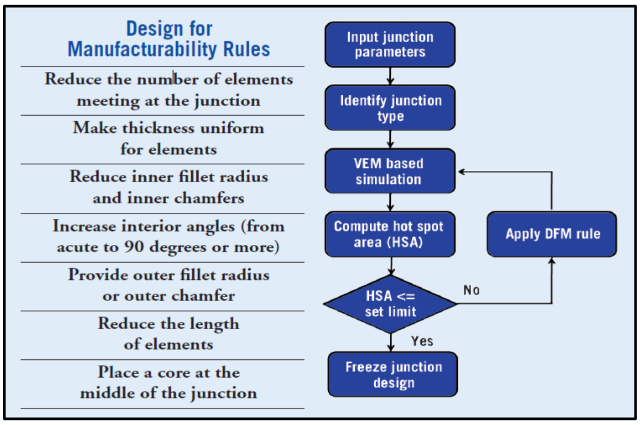


Figure 4.Casting designers can use this framework for junction redesign [5]

The conclusions of above analyses along with established guidelines can be used in a framework proposed for DFM of 3D junctions. A given junction is first classified to identify the type of junction. The hot spot area is measured and compared against a predefined limit (depending on the desired quality level). If the HSA is more than the set limit, junction DFM rule given in are applied to modify the junction design, subject to functional requirements of the part being satisfied. The process is repeated. [5]

III. PROBLEM DEFINITION

By frequent visit of industry, found that different types of defects produce in casting product. These defects are occurring at a time of solidification process. From surveying whole process of investment casting in casting company found a reason for defects in casting product. It is a sharp and corner junction in casting design.

A one of the casting product, Single head hydrant valve which we will consider for whole solution process is shown below:-

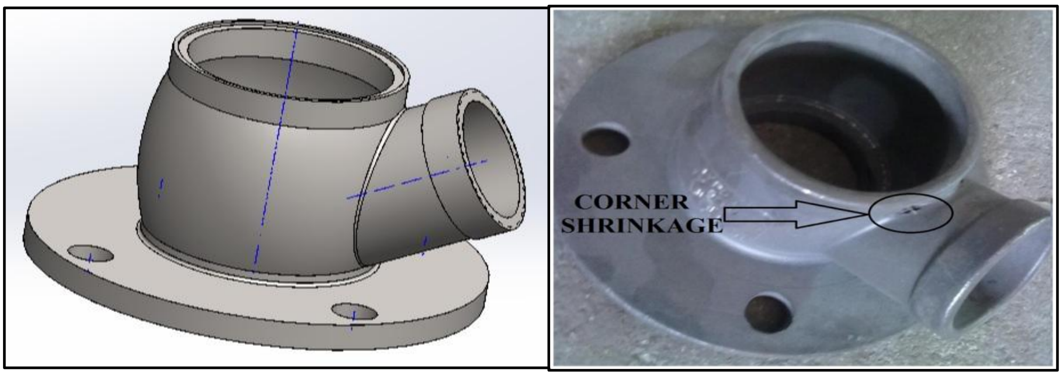


Figure 5.Single head hydrant valve body and with corner shrinkage defect

This is a single head hydrant valve which is used for firefighting equipment. Material use for made a single head hydrant valve is:-CF8M

Composition of CF8M:- (1) 18-21 chromium (2) 1.5% manganese (3) 0.08% carbon

(4) 1.5% silicon (5) 9-12% nickel (6) 2-3% molybdenum

(7) 0.4% sulphur and phosphorus

IV. EXISTING DESIGN AND SIMULATION OF SINGLE HEAD HYDRANT VALVE BODY

Existing design of hydrant valve body which is used at casting industry as shown in figure7. Through this design possibility of shrinkage defects are arise. In which one possibility is to wrong junction design in hydrant valve body design.

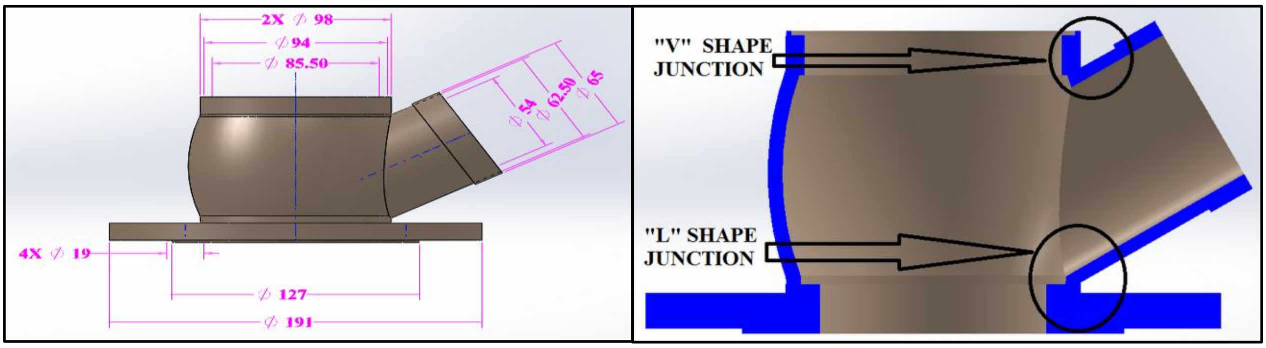


Figure 6.Dimension and "L" and "V" shape junctions in hydrant valve body

A. INFORMATION ABOUT HYDRANT VALVE BODY

1. Material grade - AISI 316SS
2. Pouring temperature - 1510^0c
3. Length - 201mm
4. Width - 192mm
5. Height - 106mm
6. Volume - 465864 mm^3
7. Surface area - 130194 mm^2
8. Weight - 3.610 kg

B. SIMULATION OF SINGLE HEAD HYDRANT VALVE

As discuss earlier, parts having shrinkage defect at the end of process. So it is necessary to reduce this defect before the shop floor trial. These types of defect can be easily identified by the simulation software before the shop floor trial.

SoftCAST™ is based on the radically new Vector Method for casting solidification analysis. Unlike the Finite Element Method (volume elements) and the Boundary Element Method (surface elements), it uses vector elements to analyze the progress of solidification inside a 3D casting model. This greatly increases the computation speed without compromising the accuracy of results. [10]

1. HOT-SPOT ANALYSIS

The most important information generated by a SoftCAST simulation is the location of the hotspots. Hotspots are the last freezing zones in a casting. SoftCAST accurately locates all hotspots in the casting, and displays them in order of their intensity (low to high intensity scale).A relative scale is used to show the hotspots at different temperature intensity bands or levels (from level 1 to level 9). Level 9 is the highest relative temperature intensity level, i.e. the lowest level by way of quality. Hotspots seen at the levels of 9 to 7 are the major hotspots. [10]

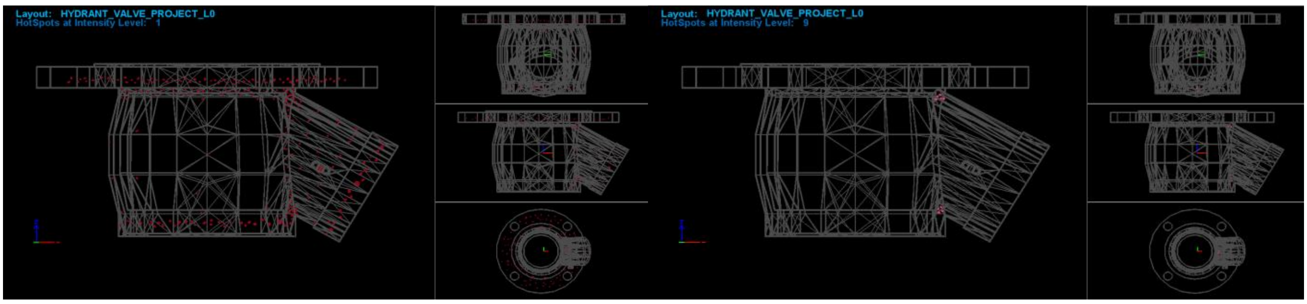


Figure 7. (a)Minor Hotspot Intensity level-1 (b) Major Hotspot Intensity level-9

2. TEMPERATURE MAP FOR HYDRANT VALVE BODY

The temperature maps within the casting, as seen through the section temperature analysis in SoftCAST, provide a wealth of information on temperature distribution, thermal gradients and moduli within the various sections. Relative temperature profiles are indicated by a colour scheme. A colour scale is shown at the bottom or side of the Temperature Map; this is a relative temperature scale. SoftCAST enables the user to take sections through the casting, in any of the three orthogonal planes: XY, YZ, or ZX. [10]

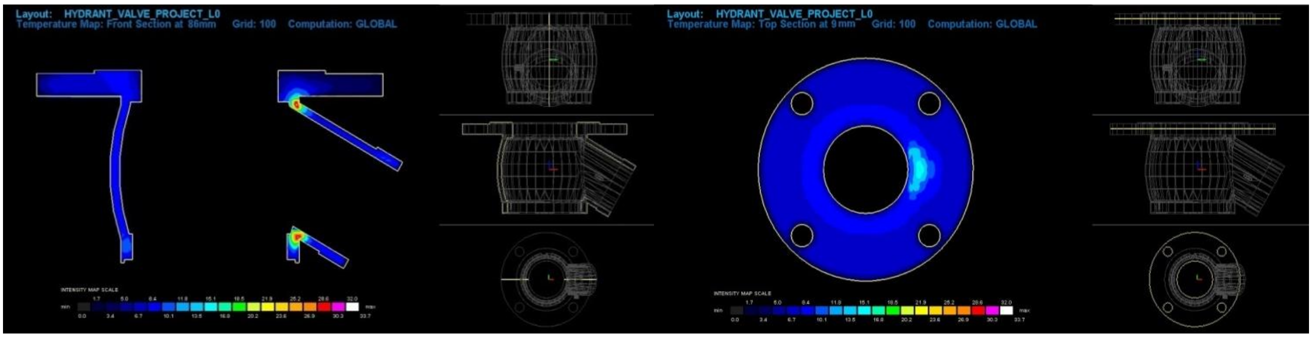


Figure 8. (a)Temperature map front section at 86 mm (b)Temperature map top section at 9 mm

V. ANALYTICAL CALCULATION

For hot-spot area calculation, mainly four parameters are influences which are:-

(1) Inner radius 'r_1' (2) Outer radius 'r_2' (3) Thickness 't' (4) Angle 'ɵ'

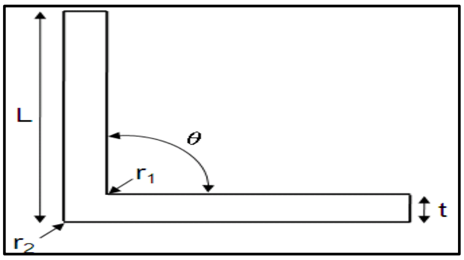


Figure 9. Parameters of junction [3]

A. HOT-SPOT AREA CALCULATION

The area of hot-spot area can be estimated using second order polynomial equation and linear equation obtained by curve fitting of the results.

Hot-spot area (mm²) = $(0.385r_1^2+10.19r_1+13.86) + (-3r_2 + 1.5)$……………………………… (1)

1. HOT-SPOT AREA CALCULATION AT "V" SHAPE JUNCTION

For Hot-Spot area calculation taking inner (r_1) and outer (r_2) radius in between 1mm to 4mm because of some manufacturing limitation and angle between V-Shape is 60° hence Hot-Spot Area calculation equation is became,

Hot-spot area (mm²) = $(0.385r_1^2+10.19r_1+13.86) + (-3r_2 + 1.5) + (-0.0003\theta^3 + 0.1153\,\theta^2 - 13.9778\,\theta + 642.4)$

But ɵ is 60° hence above equation is became,

Hot-spot area (mm²) = $(0.385r_1^2+10.19r_1+13.86) + (-3r_2 + 1.5) + 154.012$………………………….. (2)

Using equation (2) Hot-spot area is calculate and it's result shown into below table,

Sr. no	Applied fillet radius in mm		Hot-Spot Area (mm²)
	Inner radius r_1	Outer radius r_2	
1	1	1	179.947

2	1	2	173.89
3	2	2	185.292
4	1	3	170.947
6	1	4	**167.95**

Table 1.Result of HSA calculation at "V" Shape junction

2. HOT-SPOT AREA CALCULATION AT "L" SHAPE JUNCTION

For Hot-Spot area calculation taking inner (r_1) and outer (r_2) radius in between 1mm to 3.5mm because of some manufacturing limitation and angle between L-Shape junction is 90^o hence Hot-Spot Area calculation equation is became,

Hot-spot area (mm^2) = $(0.385r_1^2 + 10.19r_1 + 13.86) + (-3r_2 + 1.5) + 99.628$.......................... (3)

Using equation (3) Hot-spot area is calculate and it's result shown into below table,

Sr. no	Applied fillet radius in mm		Hot-Spot Area (mm^2)
	Inner radius r_1	Outer radius r_2	
1	1	1	122.563
2	1	2	119.6
3	2	2	130.908
4	1	3	116.53
5	1	3.5	**115.063**

Table 2.Result of HSA calculation at "L" Shape junction

B. CALCULATION OF INCREASE OF MASS AT JUNCTIONS USING INSCRIBED CIRCLE METHOD

A general rule is that the increase in mass at the joint is proportional to the square of the ratio of diameter $(D/d)^2$, and this ratio must be as small as possible. [8]

Increase of mass = $(D/d)^2$.. (4)

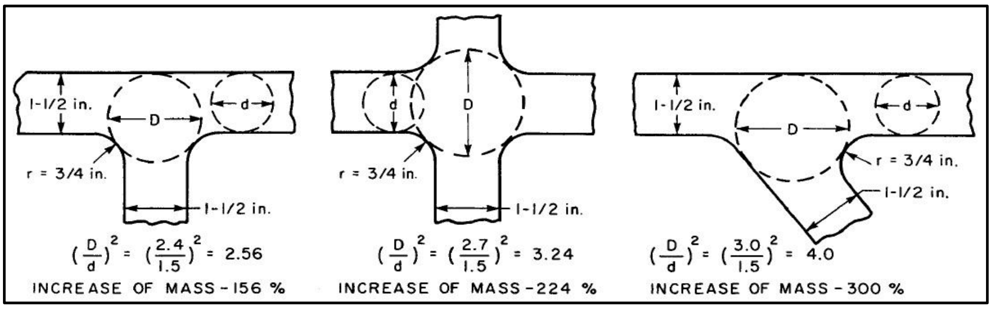


Figure 10.Increase of mass resulting from joining sections or junction [8]

1. CALCULATION OF INCREASE OF MASS AT "L" AND "V" SHAPE JUNCTION USING INSCRIBED CIRCLE METHOD IN HYDRANT VALVE BODY

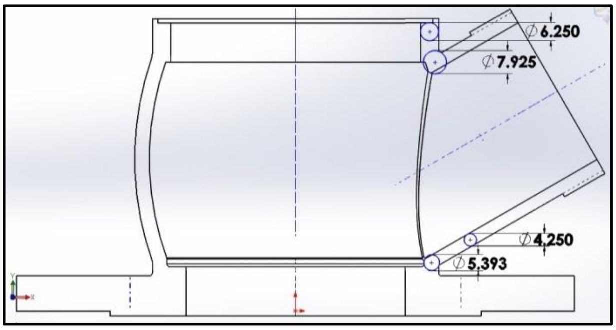


Figure 11.Increase of mass at L and V Shape junction

Using equation (4) calculation result of increase of mass is shown below table,

Sr. no	Applied fillet radius in mm				Increase of mass (%)	
	At V-Junction		At L-Junction			
	r_1	r_2	r_1	r_2	At V-Junction	At L-Junction
1	1	1	1	1	60.8	61
2	2	2	2	2	77.8	81.5
3	2	4	1	2	30.9	52.3
4	1	3	1	3	16.9	42.8
5	1	3.5	1	3.5	7.2	38.3
6	1	4	1	3.5	3.6	38.3

Table 3 Result of Increase of mass calculation at V and L Shape junction

- After Analytical calculation conclude that adding fillet radius, Inner radius,r_1= 1mm and Outer radius, r_2= 4mm at V-Shape junction and Inner radius, r_1= 1mm and Outer radius,r_2= 3.5mm at L-Shape junction in single head hydrant valve body is more suitable for minimization of hot-spot area as well as Corner Shrinkage defect.

VI. MODIFIED DESIGN AND SIMULATION OF SINGLE HEAD HYDRANT VALVE BODY

For the modification purpose, casting junction design parameters can be change.For those parameters such as, inner radius, outer radius, thickness, length and angle etc. should be taken for the new design. But it can take only two parameters which are inner radius (r_1) and outer radius (r_2). Taking Inner radius **r_1= 1mm** and Outer radius, **r_2= 4mm** at **V-Shape** junction and Inner radius, **r_1= 1mm** and Outer radius **r_2= 3.5mm** at **L-Shape** junction in single head hydrant valve body is designed which is shown below figure.

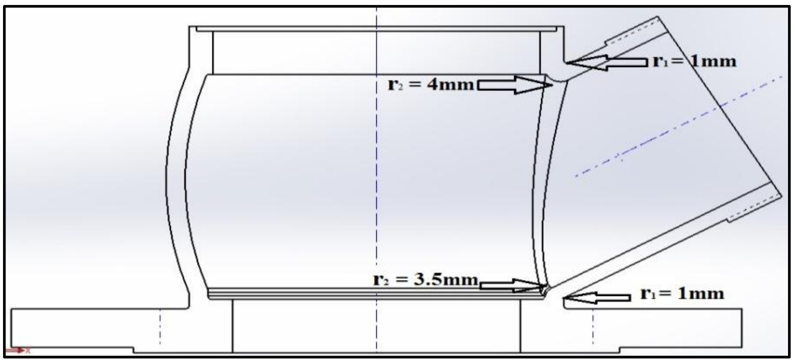


Figure 12.Applied fillet radius at "L" and "V" shape junction

Here in the new modified design is based on two parameters such as inner radius and outer radius. Both Simulation result is shown in below figure as discuss as earlier.

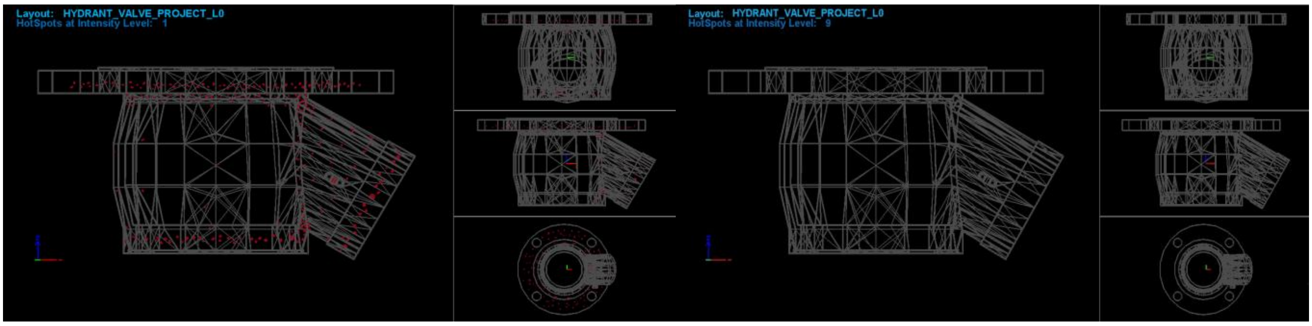


Figure 13. (a)Minor Hotspot Intensity level-1 (b) Major Hotspot Intensity level-9 (no hotspot present)

From the above two hotspot result, we can see that the hotspot is completely removed into end of solidification. Now there is no any hotspot location inside the hotspot level-9. So that, less chances of shrinkage defects inside the casting.

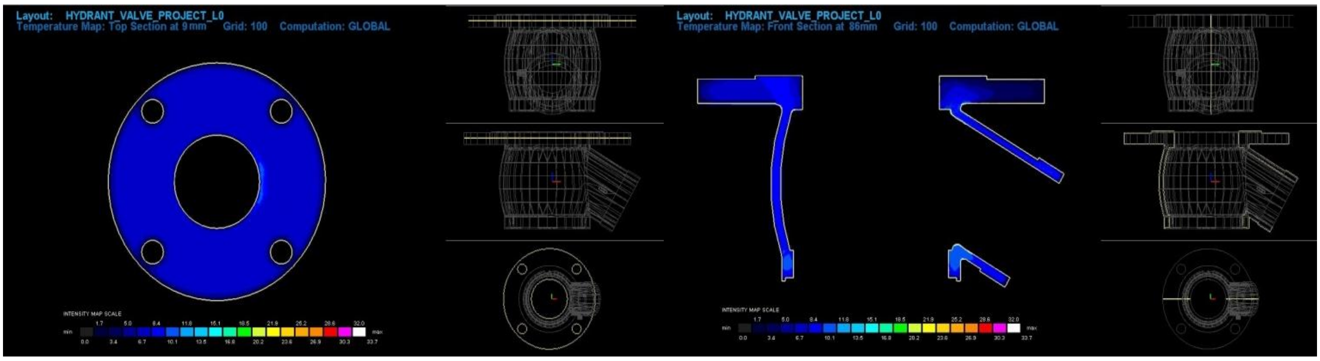


Figure 14. (a)Temperature map front section at 86 mm (b)Temperature map top section at 9 mm (modified design)

In the temperature distribution map, hotspot zone is completely removed from junction area as shown in above two different sections.

VII. CONCLUSION

Most of the castings can be manufactured as an assemblage of junctions. Casting DFM guidelines and analysis of casting junction using casting simulation software helps in solving problems in castings.Knowledge derived from the analysis of influence of geometrical parameters on hot spot area has been employed to formulate DFM guidelines for junctions. The ratio of percentage change is hot spot area to percentage change in volume is proposed for evaluating the effectiveness of various DFM rules. Using hotspot area calculation and inscribed circle method minimization of casting defects like shrinkage or corner shrinkage is done. Also these analytical methods are predicting hotspot area before shop floor trial and save time and trial cost. It concludes that use of casting DFM guidelines at design stage and casting simulation software is beneficial for minimization of casting defects.

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