ANALYSIS THE EFFECT OF GATING SYSTEM AND THICKNESS VARIATIONS ON SHRINKAGE OF A RECTANGULAR OBJECT BY SIMULATION

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Abstract

Quality can be perceived in accordance with requirements, customer needs. It, in returns, implicates necessity of verification of this accordance that is quality inspection, to improve quality of products and services. To speak about possible usage of repairing methods in firm, it is necessary to mention exact qualifications of criterions usage of quality improvement tools. Separations of quality criterions take place to investigate all spheres of formation and usage of producers: pre-production, production and after production phase. Each of these phases is characterized by occurrence a sequence of information about quality, quality features evidenced in certain forms. Results assembled at researches and estimation, on the ground of represented criterions of production can be used for effective application of different kinds of analytic tools.

Casting simulation is a new technology that allows you to design your casting process on the computer, before making expensive molds or patterns and before producing scrap parts. Using simulation, you can import your customer's 3D models and have the system tell you how many risers are required, where they should be placed, what size they should be, and what size and shape to use for sprues, runners and gates. Then you can simulate and visualize, on the computer screen, the entire process of casting the part, including pouring, solidification and shrinkage formation. Using this information, you can fine-tune your design to produce the best casting possible, at the lowest cost. You can even have the system automatically redesign the process, using optimization techniques to search for the design which gives you the optimum in quality and yield.,

In this work, we present a 3-step approach to casting defect identification, analysis and rectification. The shrinkage defect is classified in terms of their appearance, size, location, consistency, discovery stage and inspection method. This helps in correct identification of the defects. For defect analysis, the possible two factors gating system and thickness plays significant role to ensure quality by controlling shrinkage defect. The effect of change in gating system, importance of feeder and effect of thickness variations of a rectangular object on shrinkage defect was analyzed by pouring C.I., Aluminium into a sand mould. The VEM based casting simulation is used to identify the hot spot region. Based on the results and their interpretation, the optimum values of gating elements, feeder size and thickness are determined for rectification of shrinkage defect.

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It is expected that this work will be of immense importance equally to the academicians as well as to the industrial methoding engineers.

Keywords: Shrinkage, Gating System, Feeder, Simulation, Thickness, Rectangular Object

1. Introduction

The foundry industry in India is full of potential. The Indian castings are not able to compete in terms of quality, dimensional accuracy, surface finish and quality standards. It is time that the foundry industry gears up to upgrade quality, increase efficiency and reduce cost to meet the challenges of world competition. Rejection control maintains good relation with customers.

Quality control is an essential step in a foundry to assure the quality of its castings. The first step is to screen the defected castings from the sound castings. The next steps are to identify the types of the defects, find their causes, and suggest remedies, so that the defects can be eliminated in the subsequent castings.

Traditionally, diagnosis of castings defects is done in a very experience-based way. These experiences are naturally very important assets to the foundries. However, experiences go with the individual foundryman. It is very unfortunate for the foundry that the valuable experience should disappear when the individual person leaves the foundry. It is very desirable to somehow store these knowledges and experiences electronically. However, it should be realized that these experiences are not just statement-like facts that can be stored easily in a data base or a handbook. It involves a series of judgments that can only be appropriately handled in an expert system approach.

Shrinkage is probably the most difficult to overcome any problem that confront the foundrymen.Much time and study has gone into the subject and study and research is still going on. Graphs and talks have been made recommending certain size risers for certain weight castings. Sometimes the recommended riser work but more often they fail due to considering only weight of the casting. Such factors as casting design, metal temperature, pouring speed,permability of sand ,moisture control of same, mould hardness and density all have to do with metal shrinkange.Some of the wise-acres and know-it-all all boys tells us that shrinkage is caused by failure of risers and gating system to promote “controlled progressive solidification “and or “properly balanced thermal gradients”. I would construe this as meaning that the gradients should move from the areas of lowest temperature to the areas of greatest temperature, which theoretically, should be from the casting to the gating system. As usual, theoretically, the wise boys are right, but it just doesn’t work out in the practice. Sometimes the casting is of such design that is very difficult to place risers to furnish feed metal to the heavy sections where it is needed. The very important question of yield must be taken into consideration when planning the gating system for casting. The solution to this problem is an interdisciplinary, innovative design of interactive, intelligent computer system trough simulation. Now days different solidification softwares are used to predict the location and extent of shrinkage defects in complex shaped castings.VEM based solidification software is one of them, which have been validated in number of industrial case studies, it is found to be faster as well as easier to use compared to other simulation methods.

In this paper shrinkage is analyzed by placing feeder as well as optimizing gating system for rectangular objects by changing its thickness and finally validated by experiments.

2. Research Methodology

Simulation is the process of imitating a real phenomenon using a set of mathematical equations implemented in a computer program. Metal casting, which has been compared to natural phenomena such as sea wave splashing and volcanic flow, is subject to an almost infinite number of influences. Framework of this work is shown in figure1.

2.1 major factors related to casting geometry, material, and process

The major factors related to casting geometry, material, and process are considered for casting simulation in special issue of Indian foundry journal, January 2008 by B.Ravi as follows:

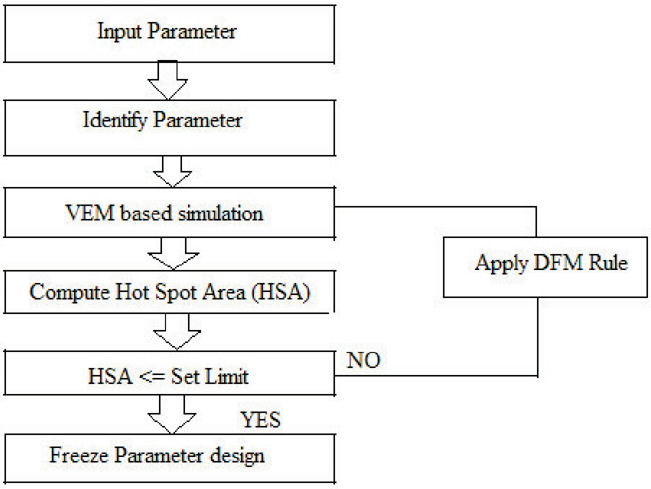

Figure 1: *Framework for parameter priority*

Geometry:

(i) Part features, including convex regions (external corners), concave regions (internal corners), cored holes, pockets, bosses, ribs, and various junctions (2D and 3D), all of which affect the flow and solidification of metal,

(ii) Layout in mould, including number of cavities, and their relative location (inter-cavity gap and cavity-to-wall gap), which affect the amount of heat absorbed by the mould,

(iii) Feedaids, including number, shape, size and location of insulating sleeves and covers, chills (external or internal), and padding, which affect the rate of heat transfer from the relevant portion of the mould.

Material:

(i) Thermo-physical properties of the metal/alloy, including its density, specific heat, thermal conductivity, latent heat, volumetric contraction during solidification, coefficient of linear expansion, viscosity and surface tension,

(ii) thermo-physical properties of mold, core and feedaid materials, including density, specific heat, thermal conductivity, coefficient of linear expansion, and modulus extension factor,

(iii) changes in properties with composition and temperature, relevant transformations (grain shape, structure, distribution), and resultant mechanical properties

Process:

(i) Turbulent flow of molten metal in the mould with splashing, stream separation and rejoining, oxidation of advancing front of metal, mould erosion, gas generation and escape through venting, coupled with heat transfer leading to reduced fluidity,

(ii) casting solidification with multiple modes of heat transfer (conduction, convection and radiation) involving non-uniform transient heat transfer rate from metal to mould, including latent heat liberation and moving liquid-solid boundary,

(iii) solid state cooling with changes in mould shape and dimensions, leading to residual stresses and/or deformation in cast part, and different grain structures affecting the final properties in different regions,

(iv) process parameters including actual composition of metal/alloy, mould size, mould compaction, mould coating, mould temperature, pouring temperature and rate, mould cooling, shake out, etc.

2.2 Casting Method and Simulation Framework

CAD model, cast metal or alloy name and type of casting process are the main inputs to the casting method and simulation programme.Orientation and parting line, core print design, and finally feeder and gating design, these four decisions are involved in this method. The major results include: method data, including solid model of core, feeder and gating channels, internal quality and casting yield.

It starts with user importing the CAD model of the cast as- part. The feeder design is carried out by identifying a suitable location to connect the feeder, computing its dimensions, creating its solid model and attaching to the part model. Then checking for presence of the hot spots inside the casting. If internal defects are predicted, the feeder design is modified. After completing feeder design, identify the suitable location of gates, computing the dimensions of gates, sprue, sprue well, runners to achieve gating design optimization. If the gating design is modified. Finally, yield is computed.

3. Proposed Approach for Analysis of Shrinkage Defect

Foundries are still using trial and error methods to solve defect related problems. It is very common to have different names for the same defects, it makes very difficult to solve the problems related to casting defects. It is always preferable to use more disciplined approach to define, identify and find out the root cause of a defect.

3.1 Proposed Classification

It is important to correctly identify the defect symptoms prior to assigning the cause to the problem. False remedies not only fail to solve the problem, they can confuse the issues and make it more difficult to cure the defect. So, the proper classification and identification of a particular defect is the basic need to correct and control the quality of castings. The nature of casting defects can be determined by correctly categorizing the shape, appearance, location and size of defects. Once casting defects are properly classified, the possible causes can be identified and the corrective action can be taken. Then a controlled and complete defect analysis can be done.

Defect classification of cast components proposed in literature or currently adopted by foundries are either on the basis of their geometry/location or on the basis of their metallurgical origin or specific causes. The International Atlas of Casting Defects (AFS, 1974) has described 30 defect types which are generally applicable to gray iron casting in sand mould. Classification of defects in certain broad categories which is based on origin of defects is also an accepted practice.

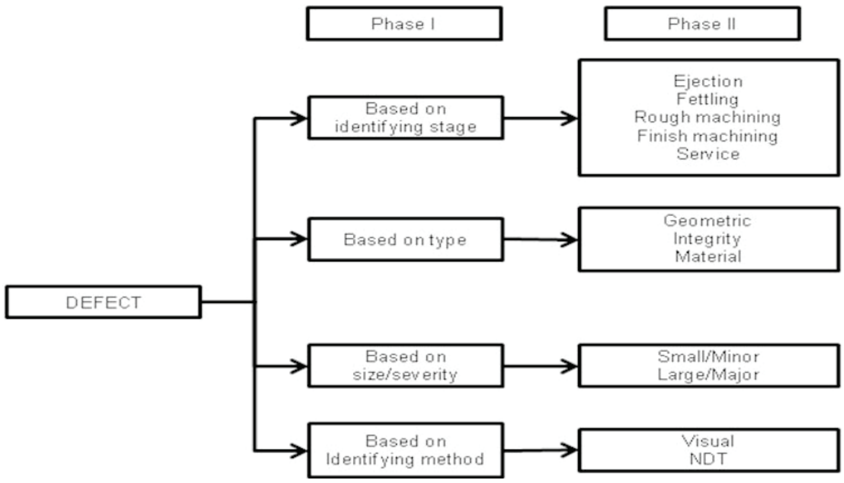

Figure 2: *Proposed classification for casting defects*

The proposed classification classifies casting defects in terms of their appearance, size, location, consistency, discovery stage and identifying method. This helps in correct identification of the defects. The proposed classification of defects is of mixed type and multi-phase, as schematically shown in Figure 2. In the first phase (phase I) the defect identifying stage, type, size/severity and identifying method is followed, taking into account the different types of controls performed on cast parts to reveal defects. Phase II is based on the sub category of the defects of phase I. Actual defect types are covered in the phase III (not shown in fig.). The final document on the classification, now in progress, a short description for each defect with illustrations and reference macro/micrographs to help readers and foundries in identifying the defects found in cast parts. One of the most common casting defects, Shrinkage, is illustrated in table 1. Shrinkage can be easily categorized by proposed classification and it is illustrated as following.

Shrinkage is categorized as geometric defect as it affects the size, dimensions and geometry of the component. It can be further elaborated by following manner. For example: shrinkage porosity is integrity type of defect because it changes integrity of cast part, Chilled zone is property related defect in casting because it change the properties of the cast part, Shrinkage geometric type of defect as it alters geometry of cast part.

It can be categorized as medium to large size defect as size of defect is medium to large.

It is generally discovered during ejection/shake-out/cleaning operation of casting process and it can be easily identified visually so it can also be categorized under category of visual.

Table1 Classification of casting defect - Shrinkage

	Type	Geometry
	Appearance	Gradual Changes in the Section
	Defect Size	Medium to large
	Location	External
	Consistency	Varying size, shape, location
	Discovery at	Ejection/shake-out/Cleaning
	Inspection	Visual

3.2 Proposed Approach for Analysis

It is analyzed by making proper design of feeder, gating system and observing effect of thickness variations of a rectangular object on shrinkage defect by pouring C.I., Aluminum.

3.2.1 Importance of Feeder

The ease of feeding of a location inside the casting is characterized by low temperature, coupled with high gradient and low cooling rate. There are major steps are considered in feeder design. The first is a suitable location on the casting surface to connect the feeder. The second involves computing the appropriate dimensions of the feeder. The third step is to create a solid model of feeder and connect it to the casting, ensuring a proper matching between the surfaces involved.

Simulated results of 40mm, 50mm and 60mm thickness of rectangular objects without feeder is shown in figure 3.Actual shrinkage for 40mm, 50mm and 60mm of rectangular objects without feeder are shown in figure 4 and Simulated results with feeders same thickness is shown in figure 5.Feeder and neck dimensions, total feeding weight and feeding yield for (100mm x 45 x 40), (100mm x 45 x 50) and (100mm x 45 x 60) rectangular objects of C.I.and Aluminium are shown in table 2 and 3.

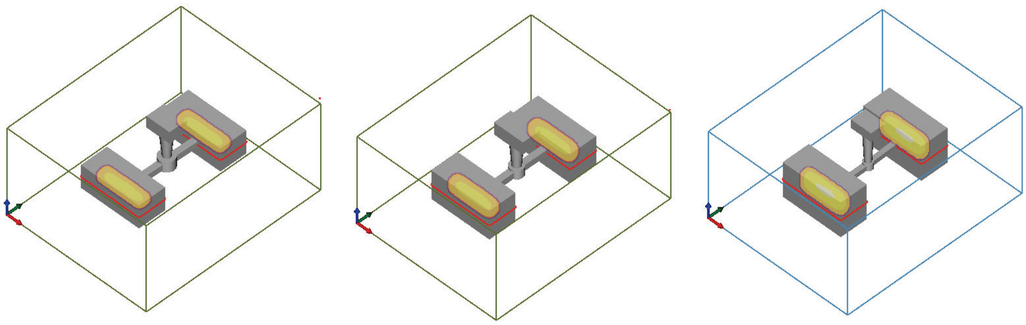

Figure3: *Simulated Results of 40mm, 50mm and 60mm Thickness of Rectangular Objects without Feeder*

Figure 4: *Actual Shrinkage for 40mm, 50mm and 60mm of Rectangular Objects Without Feeder*

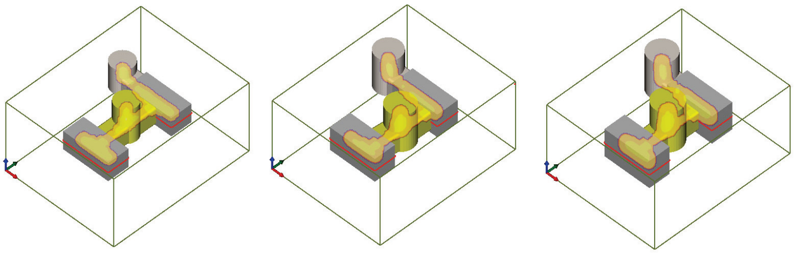

Figure5: *Simulated Results of 40mm, 50mm and 60mm Thickness of Rectangular Objects with Feeder*

Table 2 Feeder and Necks Dimensions for Different thickness of C.I.Rectangular Objects

Sr.No.	Elements	Dimensions/Parameters	(100x45x40)	(100x45x50)	(100x45x60)
1		Weight	1.3kg	1.65kg	1.92kg
	Feeder 1	Volume	174.1cm^3	220.28cm^3	256.61cm^3
	(Cylindrical)	Diameter top and bottom	47.87mm	53.74mm	57.55mm
		Height	57.44mm	64.49 mm	69.06mm
2	Neck1	Width and depth at part	37.03 mm	41.58mm	44.52 mm
	(Rectangular)	Width and depth at feeder	37.03 mm	41.58mm	44.52mm
		Length	20 mm	20 mm	20 mm
3	Neck2	Width and depth at part	37.03 mm	41.58mm	44.52 mm
	(Rectangular)	Width and depth at feeder	37.03 mm	41.58mm	44.52mm
		Length	27.25 mm	20.23 mm	16.39 mm
4	Feeder 2	Weight	846.38g	1.01Kg	1.39Kg
	(Cylindrical)	Volume	113.24cm3	135.64cm3	185.76cm3
		Diameter top and bottom	47.87 mm	50.83 mm	56.62 mm
		Height	57.44 mm	61 mm	67.95mm
5	Neck3	Width and depth at part	37.03 mm	39.32mm	43.8mm
	(Rectangular)	Width and depth at feeder	37.03 mm	39.32mm	43.8 mm
		Length	7mm	7mm	7mm
6		Total Feeding Weight	2.15kg	2.66kg	3.31kg
7		Feeding Yield	55.23%	55.96%	55.49%

Table 3 Feeder and Necks Dimensions for Different thickness of Aluminium Rectangular Objects

Sr.No.	Elements	Dimensions/Parameters	(100x45x40)	(100x45x50)	(100x45x60)
1	Feeder 1 (Cylindrical)	Weight	539.25g	705.23 g	823.85 g
		Volume	202.73cm^3	265.13 cm‡	309.72 cm‡
		Diameter top and bottom	48.23mm	54.14 mm	57.98 mm
		Height	72.34mm	81.22 mm	86.97 mm
2	Neck1 (Rectangular)	Width and depth at part	37.89 mm	42.54mm	45.55 mm
		Width and depth at feeder	37.89 mm	42.54mm	45.55 mm
		Length	20 mm	20 mm	20 mm
3	Neck2 (Rectangular)	Width and depth at part	37.89 mm	42.54mm	45.55 mm
		Width and depth at feeder	37.89 mm	42.54mm	45.55 mm
		Length	26.88 mm	19.85 mm	15.99 mm
4	Feeder 2 (Cylindrical)	Weight	335.34g	496.1g	681.41 g
		Volume	126.07cm3	186.5cm3	256.17 cm‡
		Diameter top and bottom	46.08 mm	52.48 mm	58.63 mm
		Height	69.13 mm	78.72mm	87.94 mm
5	Neck3 (Rectangular)	Width and depth at part	36.21 mm	41.23mm	46.07 mm
		Width and depth at feeder	36.21 mm	41.23mm	46.07 mm
		Length	7mm	7mm	7mm
6		Total Feeding Weight	874.59g	1.2kg	1.51kg
7		Feeding Yield	51.88%	50.04%	49.36

3.2.2 Effect of Change in Gating System

The gating system is composed of pouring basin , sprue, runner, gates and feeder. It fills the mould cavity completely before freezing. It fills the mould cavity with low velocity and little turbulence. Gating system promotes temperature gradients for directional solidification. Since the way in which liquid metal enters the mould has a deciding influence upon the quality and soundness of casting, the different passages for the molten metal are carefully designed and produced. For proper functioning of gating system, some of factors like temperature, rate of liquid metal pouring, gating design, type of pouring equipment such a ladles, pouring basin etc.needed to be controlled. Gating design includes designing of ingates, choke area, pouring basin. The gating system must be designed to ensure smooth and laminar filling of mould. Formation of various casting defects are directly related to melt entry velocity, fluid experiment equipment procedure and flow phenomenon during the mould filling stage. Optimized gating systems for (100mm x 45 x 40), (100mm x 45 x 50) and (100mm x 45 x 60) rectangular objects of C.I.and Aluminium by simulation are shown in figure 6 and 7.Sprue, sprue well, gates, runners dimensions and pouring temperature, total metal head,gating system weight,gating yield and total poured weight for same rectangular objects of C.I.and Aluminium are shown in table 4 and 5.

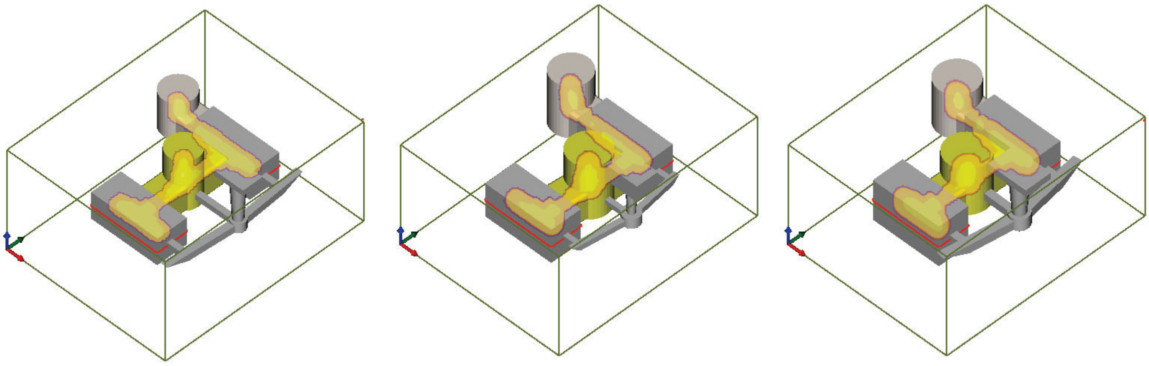

Figure 6: *Optimized Gating System for Results of 40mm, 50mm and 60mm Thickness of C.I.Rectangular Objects by Simulation.*

Table 4 Dimensions of Gating System for Different thickness of C.I.Rectangular Objects

Sr.No.	Elements	Dimensions/Parameters	(100x45x40)	(100x45x50)	(100x45x60)
1.	Sprue (Cylindrical)	Top Diameter	19.34 mm	20.14 mm	26.13 mm
		Bottom Diameter	13.28 mm	13.82 mm	17.94 mm
		Height	75 mm	75 mm	75mm
2.	Sprue Well	Diameter	20.2 mm	21.03 mm	29.2 mm
		Height	15.15 mm	15.77 mm	21.9 mm
3.	Gates	Number of Gates	3	3	3
		Total Gate Area	1.97 cm†	2.14 cm†	3.6 cm†
		Total Gating Weight	34.56 g	37.79 g	52.07 g
		Total Gating Volume	4.62 cm‡	5.06 cm‡	6.97 cm‡
4.	Gate1 (Rectangular)	Length	51.77 mm	54.28 mm	48.98 mm
		Height	8.1 mm	8.44 mm	10.95 mm
		Width	8.1 mm	8.44 mm	10.95 mm
5.	Gate2 (Rectangular)	Length	20mm	20mm	20mm
		Height	8.1 mm	8.44 mm	10.95 mm
		Width	8.1 mm	8.44 mm	10.95 mm
6.	Gate3 (Rectangular)	Length	20mm	20mm	20mm
		Height	8.1 mm	8.44 mm	10.95 mm
		Width	8.1 mm	8.44 mm	10.95 mm
7.	Runners	Number of Runners	2	2	2
		Total Runner Area	2.63 cm†	2.85 cm†	4.8 cm†
		Total Runner Weight	103.19 g	106.29 g	157.36 g
		Total Runner Volume	13.81 cm‡	14.22 cm‡	21.05 cm‡
8.	Runner1 (Rectangular)	Length	71.94 mm	72.6 mm	72.53 mm
		Height	9.93 mm	10.33 mm	13.41 mm
		Width	9.93 mm	10.33 mm	13.41 mm

Sr.No.	Elements	Dimensions/Parameters	(100x45x40)	(100x45x50)	(100x45x60)
9	Runner2 (Rectangular)	Length Height Width	70.57 9.93 mm 9.93 mm	69.4mm 10.33 mm 10.33 mm	69.52mm 13.41 mm 13.41 mm
10		Pouring Temperature	1326^0c	1326^0c	1370^0c
11		Total Metal Head	75mm	75mm	75mm
12		Gating System Weight	242.18 g	256.78g	386.88 g
13		Gating Yield	91.62 %	92.94%	91.42 %
14		Total Poured Weight	5.04 kg	6.3kg	7.82kg

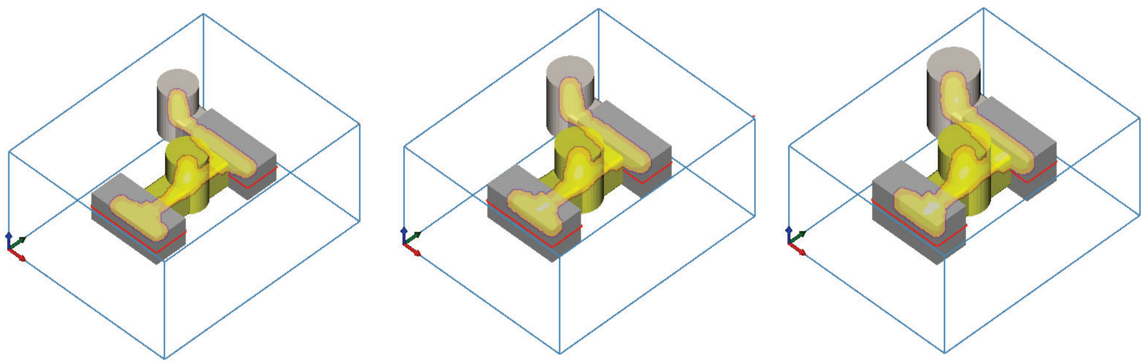

Figure 7: *Simulated Optimized Gating System for Results of 40mm, 50mm and 60mm Thickness of Aluminium Rectangular Objects by Simulation.*

Table 5. Dimensions of Gating System for Different thickness of Aluminium Rectangular Objects

Sr. No.	Elements	Dimensions/Parameters	(100x45x40)	(100x45x50)	(100x45x60)
1.	Sprue (Cylindrical)	Top Diameter Bottom Diameter Height	15.09 mm 10.36 mm 75 mm	15.34 mm 10.53 mm 75 mm	16.07 mm 11.03 mm 75mm
2.	Sprue Well	Diameter Height	20.61 mm 15.46 mm	20.95 mm 15.72 mm	21.95 mm 16.46 mm
3.	Gates	Number of Gates Total Gate Area Total Gating Weight Total Gating Volume	3 1.2 cm† 8.26 g 3.1 cm‡	3 1.24 cm† 7.8 g 2.93 cm‡	3 1.36 cm† 7.13 g 2.68 cm‡
4.	Gate1 (Rectangular)	Length Height Width	54.34 mm 6.32 mm 6.32 mm	53.35 mm 6.43 mm 6.43 mm	48.78 mm 6.73 mm 6.73 mm

Sr. No.	Elements	Dimensions/Parameters	(100x45x40)	(100x45x50)	(100x45x60)
5.	Gate2 (Rectangular)	Length Height Width	20mm 6.32 mm 6.32 mm	20mm 6.43 mm 6.43 mm	20mm 6.73 mm 6.73 mm
6.	Gate3 (Rectangular)	Length Height Width	20mm 6.32 mm 6.32 mm	20mm 6.43 mm 6.43 mm	20mm 6.73 mm 6.73 mm
7.	Runners	Number of Runners Total Runner Area Total Runner Weight Total Runner Volume	2 1.6 cm† 21.77 g 8.19 cm‡	2 1.65 cm† 22.31 g 8.39 cm‡	2 1.81 cm† 22.77 g 8.56 cm‡
8.	Runner1 (Rectangular)	Length Height Width	72.53 mm 7.75 mm 7.75 mm	73.09 mm 7.87 mm 7.87 mm	71.12 mm 8.25 mm 8.25 mm
9	Runner2 (Rectangular)	Length Height Width	69.09 mm 7.75 mm 7.75 mm	68.91 mm 7.87 mm 7.87 mm	69.89 mm 8.25 mm 8.25 mm
10		Pouring Temperature	1326^0c	1326^0c	1370^0c
11		Total Metal Head	75mm	75mm	75mm
12		Gating System Weight	47.59 g	48.2 g	49.72 g
13		Gating Yield	95.2 %	96.15 %	96.72 %
14		Total Poured Weight	1.87 kg	2.45 kg	3.02 kg

3.2.3 Effect of Variations in Thickness of Rectangular Objects

The volume of feeder is depends on the thickness of rectangular object, which, reducing the yield, affecting melting cost and productivity. As the thickness increases the hot spot is also increases and finally compensated by feeder. The effect of variations in thickness for (100mm x 45 x 40), (100mm x 45 x 50) and (100mm x 45 x 60) rectangular objects are shown in figure 8.

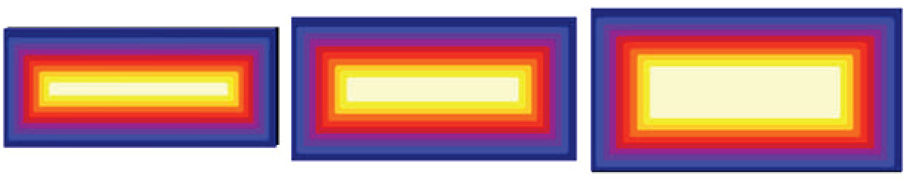

***Figure8**: The effect of variations in thickness rectangular objects*

4. Conclusion

After analyzing the effect of feeder, gating system and thickness variations on shrinkage of rectangular objects by simulation, results can be concluded as follows:

1. The user can verify if the location and size of feeder are adequate and carryout iteration of design modifications and simulation until satisfactory results are obtained.

2. The dimensions of feeder and neck are very critical and depend on the relative modulus of hot spot, feeder and type of metal.

3. For iron, the neck modulus is lower to prevent 'reverse feeding' during graphite expansion phase.

4. Gating system is influenced by part design as well as methoding; hence shrinkage defect analysis driven by casting simulation is useful for evaluating and improving castability by minor changes to part design.

5. The increase in the thickness results in increase in hot spot compensating by increased volume of feeder.

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