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Automated Gating System Design for Grey Cast Iron Casting

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ABSTRACT

An automated gating system design for grey cast iron has been developed using Python programming language. The program was based on basic scientific laws and principles related to liquid metal flow and its solidification process which were used to determine the gating system parameters for the castings. The equations and laws of gating system design were expressed as Python code while the graphical user interface (GUI) was designed using the tkinter library of Python to present a simple interface to input data and obtain results. Important factors which control the functioning of gating system such as the geometry of the basin and sprue, pouring temperature, filling time, solidification time, fluidity of the molten metal, rate of liquid metal flow and the velocity of liquid metal were taken into consideration. The developed program was found capable of generating parameters for the gating system from Python codes and GUI. It is also capable of being modified in order to design the gating system of other metals. It was therefore concluded that the system is useful in industrial process design in order to reduce manufacturing process time by eliminating repeated trial and error previously used. Hence, improving productivity and profitability in foundry work.

1. INTRODUCTION

The gating system is the passage ways or the sections through which the molten metal is channeled to the mould cavity (Karunakar, 2020; Ahmed, 2020). These sections are referred to as elements of the gating system. They include the pouring basin, sprue, sprue well, runner, ingates and riser. Each of these elements play a specific role in directing molten metal into the mould cavity to form a complete cast product.

The molten metal is first received at the pouring basin which maintains the pressure head over the sprue and further directs the liquid metal into the sprue. It also maintains the rate of liquid metal flow to reduce turbulence at the sprue entrance and assist to separate slag from metal at the point of entrance into the sprue. The sprue feeds molten metal to the runner which then passes it to the gates and finally to the cavity. Riser or feeder acts as a liquid reservoir which provides liquid to the casting during solidification (Hyung-Yoon *et al.,* 2018). The feeders appended to the casting at suitable locations are designed so that the shrinkage defects are contained within the feeders.

The design of a gating system is the major process design consideration that ensures defect free product, improve casting yield and optimize the production condition (Vaghasia, 2009; Shittu *et al*., 2018). It also promotes directional solidification which guarantees the start of solidification from point farthest to the supply of molten metal. Disturbance can be decreased by the plan of a gating framework that advances a more laminar progression of the fluid metal. When the path is made short, it will assist to keep the metal in the fluid state longer since it will get more warmth more from both the riser and the projection (Hyung-Yoon *et al.,* 2018). In the design of the gating system needed for effective manufacturing process and defect free casting, certain requirements are considered. The filling of molten metal into the mould should be at a minimum time (Ahmed, 2020). The metal flow and solidification must proceed in line with proper thermal gradient such that there will not be any solid area that will cut off flow which could lead to vacancies in the casting material. The metal flow should be regulated to ensure smooth flow and avoid erosion of the mould wall. The entrance of slag and other unwanted materials into the mould cavity should be prevented by entrapping them at the pouring basin (Ahmed, 2020). It is also expected that the correct quantity of molten metal should be cast to ensure that enough molten metal reaches all the mould cavities. Finally, in order to maximize the casting yield, the volume of the gating and risers should be decreased to the barest minimum (Nandagopal *et al.,* 2017).

The design of gating system in local foundries has been based on trial and error methods (Vaghasia, 2009). This uses limited design considerations which has led to poor quality cast product with casting defects (Adil and Mohamed, 2013). In most cases, materials and energies are wasted in the process of repeated trials. This could increase production cost and delay manufacturing process. In view of this, previous authors have attempted to use computer software to develop computer programs for gating system design (Shittu *et al.,* 2018; Sachin and Rajendra, 2016; Anjo and Khan, 2013; Vishwas *et al.,* 2020). However, it obvious that most authors did not consider in details some important casting parameters such as solidification time, which should guarantee good design of gating system that yields defect free product. This could lead to wrong computation of filling time compared to solidification time which allow solidification of metal to set in when the mold is not yet filled. Hence, there is need for modern technologies in foundries which are expected to develop an optimal production process that guarantees high quality product, quick delivery and minimum production cost (Piyapong, 2007). Therefore, this study sought to use detailed design considerations based on some basic scientific and engineering principles to develop an automated gating system design for grey cast iron using python language and carefully considering other useful parameters such as solidification time and others which previous authors omitted.

2. METHODOLOGY

The basic principle adopted for this study is based on the principle of hydraulic of fluid flow which can led to estimated value of some important casting parameters. The Python programing language was used to automate the gating system and develop the graphical user interface (GUI). Python was used in translating the mathematical formulae needed for designing the gating system into codes that the computer can understand while the tkinter library was used in building the GUI. The software was built using PyCharm IDE (Integrated Development Environment). The computation of various factors, values and parameters needed in the design of a gating system as computed from the empirical formulae and the laws of fluid mechanics are shown in subsection 2.1 – 2.7. Certain factors which control the functioning of the gating system were put into consideration. Among these factors were geometry of the basin and sprue, pouring temperature of metal, solidification time, filling time, fluidity of the molten metal, rate liquid flow, number and location of gates connecting runner and casting and velocity of liquid metal at the gate. Some of these factors were derived from basic scientific laws and principles while others were sourced from literatures.

2.1. Determination of Solidification Time

The solidification is referred to as the time that elapsed between pouring time and start of solidification. It was designed to be greater than the pouring time. This was to avoid solidification to set at time that is not appropriate which could lead to casting defects such misrun (Rahul *et al.,* 2015). Hence, the solidification time (Ts) was computed as a function of the volume of casting and its surface area according to Chvorinov's rule (Adil and Mohamed, 2013; Rashid, 2020).

$$T_S = C\left(\frac{V}{S}\right)^2 \quad (1)$$

Where S is the surface area of the cast, *V* is the volume of the cast and C is a constant that reflects mold material and metal properties. C is 65-70 s/cm^2 or 0.65-0.70 s/mm^2 for gray cast iron and sand mold combination.

2.2. Determination of Pouring Time

The pouring time was computed based on the section thickness, weight of the casting the complexity and size of the casting. It is determined by using some standard methods of calculating the pouring time for different sizes of cast iron as reported by Ahmed, (2020) and Nandagopal *et al.* (2017).

Mass less than 450 kg (i.e. $W < 450$ kg)

$$t = k\left(1.41 + \frac{T}{14.59}\right)\sqrt{W} \quad (2)$$

For W >= 450 kg:

$$t = k\left(1.236 + \frac{T}{16.65}\right)\sqrt[3]{W} \quad (3)$$

Where *k* is the fluidity constant which depend on metal composition factor, pouring temperature, metal viscosity, and rate of heat transfer. *T* is the average section thickness of the casting in mm, *t* is the pouring time in seconds and *W* is the poured weight which is the casting weight plus the weight of gating elements including risers in kg.

2.3. Determination of the Sprue Geometry

The size of the sprue was optimized to limit the flow rate of the molten metal. Hence, rectangular cross section of sprue was used as circular type was reported to have high tendency to vortex formation. The tapering of the sprue was also considered. This is due to the fact that liquid metal loose contact if the sprue is straight down the sprue as a result of aspiration. Therefore, the sprue was approximately tapered by 5% so that the molten metal by default will take less cross section at the bottom. This will leave no clearance at the bottom between the mold wall and the flow of the molten metal which will avoid the chance of aspiration (Karunakar, 2020). Applying the continuity equation for constant mass flow rate at both sprue top and sprue bottom. Assuming that the entire mold is at atmospheric pressure and that the metal in the pouring basin is at zero velocity. The continuity equation between the two points was represented as:

$$\rho A_1 V_1 = \rho A_2 V_2 \quad (4)$$

$$\frac{A_1}{A_2} = \frac{V_2}{V_1} = \frac{\sqrt{2gH_t}}{\sqrt{2gH_c}} = \frac{\sqrt{H_t}}{\sqrt{H_c}} \quad (5)$$

Where A_I is sprue top area, A_2 is sprue bottom area, H_t is distance between ladle and sprue top, H_C is distance between ladle and sprue bottom, V_1 is the velocity of liquid metal at entry point of sprue top, V_2 is the velocity of liquid metal at exit point of sprue bottom, ρ is the density of liquid metal and g is acceleration due gravity.

2.4. Determination of the Effective Sprue Height

The effective sprue height (H) depends on the casting dimension and was determined based on the type of gating system. Three basic types of gating system were considered. The values were computed as follows:

Top gate: When top gate is used H = h as shown in Figure 1

Where h is the sprue height from its top to the point of metal entry into the mold cavity, P is height of mould cavity, c is the total height of mould cavity and P_L is the parting line (Nandagopal *et al.,* 2017).

Bottom gate: When bottom gate is used, H = h – c/2 as shown in Figure 2

Parting gate: When parting gate is used H = h – P2 / 2c

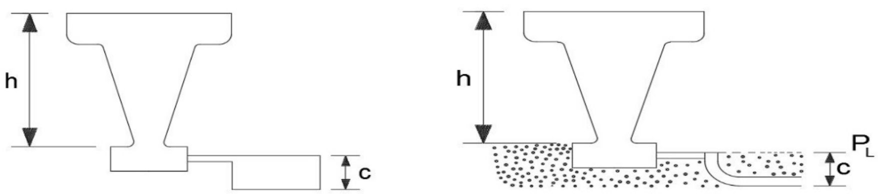

Figure 1: Top gate showing sprue height

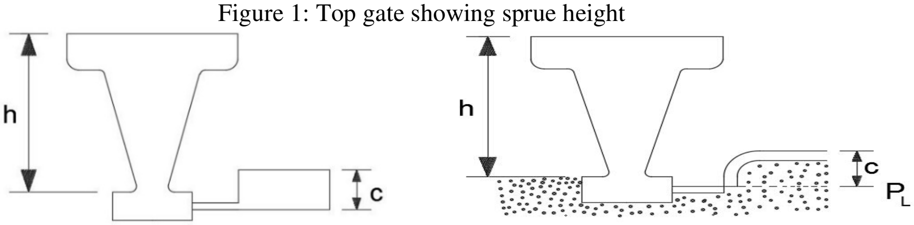

Figure 2: Bottom gate showing sprue height

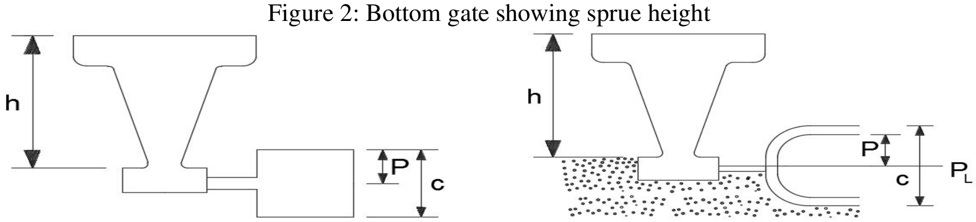

Figure 3: Parting gate showing sprue height

2.5. Determination of the Velocity of Metal Entering into the Mold Cavity

The velocity of metal (v) entering into the mold cavity was determined using basic law of hydraulics which considers metal as liquid (Nwajagu, 1994). Assuming that at the point of metal entry into the pouring basin and into the cavity, there is no loss in energies for the movement of the liquid metal. Then, the Bernouli's equation and continuity equation is of the form (Assuming the system remain at atmospheric pressure and no turbulence and friction):

$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = h_2 + \frac{p_2}{\rho g} + \frac{v_2^2}{2g} \quad (6)$$

Where h_1 and h_2 are the metallostatic thrust at point of entry into the basin and cavity respectively, p is pressure (Pa), v is liquid velocity of liquid metal (m/s), ρ is density of the liquid metal (kg/m^3) and g is acceleration due to gravity (ms^{-2}). Assuming that there is no loss in energies at the entry points, $p_1 = p_2$, $v_1 = 0$ and $h_2 = 0$.

The velocity of liquid metal at the entry point into the choke is computed as:

$$V_2 = \sqrt{2gH} \tag{7}$$

2.6. Determination of the Choke Area

This is considered as minimum cross sectional area that is necessary to inject the molten metal into the cavity of the mold (Hyung-Yoon, *et al.,* 2018). It is the main control area which meters the metal flow into the mold cavity so that the mold is completely filled within the calculated pouring time. Considering the mass flow rate as indicated in law of continuity of mass which states that the rate of flow of mass of the fluid is constant at any cross-section (Karunakar, 2020).

$$m = \rho AV = \text{Constant} \tag{8}$$

Where m is the mass of the liquid metal flowing at any cross section, A is the area of cross section at a point and V is the velocity of the liquid metal at the point.

Hence, the volume flow at a given time t at the choke area is given as:

$$A_c V_c t = \frac{W}{\rho} \tag{9}$$

Where A_c is choke area, V_c is the velocity of metal, w is the weight or mass of casting and ρ is the density of the liquid metal. Therefore, the choke area was computed as:

$$A_c = \frac{W}{\rho CtVc} = \frac{W}{\rho Ct\sqrt{2gH_c}} \tag{10}$$

Where C is the coefficient of discharge due to friction taken as 0.7 – 0.9, t is the pouring time, g is the acceleration due gravity and H_c is the height of total metal head above the choke.

2.7. Determination of the Gating Ratio

This is the proportion of the cross-section area between the sprue, runner and ingate. It is denoted as sprue area: runner area: ingate area. Based on the design of the choke, a pressurized gating system was used as considered suitable for ferrous casting (Nandagopal, *et al*., 2017). Hence, the gating system of 1:2:1 for sprue area: runner area: ingate area was used. The cross sectional areas of sprue (A_S), runner (A_R) and gate (A_G) were computed using the respective mathematical relations as follows:

$$A_S = A\frac{S}{G} \tag{11}$$

$$A_R = A\frac{R}{G} \tag{12}$$

$$A_G = A\frac{A}{NG} \tag{13}$$

Where A is the minimum cross-sectional area necessary to inject the molten metal into the cavity of the mold, $\frac{S}{G}$ is the ratio between the cross-sectional area of sprue to the total cross-sectional area of runner and ingate , $\frac{R}{G}$ is the ratio between the cross-sectional area of runner to the total cross-sectional area of sprue and ingate, $\frac{A}{NG}$ is the ratio between the minimum cross-sectional area necessary to inject the molten metal into the cavity of the mold and the number of the gate (Hyung-Yoon, *et a.l,* 2018).

The design provided multiple gate for casting greater than 450 kg with minimum ingate length of 3 – 5 times the ingate width.

2.8. Python Implementation

The equations used in the gating system design were implemented in Python by assigning the variables in these equations to Python variables. These Python expressions were then used to make computation in the gating system design. The program was divided into four phases that captures the whole gating system design process. Each phase has an input and output display area. The inputs and outputs for each phase was passed on and used as inputs in the computation for the next phase. After the completion of each phase the input panels for the next was enabled for accepting and processing inputs. These inputs and outputs were variables in the equations and relationships involved in the design of a gating system. They were accepted via the GUI and then substituted in to the Python code for use.

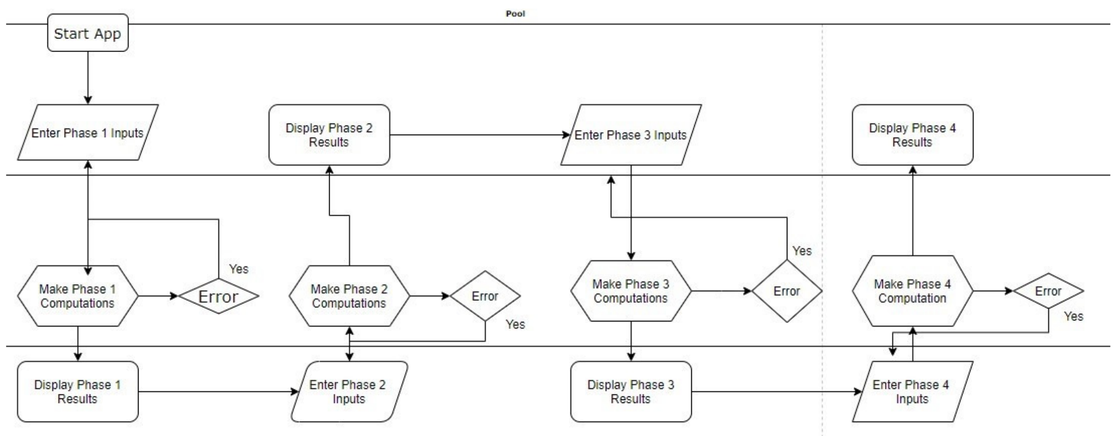

Figure 4: Flow chart showing the development of the programme

3. RESULTS AND DISCUSSION

The graphical user interface which was developed using the automated gating system design is presented in Figure 4. It has provision to display the input values with their corresponding output values generated by the automated system. The software is divided into four phases following the logical steps for the design of a gating system. Each phase has a frame containing input cells where the user can input the required values. Some of the input cells are coloured orange while other are not. These colouration indicate optional and compulsory cells. The orange coloured cells are compulsory and must be inputted before the software can comence the design of the gating system. The other cells have already provided default values which the user can change if needed. In the same phase there are the outputs cells which display the results for that phase using the inputted values or output values form previous phases. The developed software operates in the following logical steps in other to achieve the design of the gating system. The initializing window prompts the user to start the computation by inputting values for the casting weight or the casting volume, either of this values must be inputted for the program to function properly This depends on which information is readily available. Other information required here includes casting length, chemical composition of the (carbon percent, silicon percent and phosphorus percent) of the target iron, the expected yield of the casting and its effective section thickness (Shittu *et al.,* 2018). Once these are entered in the appropriate boxes, the outputs (including the poured weight, pouring temperature, fluidity, solidification time, pouring time and rate) will be displayed at the torch of the respective push button. If information is wrongly entered it can be selectively corrected by clearing the contents of the cell. The sprue window is the menu where the user decides between using a round tapered sprue or square tapered sprue. Here other information to be entered by the user includes expected height of the casting in the cope and the drag, total sprue height and basin head. The outputs from the menu include the following: effective sprue height, sprue choke area, sprue top area, base well area, base well diameter, sprue choke diameter, sprue top diameter and if square sprue is chosen, choke length and top length are obtained instead of choke and top diameters respectively. The gating system selected determines how the effective sprue head is selected.

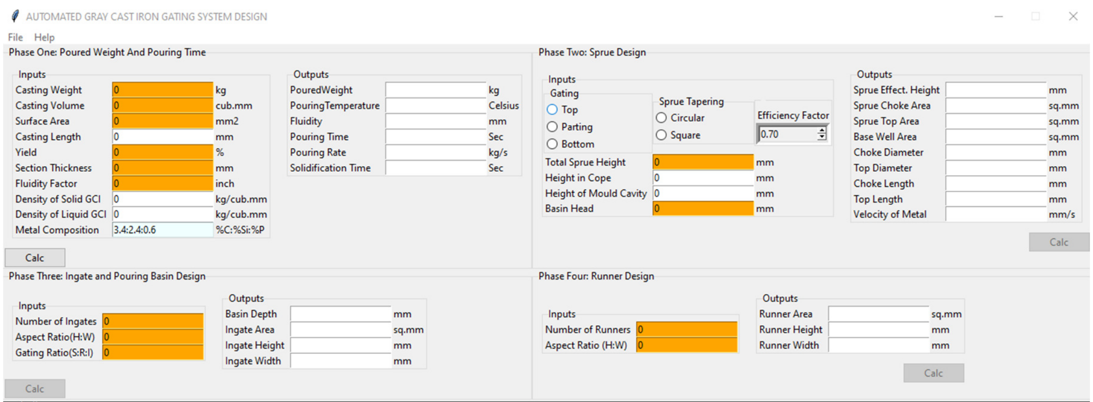

Figure 5: The graphical user interface

Table 1: Inputs from sample problem and corresponding results

Input	Value	Output	Value
		Phase one	
Casting volume	6,250,000 mm^3	Poured weight	64.2857 kg
Casting length	500 mm	Pouring temperature	1295 ºC
Yield	70 mm	Fluidity	68.3978 mm
Section thickness	50 mm	Pouring time	21.3303 s
Fluidity	22 in	Pouring rate	2.1097 kg/s
		Phase two	
Tapering	Circular	Effective sprue height	100 m
Gating	Top	Sprue choke area	441.6327 mm^2
Total sprue height	100 mm	Sprue top area	4438.354 mm^2
Efficiency factor	0.8	Choke length	21.0151 mm
Basin head	50 mm	Top length	66.621 mm
		Phase three	
Number of ingates	2	Basin depth	166.5524 mm
Aspect ratio	1:2	Ingate area	1766.5309 mm^2
Gating ratio	1:4:4	Ingate height	21.0151 mm
		Ingate width	42.0301 mm
		Phase four	
Number of runners	2	Runner area	1766.5309 mm^2
Aspect ratio	1:2	Runner height	21.0151 mm
		Runner width	42.0301 mm

Phase 3 is the ‘Ingate and pouring basin’ window by which the user specifies the number of ingates (inner gates) to be used and selects the ‘aspect ratio’ (the ratio of the height to width) of the gates. The gating ratio, is the ratio of the cross sectional area of the choke to sectional area of the runner to sectional area of the ingates, that is, choke: runner: ingate. The outputs here include ingate cross sectional area, ingate height, ingate width and basin depth. The Runner and base well window (phase 4) prompts the user to indicate the number of runner to be used (single or double runner i.e. 1 or 2). The other information required in this step is the ‘aspect ratio’ of the runner. The outputs of the menu include runner area, runner height and runner width. When casting parameters were keyed into the GUI, the available information as displayed in the Table 1 were provided. These results which were computed and displayed by the software is in line with calculated results which are based on the mathematical formulae. This shows the validity of the software and also proves that it is a quick and effective way of designing gating system for gray cast iron.

4. CONCLUSION

An automated gating system design for casting grey cast iron has been developed using Python programming language. The developed package is capable of generating gating system parameters that is defect free. The automated system was found useful in manufacturing process by reducing production process time which increases productivity and profitability of foundry work. The automated gating system design provides opportunity to improve productivity, quality and promotes new product design. The software has proved to be more powerful and quicker to retrieve result. Hence, it shows great potential for improving the design of gating system. Based on the success of this software, it can be modified so as to be capable of designing the gating system of other cast able materials like steel and aluminum alloys with similar user interface.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Adil, M.E.A. and Mohamed, I.S. (2013). Methoding Design in Sand Casting, Heuristic Rules of Methoding Design in Sand Casting: A Review. *Sudan Engineering Society Journal,* 59(1), pp. 33-40.

Ahmed, S.A.T. (2020). Casting and Welding Engineering. Lecture Note. Department of Industrial Engineering, Faculty of Engineering. Fayoum University.

Anjo, V and Khan, R. (2013). Gating System for Casting Thin Aluminium Alloy Plate. *Leonard Electronic Journal of Practice and Technologies.* 23, pp. 51 – 62

Hyung-Yoon, S., Chul-Kyu, J. and Chung-Gil, K. (2018). Design of a Gate System and Riser Optimization for Turbine Housing and the Experimentation and Simulation of Sand Casting Process. *Advances in Mechanical Engineering,* 10(8), pp. 1-12

Karunakar, D.B. (2020). Sand Casting Process- Design of Gating System. Lecture note 14, Module 02. Department of Mechanical and Industrial Engineering. Indian Institute of Technology, Rookeee, pp. 1-27.

Nandagopal, M. Sivakumar, K., Senthilkumar, G. and Sengottuvelan, M. (2017). Study of Sand Casting Gating System. *International Journal of Recent Engineering Research and Development (IJRERD).* 2(11), pp. 19-26.

Nwajagu, C.O. (1994). *Foundry Theory and Practice*. ABC Publisher ltd, Enugu. Nigeria. pp. 165 – 177.

Piyapong, M. (2007). Solidification Modelling of Iron Castings Using SOLIDcast. Thesis Submitted to Department of Industrial and Management System Engineering, College of Engineering and Mineral Resources. West Virginia University.

Rahul, T.P, Veena, S. M. and Shubhangi, S. T. (2015). Causes of Casting Defects with Remedies. *International Journal of Engineering Research and Technology*. 4(11).

Rashid, A.K.M.B. (2020). Foundry Engineering Lecture Note. MME 346. Design of Casting and Feeding Systems. Materials and Metallurgical Engineering. BUET.

Sachin, N. and Rajendra, S. (2016). Design Optimization of gating and Feeding System Through Simulation Technique for Sand Casting of Wear Plate. *Perspectives in Science.* 149, pp. 1-4

Shittu, M. D., Ibitoye, P. O., Atanda, P. O., Olawale, J. O., Oluwasegun, K. M. and Ige, O. O. (2018). Automation of Gating System Parameters for Green Sand Iron Casting. *Journal of Advances in Mathematics and Computer Science,* 27(6), pp. 1 – 15.

Vaghasia, D. (2009). Gating System Design Optimization for Sand Casting. M.Tech Dissertation. Department of Mechanical Engineering, Indian Institute of Technology. P. 41.

Vishwas, M., Athaarva, K. and Rohan, M. (2020). Gating System Design and Material Analysis for Sand Casting of a Sprocket. *International Research Journal of Engineering and Technology (IRJET),* 7(10), pp. 1518 – 1527.