Effect of Section Thickness On The Microstructure And Hardness Of Gray Cast Iron (A Simulation Study)

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***Abstract* - Cast iron being a material very sensitive to section has been a choice of automotive industries because of its versatile properties. This study was aimed to examine the effect of section thickness on microstructure of grey cast iron. Grey cast iron micro-structure consists of flakes of graphite with a matrix of pearlite or ferrite. It was found in this study that size of the graphite flake changes with the change in cooling rate. Flake size affects the properties like hardness, UTS and damping capacity of grey iron. It was observed that small section thickness contains small graphite flakes, whereas thick sections consist of larger graphite flakes. Hardness of thin section was also found greater than thick section. The hardness results obtained from Pro-cast simulation were validated and it was found that simulation results are in quite agreement with experimental results. This paper also provides the heat transfer model of Pro-cast and its sequential steps to follow for simulation of grey iron solidification.**

***Keywords - Simulation, ProCast, Gray iron, hardness, heat transfer*.**

INTRODUCTION

Casting is the most important process in manufacturing and sand casting is the most convenient process in foundry. Most of the liquid metal can be poured into the sand mould and any size can be cast. So,sand casting becomes popular day by day. Nowadays, people are using powerful software to control the quality of the materials which reduce the wastage and cost of the final product. Solidification rate of molten metal in the sand mould depends on the thermal conductivity of the mould material, casting design and the direction of heat-flow into the mould wall. If the heat-flow through the mould is very quick, the solidification rate will be high at that point and will affect the microstructure and properties of the materials [1**].** Gray cast iron (GCI) remains the most important casting material with over 70% of the total world's production tonnage [2].Graphitic cast iron has a dark gray or almost black fracture. The structure of GCI depends on chemical composition before the casting process, inoculants and cooling conditions [3]. Upon small degrees of super cooling, graphite is formed when the cast iron solidifies from its liquid state. Slow cooling promotes graphite formation whereas rapid cooling partly or completely suppresses graphitization and leads to the formation of cementite or carbides [4]. The effect of high cooling rates in producing fine structures results in development of high-strength cast alloys. The decrease in under cooling temperature of a melt increases the number of effective nuclei relative to the growth rate, the latter being restricted by the rate at which the latent heat of crystallization can be dissipated. For cast iron foundries, the use of casting process simulation has become an important instrument to predict the robustness and reliability of their processes, especially since the influence of alloying elements, melting practice and metallurgy need to be considered to quantify the special shrinkage and solidification behavior of cast iron. This allows the prediction of local structures, phases and ultimately the local mechanical properties of cast irons, to asses casting quality in the foundry but also to make use of this quantitative information during design of the casting. The numerical simulation has a great quality of potential in increasing the productivity of the metal casting industry by shortening time. The microstructure of grey iron is characterized by graphite lamellas, which disperse into the ferrous matrix. Foundry to foundry practices can influence the nucleation and growth of graphite flakes, and the size and type of graphite flakes enhance the desired properties. The amount of graphite and the size, morphology, and distribution of graphite lamellas are critical in determining the mechanical behavior of grey iron [5].Cooling rates have been determined experimentally by measuring the dendritic arm spacing and Secondary dendritic arm Spacing from the microstructure. Results show that the morphology of graphite, dendritic arm spacing and secondary dendritic arm spacing as well as the interlamellar spacing of eutectic structure depend on the casting thickness. These decreases as the thickness of castings decrease because thinner section of casting has higher rate of cooling than the thicker section [6-7]. Hardness and ultimate tensile strength are the most commonly specified properties for iron castings. Hardness is a relatively good indication of machinability; however, gray and ductile iron with the same hardness can exhibit appreciable differences in tool life. Properties are also influenced by the section thickness in which the metal solidifies and the manner in which the metal cools. The qualification results from the fact that the properties of iron are directly influenced by the rate of solidification and subsequent cooling. Appreciably different properties in various portions of a casting are apt to occur if the sections have sufficiently large differences in thickness or shape to cause a significant variation in cooling rate. That is, if the microstructure of either contains some free carbide, machinability is reduced much more than indicated by the small increase in hardness [8]. In this work simulation results of cooling rate and hardness were in agreement with the experimental results.

1. MATHEMATICAL MODELING

In the present study mathematical model of solidification of Grayiron in stepped bar was carried out on the platform of ProCast 2011. ProCast is a commercial software based on finite element method. Numerical simulations of the stepped bar castings were conducted by solving the 3-D continuity, Navier–Stokes and energy equations. Dimensions and design of Stepped bar of casting are shown in the Figure 1. The mesh of the computational domain was selected after mesh independent test to carry out the simulation. Mold walls temperatures were initialized at room temperature (30° C). The pouring temperature of liquid metal of Gray iron was 1380° C. The thermo physical properties of Gray iron are given in Table 1. [13]

Properties	Value
Thermal conductivity	33.1 W/m/K
Density	6560 Kg/m^3
Specific heat	0.91 kJ/kg/K
Latent heat	242 KJ/kg
Solidus Temperature	1153°C
Liquidus Temperature	1195°C

TABLE: 1 THERMOPHYSICAL PROPERTIES OF GRAY CAST IRON

To conduct the solidification heat-transfer analysis for the Cast iron during the cooling three steps have to be taken. They are the pre-processing, solidification heat-transfer analysis, and post-processing steps.

A. Pre-processing step

First, the solid model of the component, including its shape and dimension, has to be constructed on the computer. Then the solid needs to be divided into a mesh system for the numerical analysis to be conducted. Since the heat-transfer analysis in this study employs the explicit finite different method, the mesh system generated needs to be a finite difference mesh system which is composed of a large number of tetrahedral blocks. Every element in the mesh system may not consist of more than one material, which will cause problems in the analysis. To investigate the solidification behavior of the alloy. The number of elements in the mesh system has to be very large for the accuracy of the process. Certain problems arise during the mesh system is generated. As the appropriate mesh system is obtained, each and every element is designated with its corresponding material. Then the thermal and physical properties of the materials such as density, thermal conductivity, specific heat, latent heat, and so forth have to be entered.

B. Solidification heat-transfer analysis

The main concern in this study is to simulate the temperature distribution and variation during the cooling stage. There are two major mechanisms used by procast for the heat of the component to be extracted. One is the extraction of heat through conduction. The other is to lose heat through convection to its cooler environment. The governing differential equations of these two heat-transfer mechanisms are described as follows.

- Conductive heat-transfer equation

$$Q_1 = -kAdt/dx \quad (1)$$

Where k is the thermal conductivity J/m ^{0}C; A is the cross-sectional area, m^2 and dt/dx is the temperature gradient, ^{0}C/m.

- Convective heat-transfer

$$q = hA(T-T_1) \quad (2)$$

h is the heat-transfer coefficient for convection, J/sm^2 ^{0}C; A is the surface area, m^2; T_1 is the atmosphere temperature, ^{0}C. To calculate for the temperature change for each and every element, the principle of enthalpy conservation is applied.The procedure is to calculate the amount of heat exchange of the concerned element with all its neighbours, either by conduction or by convection. The temperature change can then be calculated based on the net amount of enthalpy gain (or loss).

C. Post-processing step

In this step, the simulated results are to be displayed on the computer screen mainly by using computer graphics. In this study, the temperature distribution and shrinkage porosity are the primary concerns. Therefore, these thermal data of the alloy are displayed by color contour plots after simulations are completed. As described above that one of the main defects to be concerned here is the shrinkage porosity in the casting. It is then very desirable to be able to display directly the situation of the Color contours are also used to demonstrate the distribution of the shrinkage porosity.

2. BOUNDARY CONDITIONS

The metal surface initially in contact with the mould is considered to be a free surface during the complete calculation, but penetration of the mould is prevented. Thus, the moving interface can compensate the material deficit. At the outside of the green sand mould heat is extracted by natural convection only. At the metal mould interface, a heat transfer coefficient accounts for the thermal resistance at the interface. It is assumed that this heat transfer is not influenced by the movement of the free surface.

EXPERIMENTS

Sand mould was made of silica sand of AFS 67 grain fineness number, 4.5% bentonite and water were added. The mixture was prepared in sand Muller. After mixing mould is prepared and allowed to dry for 5 hours. 3-D solid and meshed model of stepped bar is shown in the Figure 1. Dimensions of each step of stepped bar are given in Table 2

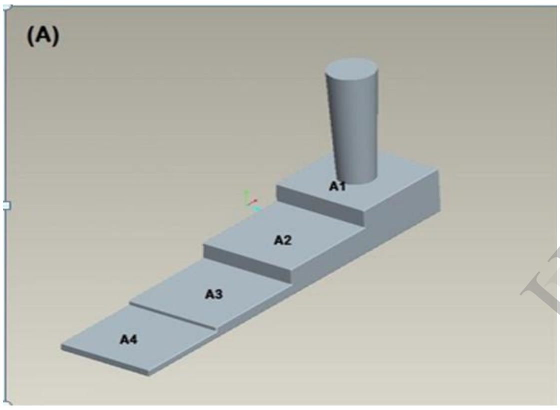


Fig.1. (A) 3-D solid model

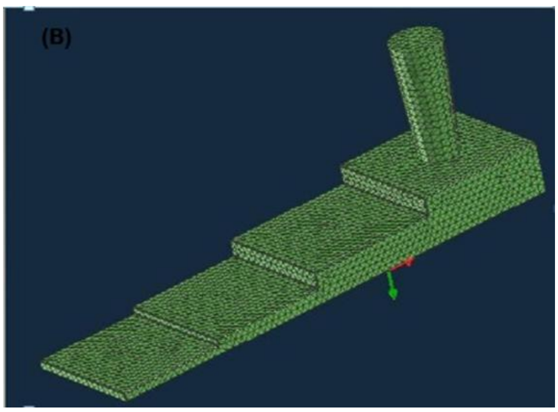


Fig.1. (B) Meshed model

Step	Dimension
A4	50×54×3
A3	50×54×6
A2	50×54×10
A1	50×54×16

TABLE.2. DIMENSIONS OF DIFFERENT STEP OF STEPPED BAR

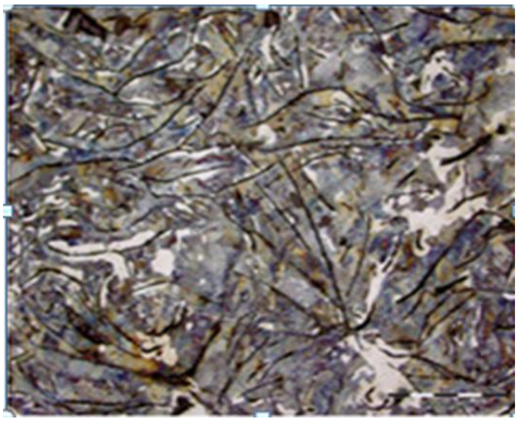
Melting was carried out in a induction melting furnace.The charge material were charged vertically so as to fall freely without bridging. Castings were made in sand mold. The pouring temperature was monitored using thermocouple. The thermocouple was connected by coaxial cables to a data logger interfaced with a computer, and the temperature data were acquired automatically. In this method molten metal at a fixed pouring temperature of 1380˚C was cast into the mould by directly pouring in the cavity. A sand mould solidifies in air in the experiments and the solidification should be in such a way that the heat was extracted, promoting vertical upward directional solidification and each steps were cut for making Metallographic specimen. The thermo physical properties of cast iron, which were used to run the necessary simulation in Procast for validating with the experimental observation are shown in Table.1.As-cast specimens were sectioned from the casting grinded, polished and etched to reveal the microstructure (the etchant used was Nital). The microstructural characterization was carried out by using an optical microscope associated with an image processing system.

Element	Amount (wt %)
C	3.25
Si	1.85
P	0.02
S	0.08
Cu	0.31
Mn	0.36
Sn	0.035

TABLE: 3 BATH CHEMISTRY COMPOSITION OF GRAY IRON

MICROSTRUCTURES

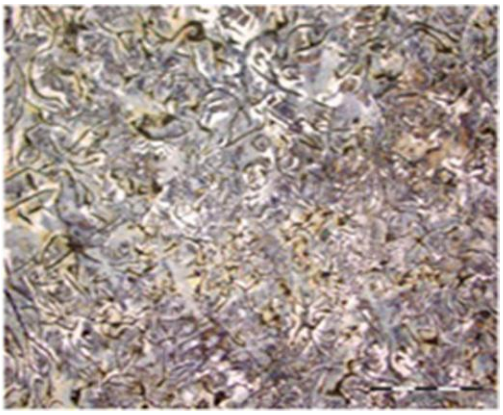
Typical microstructures observed in each step of the casting of Cast iron alloy is shown in Fig.2. The chemical composition of cast test specimen was determined using optical emission spectrometer. The obtained composition of gray cast iron is given in the Table 3. Microstructures of thinner sections are fine compare to thicker sections; it is due to difference in cooling rate. Since cooling rate of thin section is higher than the thick section of stepped bar.



a) Section thickness 13mm

b) Section thickness 10mm

c) Section thickness 6mm



d) Section thickness 3mm

Fig.2. Microstructure of different step of stepped bar

RESULTS AND DISCUSSION

A. Simulation of Solidification of Stepped bar and its validation.

Solidification heat-transfer analysis is conducted using Procast 2011. It takes about 2 hr for a personal computer to complete the analysis. Numerical simulations need to be validated before the simulated results can be further utilized to investigate the concerned phenomena.It would be most desirable to measure the temperature conditions are measured by inserting thermocouple on the top surface of the casting. The temperature is affected by convection with the atmosphere as well as by conduction through the sand mould. The temperature variation is recorded for the cooling stage. Cooling rate curves for stepped bar casting are shown in the Fig.5. The measured temperature data is then compared to the simulated result. Numerical models usually need to be verified to be grid-independent. After the previous simulation, the stepped bar is again re-meshed into a finer grid system. The solidification heat transfer simulation is then conducted. It can be seen that the results obtained from the finer mesh system is very close to that of the coarse one and both results match the measurement rather well.

B. Hardness

The evaluation of the hardness can be done using BHN. Hardness is a measure of a material's resistance to localized plastic deformation (e.g., a small dent or a scratch). Hardness tests are performed more frequently than any other mechanical test for several reasons; they are simple and inexpensive (ordinarily no special specimen need be prepared, and the testing apparatus is relatively inexpensive), the test is destructive in nature. Hardness value for stepped bar is shown in Fig. 3 & 4.

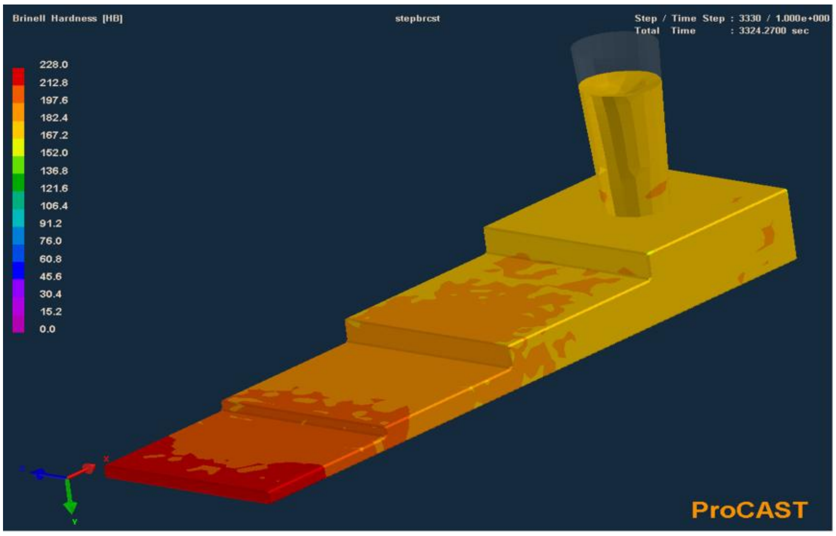


Fig.3. Hardness of different section using ProCast

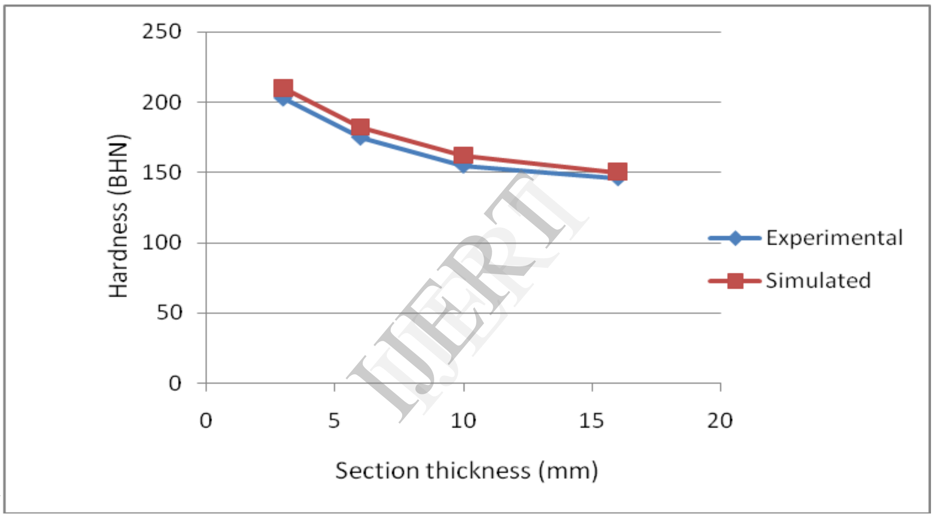


Fig.4. Hardness of different section of stepped bar.

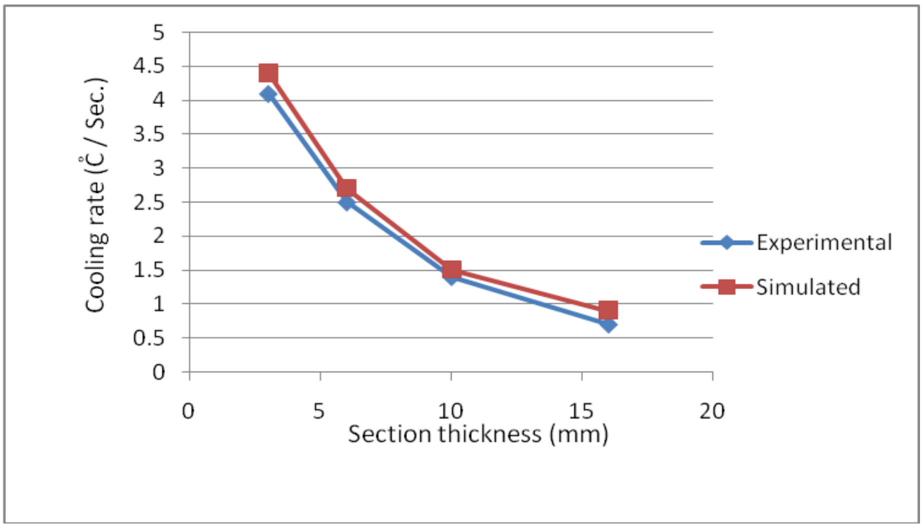


Fig.5. Cooling rate of different section of stepped bar

CONCLUSIONS

It was observed that cooling rate decreases with the increase in thickness of the step bar. Cooling rate affects the mechanical properties as well as micro-structural properties of the grey iron casting. Points which have been concluded are listed below:

1. Thin section of grey iron contains smaller graphite flake size where thicker sections contain larger graphite flakes.
2. The hardness of thin section of grey iron was found higher than that of thick sections, hardness was found to decrease as section thickness increases.
3. The micro-structure of grey iron in thick section was found to consist of larger graphite flakes, ferrite and small sections of pearlite.
4. Thin section were found to consist of small graphite flakes, pearlite and small sections of ferrite.

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