Controlled Solidification Process In Sand Mould Casting (Carbon Steel) To Achieve Uniform Ferrite Structure And Increase The Riser Efficiency

Girish Narayan, Tapan Kidambi, Abhishek A, Abhishek Hariths

Abstract: Objective: The objective was to obtain a sound casting with focus on optimization of molten metal consumption while simultaneously achieving a uniform ferrite structure in the casting. Methodology: To obtain the required microstructure, a water jacket was introduced into the mould to achieve the desired solidification rate. This was found to enhance the formation of uniform ferrite structure in the casting body and reduce the molten metal requirement. Controlled solidification is dependent on the geometrical modulus of the casting. The modulus decreases as the metal solidifies during the process of casting. After calculating the modulus of the specific job the hotspots of the body and the in-gates were identified. Based on this analysis an improvised water jacket circuit was provided in the mould. The water flow rate was designed as per the molten metal requirement of the casting. Experiments were conducted on a particular job for various water flow rates and moduli to achieve the required micro-structure. Results: The introduction of cooling line inside the mould showed significant improvement in formation of Ferrite structure. At higher solidification rates, the requirement of molten metal was found to reduce drastically. This process increased the efficiency of the risers with improved flat feeding. The cavity formation was less and safety margin (normally considered 25mm) was found to reduce to 15 mm. The decline in pearlite (black regions) & enhanced uniformity in ferrite (white regions) structure improves the quality of casting in terms of strength, ductility & toughness.

Index Terms Ferrite, Metal optimization, Modulus, Quality, Riser efficiency, Shrinkage, Water flow rate.

1 INTRODUCTION

The sound casting in a foundry depends on various factors like Modulus of job, gating system (efficiency of the riser), solidification time (casting in the mould for ‘x’ number of hours), fettling and heat treatment. The actual practice is to calculate the modulus of the casting body using the standard formula set by N. Chvorinov which is the ratio of melt volume (V) to the surface area (A). This is denoted by K_c. Based on the K_c calculation the gating system (i.e. Methoding) like position of the down sprue, runners, risers etc. are placed. The sketch of the job (Production) on which the experiment was conducted is shown in fig 1. In previous studies solidification rate was not given due importance and fast controlled cooling was not put into practice. However in the present set of experiments more emphasis was placed on the formation of ferrite structure, which in turn increase the efficiency of the riser.

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This could have been achieved only by faster cooling rate inside the mould. A media was introduced in the mould to facilitate the process. Initially a plastic pipe was introduced inside the mould. The actual methoding calculation for the particular job had riser efficiency of 35%.The media considered here was compressed air to achieve the required results. The results were not satisfactory with respect to the formation of ferrite structure. In the next trial, it was decided to circulate water through the mould where the cooling had to take place faster in the available smaller surface area. The riser efficiency increased to 50% and flat feeding was highly pronounced. The factor of safety margin for modulus efficiency calculation was extremely high in the methoding. The efficiency was increased and the experiments were conducted. The water cooling rate based on the heat flux (Q) at the interface of sand and the water jacket was calculated at 1 L.P.M. with 2 inlets and 2 outlets. The method of introducing water cooling brings into sharp focus the need to re-evaluate the calculations involved in methoding process dealing with material consumption and yield criteria.

2 METHODOLOGY

The methodology follows a fourfold process as discussed below

1. Hot zone identification
2. Modulus calculation
3. Molten metal optimization by increasing riser efficiency
4. Ferrite structure formation

2.1 Hot Zone Identification

A particular job as shown in fig 1.was considered and based on its geometry, the hot zones were identified. These are the critical areas where cooling had to be achieved in a rapid yet controlled manner. Hence the modulus for various sections was calculated.

2.2 Modulus Calculation

The modulus for section such as the sleeves, risers and core body were calculated according to Eqn. 1.

2.3 Molten metal optimization by increasing riser efficiency

With the modulus and the hot zones in hand, a cooling circuit was designed. The idea was to increase the cooling rate which would optimize the liquid metal consumption. The media considered for the process were air and water. Plastic pipes were initially considered when air was used as a cooling medium. The circuit was designed with 2 inlets and 2 outlets. It was found that there was no increase in yield efficiency; the reason being flat feeding in the riser sleeve was not noticeable after solidification. Copper pipes were introduced instead of plastic with the same design. The medium considered here was water. The water at a fixed flow rate was circulated in the circuit. There was an enormous increase in riser sleeve efficiency. Flat feeding was also observed thus reducing the molten metal requirement. The copper pipes were in direct contact with the sand a heat transfer diagram as shown in figure 2 was used to obtain the temperatures at various sections.

2.4 Ferrite Structure formation

In the air cooled circuit it was found that distorted ferrite and pearlite structures were formed. The pearlite formation was predominant. Figure 3.9 and 3.10 In the water cooled more uniform ferrite formation was observed. These are shown in the figures 3.1 to 3.8.

3 Analysis

The prime objective in most engineering cases (sand mould casting) is to achieve a rapid rate of heat transfer as it facilitates fine grain structure in metal which imparts strength and hardness to the metal. This rapid rate of heat transfer is achieved by introducing a water circuit line within the mould from a distance of the in gates. The rapid rate of heat transfer can induce brittleness in alloy casting along with poor impact properties. Slow rate of heat transfer on the other hand, can induce problems of segregation especially predominant in alloys, long columnar grains and softness in the casting. These are detrimental to the further application of the casting. So, in most practical conditions an optimum rate of heat transfer is desirable which should facilitate a high strength, fine–grained material with good mechanical properties. This can be achieved to the maximum percentage by calculating the thermal gradient (ΔT) which is dependent on modulus of the job (K_c) and flow rate of the media (m). The physical system considered in the present study is shown in Fig 2. The vertical side walls of the mould are of height H and maintained at ambient temperature (T_A) while the connecting horizontal pipe of length 'L' at X_2 are considered adiabatic. In the case of water cooling, convection was considered. However, the calculation of Reynolds Number R_e yielded a very negligible value. This implied that convection heat transfer was a minimal factor and hence was neglected altogether. The entire heat transfer phenomena was treated as a case of conduction. At time t=0, the liquid metal poring is initiated through the in gates. There is an impulsive rise in temperature in the vertical side walls to T_H where, $T_H > T_A$. The basic assumption in the equation 2 is to maintain the temperature at L-X_1 at 1300 °C. A water jacket (copper pipe) of internal diameter 6mm and wall thickness 0.5mm is used. Water flow rate of 1 L.P.M. was calculated based on the Fourier equation for one dimensional steady state heat transfer. The heat flux obtained at the interface (L-x_1) was 1560 J/mm-s. The heat transfer for this process follows steady state conduction laws. The dimensionless equation is derived as Eqn.34.

4 Results

Based on the experiments conducted on a particular job for the yield efficiency are given below: The normal methoding process as employed by the industry was by considering the sleeve efficiency at 35%. In the air and water cooled system the sleeve efficiency was increased to 50%. Though the job was okay in all aspects, the ferrite formation was scattered in air cooled compared to water cooled. However the air cooled system was rejected at the Radiography Test (RGT) and Level 3 defects were present indicating shrinkage. The next trials were conducted with an increased efficiency to 75% for the water cooled system. Uniform ferrite structure was obtained. Level 2 defects were observed in RGT indicating metal impurity defects inclusions.

5 Equations, figures and tables

$$K = V/A \qquad (1)$$

Where V=melt volume and a=surface area.

$$Q = K/x_1 \qquad (2)$$

Where K=constant depending on the area (A_s) and temperature difference (ΔT)

X_1=fraction of the length of the mould in mm.

$$\int_0^m \int_0^K dT - \int_{T1}^{T2} dT = -At^2 - Bt + \alpha - \beta + ct \qquad (3)$$

Where

K=modulus of the job,

M=flow rate in LPM,

T=Log_2(time) in minutes,

Constants =A, B, C, α, β

T_1= inner surface temperature at x_3

T_2=outer surface temperature at x_3

$T_1 > T_2$ and $T_1 > 600^0$C

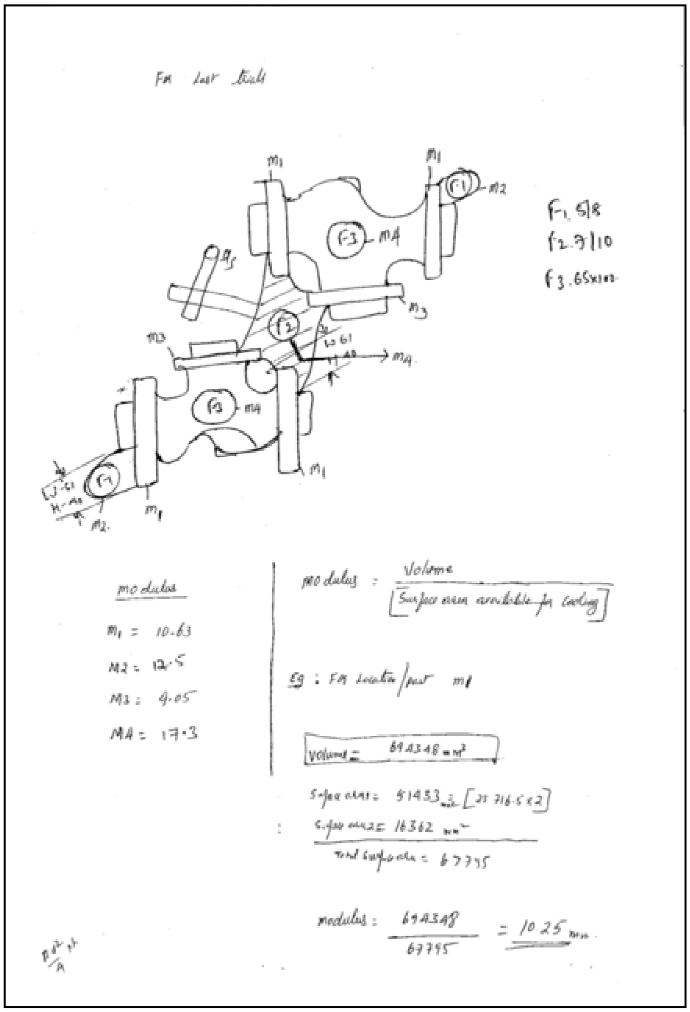

Fig 1

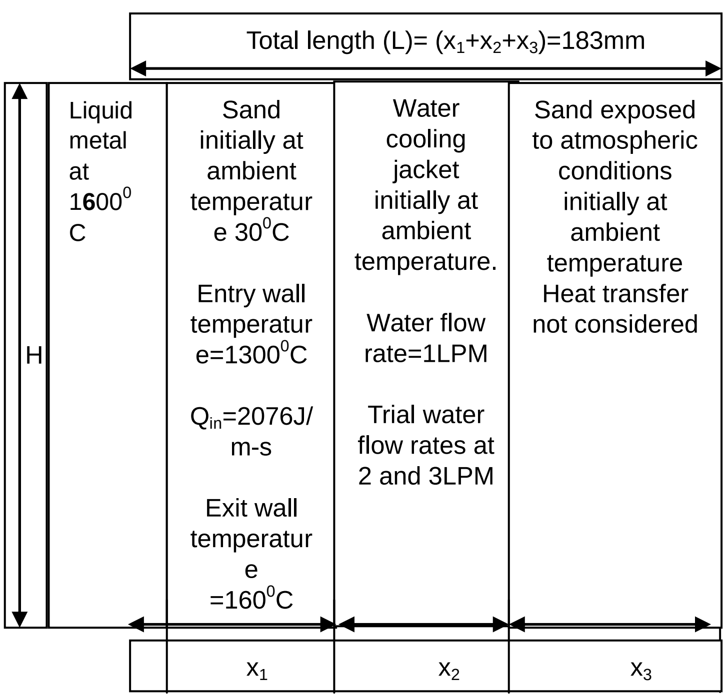

Fig 2

Water Cooled (Inner surface – Body/Seat Ring)

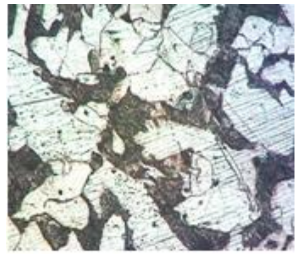

Fig. 3.1

Fig. 3.2

Water cooled (Inner surface - Flange)

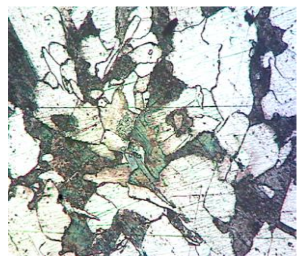

Fig. 3.3

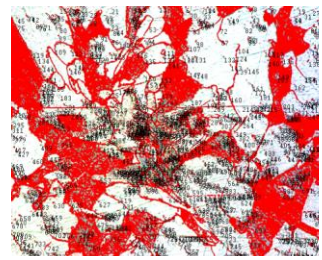

Fig. 3.4

Water Cooled (Outer Surface – Body/ Seat Ring)

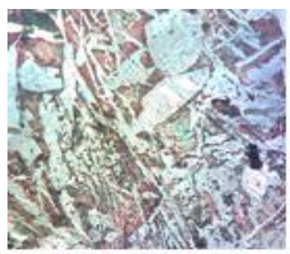

Fig. 3.5

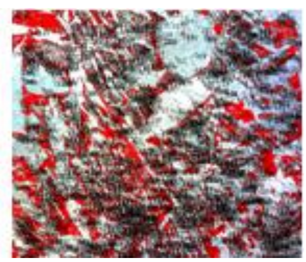

Fig. 3.6

Water Cooled (Outer Surface – Flange)

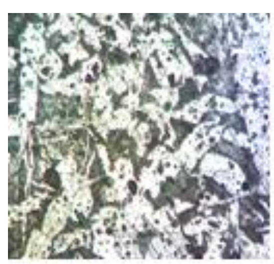

Fig. 3.7

Fig. 3.8

Air Cooled after Heat Treatment

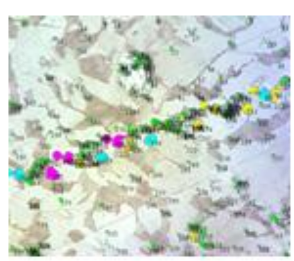

Fig. 3.9

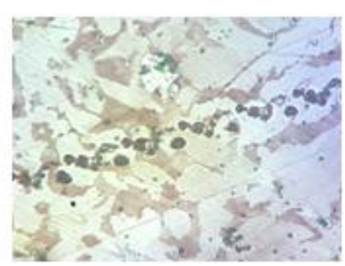

Fig. 3.10

Time temperature graph showing the temperature in (^{0}C) on the y axis, with respect to log_2 time (in minutes) on the x axis

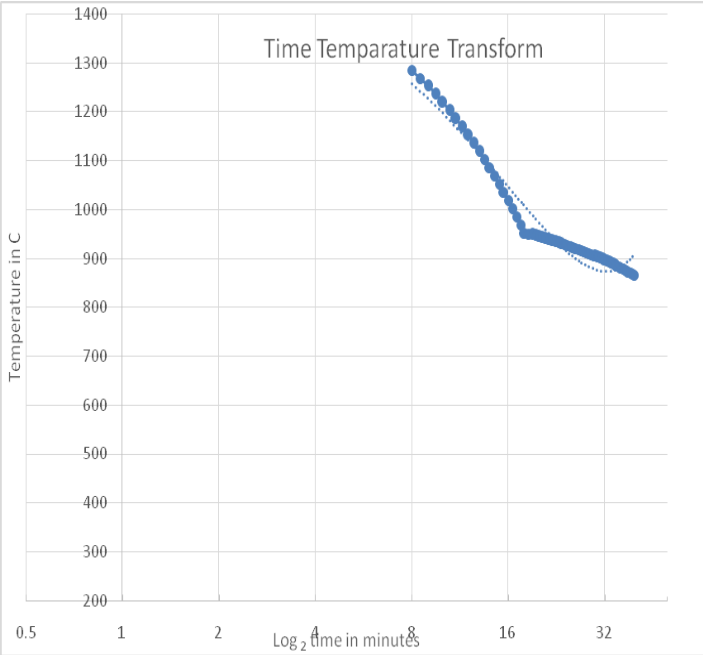

Fig 4

JOB FOR TRAIL	120018	WEIGHT : 20 KGS	PCS PER BOX : 2
TRIAL NUM	DESC1	DESC2	DESC3
TRAIL 1	120018, JOB CONSIDERED. SLEEVE WAS CALCULATED WITH 35 % EFFECIENCY	SIDE FLANGE SLEEVE 6/9 , CENTER SLEEVE 80 X 125, BELLY 65 X 100	CASTING WAS NORMAL AND OK IN RT. LIQUID WEIGHT WAS 66 KGS. YIELD OBSERVED 60.61 %
TRAIL 2	120018, JOB CONSIDERED. SLEEVE WAS CALCULATED WITH 50 % EFFECIENCY. PROVIDED WATER COOLING WITH PLASTIC PIPE. FLOW RATE WAS 2 LPM WITH 2 INLETS AND 2 OUTLETS	INSTEAD OF 6/9 SLEEVE, USED 5/8 SLEEVE, BELLY SLEEVE KEPT SAME 65 X 100, CENTER SLEEVE REDEUCED FROM 80 X 125 TO 70 X 100	CASTING WAS NORMAL AND OK IN RT. LIQUID WEIGHT WAS 62 KGS. YIELD OBSERVED 64.52 % THE CASTING WITHOUT WATER COOLING WAS ALSO FOUND OK. WE OBSERVED THE FLAT FEEDING WAS BETTER IN WATER COOLED MOULD
TRAIL 3	120018, JOB CONSIDERED. SLEEVE WAS CALCULATED WITH 75 % EFFECIENCY. PROVIDED WATER COOLING WITH COPPER PIPE. FLOW RATE WAS 3 LPM WITH 4 INLETS AND 4 OUTLETS	INSTEAD OF 5/8 SLEEVE, USED 4/7 SLEEVE, BELLY SLEEVE 65 X 100 CHANGED TO 6/9, CENTER SLEEVE REDEUCED FROM 70X 100 TO 60 X 75	CASTING WITH WATER COOLING WAS OK (L2) IN RT BUT CASTING WITHOUT COOLING HAD SHRINKAGE OF L4 IN FLANGE AND BOTTOM SIDE OF BELLY.THE FLAT FEEDING WAS MORE IN WATER COOLED MOULD. THE SAFETY MARGIN WAS OBSERVED TO BE 15 MM IN WATER COOLED MOULD. LIQUID WEIGHT IS 58 KGS. YIELD OBSERVED 68.97 %

Result Table, 1

6 CONCLUSIONS

Lot of journal studies were done in introducing cooling media within the mould in sand mould casting. Unfortunately no articles in any journal were available dealing with this particular research aspect. The closest article that was found, dealt with the solidification process for investment casting without any cooling media. Initial research in sand mould casting has yielded good results in terms of ferrite formation in the casting and molten metal saving has increased by 13.3%. Refer Result table 1. Presently no existing software has the features to perform the modeling and simulation for this particular research process. The next level of research will be dedicated to developing a software for modeling and simulation of this process. The development of software is expected to open new avenues for future development of the same process. The results achieved can revive interest in the research field of sand mould casting.

ACKNOWLEDGMENT

We would like to express our deepest gratitude to SREE SHIVA SAI CAST PRIVATE LIMITED, SHIMOGA -FOR GIVING US AN OPPORTUNITY TO ACCOMPLISH THIS RESEARCH. FORBES MARSHALL PVT. LTD, PUNE - PROVIDING THEIR CONTROLLED DRAWING FOR RESEARCH TRIALS.

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