# Proposed methodology to allow bottom pour in a less than 400 kg ladle with steel thermal masses in Investment Shell Casting Process

Nilesh P. Vanikar[1], Dr.Prof. Shantipal S. Ohol[2,] , Tanay R. Anjikar[3]
*[1,2]Department of Mechanical Engineering, College of Engineering, Pune*
*[3]Siddhalaxmi Engineering Pvt. Ltd.*
*[1]Email: nvanikar@vsnl.net*

**Abstract:** Bottom pour of certain metal alloys is used regularly in casting industries. Good quality castings are produces as optimization of parameters like pour height, metal flow and temperature range of pouring etc. can easily be achieved. Metal slag related issues are also avoided resulting in less inclusion defects. But this process is used only for large mass of metal (> 1100 kgs) due to various reasons. Solutions to come up with a smaller mass of metal (< 500 kgs) are discussed here to achieve same advantages as by bottom pour for large mass of specific metal alloys. Specific example for bottom pour using stopper rod for ASTM 351A/CFM 8 is discussed for experimentation in investment casting process based on these solutions.

**Keywords:** Bottom Pour, stopper rod, preheat temperature, heat loss, gas preheat, continuous heat, safety

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## I. INTRODUCTION

For many years bottom pour using stopper road or sliding strip mechanisms are used for alloys which can hold a molten metal stage for a long period of time and have long range of temperature and superheat before solidification starts e.g. most of Cast iron grades. It is proven that this method if used correctly is much easier to operate and gives consistent quality castings. The reason being that consistency of important parameters of pouring like Pour height, Flow rate of metal, Temperature range of pour can be optimized simply and quickly. So far this is been used only in large foundries and a mass of ladle over and above 3 Tons on average. It is not used for smaller masses of molten metal currently due to heat loss issues related to small mass of metal and early solidification of the same. To overcome this problem some techniques are suggested and discussed. The basic sketch of bottom pour using stopper rod is as shown in Fig 1 and example of actual practice in Fig. 2 respectively.

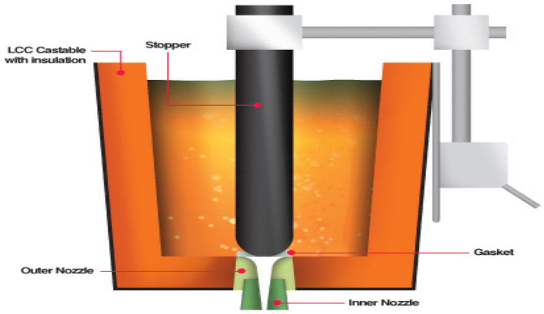

Fig. 1: Bottom Pour Concept Sketch

Fig.2: Bottom Pour Actual Process

It consists of a stopper rod with a stopper nozzle made of graphite, ceramic or similar material that does not adhere, reacts or melt with the respective metal alloy to be poured. For successful implementation of this system following parameters play the major role namely,

i) Metal Properties
ii) Heat loss during pouring process

Metal properties are important due to the fact that once the ladle is filled up with metal at almost furnace temperature and pouring is in process, certain time is required and more the time pour properties it can sustain is better as no extra heat is being provided during pour process. Most of the cast iron grades come under this category. Also it needs to have a wide range of superheat over the melting point before oxidation starts.

Now heat loss during the metal pour is a main concern in this process. This happens due to surrounding temperature, heat dissipation rate, movement of the mechanism etc. The overall Heat Transfer Coefficient (HTC) between the ambient and shell mold, $h_a$ can be given as a function of the convection heat transfer coefficient, $h_{ma}$, and shell emissivity [13] as:

$h_a = h_{ma} + h_R = h_{ma} + \sigma\varepsilon( T^2 + T^2_A )( T + T_A)$……………………….1

where $h_R$ is an effective radiation HTC, T is the temperature of the surface [K], and $T_A$ is ambient temperature [K]. There are different correlations for the HTC depending on the characteristic length of the surface and surface orientation, i.e., vertical and horizontal (Most of correlations on natural convection are given in terms of the Nusselt number, NuL , and Rayeigh number, RaL

$NuL = h_{ma} L/ k$ and $RaL = g\beta(T_S - T_\infty ) L^3/v\alpha$……………………..2

where g = gravitational acceleration, β is the thermal expansion coefficient, v is the kinematic viscosity of the fluid, L is the characteristic length scale, and α is the thermal diffusivity, $T_S$ is the surface temperature, and $T_\infty$ is the ambient temperature. For air at ambient temperature, the thermal conductivity k=2.6E-2 W/mK and $g\beta/v\alpha$ = 9.07E+7 [$1/m^3$ K].

The characteristic length scale, L for a surface can be computed as the ratio between the surface area, A, and its perimeter, p, i.e., L=A/p. The HTC is determined from the Nusselt number, as:

$h_{ma} =( k/ L) * NuL$…………………………………………………3

## II. BACKGROUND

When history was checked for the bottom pour it was realized that is used commonly for specific industries and advantages of this process are limited only to those certain alloys and big casting industry only. Things needed to be studied and analyzed why it is not been used for smaller mass of metal and still get advantages of the process. Experiment with ASTM 3511A (Referred henceforth as “metal” ) discussed here for an investment casting process. Properties are as per Table I. Main reason being that it needs preheating of silica shells and it might help the problem of heat loss for a small mass ladle. Problems were faced as discussed above.

Current process in a certain foundry discussed here uses hand pour with ladle size of 20-25 kgs of metal. Furnace capacity is 300 kg. So minimum 12 pour cycles are done and furnace is kept on during these cycles (Power consumption). Bottom pour in this case will reduce this extra cost of electricity once all the metal is poured in specially designed ladle (one time pour) .

## III. PROPOSITION FOR EXPERIMENTATION:

Experimentation of bottom pour for ASTM 351 A through 300 kg ladle in Investment Casting Process

| | | | |
|---|---|---|---|
| Carbon | 0.08 % Max | Tensile Strength | 70,000 psi Min |
| Manganese | 1.50 % Max | Yield Strength | 30,000 psi Min |
| Silicon | 1.50 % Max | Elongation at 2 in | 30.00 % Min |
| Phosphorus | 0.040 % Max | - | - |
| Sulphur | 0.040 % Max | - | - |
| Nickel | 9.0 - 12.0 % | - | - |
| Chromium | 18.0 – 2.21 % | - | - |
| Molybdenum | 2.0 – 3.0 % | - | - |

**Table 1: Chemical Composition of and Mechanical Properties ASTM 351 A**

Heat is lost mainly to ladle refractory, molten metal surface open to atmosphere and stopper rod mechanism. These are usually called as heat sinks. To overcome these issues of heat loss following areas are suggested for modification for small mass ladle use effectively for bottom pour.

**i)** Use of superheat of molten metal in furnace - Superheating (sometimes referred to as boiling retardation, or boiling delay) is the phenomenon in which a liquid is heated to a temperature higher than its boiling point, without boiling. Preheat of temperature should be utilized as much as where no oxidation will start causing blow holes and gas issues in castings[16]. This gives more time and range of temperature of metal to sustain its cast ability[12] properties for more time. This maximum superheat information can be obtained from specifications for typical alloy. Melting point of ASTM 351 A is 1580 $^0$C (2876 $^0$F) and can achieve superheat up to 1660 $^0$C (3020 $^0$F)

**ii)** Increasing of refractory strength to sustain heat effectively – More effective refractory \ metals with right thickness and strength to be used and right cross section area of the chosen refractory are to be used. In this case, SUPERHEAT SUPREME A (Vibration Cast) is used with following composition and properties given in Table II.
Composition: $Al_2O_3$ -77.6 %; $SiO_2$ –13.5%; CaO – 4.4 %; $TiO_2$ – 2.3 %; $Fe_2O_3$ -1.4 %; Other – 0.8 %

| Temperature | | Density | | Linear Expansion | MOR | | Porosity |
|---|---|---|---|---|---|---|---|
| Deg C | Deg F | gm/cm$^3$ | lb/ft$^3$ | % | MPa | psi | % |
| 110 | 230 | 2.45 | 1.53 | - | 7.6 | 1100 | 21.7 |
| 1315 | 2400 | 2.4 | 1.5 | -0.1 | 9.3 | 1350 | 29.2 |
| 1400 | 2550 | 2.65 | 1.67 | -2.9 | 18 | 2700 | 19.4 |
| 1480 | 2700 | 2.8 | 1,78 | -4.5 | 26,0 | 3780 | 5.5 |

Table II: Properties of SUPERHEAT SUPREME A (Vibration Cast) [15]

**iii)** Preheat of a Ladle inner surfaces in contact with molten metal to such extend where Delta T of metal temperature and refractory temperature and stopper road mechanism elements is as low as possible. This is possible through a gas or oil nozzle heating as shown in Figure 3**.** Suggestion is to preheat ladle to 1000-1100 $^0$ C with the use of gas burner using LPG (in process). The use of S-80 blower burner is decided to use as it give longer, thinner yet a fame temperature up 1200 $^0$C ( 2192 $^0$F). Details of assembly for S-80 burner, holding pipe, flexible gas pipe and adjustable regulator that is fits on home and industrial cylinders is shown in fig 5. Type of flame obtained from S-80 is show in Fig. 6. Currently oil burner is used where maximum preheat temperature achieved is only up to 600-700 $^0$C (1112-1292 $^0$F). This can also be used as high flame burner on top of the molten metal continuously while pouring through ladle is in progress.

**Fig. 3: Oil Nozzle Preheat Current)**

**Fig 4: Heated Ceramic and Stopper Rod**

**iv)** This may take 3-4 hours to reduce Delta T to minim value but is cheaper than keeping induction furnace on till all heat is emptied in pouring. Inside geometry of ladle to be designed in such a manner so that molten metal flow through the bottom nozzle is smooth and with a minimum resistance from the geometry, This includes proper basin structure having appropriate taper from top to bottom and bottom area (Thickness of 2” (5 cm) at top to 3”(5.5 cm) over the height of 16”(41 cm)) to as close to semispherical without any rough edges (Fig. 4). Outside material of fabrication in 3/4” mild steel. Details of S-80 burner are given in table no III.

**Fig. 5: S-80 Preheat Assembly unit**[17]

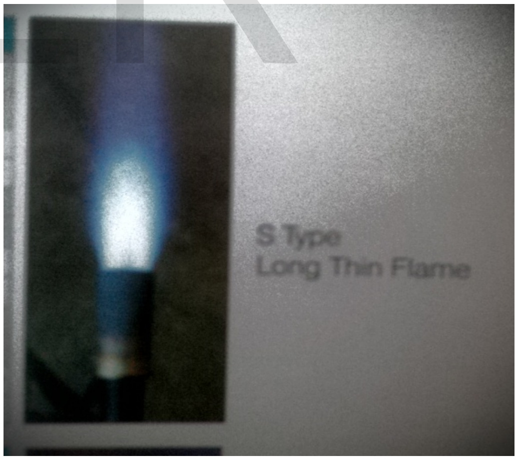

**Fig 6: Long Thin Flame from S-80**[17]

| Model | Length | Head D | Working Pressure | | Consumption/Hr | | Rated Heat output | |
|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max |
| S-80 | 383 mm | 50 mm | 0.14 kg/cm$^2$ | 1.40 kg/cm$^2$ | 2.70 kg | 7.61 kg | 65,000 kcal/hr | 84,670 kcal/hr |
| | 15.01 in | 2 in | 2.0 psgi | 20.0 psgi | 6 lbs | 16.9 lbs | 1,20,000 btu/hr | 3,36,000 btu/hr |

Table III: Properties of S – 80 burner [17]

**v)** Preheating of shells to optimum (to be decide) to reduce heat difference between pour metal and shell.

**vi)** Reduction of transfer time- This means that ideally there should not be any time lapse for metal pour from furnace and reheating of ladle is stopped.

**vii)** Safety – To avoid spattering of metal and to locate pour cups conical safeguard is attached outside pour nozzle.

## IV. SUGGESTED DESIGN OF EXPERIMENT: Factorial design of $2^{3:}$ TABLE IV

*Factors:*

1) Pour Height - (1-3” from Pour Cup -) ; - (1-3” from Pour Cup +)
2) Pour Temperature – (1610-1625 Deg C -) ; – (1626-1645 Deg C +)
3) Preheated Shell temperature – (800 -900 Deg C -) ; (901 -1000 Deg C +)

| Sr. No. | Pour Height (mgh) | Temperature | Shell Temperature |
|---|---|---|---|
| 1 | + | + | + |
| 2 | + | + | - |
| 3 | + | - | - |
| 4 | + | - | + |
| 5 | - | + | + |
| 6 | - | + | - |
| 7 | - | - | + |
| 8 | - | - | - |

Table IV: Proposed design of Experiment

Obtained results and Analysis procedure has to be determined for final correlations for optimization process with respect to defects as inclusion, cold shut and mechanical properties of castings produces from experimentation.

## V. CONCLUSION

So far, bottom pour is used only for masses of metal alloys of Cast Iron and Steel alloys. Advantages of this process are not yet been used successfully for small masses of alloys. Many medium scale set up of foundries can use this method for their regular production if proper solutions and modifications are done to the existing process accordingly. An initial step is taken to progress in the direction with specific alloy and specific foundry process but can be continued to streamline directions for all widely used cast alloys and processes. This will certainly give simple optimization techniques for key parameters like pour height, flow, temperature control etc with better quality castings.

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