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Design of Tapered Riser Using Basic Hydraulic Principles

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ABSTRACT: *In sand casting, the design of gating and riser system plays an important role in the quality of the casting. Poor designs of these two parameters lead to major defects such as incomplete filling, porosity, and re-oxidation inclusions. These defects cause the castings to be susceptible to failure during their use. A riser system with high volume to surface area ratio gives a sound casting. The conventional casting setup used in many foundries incorporates the use of cylindrical risers. Improvement of the gating and riser system by use of computational analysis was carried out. Through several computational analyses, it was concluded that a casting with minimal defects could be obtained by modifying a cylindrical riser to form a tapered riser which has a higher volume to surface area ratio.*

Keywords -*Casting defects, Chvorinov's rule, cylindrical riser, hydraulic principles, tapered riser*

I. INTRODUCTION

In spite of the extensive research that has been done in attempts to reduce casting defects, production of a defect free casting still remains a major challenge in the casting industry. The occurrence of most defects is often related to the flow of molten metal (fluid flow phenomena) during pouring and solidification stages [1]. Mechanical properties such as hardness, tensile strength, ease of machinability, fatigue endurance, resistance to fracture and so forth, of cast parts are usually affected by the rate of solidification. Figure 1 shows a typical gating system.

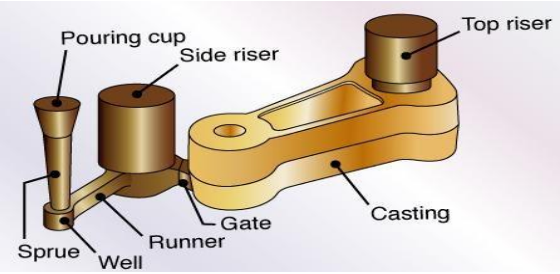

Figure 1: Typical gating system

The design of the gating system and the riser system are critical in the production of quality sand casting products. This research paper focuses on the design and improvement of risers. A riser is a passage made in the cope through which the moltenmetal rises after the mold is filled [2]. Risers serve dual function, they compensate for solidification shrinkage and heat source so that they freeze last and promote directional solidification. Casting process design is important for production quality and efficiency [3].

Most casting designs in the foundries are done on shop floor by trial and error basis [4]. This is time consuming, costly and encourages presence of defects in the final product. This approach makes the design of gating system arduous. The trial and error method can be eliminated by use of a computational approach based on the dimensions of the part to be cast. Up to date, researchers have explored various computational and simulation approaches to minimize the occurrence of these defects. Martin (1953) investigated on the relationship between the dimensions of the gating system with that of the weight of the casting [5]. He concluded that the in-gate area is inversely proportional to the square root of the effective head and the function of the casting weight. He also established that the loss coefficient for molten metal is of the same order to that of the water.

Wallace et al (1957) provided guidelines for the design of the gating system that was meant to be economical [6]. They suggested that selection of optimum pouring rate and time should be made first as closely as practicable with the function of an ideal gating system. Desai and Raghav designed the special gate sticking on the pattern in draining the gas while pouring the molten metal. However, these researches do not provide a suitable gating system to reduce incomplete filling defects in castings. In particular, these experiments used the trial and error method to conduct the solutions hence the experiments wasted a lot of material and took a lot of time [7, 8].
Flemings et al (1960) came up with a functionality of every element of gating system.
This was done with an illustration using the aluminum casting and showed the essence of good gating system. Most of the salient features were discussed systematically but never compared or gave a hint of the best type of the riser or sprue i.e. cylindrical or tapered [9]. Chamber et al (1943) engaged in an investigation on casting and came up with conclusion that a proper riser shape, size and geometry as well as location of the riser inlets should be determined well to minimize the ratio of the gross weight to net weight. The tapper sprue minimizes overtaxing and aspiration as compared to the cylindrical. This helps to stream line the flow of metal hence reducing the effects of the turbulence [10]. The computational analysis presented in this research paper uses basic hydraulic principles in the gating system and Chvorinov's rule for the calculation of the appropriate riser dimensions. This approach has major advantage over the shop floor trial and error method.

II. DESIGN METHODS AND CALCULATIONS

The relationship between volume & area of the part to be cast and the size of risers are important in the entire process of casting. To improve the gating system while focusing on riser design, it is vital to understand certain hydraulic parameters.

Hydraulic Principles Used in the Gating System

2.1.1 Nature of flow

The nature of flow of the molten metal in the gating system can be established by calculating the Reynolds number.

2.1.2 Reynolds number

Reynolds number is the ratio of momentum to viscosity and is usually given as;

$$Re = \frac{density * velocity * diameter}{viscosity}$$

$$Re = \frac{\rho V d}{\mu} (1)$$

Where Re=Reynolds number

ρ= density of the molten metal

V = mean velocity of flow

D = diameter of the tabular flow

μ= viscosity of the molten metal

A Reynolds number below 2000 gives a laminar flow while a number above 2000 leads to a turbulent flow.

Bernoulli's Theorem

To calculate flow velocities, we assumed a steady state and incompressible flow. Using Bernoulli's equation of flow given as

$$h1 + \frac{P1}{\rho} + \frac{V1^2}{2g} + F1 = h2 + \frac{P2}{\rho} + \frac{V2^2}{2g} + F2 \quad (2)$$

Where

h =height of the molten metal (*cm)*

p=static pressure N/cm^2

v= velocity of the molten metal *cm/s*

g=acceleration due to gravity

ρ= density of the molten metal g/cm^3

F=head losses due to friction *cm*

Ignoring friction forces, the Bernoulli's equation reduces to;

$$h + \frac{P}{\rho g} + \frac{V^2}{2g} = constant \qquad (3)$$

The velocity of the molten metal at the base of the sprue can be determined from (3). If we take a point 1 at the top of the sprue and point 2 at its base and using point 2 as the reference plane, then the head at that point is zero (h_2=0) and h_1 is the height (length) of the sprue.

When the metal is poured into the pouring cup and overflows down the sprue, its initial velocity at the top is zero (v_1=0) and assuming that atmospheric pressure is maintained, then the equation of velocity reduces to;

$$h_1 = \frac{{v_2}^2}{2g} \qquad (4)$$

Making v_2 the subject of the formula gives;

$$v_2 = \sqrt{2gh_1} \qquad (5)$$

Continuity Law

Continuity law states that the volume rate of flow remains constant throughout the liquid.

Continuity is expressed as;

$$Q = V_1 A_1 = V_2 A_2 \quad (6)$$

Where: Q = volumetric flow rate cm^3/s

A= area cm^2

v = velocity

The continuity relationship clearly shows that increase in area results in a decrease in velocity.

Mold Filling Time

Aluminum should be poured at a slow rate in order to avoid turbulence, aspiration and drossing.

Using continuity;

$$Q = V_g A_g = V_2 A_2 \qquad (7)$$

And assuming $A_g = A_2$

The velocity of the molten metals in the gating system $V_g = V_2 = \sqrt{2gh_1}$ where h_1 is the height of the sprue.

Therefore,

$$moldfillingtime = \frac{volumeofmold}{A_g * V_g} \quad (8)$$

Calculation of the Solidification Time

Chvorinov's rule

The total solidification time is the time required for the casting to solidify after pouring. This time is dependent on the size and shape of the casting by an empirical relationship known as Chvorinov's rule, which states;

$$T_{TS=C_m}\left(\frac{V}{A}\right)^n \quad (9)$$

Where TS = total solidification time (min)

V = volume of the casting cm^3

A= surface area of the casting cm^2

n = an exponent taken to be 1.5 – 2

C_m = mold constant min/cm^2

The value of C_m depends on the particular conditions of the casting operation, including mold material (e.g. specific heat, thermal conductivity), thermal properties of the cast metal (e.g., heat of fusion, specific heat, thermal conductivity), and pouring temperature relative to the melting point of the metal.

Since Chvorinov's rule indicates that a casting with a higher volume-to-surface area ratio will cool and solidify more slowly than one with a lower ratio. We used this principle in designing the riser in a mold.

Also, since the metal in the riser must remain in the liquid phase longer than the casting, TS_{riser} must exceed$TS_{casting}$.

In our methodology, we designed appropriate risers for casting based in the plate shown below.

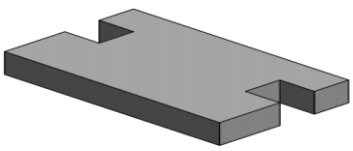

Figure 2:3D view of the sample casting template

Figure 3: Front view of the sample casting plate

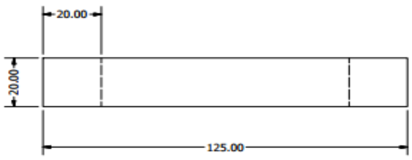

Figure 4: Side view of the sample plate

Volume of the aluminum plate = 171.5 cm^3

Surface area of the plate = 243.5cm^2

Riser Design Requirements

For the aluminum rectangular plate above, we designed both cylindrical and tapered riser that will be able to compensate for shrinkage, and remain molten until after the casing solidifies.

Using Chvorinov's rule, solidification time is given by;

$$T_{TS=C_m}\left(\frac{V}{A}\right)^n$$

The mold constant C_m depends on the material to be cast and for aluminum, $C_m = 3.5\ min/cm^2$

n=2

The total solidification time for the plate is calculated and found to be 1.74 *min.*

Since the solidification time for the riser is 1.25 times that of the casting, the total solidification time for riser is 2.174 *min*

Cylindrical riser

Figure 5: Cylindrical riser

We used chvorinov's rule to get the dimensions of the cylindrical riser. A diameter: height ratio of 1:1 was assumed.

Using the relation

$$T_{TS=C_m}\left(\frac{V}{A}\right)^n$$

We found that the appropriate diameter for the cylindrical riser is *3.94 cm= 4.0 cm.*

The volume to surface area ratio of the cylindrical riser was found to be ***0.79***

Tapered riser

For a sound casting, the volume to area ratio of the cylinder must be as high as possible. To maximize the volume to area ratio, the area of the riser should be minimized. We introduced a taper in the calculated cylindrical riser and investigate if by so doing, the volume to area ratio would be maximized.

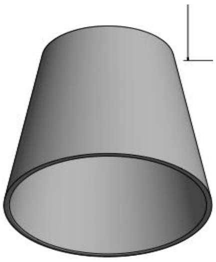

Figure 6: Isometric view of a tapered riser

To find the smaller radius r, we apply a taper at a various angles and calculate the volume to area ratio at each case.

Different angles of taper were applied and the resulting volume to surface area ratio tabulated as shown in the table below.

Table 1: Table indicating taper angles and their respective volume to surface area ratio

Angle of taper(degrees)	Volume to Surface area ratio
5°	1.21
9°	1.21
10°	1.20
11°	1.21
15°	1.21
20°	0.98
30°	Inapplicable
45°	Inapplicable

III. DISCUSIONS

From the above cases of the tapered riser, it can be noted that the volume to area ratio of the riser is higher when the angle of taper is $5°\ to\ 15°$giving a volume to surface area ratio of a value around 1.21 as compared to the cylindrical riser of the same dimensions with a volume to surface area ratio of 0.79.This can be concluded that applying a slight taper to the appropriate cylindrical riser to form a riser in the shape of a conical frustum at a taper, preferably $5°\ to\ 15°$helps maximize the volume to area ratio hence increasing the chances of producing a sound casting.

IV. CONCLUSION

Through computational approach, tapered as well as cylindrical risers were analyzed. A tapered riser was found to give a more sound casting than a cylindrical riser did. The use of hydraulic principles makes thewhole design process fast, easy to use, and reliable as compared to the shop floor trials. Computational analysis is suitable for all shapes whether complex or simple. It also gives a better yield product within a less time compared to shop floor trials. The defects are decreased by a great percentage meaning the end product is of a higher quality.

V. Acknowledgements

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