GATING AND RISERING A TYPICAL CASTING

TRIALING AIDED BY SOLIDCast™

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08P630
"If metals are perfectly inert chemically, if they absorbed no gases, if they exhibited no shrinkage on cooling, and if they were not erosive to the mold and of various specific gravities, it would much simpler to make a casting. Unfortunately the reverse is true..."

-Richard W Heine

Though we have a number of scientific approaches to the design of the gating and risering most foundries still prefer to have the traditional way of designing gating & feeding systems by trials and experimentations. Designing a gating system in a purely scientific way demands through knowledge in the thermal and fluid dynamics field. Well this assignment utilizes a classic fluid dynamical approach to design the gating with limited amount of empirical results concluded by the leading researchers of 1960s. An empirical way of risering is also formulated with some little success without following the results concluded by prior researchers. As it is a completely theoretical try, the concluded results may not match with the real time situations. And this is where we take the aid of simulation programs. The results of the simulations are considered and the gating system is tuned in such a way that the practical application of the proposed system becomes possible. Here we make use of SOLIDCast™ - one of the leading finite element based casting solidification modeling software.

**LIMITATIONS OF SOLIDCast™**

Let us first discuss about the limitations of the this software so that over expectation about the results is eliminated.

- It can calculate approximate flow of the metal and heat loss during the flow but cannot calculate turbulence from the flow.
- The software collects only the temperature and time data during simulations and do all plots based on this data.
- It cannot predict porosities occurring in the casting because of pressure that may occur in various parts of the casting.
- All predictions are done based on the 4 parameters namely Temperature, Time, Distance, and gravity effects in some cases.
- In certain cases a part of the casting comes down below the critical fraction solid point before the pouring is finished, but all time plots are started from the moment the pouring is finished, which leads to errors in the time plots.
- In addition to the above limitation, the software assumes that the entire metal in the mould just after pouring is at the same temperature which is equivalent to the pouring temperature.

Let this assignment may be formulated to look like a case study of a practical casting.

XXXX GmbH & Co. have placed their order to make castings of a pressure plate with the following dimensions and the materials. Our job is to design a practical gating and risering systems for the proposed casting such that the soundness of the casting and the yield is ensured.
MATERIAL:
GG25 - ASTM - A48 40b

UNDIMENSIONED:
RADII - 3mm

SIDE NOTE:
AFTER MACHINING
THE FRICTION
SURFACE MUST
BE FREE OF PIN
HOLES AND
SHRINKAGE CAVITIES

REMOVE ALL BURRS
AND SHRAP EDGES

ALL DIMENSIONS ARE IN mm

23XXXX52    XXXX GmbH & Co.
CONFIDENTIAL    02 JULY 2010
SCALE 1 : 2

PRESSUR
PLATE
ANALYSIS OF THE DRAWING

The drawing is converted into a part file in ProE®. With the help of the analyze function of the modeling software the following conclusions are made.

VOLUME : $8.796 \times 10^{-4} \text{ m}^3$
SURFACE AREA : $1.468 \times 10^{-1} \text{ m}^2$
MODULUS : $5.992 \times 10^{-3} \text{ m}$
CENTER OF GRAVITY : $8.787 \times 10^{-3} \text{ m}$

SIDE NOTE ANALYSIS

As the friction surface is supposed to be machined, a proof machining operation is recommended. As the friction surface must be free from defects it is recommended to check for both macro and micro shrinkage. Further it is a clutch plate that is expected to rotate a very high speeds. This makes it unavoidable to maintain the soundness of the casting. Any changes in the localized material density may lead to very high centrifugal forces.

MATERIAL ANALYSIS

The material supposed to be used for casting is GG25

This is classified as grey cast iron with lamellar graphite.

IDENTICAL GRADES

- **GERMANY** GG-25 / EN GJL 250
- **FRANCE** NF Ft 25 D
- **GREAT BRITAIN** BS Grade 220/ Grade 260
- **NETHERLANDS** NEN GG25
- **SWEDEN** MNC 0- 25-00
- **USA** ASTM A48 Grade 40B
- **ITALY** UNI G25
- **JAPAN** J159 FC25
- **RUSSIA** GOST Sc25

MICROSTRUCTURE

This is a 1 : 500 zoomed microstructure of GG25 on the left and a 1 : 100 zoomed microstructure on the right. The microstructure has pearlite with fine lamellar graphite.
PROPERTIES OF GG25 REQUIRED FOR ANALYSIS

- Thermal Conductivity = 53.329 W/m.K
- Specific Heat Capacity = 460.24 J/kg.K
- Density = 7150 kg/m³
- Latent Heat Of Fusion = 230115.6 J/kg
- Solidus temperature = 1122.203°C
- Liquidus temperature = 1197.91684°C
- Freezing range = 75.71384°C

CHEMICAL COMPOSITION OF GG25 REQUIRED FOR ANALYSIS

- % of C = 3.4%
- % of Si = 2.4%
- % of P = 0.15
- Carbon Equivalent (CE) = $3.4 + \frac{2.4}{4} + \frac{0.15}{2} = 4.075 \approx 4$

ASSUMPTIONS TO BE CONSIDERED FOR SIMULATION AND DESIGN

- Section thickness is twice the smallest distance from the surface to the centre of gravity (to be specific from the friction surface)
- Pouring temperature is with 200°C superheat.
- There is a 75°F heat loss to the surrounding on pouring. i.e., temperature of metal in the mould is pouring temperature - 75°F.
- We have no back pressure while pouring, i.e., the pressure at the ingate opening is same as the atmospheric pressure at the top of the sprue.
- Surface roughness of the mould formed is 2mm.
- The fluid and thermal properties of the metal remain constant throughout the pouring operation.
- The assumed mould thickness is 25mm.

RESULT OF THE IRON PROPERTY CALCULATOR MODULE OF SOLIDCast™

We need these results for our theoretical calculations and to fine tune SOLIDCast™ for a perfect simulation. This iron property calculator. This module's algorithm is based on the VDG Nomogram published by the German Iron Society.

- Critical Fraction Solid Point = 58 % solid
- Shrinkage at liquidus = 3.1 %
- Shrinkage at CFS Point = 5.1 %
- Shrinkage at solidus = 3.7 %
- Shrinkage time in % of Solidification Time = 50.09%
Therefore this is a hypo eutectic alloy by analyzing its shrinkage characteristics.

**APPLIED CONCLUSIONS AND EMPIRICAL RESULTS**

- Fluidity = $14.9 \times CE + 0.05 \times T_p - 155$ inch
  
  Where
  
  - $CE =$ Carbon Equivalent
  - $T_p =$ Pouring Temperature in °F

- Optimal Pouring Time = $\frac{F}{40} \left( 0.95 + \frac{T}{0.853} \right) \sqrt[3]{W}$

  Where

  - $F =$ Fluidity in inches
  - $T =$ Section Thickness in inches
  - $W =$ Weight in pounds

- Chvorinov have concluded that $t_f = \frac{V^2}{A^2}$

  Where

  - $t_f =$ Freezing time
  - $V =$ Volume of the casting
  - $A =$ Surface area

- “In General the velocity of the molten metal must be kept below 1 m/s for ferrous metals.”

*NOTE: The first and the last results were contributed by B. Ravi and the Optimal filling time relation was proposed by Richard W. Heine

**THE FIRST GATE**

Let me first list out the requirements of a good gate and our present aim

- The gate must fill the entire casting before its fluidity is lost i.e., within the recommended pouring time limits.
- The gate must not entertain any backflow of the metal because of the graphitization expansion of the grey cast iron.
- The gate must introduce molten metal into the mould with minimum turbulence and must reduce turbulence in the runner regions.
- Though iron is not a dross forming substance, it is ferrous alloy with extreme melting temperatures and hence its velocity must be controlled with a greater care.
- The yield must be increased.

Fluidity is = $14.9 \times 4.075 + 0.05 \times 2552 - 155 = 33.3175$

Optimal pouring time = $\frac{33.3175}{40} \left( 0.95 + \frac{8.787 \times 25.4}{0.853} \right) \sqrt[3]{13.86557} = 5.4622$ seconds

As a precaution let us design the gate for 5s.
In order to apply the fluid mechanic properties to the gating, we need some fluid related properties of the molten metal.

**FLUID PROPERTIES OF MOLTEN IRON**

- Dynamic viscosity of the molten iron = 0.006 Ns/m²
- Density of the molten iron at the pouring temperature.

Considering mass balance

\[ \rho_s \cdot V_s = \rho_i \cdot V_l \]

As we have 5.1% shrinkage on cooling (an approximate value - excluding graphitization)

\[ 7150 \times V_s = \rho_i \times (V_s + 0.051 \times V_s) \]

Therefore \( \rho_i = 6803.045 \)

**PRIOR DISCUSSIONS FOR GATE DESIGN**

This is going to be first attempt and hence is tried without feeding. Feeding is not so compulsory as this is grey iron we are dealing with and hence graphitization will account for some expansion to counteract the cooling shrinkage. As the friction surface is expected to be absolutely defect free it is kept at the bottom to reduce void related defects. Further it is the surface to be machined, by placing this at the bottom we can reduce the machining allowances to be given which in turn increases net yield. The gating ratio that is likely to be applied is 1.5:2:1. This may seem contradictory as this is the gating ratio for a pressurized gating system. On having a closer look, this is a partially pressurized system. Such a gating system is applied to increase the yield. The runner alone is given a larger cross-sectional area to reduce the velocity and to aid in slag removal. As the casting is of a very small section thickness, the metallostatic head introduced is very less, and hence a lesser velocity of metal is achieved.

**DESIGN CALCULATIONS**

One can never achieve a laminar flow while introducing metal into the mould. But the degree of turbulence must be as low as possible. For less turbulent flow the velocity must be as small as possible and hence the cross-sectional area of the gating system must be as big as possible. But it must not be so big so that fettling becomes a handicap.

Ideal cross-sectional area of a single ingate that satisfy the needs is 300mm² (44.5 x 13.5 mm² is the maximum ingate area if fed through the projections. Half of this area is recommended as we aspire easiness in fettling)

Let us verify if this area is suitable or else we have to go for a much larger area.

Volume flow rate to be achieved is \( \frac{8.796 \times 10^{-4}}{5} \text{ m}^3/\text{s} \)
Therefore considering constant density as one of the assumptions,

\[
\text{Velocity} = \frac{\text{velocity}}{5} \times \frac{1}{300 \times 10^{-6}} = 0.5864
\]

This is an extremely ideal velocity.

The modulus of the ingate must be such that it freezes just after the first half (50.09 % of total time) of solidification to prevent backflow of the solid metal because of graphitization expansion and hence to achieve a sound casting of uniform high density i.e., free from micro porosity (the gas bubbles are expelled out because of the high internal pressure created.)

**NOTE**: The mould be of sufficient strength to withstand the internal forces or else it fails and breaks down leading to a catastrophic disaster.

Let us apply the Chvorinov's rule to decide the modulus.

\[
V_c = \text{Volume of the casting}
\]

\[
V_g = \text{Volume of the ingate portion}
\]

\[
A_c = \text{Surface area of casting}
\]

\[
A_g = \text{Surface area of ingate portion}
\]

\[
t_f = \text{Freezing time of the casting}
\]

Our goal is that, freezing time of the ingate portion = \(\frac{\text{freezing time of the casting}}{2}\)

\[
\frac{V_c}{A_c} \propto t_f^{-2}
\]

\[
\frac{V_g}{A_g} \propto \left[\frac{t_f}{2}\right]^2
\]

\[\therefore \text{modulus of gate} = \frac{\text{modulus of casting}}{4} = \frac{5.992 \times 10^{-3}}{4} = 1.498 \times 10^{-3} \text{ m}\]

Let the dimensions of the ingate cuboid be 5 mm, 30 mm and x mm.

\[
\frac{5 \times 30 \times x}{2(30 \times x + 5 \times x)} = 2.14 \quad \text{(irrespective of x) this is greater than 1.498 but can satisfy our aim to a certain extent.}
\]

**According to the adapted gating ratio,**

Total Ingate Area = 300 mm\(^2\)

Total Runner Area = 600 mm\(^2\)

Sprue's bottom Area = 450 mm\(^2\)
Anyway in a pressurized system the sprue top and bottom area can be the same. Not much of the streamlining is required as the gate is always full.

Now, let us design a gate for the application using a modeling software preferably ProE®.

The only parameter left is the effective head to be provided which is terms of the height of the sprue.

**CALCULATION FOR HEIGHT OF SPRUE**

The gate that is proposed is

![Diagram of the proposed gate](image.png)

The areas prone for major friction head losses is the runner which can be divided into two parts, the straight one and the curved part.

**HEAD LOSS CALCULATION FOR THE STRAIGHT PART**

length \( L = 86 \text{ mm} \)

hydraulic diameter \( D = 24 \text{ mm} \)

Surface roughness \( \epsilon = 2 \text{ mm} \) (assumption)

\[
\text{velocity} = \frac{\text{volume flow rate}}{\text{cross-sectional area}}
\]
\[
\begin{align*}
  v & = \frac{8.796 \times 10^{-4}}{5 \times 600 \times 10^{-6}} \\
  v & = 0.2932 \text{ m/s}
\end{align*}
\]

From Haaland's equation to find Darcy's friction factor,

\[
\frac{1}{\sqrt{f}} = -1.8 \log \left\{ \frac{6.9}{Re} + \left( \frac{\varepsilon/D}{3.78} \right)^{1.11} \right\}
\]

Reynold's number \( Re = \frac{6803.045 \times 0.2932 \times 24 \times 10^{-3}}{0.006} \)

\[= 7978.6111\]

\( f = 0.094838 \)

Head loss = \( \frac{fv^2}{2gD} \)

\[
= \frac{0.094838 \times 0.086 \times 0.2932^2}{2 \times 9.81 \times 0.024}
\]

\[= 1.5 \text{ mm}\]

**HEAD LOSS CALCULATION FOR THE CURVED PART**

length L = Radius x angle

\[= 197 \text{ mm} \times 155.8 \times \frac{\pi}{180}\]

\[= 0.5357 \text{ m}\]

hydraulic diameter \( D = 17.1429 \text{ mm}\)

Surface roughness \( \varepsilon = 2 \text{ mm} \) (assumption)

velocity = \( \frac{\text{volume flow rate}}{\text{cross-sectional area}} \)

\[
\begin{align*}
  v & = \frac{8.796 \times 10^{-4}}{5 \times 600 \times 10^{-6}} \\
  v & = 0.2932 \text{ m/s}
\end{align*}
\]

From Haaland's equation to find Darcy's friction factor,

\[
\frac{1}{\sqrt{f}} = -1.8 \log \left\{ \frac{6.9}{Re} + \left( \frac{\varepsilon/D}{3.78} \right)^{1.11} \right\}
\]

Reynold's number \( Re = \frac{6803.045 \times 0.2932 \times 17.1429 \times 10^{-3}}{0.006} \)

\[= 5700\]
f = 0.1144
Head loss = \( \frac{ftv^2}{2gD} \)
\[ = \frac{0.1144 \times 0.5357 \times 0.2932^2}{2 \times 9.81 \times 0.0171429} \]
\[ = 15.67 \text{ mm} \]

**MINOR HEAD LOSSES IN THE ENTIRE GATING SYSTEM**

There are 6 sharp sudden dimension changes in the gating system that are potential head loss risers.

At the ingate area smaller and bigger hydraulic diameters at a ratio of 1 : 3

At the runner branch smaller and bigger hydraulic diameters at a ratio of 3 : 4

At the top of the well the ratio is 1 : 2

At the exit of the well the ratio is 1 : 1.5

At the turbulent we have the loss coefficient of 1 (totally)

In such a case loss coefficient can be expressed as

\[ k = (1 - \frac{d_1^2}{d_2^2})^2 \]

\[ \because \text{ total } k = 2 \times 0.8 + 2 \times 0.2 + 0.3 + 0.5625 + 1 = 3.8625 \]

Head loss = \( \frac{kv^2}{2g} \)
\[ = \frac{3.8625 \times 0.5864^2}{2 \times 9.81} = 67.7 \text{ mm} \] (The highest in the entire gating system i.e., at the ingate is taken here)

**MANIPULATION OF HEIGHT OF SPRUE**

Total head loss = 1.5+15.67+67.7 \approx 85 \text{ mm}

Bernoulli’s formula is

\[ \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + \text{head loss} \]
\[ P_1 = P_2 \text{ (Assumption)} \]
\[ V_1 = \frac{8.796 \times 10^{-4}}{5 \times 450 \times 10^{-6}} = 0.3909 \]
\[ V_2 = \frac{8.796 \times 10^{-4}}{5 \times 300 \times 10^{-6}} = 0.5864 \]

now from Bernoulli's equation,

Difference in height between levels 1 & 2 is

\[
z_1 - z_2 = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} + \text{head loss}
\]

\[
= \frac{0.5864^2}{2 \times 9.81} - \frac{0.3909^2}{2 \times 9.81} + 85 \times 10^{-3}
\]

\[ = 94.7 \text{ mm} \]

Therefore height of the sprue \( \approx 75 \text{ mm} \) (from the reference diagram in the previous page)

**FURTHER MODIFICATIONS FOR THE SPRUE**

Stream lining of the sprue is optional as this is a pressurized gating system. A pouring cup shall be introduced to reduce turbulence and to make it easy for the worker to pour the metal at the necessary pouring rate. Let us have a pouring head of 5mm. The finalized Gate is...
SIMULATION AND ITS RESULTS
The casting and gate which are separately modeled are assembled in the Assembly feature of ProE® and converted into the Stereo lithographic Format (*.STL) and exported into SOLIDCast™ for simulation.

The results of the simulation leads us onto the further discussion of improving the gating system.

The STL format approximates all the curved faces into a set of planes and generates a model as follows
Now as we lack the flow simulation module in SOLIDCast™. We need to calculate the pouring time for the entire system.

As our volume flow rate is fixed,

Volume of the entire system = \(1.188 \times 10^{-3} \text{ m}^3\)

Pre-determined volume flow rate = \(1.7592 \times 10^{-4} \text{ m}^3/\text{s}\)

Filling Time = \(6.75 \approx 7\) s

**ANALYSIS OF THE SIMULATION**

**CRITICAL FRACTION SOLIDIFICATION TIME**

The above is the plot of the regions and time to achieve the critical solid fraction point. By taking a closer look at the ingate area, just before the entrance region we have purple color which corresponds to approximately 0.8 minutes and just after the ingate area the casting has a red color which approximately corresponds to 1.6 minutes. Thus it is evident that the ingate freezes in half the time as the casting and hence prevents the backflow of metal because of graphitization. This is the basic necessity of the gating system bringing in grey iron.
COOLING RATE

SOLIDCast™ records the temperature and time data during simulation and with those recorded data, it plots the cooling rate at different points. It is really wonderful to have a uniform cooling rate throughout the casting and hence a uniform microstructure of grey iron.

TEMPERATURE GRADIENT

The temperature gradient is one of the most important criterion to predict localized directional solidification. The darker areas in the plot shows the places where the temperature gradient is more, i.e., a larger driving force for solidification. The lighter areas show the places of stagnation solidification and lowest thermal gradient. These areas are the places prone for centerline shrinkage in the case of pure metals, but in our case it the probable area for dispersed shrinkage. Anyway one cannot conclude anything with temperature gradient plot and this is the main disadvantage of the method. In addition to this, it is grey iron we are dealing with and this can compensate shrinkage.
NIYAMA CRITERION

The Niyama criterion is the custom criterion developed by Dr. Niyama, a Japanese researcher. This is manipulated using the temperature gradient and the cooling rate. This is basically a prediction of directional solidification. He actually formulated this criterion for prediction of dispersed shrinkage in steel castings, which he managed to extend to other alloys also. He have concluded that a value of 0 - 0.75 at any point of the casting is a potential region for dispersed porosity. The lower the value the larger is the probability for porosity. Any way our casting has a value no way near the critical value limits. But this does not mean that we are safe as the Niyama criterion does not consider the gravity into account. For accurate plotting of results we have to switch either to the FCC Custom criterion or the Metal density plotter.

FCC CUSTOM CRITERION

This is again another custom criterion created by F. Chiesa of the Universite de Trois - Rivieres in Quebec. This is a criterion that takes the solidus velocity (The velocity with which the solidus wave front moves in the molten metal pool) and local solidification time. This is again a way to predict porosity. The results of this criterion is interpreted in the exact opposite way of that of the Niyama criterion. The higher the value of the criterion, the more is the probability for the shrinkage. Generally the critical limit is between the maximum value and 40% of the maximum value. Once again the results are negative with no porosity.
Any way the above two criterions are expected to give negative results as these are not optimized methods for detection of porosity in cast irons which undergoes complex solidification methods. A more generalized and a more accurate method have been devised for accurate prediction of porosity termed as the "Material Density". This is the only criterion that takes the gravitational forces into account. This is reliable enough to predict even piping of risers.

**MATERIAL DENSITY ANALYSIS**

The results of this analysis the simplest of all the analyses. It generates a value between 0 and 1 for all the points in the casting. the result 1 means that the casting has 100% solid without porosity. 0.99 means that we have 1% porosity and 99% solid. and the value 0% means that it is a cavity with no metal.

This gives more reliable results for ferrous castings. The results when analyzed gives the presence, distribution and the amount of the porosity existing. We have severe porosity at both the ingates. The result is also fascinating as it has predicted the pipe that occurred in the sprue.

Now the results concluded by analysis of the temperature gradient are found to be true. The lightest areas in the casting had some shrinkage porosity too.
As it comes for Grey iron, all feeding stays in the scenario only till the critical fraction solid point is reached. Above, is a plot of regions which remain well above the critical fraction solidification time. These areas must never get isolated. If they get isolated, then no feeding can reach them. Even though graphitization compensates, the graphite formed will be very porous and localized density is lost. This again proved to be a fair reasoning for the results of the density plot.

Now our objective gets clear that we have to make changes in the gating system to acquire a shrinkage free casting. Generally this is considered as an acceptable level of porosity as far as grey iron is considered. But this is a special scenario where very huge centrifugal forces occurs because of localized micro porosity. Hence Risering becomes compulsory.

We still have a little more generalized analyses which are of considerable importance.
Hot spots are areas which freeze at the last. This is simple yet effective plot that may say whether a spot may have some problems. Well this is incapable to predict the severity of the defect or the defect itself.

In grey iron castings hot spots do not disturb much until they are exposed to machining. These hot spots may be of carbide and may also have shrinkage cavity. The material density plot confirmed that we have no shrinkage cavity of that sort. But still carbide formation will be a problem as it come in the face that is machined. It also affects the service of the casting as this is a friction pressure plate and carbide causes excessive wear on the mating component and the graphite dependent lubrication is lost
which leads to the failure of the casting during service. One cannot forget about the brittleness of the carbide too.

**HOT TEAR ANALYSIS**

This is one more custom criterion analysis which predicts potential areas for hot tears. Though this is not a major problem during gating. Foundry men have to adjust their sand properties to prevent this. This plot is made considering the solidification time gradient. Higher the value the more is the potential for hot tear.

Now our next objective is to place a riser for our casting.
RISERING

As far as shrinkage is concerned, it happens in three phases

- liquid to liquidus shrinkage
- liquidus to solidus shrinkage
- solid state shrinkage

The first two of the shrinkage must be compensated by the riser as the last one is taken care of by the shrinkage allowances provided. Empirically speaking, shrinkages in casting can never be removed they can only be shifted from the casting to the riser to ensure soundness of the end product.

OBJECTIVE OF OUR RISER

- It must compensate entire liquid level shrinkage in the casting.
- It must feed the shrinkage occurring at the ingate.

PLACEMENT OF RISER

Though we have isolated solidification in the other parts of the casting (particularly near the stem where gating is not done) the defects at those places are not threatening. Let us try with two simple risers near the ingates. The main advantage of having such a system is

- Bulky risers are eliminated
- Fettling is much simpler
- Yield is increased

GENERAL DESIGN ABOUT RISER DESIGN

Shrinkage at the liquid state is 3.1%. The volume of the liquid metal in the mould just after pouring is $8.796 \times 10^{-4}$ m$^3$. Therefore volume to be fed by the riser to compensate this is $8.796 \times 10^{-4}$ m$^3$ * 0.031 which turns out to be $2.73 \times 10^{-5}$ m$^3$. We have severe shrinkage at the stem part. The volume that had the 0.7 density can be approximated as a cuboid of the least thickness in stem. i.e., 44.5x13.5x25.75 mm cube. Now the approximate volume of this shrinkage is $4.6408 \times 10^{-6}$ m$^3$. (considering 30 % shrinkage - as we have 0.7 density at that region.) Now this shrinkage is not in the liquid state and hence the riser have to pipe to feed it.

The shrinkage cavity because of the first stage shrinkage resembles a cylinder, whereas the second stage shrinkage resembles a cone.

Grey iron can generally be made void of shrinkage by increasing gate dimensions with would eventually feed. Here we go for risers so that that the gate size is small enough ideal for fettling and top risers are added in the gates so that separate fettling of risers is also avoided.

RISER DESIGN CALCULATIONS

Let us divide the height of the sprue into 3 sections

- To compensate liquid state shrinkage
- To compensate piping shrinkage
• Clearance volume for a safety factor and to bring in directional solidification.

Height of the sprue in terms of diameter

\[
\frac{\pi}{4} \times d^2 \times h_1 = 2.73 \times 10^{-5}
\]

\[
h_1 = \frac{3.47 \times 10^{-5}}{d^2 \times 2}
\]

we have this 2 because we are about to have two risers.

Height of the sprue to compensate second stage shrinkage by considering volume of cone relations.

\[
\frac{1}{3} \times \frac{\pi}{4} \times d^2 \times h_2 = 4.6408 \times 10^{-6}
\]

\[
h_2 = \frac{1.7727 \times 10^{-5}}{d^2}
\]

Let the clearance height be 0.75 \( d \)

as we have assumed that the height of the sprue is 1.5 times its diameter

\[
\frac{3.47 \times 10^{-5}}{d^2 \times 2} + \frac{1.7727 \times 10^{-5}}{d^2} + 0.75 \ d = 1.5d
\]

Solving the above equation \( d = 0.036 \ m \approx 36 \text{mm} \)

Along with the riser and with the same flow rate, we have the pouring time as 5.2 s which is well within the limits, or else it would have been like, we have to design the gate again.

This is the general diagram of the casting with risers...
MATERIAL DENSITY ANALYSIS

It has been found that the shrinkages predicted by the material density function have been wiped off to the riser. This is a positive move. Now the casting is sound. The next diagram neatly visualises the piping in the riser.

CRITICAL FRACTION COOLING TIME

Now too we have isolated parts in the casting, but the shrinkages in the casting are considerably removed. In order to prevent this, again we have to go for bulky risers which decreases the yield. Because of this we may have hot spots too in the casting. In order to completely eliminate the defects we have to go for a separate design of gating system. This is because we have designed the ingate to freeze before the casting and so the riser cannot communicate with hot spot. This gate is sufficient enough to make a shrinkage free casting as we have some graphitization expansion.
HOT SPOT ANALYSIS

By having a look at the hot spots found here, they are distributed over the circumference. They can be removed only by adapting bulk risers which spoil the yield to a large extent. Let us go for a special design that increases the yield and which increases the productivity with absolutely no hot spots in the casting.

Unless otherwise these hot spots have to be completely removed, this is a descent gating system to produce a sound casting.

MILD CHANGES

The occurrence of the hot spot can be controlled in the casting by the addition of chills. Hot spots are reduced to a great extent. Of course the probability of hot spots occurring the surface to be machined is less.

We do have cost factor involved while using these chills and we do have some hot tear problems to deal with.
**YIELD Calculation**

Weight of the casting = 6.29 kg

Weight of the entire solidified part = 6.29 + 3.15

Yield = 66.6%

A better gating system can be produced too...

**GATING SYSTEM - HIGH YIELD VERSION**

As it had been concluded by the above gating trials that a rises is compulsory let us first design the riser and the tree behind that. In the next step let us design the down sprue and the initial gating for the predetermined tree.

This time we are concentrating more on the directional solidification as our aim is to get perfect directional solidification and perfectly hot spot free. We have traditionally gated through the stem whose modulus (when approximated as a cube 44.5x13.5x25.75) is 3.69 mm where as the modulus of the casting is 5.9 mm. Lets again use a chill to regulate the directional solidification.

Riser becomes compulsory at the ingate. Therefore if we group the castings near the ingate, a single riser can be used to ingate feed all of them. Let us design with three ingates grouped together. Also by keeping the riser at the ingate, we ensure that hot metal gets into the riser.

**NECESSITY FOR A CHILL**

- To maintain yield without going for a bigger riser.
- Even foolishly bulky feeders could not feed effectively. This statement is substantiated by the following figures. (hot spots are not of actual sizes, they are magnified). We can get somewhat better results with a chill.
**RISER DESIGN**

The design of riser is exactly same as we did in the previous section. we consider shrinkage in three sections, by similar empirical assumptions calculations are made. Here we have one riser feeding 3 castings.

in short,

Height of the sprue in terms of diameter for liquid state shrinkage

\[
\frac{\pi}{4} \times d^2 \times h1 = 2.73 \times 10^{-5} \times 3
\]

\[
h1 = \frac{3.47 \times 10^{-5}}{d^2} \times 3
\]

we have this 3 because we are about to feed 3 castings.

Height of the sprue to compensate second stage shrinkage by considering volume of cone relations.

\[
\frac{1}{3} \times \frac{\pi}{4} \times d^2 \times h2 = 4.6408 \times 10^{-6} \times 3
\]

\[
h2 = \frac{1.7727 \times 10^{-5}}{d^2} \times 3
\]

Let the clearance height be 0.75 d

as we have assumed that the height of the sprue is 1.5 times its diameter

\[
\frac{3.47 \times 10^{-5} \times 3}{d^2} + \frac{1.7727 \times 10^{-5} \times 3}{d^2} + 0.75 \times d = 1.5d
\]

Solving the above equation \( d = 0.0595 \, \text{m} \approx 60\,\text{mm} \)

This is analogous to a side gate. Let us have a hemispherical bottom to reduce surface area and hence to increase modulus.

**GATE DESIGN - AFTER RISER**

The only part of gate that is to be designed after the riser is the ingate. We have to be careful as this ingate part is also the neck of the riser and must have a modulus greater than that of the casting.

Let us assume a total ingate area of 600mm\(^2\)

We have 3 ingates.

Let us assume dimensions 10mm, 20mm, \(x\) mm
Assuming modulus of neck as that of the part it attaches with. (i.e., 3.69 = let us approximate it as 3 as we lose two surface areas one to the casting and the other to the riser.

\[
\frac{10 \times 20 \times X}{2(10 \times X \times 20 \times X)} = 3.333333
\]

3.333 is the maximum irrespective of x. This value is near 3.69 and hence can somewhat feed our casting. Though this is less than 3.69 the temperature and very high modulus of the riser will take care of the directional solidification.

Let's take as x as 20mm this is well below 25mm (half of diameter of riser - according to the conclusions of Heine). This is the proposed feeding system.

**MATERIAL DENSITY**

We do have some shrinkage at the stem near ingate. Let us increase the riser dimensions and decrease the ingate length to avoid this. Let us do the next trialing along with the entire gate.
HOT SPOT
Hot spots have been significantly reduced with the use of chills.

GATE DESIGN - SECOND PHASE
The length of the ingate must be reduced to get directional solidification towards the riser. But the length cannot be reduced more as we have dimensional constrains. Let's increase the diameter.

Now let us have a cylindrical riser with \( H = D \). Here \( D = 85 \text{mm} \)

Volume of the entire casting along with the riser is \( = 8.796 \times 10^{-4} \times 3 + 4.95 \times 10^{-4} = 3.1338 \times 10^{-3} \text{mm}^3 \)

Weight of our volume of interest is \( = 22.41 \text{kg} \)
\( = 49.39 \text{lb} \)

Section thickness is \( 6.79 \text{mm} \times 2 = 13.58 \text{mm} = 0.535'' \)

Optimal pouring time \( = \frac{33.3175}{40} \left( 0.95 + \frac{0.535}{0.853} \right) \sqrt{49.39} = 9.23\text{s} \)

Considering some safety factor let us take the optimum pouring time as 9s

Volume flow rate is \( = \frac{3.1338 \times 10^{-3}}{9} = 3.482 \times 10^{-4} \text{m}^3/\text{s} \)

Velocity at the ingate is \( \frac{3.482 \times 10^{-4}}{600 \times 10^{-6}} = 0.58 \text{ m/s} \)
This is within the critical limit.

As we have adapted the gating ration 1.5:2:1

TOTAL RUNNER AREA = 1200 mm²

SPRUE BOTTOM AREA = 900 mm²

Let us omit the runner as we directly feed into the riser. This increases the yield too. Let us try with the fountain gate gated at the bottom of the sprue.

**ADVANTAGES OF HORN GATE - FOUNTAIN GATE**

- It streamlined so that aspiration is reduced.
- Yield is increased as the well is omitted.
- This type of gating is extremely optimal to gate into risers as the fountain effect flushes in fresh molten metal which confirms hot metal supply to the riser.
- Mould erosion is also reduced as it points the top of the mould.

The only disadvantage is that air entraption take place in the initial stages of filling. As grey iron is not prone for slag and dross formation because of this, this king of gating system can be adapted.

**CALCULATION FOR HEIGHT OF SPRUE**

**LOSS BECAUSE OF THE HORN LENGHT**

length L = 284 mm

hydraulic diameter D = 34 mm

Surface roughness $\varepsilon = 2$mm (assumption)

velocity $v = \frac{\text{volume flow rate}}{\text{cross-sectional area}}$

$v = \frac{3.482 \times 10^{-4}}{900 \times 10^{-6}}$

$v = 0.3868$ m/s

From Haaland's equation to find Darcy's friction factor,

$$\frac{1}{\sqrt{f}} = -1.8 \log \left( \frac{6.9}{Re} + \left( \frac{\varepsilon/D}{3.78} \right)^{1.11} \right)$$

Reynold's number $Re = \frac{6803.045 \times 0.3868 \times 34 \times 10^{-3}}{0.006}$

$= 14911.368$

$f = 0.0789$
MINOR LOSS CALCULATION

We have a horn exit loss coefficient as 1

Ingate inlet has 0.5 and turbulent ingate exit has 1 as loss coefficients respectively. We have 3 ingates

Total \( k = 5.5 \)

Head loss = \( \frac{kv^2}{2g} \)

\[
= \frac{5.5 \times 0.58^2}{2 \times 9.81} = 94.3 \text{ mm} \quad (\text{The highest in the entire gating system i.e., at the ingate is taken here})
\]

MANIPULATION OF HEIGHT OF SPRUE

Total head loss = 94.3 + 5.025 \( \approx 100 \text{ mm} \)

Bernoulli’s formula is

\[
\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + \text{head loss}
\]

\( P_1 = P_2 \) (Assumption)

\[
V_1 = \frac{3.482 \times 10^{-4}}{900 \times 10^{-6}} = 0.3868
\]

\[
V_2 = \frac{3.482 \times 10^{-4}}{600 \times 10^{-6}} = 0.58
\]

now from Bernoulli’s equation,

Difference in height between levels 1 & 2 is

\[
z_1 - z_2 = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} + \text{head loss}
\]

\[
= (0.58^2 - 0.3868^2)/(2 \times 9.81) + 100 \times 10^{-3}
\]

\[
= 109.5 \text{ mm}
\]

Therefore height of the sprue \( \approx 110 \text{ mm} \)
The finalized gate is...

MATERIAL DENSITY ANALYSIS

The density problem at the stem is reduced to a great extent by this gating system.
HOT SPOTS
Hot spots also remain considerably reduced

CRITICAL FRACTION SOLID TIME
While analyzing the critical fraction time, isolated solidification areas are reduced to a great extent.
FCC CUSTOM CRITERION

This FCC Custom criterion also shows nil defects in the casting.

We have left off Niyama criterion as it is misleading in case of ferrous castings.

YIELD CALCULATION

Total volume of the present gating system along with the casting is \(3.449 \times 10^{-3} \text{ mm}^3\)

The yield with the present gating system is \(\frac{6.29 \times 10^{-3}}{24.66} = 76.52\%\)

ANALYSIS OF THE FINAL RESULTS

- We have a good yield.
- No shrinkages are predicted by FCC and material density analyses.
- We use bulky copper chills. These can be replaced by thick copper rings.
- We have reasonable directional solidification.
- The only problem that is not resolved is minute amount of hot spots at the extreme circumference of the pressure plate. As they don’t hinder machining or during service they can be generally left off.
- This yield can be further increased by having small risers with insulation sleeves or by using a different type of gating system.
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