# EXPERIMENTAL TECHNIQUE TOWARDS METHODING OF TURBINE BOWL CASTING

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**Abstract:** *The present work experimentally investigates Methoding of Turbine Bowl Casting based on the fact of utiliz-ing maximum feeding distance of riser in the sand mould for large size casting without defect in Bowl casting, to re-duced the weight of Bowl & improve the rpm & efficiency which is simulated using the solstar software. Casting is an ideal method for modelling. If the process of filling a mould with liquid metal and its subsequent solidification could be accurately and quickly modelled by computer, shrinkage cavities and other potential defects could be predicted. The effect of changing the gating system, the position and size of feeders and even the casting design could be simulated. The casting method could then be optimized before the design and method are finalized, so avoiding expensive and time consuming foundry trials.*

**KeyWords:** Feeding *Distance* (FD), Lateral Feeding Distance (LFD), End Zone Length (EZL), Riser Zone Length (RZL)

## 1. INTRODUCTION

Methoding of bowl casting need empirical rules as ex-plained in experimental procedure. This was subse-quently verified by simulation using AUTO-CAD and SOLSTAR software's.CFFP made 200 to 300 casting per annum. Bowl is a part of pulveriser made by plain car-bon steel and it is made first time in CFFP (36 nos. in the year 2008-2009). The castng of bowl has diameter 3035 mm. Thus it is large and heavy casting. So pattern of bowl is bulky. In methoding of bowl casting the problem comes in selection of the parting line so that moulding becomes easy, saves sand consumption and liquid metal requirement. The selection of number of risers for suc-cessful feeding was a critical problem.

During methoding, it was decided to provide self core after selecting parting line for ease of moulding.Then there was question of saving liquid metal. So threrfore it is decided to analyse the problem using solstar simulation software with exothermic/insulating risers *that* can give desirable result i.e. without shrinkage defect.

So the methoding of Turbine Bowl Casting was done in systematic steps. Entire precautions were taken to make the casting right first time as it was a new casting. All the steps like, collection of plate sections for modulus calculation, identification of hot spots, design and location of risers and riser's necks, feeding distance verification, deciding number of risers and locating the 40 chills have been found to be satisfactory in simulation process.

The thermal analysis and solidification simulation per-formed by the SOLSTAR software predicted no shrink-age or any other kind of defect.

At the end when the casting was actually made, no de-fects of any kind were found on the surface or inside the casting section at any location(figure 1.2).So the various calculations of the methoding used predictions of sound-ness of casting by simulation was fully validated by pro-duction of the sound casting right first time.

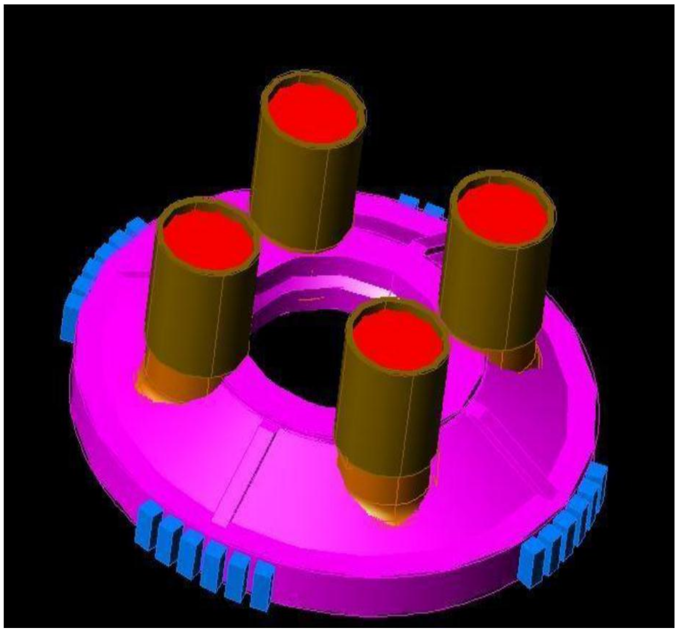


Figure-1.1. 3-D solid Model of bowl with chill, riser sleeves and neck

Figure-1.2 Casted view of Bowl

## 2. LITERATURE REVIEW:

### 2.1 'FEEDER', 'FEEDER HEAD' OR A 'RISER'

During the cooling and solidification of most metals and alloys, there is a reduction in the metal volume known as shrinkage. To avoid shrinkage porosity, it is necessary to ensure that there is a sufficient supply of additional molten metal, available as the casting is solidifying, to fill the cavities that would otherwise form. This is known as 'feeding the casting' and the reservoir that supplies the feed metal is known as a '**feeder', 'feeder head' or a 'riser'.**

Since liquid metal from the feeder cannot reach for an indefinite distance into the casting, it follows that one feeder may only be capable of feeding part of the whole casting. The feeding distance must therefore be calculated to determine the number of feeders required to feed any given casting.

The last region to solidify in such a casting section is termed a ***hot spot***. Once the hot spots in a casting are identified, a riser must be placed adjacent to each hot spot. This ensures that feed metal will be available to feed each hot spot until solidification is complete.

The riser also serves as a **heat reservoir**, creating a temperature gradient that induces **directional solidification.** Without directional solidification, liquid metal in the casting may be cut off from the riser, resulting in the development of internal porosity. Two criteria determine whether or not a riser is adequate: 1) the solidification time of the riser relative to that of the casting, and 2) the feeding distance of the riser.

The **feeding distance (FD)** is the maximum distance over which a riser can supply feed metal such that the casting section remains relatively free of internal porosity.

When multiple risers are present, the feeding between the risers is called lateral feeding, **the lateral feeding distance (LFD)**

There are two terms that are important to understand when considering feeding distances: riser zone and end zone. Since the riser remains hotter than the casting section to be fed, it provides a temperature gradient that facilitates feeding. The length over which this riser effect acts to prevent shrinkage porosity is called the riser zone length (RZL). This is illustrated for a top riser in Figure 6. The cooling effect of the mold at the end of a casting section also provides a temperature gradient along the length of the casting section to be fed. This is called the end effect, and it produces a sound casting over the so-called end zone length (EZL). This is depicted in Figure 7. The feeding distances are functions of RZL and EZL.

**2.2 Chills:**

Chill blocks are inserted into the mold to enhance the feeding distance by creating a steeper temperature gradient. The chill surface in contact with the casting must be clean and dry. Surface roughness has little effect on heat transfer characteristics. Chills can be used with a thin refractory coating or carbon black. Cast iron or steel chills, for all practical purposes, are equally effective. Water-cooled copper chills are more effective than uncooled cast iron or graphite. However, the effectiveness of these external chills is greatly reduced by the formation of a gap at the casting/chill interface as the casting shrinks away from the chill. Graphite chills may deteriorate with use. Chills are used at the end of casting sections ("end chills") and as "drag chills" between two risers.

**2.3 Gating System Design:**

The liquid metal that runs through various channels in the mould obeys the Bernoulli theorem states that the total energy constant at any section. The same stated in the equation from ignoring frictional losses is

$$H+P/W+V^2/2g = \text{constant}$$

Where:

H = potential head, m

P = pressure

V = liquid velocity, m/s

g = gravitational constant on earth, 9.8 $m/s^2$

Quantitavely Bernoulli's theorem may not be applied; it helps to understand quantitavely, the metal flow in the sand mould. As the metal enters in the pouring basin it has the highest potential energy with no kinetic or pressure energies. But as the metal moves through the gating system, a loss of energy occurs because of the friction between the molten metal and the mould walls. Also heat is continuously lost through the mould material through it is not represented in the Bernoulli's equation [29]. This lets the casting solidify.

Another law of fluid mechanics, which is useful in understanding the gating behaviour, is the law of continuity, which says the volume of metal flowing at any section in the mould is constant. The same in the equation form can be

$$Q = A1V1 = A2V2$$

Where,

Q = rate of flow, $m^3/s$

A = area of cross-section, $m^2$

V = velocity of metal flow, m/s

It was suggested earlier that the sprues are tapered to reduce the aspiration of air due to increases velocity as the metal enters or flows down the sprue. This conclusion was drawn by applying the above equation of continuity along with the Bernoulli's equation.

**Sprue:**

The Sprue should be tapered down to take into the account the gain in velocity of the metal as it flows down reducing the air aspiration. The exact tapering can be calculated by the equation of continuity. Denoting the top and chock section of the sprue by the subscript t and c respectively, we get

$$A1V1 = A2V2$$

**Gating Ratio:**

The gating ratio refers to the proportion of the cross sectional areas between the sprue, runner, and ingates and is generally denoted as sprue area: runner area: ingate area. Depending on the choke area there can be two types of gating system:

1. Non-pressurized
2. pressurized

**A Non-pressurized gating system** having choke at the bottom of the sprue base, having total runner area and ingates then the sprue area. In this system there is no pressure existing in the metal flow system and thus it helps reduce turbulence. This is particularly useful for the casting drossy alloys such as aluminum and magnesium alloys. There have tapered sprue, sprue base well and pouring basins. When the metal is to enter the mould cavity through multiple ingates, the cross-section of the runner should accordingly be reduced at each of a runner break up to allow for equal distribution of metal through all ingates.

**A pressurized gating system:**

Normally having the ingate area smaller, thus maintaining the back pressure throughout the gating system. Because of this back pressure in this gating system, there is more turbulence and generally flows full and there by can minimize the air aspiration even when a straight sprue is used (after the initial stages of pouring).These system s generally provide a higher casting yield since the volume of metal use up in the runners and ingates is reduced. Because of the turbulence and the associated dross formation, this type of gating is not used for light alloys but can be advantageously used for ferrous casting.

For steel a Non-pressurized gating system used

**Nozzle: sprue: Runner: Ingate**

1:1.4-1.7: 2.5-4: 4-7

## 3. Experimental Procedures

### 3.1 Problem Visualization

The work is based on the fact of utilizing maximum feeding distance of riser in the sand mould for large size casting without defect in Bowl casting, which is simulated using the solstar software.

**Table 3.1 Chemical analysis of bowl casting**

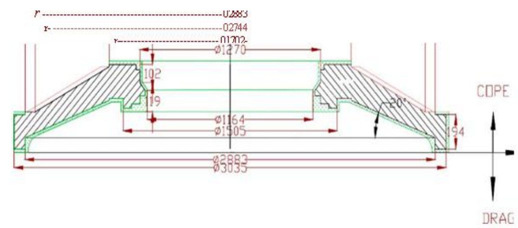
| *METAL GRADE* | *COMPOSITION SPECIFIED* | *C MAX* | *S MAX* | *P MAX* | *Si MAX* | *Mn MAX* | *Ni MAX* | *Cr MAX* | *Mo MAX* | *V MAX* | *Cu MAX* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *AA1 9511* | | *0.25* | *0.045* | *0.040* | *0.60* | *1.20* | *0.50* | *0.50* | *0.20* | *0.030* | *0.30* |

### 3.2_Methoding of "BowL" or Technology Preparation of "bowl"

1. Drawing no. - 0-61-104-00568/T
2. Material grade - plain carbon steel
3. As cast weight - 10000 kg

### 3.3 Steps for Technology Preparation-

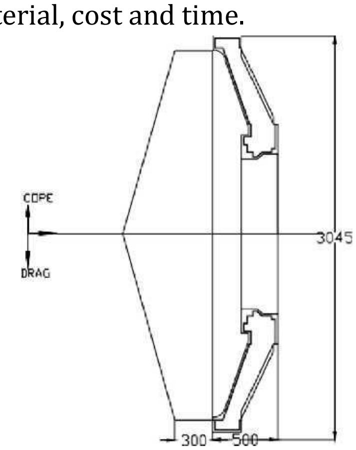
1. **Study of component drawing:**




See the different view of component, Machining allowances and tolerances are carefully observed. And take double allowances 15 to 20 mm as mention in the component drawing for machining.

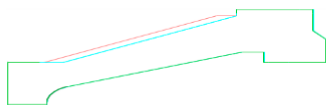
**Selection of parting line:**

Correct selection of parting plane is very important for saving of material, cost and time.




2. **Modulus calculation of piece:**

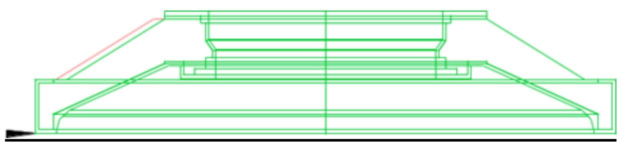
➢ Draw the 2-D drawing of component on Auto-Cad and calculate the area. A = 194024.75 $mm^2$ = 19.4 $dm^2$



**2-D drawing of component on Auto-Cad**

- Once area is calculated, then calculate volume.

V = 1251618545.8 mm$^3$ = 1251.6 dm$^3$



**3-D drawing of component on Auto-Cad**

- Calculate the hot spot thickness (maximum inscribed diameter)

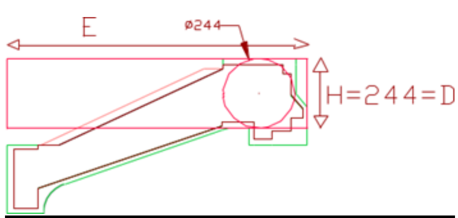



Figure shows location of hot-spot in the 2-D of bowl on Auto-Cad

We know H = 244 mm = D = 2.44 dm

Area=E/H

E=AREA/H

=19.4/H

=19.4/2.44

=7.95 dm

Modulus= Volume/Cooling Surface Are or Area/Peremeter

=19.4/2(7.95+2.44)

=0.92dm OR 9.2 cm

## 3. Feeding distance and extremity effect calculation:

Feeding distance or "feeding area" "Al"

Directional solidification occurs from the low temperature areas towards the high temperature areas around hot-top.

The parts of the piece located between hot-top, which will be free from shrinkage, are referred to as "feeding areas".

**Calculation of "feeding area":**

Al = n x H with n function of ŗ and H; ŗ = E/H

Note – numerator is always more than that of denominator.

ŗ = E/H=7.95/2.44=3.26

For ŗ = 3.26, value of n from graph 5 is 1.6.

Feeding distance (Al) = n x H = 1.6 x 2.44 = 3.904 dm

**Extremity effect or "extremity areas" "Ex"**

The free ends of the piece diffuse rapidly heat through the sand of the mould, thus generating a directional solidification process and the sound part is called "extremity area".

In case of Round type piece, there is no extremity effect.

"BOWL" is a round shape so extremity effect is zero.

## 4. Calculation of hot-top diameter:

**Modulus of hot-top (Mm) = 1.2 x Mp**

D hot-top (Ø) = Yx Mp

D hot-top (Ø) = 6 x Mp (for Ring type hot-top)

= 4.8 x Mp (for spot type hot-top)

We have taken spot hot-top –

D hot-top (Ø) = 4.8 x Mp

= 4.8 x 0.92

= 4.416 dm

## 5. Calculation of number of hot-tops:

**n**" is the number of hot-top required for a proper feeding of the piece.

Its value is dependent on:

A.The feeding distance

B.The extremity effect

C. The diameter of hot-top

After the feeding distance, the extremity effect, the approximate diameter of the hot-top, It is simple to determine the number of hot-tops to suit the part to be fed.

## 6. Neck calculation:

Diameter of the neck Dc = 4.2 to 4.4 Mp , Height of the neck Hc = 0.15 Dc with a minimum of 25 mm to allow flame cutting.

## 7. Padding calculation

## 8. Chills calculation

Let E be the casting thickness and e the thickness of the chill, the maximum effect of surface chill is

e = E/2 i.e equal to the casting modulus.

If the chills is placed on vertical side of the casting the module of the chill is equal to 0.7 times the module, e= 0.7 E.

In "BOWL", at outer surface E=116,

e = 0.7 x E = 0.7 x 116 = 81.2Ξ 100 mm

Use 6 chills together and distance between them is 56.

W = 1 x e = 100 mm

L = 2 x e = 2 x 100 = 200 mm

H = 1 x e = 100 mm

Six chills used at four places so total 24 chills used of 100 x 200 x100.

Second type of chills used at ribs of following dimensions.

E =0.7 x E

= 0.7 x 122

= 85.2 Ξ 100 mm

Use four chills together and distance between them is 50 mm.

W = 1 x e = 100 mm

L = 1 x e = 100 mm

H = 1 x e = 100 mm

Four chills used at four places so total sixteen chills of 100 x 100 x 100.

## 9. Gating system calculation

For steel a Non-pressurized gating system used

Nozzle: sprue: Runner: Ingate

1: 1.4-1.7: 2.5-4: 4-7

**Nozzle Size**

For 15 Ton nozzle of 80 x 2

**Sprue size calculation**

Nozzle: sprue = 1: 1.4

1.4 x area of nozzle = area of sprue

**1.4 x ($D^2$ nz /4) = ($D^2$ sp /4)**

$D^2$sp = 1.4 x $80^2$

Dsp = 94.6 Ξ 100 mm

**Runner size calculation**

Nozzle: runner = 1: 2.5

2.5 x area of nozzle = area of runner

**2.5 x ($D^2$ nz /4) = ($D^2$ runner /4) x 2**

(e take two side opening of runner)

Drunner = 89 Ξ 100 mm

**Ingate size calculation**

We require 8 nos. of ingate according to the BOWL shape.

Nozzle: ingate = 1: 4

1.4 x area of nozzle = area of ingate x ($D^2$ nz /4) = ($D^2$ ingate /4) x 8

$D_{ingate}$ Ξ 80 mm

**Exothermic/Insulating powder calculation**

Take 10-25% of riser height

Thus 10% of 550 = 55mm

**11 –As Cast Liquid Metal Requirement-**

Liquid metal required for casting before machining = total volume of casting x density of steel

Volume of the casting without ribs = 1251.6 $dm^3$

Component of "BOWL" have four ribs so,

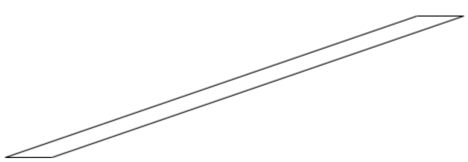


**Figure 39 A 2-D drawing of rib on Auto-Cad**

Area of one rib = 1.5 $dm^2$

Volume of one rib = 1.5 x 1.30 = 1.95 $dm^3$

Volume of four ribs = 1.95 x 4 = 7.8 $dm^3$

Total volume = 1251.6 + 7.8

= 1259.4 $dm^3$

Density of steel = 7.8 kg/$dm^3$ or 7.8 g/cc or 7800 kg/$m^3$

Liquid metal required for casting before machining =

1259.4 x 7800 = 9823.4 Kgs

Approximately 10 TONNE

Figure 3.1 of Pattern of Bowl

Figure 3.2 Self core-1 of Bowl

Figure 3.3 core-2 of Bowl

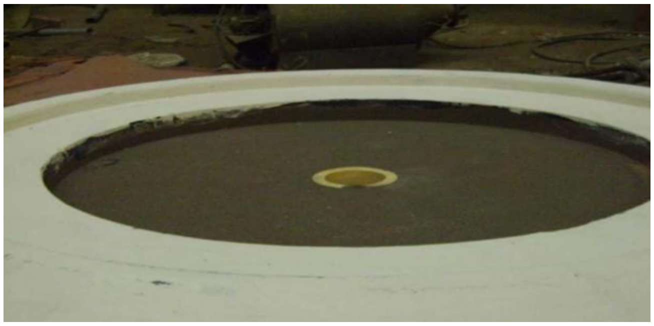


Figure 3.4 core print of core no.-2 of Bowl

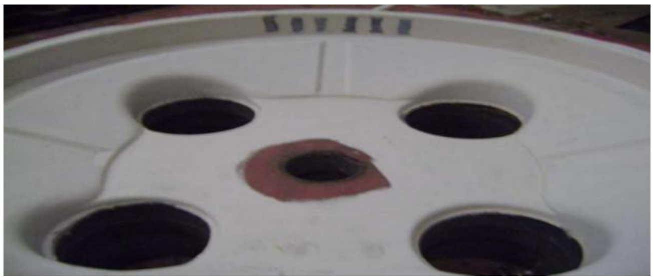


Figure 3.5 Mould cavitiy of of Bowl including 4 risers

Figure 3.6 Core Setting of core no.2

Figure 3.7 mould closing of Bowl

Figure 3.8 ready for Pouring Bowl

## Result & Discussion, Observations

Casting process is an ideal technique for modelling. If the process of filling a mould with liquid metal and its subsequent solidification could be accurately and quickly modelled by computer, shrinkage cavities and other potential defects could be predicted. The effect of changing the gating system, the position and size of feeders and even the casting design could be simulated. Casting method could then be optimised before the design and method are finalised, so avoiding expensive and time consuming foundry trials.

Due to numerous availability of commercial software packages process improving all the time. The modelling of heat flow and solidification of castings is now well advanced. Modelling the filling of castings is more difficult since both turbulent and quiescent flow in complex shaped cavities may be involved. The effects of surface oxide films and bubble entrainment are further complications and it is not easy to check the predictions experimentally in complex moulds.

## 4.1 Solidification modeling

Purpose of solidification modeling

1. Predict the pattern of solidification, indicating where shrinkage cavities and associated defects may arise.
2. Simulate solidification with the casting in various positions, so that the optimum position may be selected.
3. Calculate the volumes and weights of all the different materials in the solid model. Provide a

choice of quality levels, allowing for example the highlighting or ignoring of micro-porosity.

## 4.2 Mould filling simulation

MAGMA soft have developed such programs which allow the visualization and animation of the movement of the melt surface during filling.

## 4.3 The Solstar solidification program

(1) Using the casting drawing, determine model scale and element size.

(2) Create the solid model of the casting.

(3) Create the solid model of the proposed production method (feeders, chills, insulators etc.). Use the program's own feeder-size calculator if required.

(4) Perform thermal analysis to establish the order of solidification.

(5) Perform solidification simulation to a set quality standard, for the selected alloy incorporating shrinkage percentage, in gate effects etc. This results in the model being changed to the predicted final shape (internal and external) of the casting showing size, shape and location of shrinkage cavities in casting and feeders.

(6) Investigate with the help non-destructive testing assumed shrinkage by viewing and plotting of 3D 'X-rays' and sections of the model in 2D slices or 3D sections and relating predicted defects to solidification contours and required quality standards.

(7) If assumed defects do not meet the required quality standard, develop an improved production method and repeat the procedures.

## 4.4 Solid modeling

Create a three-dimensional model of the component with its associated method. This will often take the greatest proportion of time, as much as 70%. The SOLSTAR program has its own solid modeller/mesh generator capable of modelling the most complex casting shapes. Depending on the computer hardware specification, models can contain up to 256 million elements but most models use between 2 and 64 million elements. Figure 1.1 shows a solid model of a 466 kg steel Bowl casting containing 40 million elements produced in less than 3 hours.

It is possible to transfer 3D models from any other CAD system using Stereolithography STL files created by them. These models can then be manipulated within the solidification software so that the method can be added.

## 4.5 Thermal analysis

Calculates the simulated heat flow between the elements of the solid model which gives a 'thermal picture' of the conditions prevailing at a specific point in time. SOLSTAR's thermal analysis simulates 'heat flow' in 26 directions, with each cuboid element of metal, mould, chill etc. being the equivalent of the centre block of a 'Rubik' cube (27 cubes).

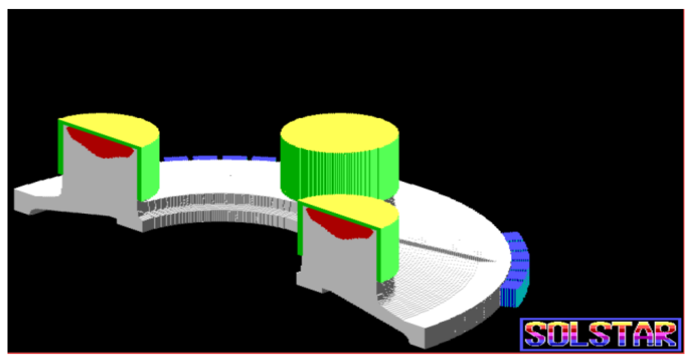



Figure 4.1 Solidification of contour for half section of Bowl casting in Solstar

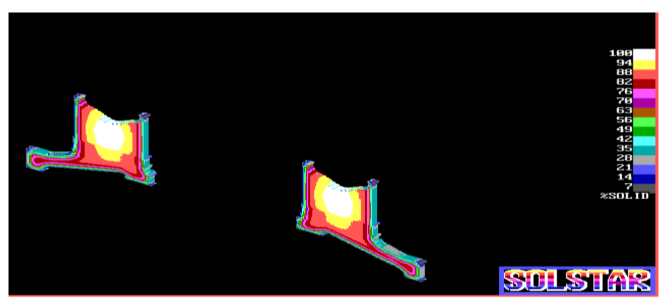



Figure 4.2 Thermal analysis section of Bowl casting in Solstar

## 4.6 Solidification simulation

Allocated an order of solidification. SOLSTAR then carries out a solidification simulation of the metal elements, by solidifying.

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(1) The solidified elements are assumed to have increased in density, accompanied by a loss of volume.

(2) This loss (liquid shrinkage) is calculated by multiplying the number of solidifying elements by the input shrinkage factor for the alloy.

(3) The software calculates (according to the alloy and the required quality standard) whether this shrinkage will manifest itself in the form of a cavity and, if so, how big the cavity will be.

(4) The resultant cavity is placed in the remaining liquid of the section of which it is a part. Where it resides in this remaining liquid depends on the type of alloy.

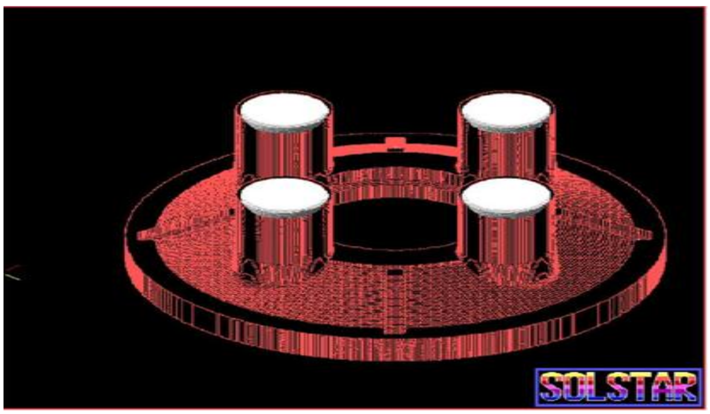


Figure 4.3 X-Ray plot of Bowl Casting

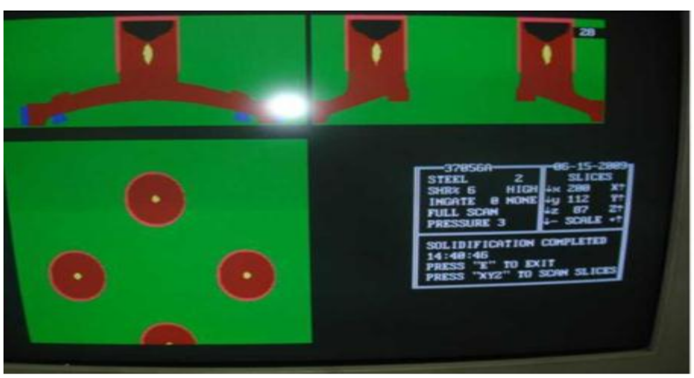


Figure 4.4 Solidification of different section of Bowl casting in Solstar

## 4.7 Feeder size and weight calculations

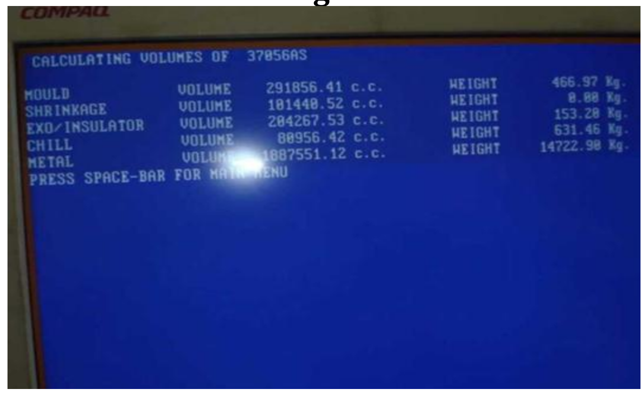


Figure 4.5 Calculations of Volumes of Bowl Casting

## 4.8 Cost benefits of solidification simulation

Table Shows a simplified trialling process for making a cast component, the cycle may need repeating several times before product of acceptable quality is made. Solidification simulation software such as SOLSTAR can be used to electronically sample the method and cut down on the

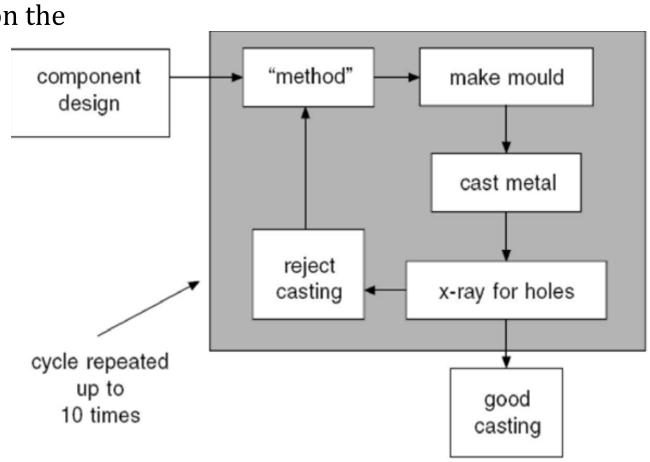


Figure **4.6** Trialling process for making a cast component of acceptableable quality

**Table-4.1**. Pre & post Solstar methoding accuracy in Steel Foundry.

| Trial methods | Before SOLSTAR | Using SOLSTAR |
|---|---|---|
| Right first time | 50% | 99% |
| Two attempts | 85% | 100% |
| Three attempts | 98% | 100% |

Table-4.2. Probability of right first time reported by Sol-star user

| | |
|---|---|
| Steel | 99% |
| Iron | 90-99% |
| Non-Ferrous<br>(short freezing range alloys) | 99% |
| Non-Ferrous<br>(long freezing range alloys) | 85-95% |

## 5. Conclusions

Based on the present work following conclusions have been drawn:

1. Riser and gating system were designed applying empirical rules and technological prudence. From the simulation of solidification it was found that the design of risers and gating system are working well. The actual manufacturing of the bowl casting was found to be successful and no defects were found in the casting.

2. The design of the riser and gating system found alright on verification by simulation saved valuable time and any trial production.

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