International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 06 | June 2019 www.irjet.net p-ISSN: 2395-0072

Optimal Riser Design for Sand Casting of Drop Ball using Constraint Optimization Technique

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Abstract - *Riser design plays a vital role during the casting of component taken for casting in this research is a drop ball of mass 11370 kg and this drop ball is made up of steel. Increasing the casting yield by optimizing the volume of riser for the casting of drop ball such that the shrinkage defects and hot spots are eliminated is the main objective of this research.*

Mathematical formulation of the riser considering neck and insulating sleeve is made and has been coded in MATLAB using constrained optimization technique from which optimum dimension of riser is to be obtained and had been compared with the manufacturing of drop ball in industry and it has been found that 16.6% reduction in the volume of riser is obtained which in turns increasing casting yield. The result obtained via constrained optimization technique is also been found by modulus method without neck..

Key Words: Casting yield, drop ball, riser, constrained optimization,

1. INTRODUCTION

Casting is one of the earliest metal-shaping methods known to human beings. It generally means, pouring molten metal into a mould with a cavity of the shape to be made, and allowing it to solidify. When solidified, the desired metal object is taken out from the mould either by breaking the mould or taking the mould apart. The solidified object is called casting. This process is also called casting process or foundry.

Based on the literature survey, one of the researches works from university of roorkee by j.l gaindhar where mathematical formulation for different shapes and conditions like modulus extension factor, neck, different shapes of neck etc. Were made for the riser. One of such mathematical formulation for cylindrical riser of insulating material with cylindrical neck is taken in this research work and this is made for the casting of drop ball. A drop ball is used in Grinding Ring latter is used for crushing of coal.

1.1 Material of drop ball

The material for drop ball is steel which undergoes 6% of volumetric shrinkages upon solidification, its specifications as per industry are:-

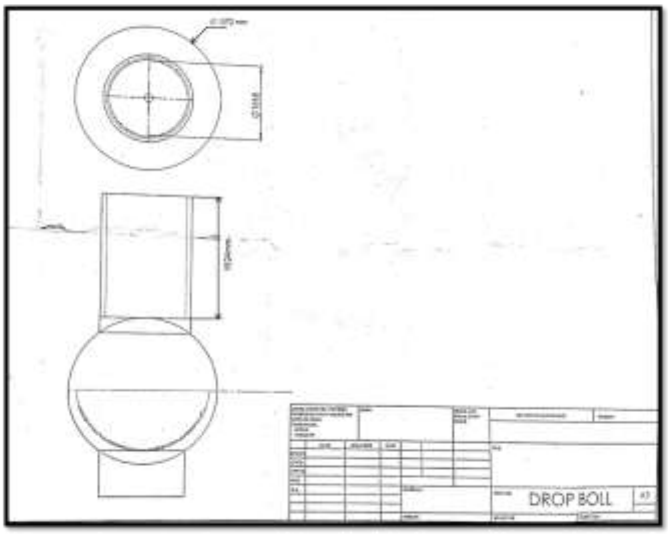


Fig.-1: Drawing of drop ball

1.2 CHEMICAL COMPOSITION

Table-1: Chemical composition

Elements	C	Mn	C	S	P	Cu
%	0.24	1.10	0.45	0.015	0.02	0.40
Elements	Ni	Cr	Mo	V	Al	Fe
%	0.35	0.15	0.05	0.05	0.04	Bal.
The total of these specified residual elements (Cu+Ni+Cr+Mo+V)= 1% Maximum.						

2. MATHEMATICAL FORMULATION

2.1 NECESSARY CONDITION FOR RISER DESIGN

1. The metal in the riser should solidify at the end i.e. the solidification time of the riser must be greater than the solidification time of casting.
2. The riser volume should be sufficient for compensating the shrinkage in the casting hence the volume of the riser must be greater than the shrinkage volume of casting.

Riser is mainly used in the casting process in order to compensate the liquid shrinkage taking place in the casting; it acts as a reservoir of molten metal provided in the casting so that hot metal can flow back in the casting cavity when there is a reduction in volume of metal due to solidification.

In this research work a cylindrical top riser with circular cross section of neck surrounded by insulating sleeve is used or we can say a cylindrical neck with insulating sleeve is used.

2.1.1 Fr.om the 1st necessary conditions for the design of riser

$$Tr > Tc$$

$$Br\left(\frac{Vr}{(S.A)r}\right)^2 > Bc\left(\frac{Vc}{(S.A)c-(S.A)j}\right)^2 \quad \ldots\ldots\ldots\ldots (2.1)$$

Let

$$E = \left(\frac{Bc}{Br}\right)^{\frac{1}{2}} * \left(\frac{Vc}{(S.A)c}\right)$$

Since (Bc=Br), Because solidification constant is same for both riser and casting.

(S.A)j=0, As surface area of junction is considered in surface area of casting itself.

As we have taken insulating sleeve the equation becomes

$$E = \left(\frac{Vc}{(S.A)c}\right) * \frac{1}{f}$$

So,

$$\left(\frac{Vr}{(S.A)r}\right) > E \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

Substituting the values of Vr, SAr and E in equation 1 we get,

$$\left[\frac{4E}{Dr} + \frac{E}{Hr}(2+4\beta\gamma-\beta^2) - \beta^2\gamma * \frac{\mathrm{Dr}}{\mathrm{Hr}}\right] < 1 \quad \ldots\ldots\ldots (2.3)$$

Where:

Vc = Volume of casting, (S.A)c = Surface area of casting

Vr = volume of riser, (S.A)r = surface area of riser

(S.A)j = surface area of junction, Bc= solidification constant of casting, Br=solidification constant of riser, Dr= dia of riser Hr= height of riser, Dn= Dia of neck, Hn= Height of neck

$$\beta = \frac{Dn}{Dr}, \quad \gamma = \frac{Hn}{Dr}$$

E, γ, β are the constants taken for ease of calculation.

f is a modulus extension factor, taking as an insulating riser. The value of *f* is 1.3 for longer insulating sleeves. As stated above E=Vc/((S.A)c **f)*

E=1.35/(5.914*1.3) =0.175 m.

2.1.2 From the 2nd necessary conditions of the design of riser

Vr > Vs

Vs=0.06*1.35 =0.081 m^3.

Hence our objective function becomes

Minimize $\mathrm{Vr} = \frac{\pi}{4} * \mathrm{Dr}^2 * Hr + \frac{\pi}{4}\beta^2\gamma * \mathrm{Dr}^3$

S.T.

$$\left[\frac{4E}{Dr} + \frac{E}{Hr}(2+4\beta\gamma-\beta^2) - \beta^2\gamma * \frac{\mathrm{Dr}}{\mathrm{Hr}}\right] < 1$$

Vr > Vs

2.1.3 MULTIVARIABLE CONSTRAINT OPTIMIZATION

The objective function and constraints functions can be formulated as written below:

Min: f(p1,p2,p3....pn)

Subject to: [g(p1,p2,p3....pn)] ≥ 0

It is required to choose the different values of p1,p2,p3....pn to minimize the objective function (f)

The function (x1,x2,x3,x4), represents a constraint

Step 1: setup the problem

The setup for this problem is written as,

l(p1,p2,p3....pn,λ) =f(p1,p2,p3....pn)−λg(p1,p2,p3....pn)

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 06 | June 2019 www.irjet.net p-ISSN: 2395-0072

Step 2: For optimal condition, take the partial derivative of (l)with respect to each variable and set it equal to zero

$$\frac{\partial l}{\partial p1} = \frac{\partial f}{\partial p1} - \lambda \frac{\partial g}{\partial p1} = 0$$

$$\frac{\partial l}{\partial p2} = \frac{\partial f}{\partial p2} - \lambda \frac{\partial g}{\partial p2} = 0$$

$$\frac{\partial l}{\partial pn} = \frac{\partial f}{\partial pn} - \lambda \frac{\partial g}{\partial pn} = 0$$

Step 3: Solve above system of equations using any multivariable system of equation solver

In this method, initially the initial conditions are guessed (x0, as mentioned in (MATLAB code) and find the objective function's value.

Go for next iteration and find the solution, again find the corresponding objective function's value till the error between two consecutive function's value reaches to ϵ= 10−6 ($Defined\ by\ user$).

However, MATLAB uses any best method to solve the system of non-linear equation. These methods are already inbuilt in MATLAB '*fmincon*' code.

By using this optimization technique we get:

(Vr) = 1.03 m^3

Dr = 1.05 m

Hr = 1.05 m

Gamma (γ) = 0.5

Beta (β)= 0.5

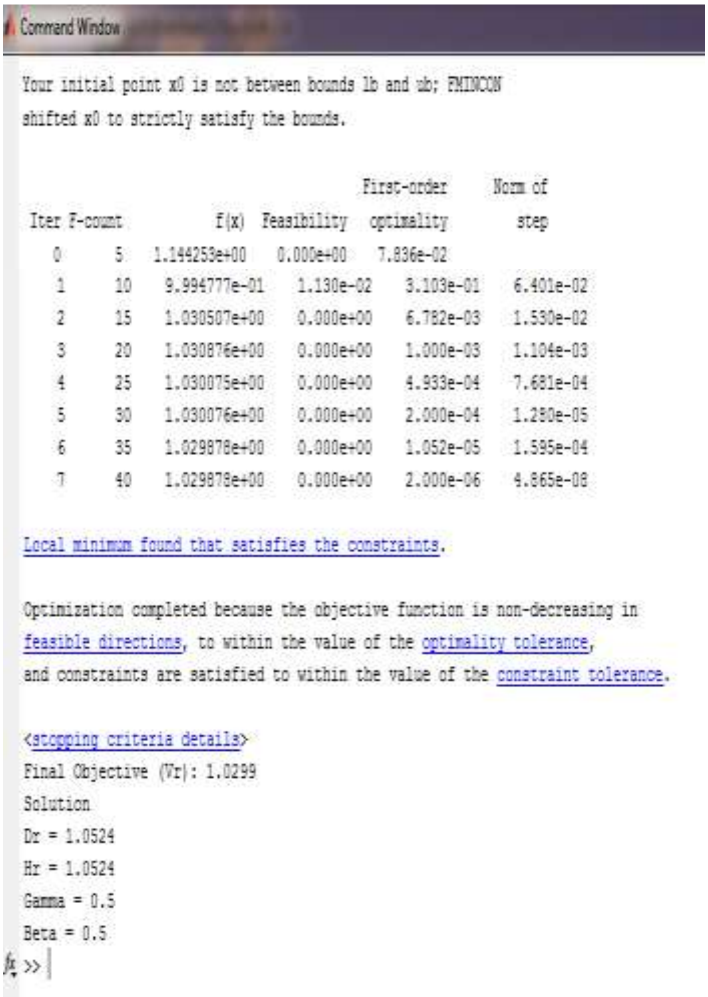
3. RESULTS AND DISCUSSIONS

The values obtained from the Constrained optimization technique are:-

Vr = 1.03 m^3, Dr = 1.05 m

Hr = 1.05 m, γ = 0.5

β = 0.5



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Command Window

Your initial point x0 is not between bounds lb and ub; FMINCON
shifted x0 to strictly satisfy the bounds.

                                        First-order      Norm of
 Iter F-count            f(x)  Feasibility   optimality         step
    0       5    1.144253e+00    0.000e+00    7.836e-02
    1      10    9.994777e-01    1.130e-02    3.103e-01    6.401e-02
    2      15    1.030507e+00    0.000e+00    6.782e-03    1.530e-02
    3      20    1.030876e+00    0.000e+00    1.000e-03    1.104e-03
    4      25    1.030075e+00    0.000e+00    4.933e-04    7.681e-04
    5      30    1.030076e+00    0.000e+00    2.000e-04    1.280e-05
    6      35    1.029878e+00    0.000e+00    1.052e-05    1.595e-04
    7      40    1.029878e+00    0.000e+00    2.000e-06    4.865e-08

Local minimum found that satisfies the constraints.

Optimization completed because the objective function is non-decreasing in
feasible directions, to within the value of the optimality tolerance,
and constraints are satisfied to within the value of the constraint tolerance.

<stopping criteria details>
Final Objective (Vr): 1.0299
Solution
Dr = 1.0524
Hr = 1.0524
Gamma = 0.5
Beta = 0.5
>>
```

Fig.-2: MATLAB Result

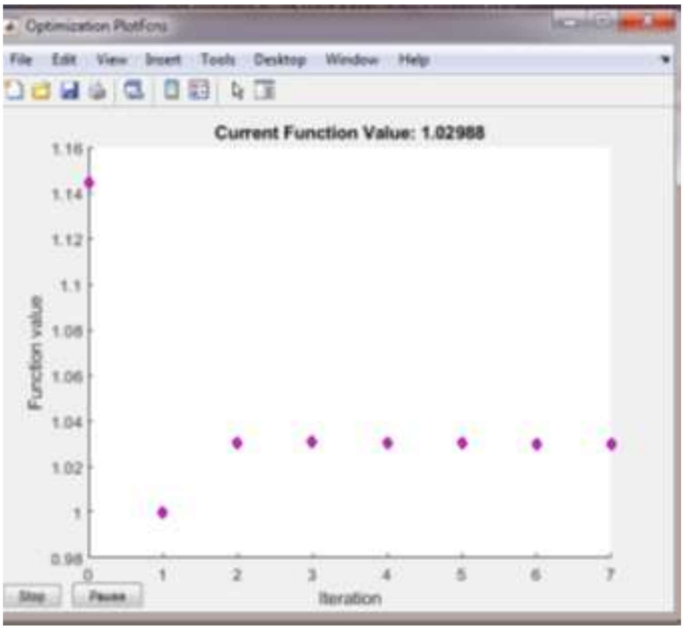

Fig.-3: Graph between No. of itration and Vr.

The riser used in industries was of dimension:

Dr = 40 Inch, Hr = 60 inch.

Dr = 1.016m, Hr = 1.524m

Vr = 1.236 m^3

Which gives a total volume of RISER of simplex industries as = 1.236 m^3

Total volume of Riser obtained in this project is = 1.0299 m^3

Which gives us a % reduction of volume = 16.67%

On comparing the volume of riser obtained by the industry with the constrained optimization technique used in this project we found that 16.67% reduction in the volume of riser was obtained thereby increasing casting yield, which was the objective of this project work.

3.1 RISER DESIGN BY MODULUS METHOD

$$Mr = \frac{1.2}{f} * Mc \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

$$Mr = Vr / (S.A)r \quad \ldots\ldots\ldots\ldots\ldots (3.2)$$

$$Mc = \frac{Vc}{(S.A)c}$$

$$Mc = \frac{Dc}{6} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.3)}$$

Where Diameter of the sphere Dc =1.372 m

For riser design the relationship between Dr and Hr must be known, for that surface area of riser must be minimized for the given volume of riser.

$$Vr = \frac{\pi}{4} * Dr^2 * Hr \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

$$(S.A)r = \pi * Dr * Hr + \frac{\pi}{4} * Dr^2 \quad \ldots\ldots (3.5)$$

For minimizing (S.A)r, differentiating w.r.t diameter of riser, we get

Dr =2*Hr. ………………….(3.6)

Substituting the value of (3.2), (3.3), (3.4), (3.5), (3.6) in (3.1) we get:-

Dr = 1.266m

Hr = 0.633 m

Vr = 0.8 m^3

On comparing the volume of riser obtained by the conventional modulus method with the constrained optimization technique used in this project, we found that the size of riser by modulus method is less than that of constrained optimization technique but since the modulus method did not take neck into account which is the important part of casting, the riser volume will definitely increase when taken neck into account. As the expression of volume of riser comprising neck involves four unknowns which are not possible to solve by modulus method.

4. CONCLUSION

The volume of riser obtained by constrained optimization technique was found to be 1.0299 m^3 and when compared with the volume of riser obtained by industry, 16.67 % reduction in the volume of riser was found. The volume of riser obtained by constrained optimization technique was also justified by the modulus method of riser design. With the use of chills and padding the optimum dimensions can also be calculated.

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