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DESIGN PARAMETERS FOR THE BOTTOM PLATE OF A 300KG CAPACITY CUPOLA FURNACE.

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ABSTRACT

The modification of microstructures to achieve desired properties is a fundamental approach in metallic materials development. Heat-treatment which is one of the primary routes of developing microstructures requires the use of well designed furnaces to be able to attain desired temperatures and a good designed furnace such as cupola must have bottom plate strong enough to withstand the heavy mass. Heat-treatment furnaces with effective temperature sensing, heat retaining capacity and controlled environment are necessary for heat-treatment operations to be successfully performed. Some of the parts of furnace considered during design is the bottom plate. This paper have discussed the design parameters for a furnace bottom plate. The plate was used when operating a design and fabricated cupola furnace, tested and the result shows that the design analysis can be adopted.

Keywords: Furnace, Bottom Plate, Rigidity, Cupola
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INTRODUCTION

Metal casting remains all basically essential industry, as necessary to space vehicles as it was to mankind's very first machines. As science is applied more and more, so the skill, education and pay of foundry men goes up and ever up, increasing in turn the total wealth of the world. There is no better example of true creation of national wealth than the work of foundry man. He takes a raw material and through both art and science, creates a product that add direct value to our society's ever progressing way of life(Nwaogu, C.O. Foundry (1994). All these contributions of foundry work towards better way of life, cannot be achieved without the most important or the backbone of the foundry itself, this is nothing but a foundry furnace, which takes in a solid raw materials and transformed it into a molten iron of desired pouring temperature through the application of heat generated by the healing elements or fossil fuel. Known as the original recycler, the foundry industry through proper utilization of heat generated inside the foundry furnace, gives a new useful life to as many as 15 million tons of scrap metal each year that would otherwise be rendered useless.

The cupola is a cylindrical shaft furnace working in the principle of counter flow. From the top, through the opening for charging, the charging materials are fed – metal charge, fuel (coke) and flux(lime stone). From below, through the tuyeres, the air necessary for burning the fuel is blown. From the heat generated during burning, the charging materials melt. This melting is done at some distance from the tuyere called melting zone. Under (below) it the coke bed is situated. During the process of melting, the height of the coke bed is constant (fixed), the quantity of the coke which burns from the coke bed is replaced from new in-coming portions of coke. .(P.O; Daniel,(2001).

Depending on their design, cupola is divided into two types: usual and special cupola. The usual cupolas are with one or several tuyeres. They work with cold air at normal oxygen content and have no water cooling. The rest of the designs are classified as special cupolas. Both usual and special cupolas are divided into cupola with reservoir and cupolas without reserviour. The condition of work of a cupola will determine whether it will be with or without reservoir. In foundry, producing small casting cupola without reserviour can be used. Cupola with static (immovable) and movable (tilting) a lot or batch production mainly in casting of a lot or batch production mainly in casting of medium and large castings.

METODOLOGY

The design of the bottom plate of the cupola furnace depends entirely on the total mass acting down and the stress initiated by this mass.

Let now calculate the total mass acting on the cupola. The total mass includes the mass of the steel casing, mass of the refractory lining and the masses of the flanges and wind jacket.

2.1 Mass of the Steel Shell

The mass of the steel shell determined as:

- Material of the shell is mild steel
- Density of mild steel 7800 Kg/m^2

- Outer diameter of the shell D = 410mm
- Inner diameter of the shell d = 400mm
- Thickness of the shell t = 5mm

Mass = Density x Volume 2.6

Volume = Area x height

The area of the shell is calculated as:

$$Area = \frac{\pi(D^2 - d^2)}{4}$$

$$= \frac{\pi(0.412 \times 0.4^2)}{4} = 0.00636m^2$$

Total of the shell h = 200mm = 2m

∴ Volume = Area x height

= 0.00636 x 2 = 0.0127m^3

From eqn. 2.6

Mass of the shell = 0.0127 x 7800

= 99.2429Kg

2.2 Mass of the Refractories Materials

Thickness of the refractories = 750 mm

Inner diameter of the furnace = 250mm

Outer diameter of the refractories = 400mm

Height of refractories = 2m

Area of the refractories

$$= \frac{\pi(0.4^2 - 0.25^2)}{4}$$

= 0.0765m^2

Volume = 0.0765 x 2 = 0.1532m^3

Out of the above volume of refractory lining alumina refractory occupied 35% of the total volume while the fire clay occupies 65%.

∴ For alumina

$$\text{Volume occupied} = \frac{35}{100} \times 0.1532$$

$$0.0536m^3$$

Mass of alumina = 0.0536 x 8500

= 455.55kg

1. Mass of the fire clay:

From the total volume occupied by the refractory lining, fire clay occupies 65%.

Volume occupied by the fire clay

$$V = \frac{65}{100} \times \text{total volume of the refractory}$$

$$= 0.65 \times 0.1532$$

$$0.09958\text{m}^2$$

Mass of fire clay = density x volume

Density of fire clay = 2,640 Kg/m^3

Mass = 2640 x 0.09958

= 262.8912Kg

- Assume masses of flanges and the mass of the bolts and nuts, be 30Kg.

2.3 Total Mass of the furnace acting on the bottom plate

The total mass of the furnace on the bottom plate of 250mm central hole is obtained by adding the above calculated mass:

Total Mass = Mass of the shell + Mass of the refractory lining + Mass of flanges

Total mass = 99.2429 + 455.77 + 262.8912 + 30

= 849.9041

≏ 850Kg

2.4 Total weight acting on the Bottom Plate

$W_{total} = M_{total}$ x 9.81

= 850 x 9.81

= 8317.9392N

= 8.3179KN

≏ 8.3KN

2.5 Determination of normal stress acting on the bottom plate

The normal stress acting on the bottom plate 13

$$\sigma = \frac{F}{A} \text{..............................} eqn2.3$$

Where, F = Total force acting = W

A = Cross sectional area of the plate

$$A = \frac{\pi(D^2 - d^2)}{4} = \frac{\pi(0.4^2 - 0.25^2)}{4}$$

$$= 0.0766m^2$$

$$\sigma = \frac{8.3 \times 10^3}{0.0766} = 108355.0914N/m^2$$

2.6 Determination of the thermal stress developed in the bottom plate:

Changes in temperatures causes thermal effects on materials. Some of these thermal effects include thermal stress, strain, and deformation. If this change in temperature makes a body to expands freely with rises in temperature, then there is no stress induced in the body. But if deformation is prevented as in case of the bottom plate of the furnace because, the bottom plate is bolted to the stands, then some stress will be induced in it and these stresses are called thermal stresses.

The Thermal stress is related with change in temperature in the equation below.

$$\sigma_t = \alpha \Delta T E .... eqn 2.4$$

Where,

σ_t = Thermal stress

ΔT = change in temperature

α = Linear coefficient of expansion of the material

E = young modulus of the material.

Now, to calculate the thermal stress induced in the bottom plate eqn 2.4 now applied

Let T_2 = The maximum temperature attained by the bottom plate

T_1 = initial room temperature of the bottom plate

$E = 200 \times 10^9 N/m^2$

α for mild stress = $12 \times 10^{-6}/^0C$

$T_1 = 27^0C$

T_2 = 96.7^{0}C (combustion analysis)

$\therefore \sigma_t$ = 12 x 10^{-6} x (96.7 – 27) x 200 x 10^9

= 167280000 N/M^2

= 167.28MN/M^2

Based on the above calculated normal and thermal stresses, it is clear that the thermal stress developed in the bottom plate is more than that of the normal stress, therefore, the thermal stress is considered in designing the bottom plate as the maximum stress.

2.5 Determination of the thickness of the bottom plate

In order to determine the thickness of the steel plate that can withstand maximum stress developed, the equation below in now applied for a plate with a central hole.

$$\sigma \max = K_1 \frac{Pa^2}{h^2} .... .eqn.2.5$$

(ref…..)

Where,

σMax = Maximum stress

P = Normal stress

a = Outer diameter of the furnace

h = thickness of the stress

k = constant coefficient

K is determined from the table depending on the type of loading on the plate and the ratio $\frac{a}{r_o}$

Where r_o is the central hole radius.

∴ in this case, the furnace

$$\frac{a}{r_o} = \frac{0.4}{0.25} = 1.6$$

From the table the close value of K corresponding to 1.6 is 0.480

∴ Max = 167.28MN/m^2

P = 108.3551 KN/m^2

h = ?

K = 0.480

From eqn. 2.5

$$h = \sqrt{\frac{KPa^2}{\sigma \max}}$$

$$= \left(\frac{0.480 \times 108.3551 \times 10^3 \times 0.4^2}{167.28 \times 10^6} \right)^{1/2}$$

$$= \left(\frac{8321.6717}{167.28 \times 10^6} \right)^{1/2}$$

$$= 0.0071m$$
$$= 7.1mm$$

7.1mm is the calculated thickness of mild steel that can withstand the maximum stress developed in the steel. Therefore, 10mm thickness, is quite satisfactory and is used and as the thickness of the bottom plate.

2.6 Design of the Central Bottom Plate

Central bottom plate is a circular plate which is hinged at to the bottom plate to cover the opening of the central hole i.e. the opening of the inside diameter of the cupola. The diameter of the central bottom plate is designed a little bit more than the diameter of the central hole so that, it sits properly and hinged at one end and provides with a lock at the other end. The central bottom plate is responsible for carrying and supporting the weight of the charges and the rammed sand. It is designed with a small openings of 3mm diameter to provide exit of the gases from the molten iron.

The design parameters for determining the thickness of the central bottom plate is as follows:

Maximum calculated stress = The thermal stress

As calculated is eqn. 2.4 above

$\sigma max = \sigma_t = 167.28MN/M^2$

Normal stress = P

As calculated in eqn. 2.3

$\sigma = P = 108.3551 \times 10^3 N/M^2$

since the maximum stress is thermal stress, the flexure formula is now applied to calculate the required thickness.

$$\sigma \max = \frac{3}{4} P \frac{a^2}{b^2} \text{.......... ....} eqn2.6$$

(ref……..)

Where

σmax = Maximum stress i.e. the thermal stress

P = Normal stress

a = circular hole diameter

b = The thickness of the plate

∴ from 2.6

$$167.28 \times 10^6 = \frac{3}{4} \times 108.3551 \times 10^3 \times \frac{(0.25)^2}{b^2}$$

$$b^2 = \frac{5079.1453}{167.28 \times 10^6}$$

$$b^2 = 3.0363 \times 10^{-5}$$

$$b = \sqrt{3.0363 \times 10^{-5}}$$

$$b = 5.5103 \times 10^{-3} M$$

$$= 5.5103 mm$$

From the above calculated values the required thickness of the mild steel plate that can withstand the stresses is 5.5mm, to take care of the weaknesses as a result of small openings on the bottom plates, a 10mm thick mild steel plate is used as the central bottom plate.

CONCLUSION

The design of the bottom plate of the cupola furnace depends entirely on the total mass acting down and the stress initiated by this mass. The total mass includes the mass of the steel casing, mass of the refractory lining and the masses of the flanges and wind jacket, all these were calculated in the analysis. This paper have discussed the design parameters for a furnace bottom plate. The design was applied in the fabrication of furnace parts and used when operating a design and fabricated cupola furnace, It was tested and the results shows that the design analysis can be adopted.

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