Development Of An Innovative Multi-Operational Furnace

Subhash Waghmare, Sagar Shelare, Piyush Sirsat, Nilesh Pathare and Shrikant Awatade

Abstract: The heat treatment procedures of any material require multiple operations which are to be performed in different furnaces. This procedure is requires much more time and quite expensive. This interest has encouraged the researchers to develop a new furnace. Proposed research work focuses on the development of innovative type of multi-operational furnace in which many heat treatment procedures can be performed in one heating chamber.

Index Terms: Multi operational furnace; heat treatment, annealing, normalizing, quenching, carburizing, fire brick, melting process.

1. INTRODUCTION

IN earlier days the metallic machine parts are manufactured and used in machines in the absence of heat treatment due to that the machine parts get easily wear out in very short duration, parts get corroded easily due to water and air contact, the metallic parts have to check time to time for better machining operations [1]. Due to such difficulties the machine has very less life span and manufacturing cost get increases. To overcome such difficulties manufacturer investigate a treatment due to which the metallic parts have very less corrosion, less wear and tear and increased life span of machine [2].This treatment is named as heat treatment process. In this process, the metallic parts are heated about their melting temperature and suddenly cooled due to which the metallic bonds get strong enough that they don't break easily [3], [4], [5] i.e. the metallic properties get changed by controlling the heat supplied, cooling time and the different metallic properties can be obtained [6]. But for performing various heat treatment procedures certain different type of furnaces are required which are difficult to maintain and costly due to maintenance and running cost [1], [2]. To overcome such difficulties, this new multi-operational furnace is developed which runs on electrical energy in which various heat treatment procedures such as annealing, normalizing, quenching, carburizing, aluminum melting, tempering etc. can be conducted.

2 DEVELOPMENT OF INNOVATIVE FURNACE

Following components are used for manufacturing of the furnace:

- *Subhash Waghmare is working as an Assistant Professor, Mechanical Engineering Department, Priyadarshini College of Engineering, RTM Nagpur University, Nagpur - 440019, Maharashtra, India, PH-09423423905. E-mail: subhashwaghmare1981@gmail.com*
- *Sagar Shelare is working as an Assistant Professor, Mechanical Engineering Department, Priyadarshini College of Engineering, RTM Nagpur University, Nagpur - 440019, Maharashtra, India, PH-09890027265. E-mail: sagmech24@gmail.com*
- *Piyush Sirsat is working as an Assistant Professor, Mechanical Engineering Department, Priyadarshini College of Engineering, RTM Nagpur University, Nagpur - 440019, Maharashtra, India, PH-09890754116. E-mail: piyush.sirsat51083@gmail.com*
- *Nilesh Pathare is working as an Assistant Professor, Mechanical Engineering Department, Priyadarshini College of Engineering, RTM Nagpur University, Nagpur - 440019, Maharashtra, India, PH-09011084355. E-mail: pathare_nr@rediffmail.com*
- *Shrikant Awatade is working as an Assistant Professor, Mechanical Engineering Department, Priyadarshini College of Engineering, RTM Nagpur University, Nagpur - 440019, Maharashtra, India, PH-08698935990. E-mail: sm_awatade@rediffmail.com*

2.1 Heating Coil

A heating coil used is of Nichrome 80/20 material (80% and 20% nickel and chromium respectively).This is a best material due to its higher resistance. While it heated firstly, it shapes the adherent coating of chromium oxide [4]. Material beneath of a coating not oxidizes, maintaining a wire by burning out and/or breaking. The specifications of various components of heating coils are given in the Table-I

2.2 Compensating Cable

Connecting cables are used to connect thermocouples to other processing instruments. These are of two types: extension cables and compensating cables Augmentation links are connecting cables among conductors of similar material as that of thermocouple. Therefore, expansion cables are dependent upon a similar accuracy constrains like a thermocouples. Diameter of used cable is 1.7mm. The following criterion has thought about choosing a proper material:

i. Mechanical and Chemical resistance to encompassing atmosphere
ii. Insulation resistance
iii. Temperature range
iv. Flexibility.

TABLE 1

SPECIFICATIONS OF HEATING COILS

Material	Nichrome
Melting Point	1250^{0}C – 1300^{0}C
Number of turns	935
Pitch	2.9mm
Diameter of wire	1.7mm
Coil Outer Diameter	15mm
Coil Inner Diameter	11.6mm

2.3 Fire Bricks

A fire brick / refractory brick has used in this furnace for inside surface lining. A fire brick is constructed fundamentally to sustain the higher temperature but also have lower thermal conductivity for more efficiency of energy [1], [3], [4]. A refractory material holds its quality at higher temperatures. Refractory are non metallic materials which are relevant to structures or as parts of structure that are presented to conditions over 1000 °C because of having their physical and chemical properties. Depending upon working condition, they should be resistant to thermal shock, be chemically inactive, or potentially have scopes of thermal conductivity and of the coefficient of thermal expansion. Oxides of al, si and mg are mostly utilized into manufacturing of refractory.

Fig. 1. High Alumina Fire Bricks.

2.4 Ceramic Blanket
High temperature insulation wool (HTIW), known as ceramic blanket are utilized into a inside surface of a outer cylinder. Ceramic blanket having thermal conductivity 1.06 W/Mk [7], [8].
Characteristics:
a) Lower thermal conductivity
b) Higher shock resistance
c) Lower capacity of heat storage
d) Inorganic - smoke free
Specification:
a) Density - 128 kg/m^3
b) Thickness -1 inch
c) Sustainable Temperature - 1600^{0}C

2.5 Temperature Controller
On/off type temperature controller is utilizes to control the temperature. An input to temperature controller is given by temperature sensor whereas output is connected at control element i.e. heating coil.
The following factors are selected for a controller:

i. Input sensor type
ii. temperature range
iii. Output type required
iv. Algorithm control needed
v. Types and number of outputs

2.6 Proportional Control
A proportional control is utilized for elimination of cycling by on/off control. The proportional control diminishes a normal power provided to heater as the temperature reaches to the preset point. At preset point, an output on/off proportion is equal; means on and off time is equivalent. If a temperature is additional from the set point, on/off times change with respect to temperature deviation.

Fig. 2. Proportional Controller

2.7 PID Control
PID controller has used to combine proportional control with extra adjustments. PID control is also helpful for automatically recompense into system.

2.8 Muffle Furnace
Arrangement of Carbon Aerogel is done inside muffle furnace [9] in N_2 packed air. This muffle furnace is manufactured at Workshop of Priyadarshini College of Engineering Nagpur. Various important component used in this furnace are:

2.8.1 Furnace Cylinder
Furnace cylinder is made up of 45 cm gauge Metal Sheet material. Vertical height of a cylinder is 45 cm barring dish end. Considering the dish end vertical height is 65 cm and inside diameter is 43.5 cm.

2.8.2 Flange
A flange is provided which is manufactured with sheet metal with 20 mm thick. A provision of groove is made there for suitability of thick rope having 6 mm radius.

2.8.3 Pressure Gauge
Pressure gauge is fitted at top side of a dish end with 20 PSI rating.

2.8.4 Safety Valve
It is utilized for furnace safety due to high pressure inside a furnace cylinder whenever pressure or temperature exceeds desired limits.

2.8.5 Thermometer
Measurement of furnace temperature is done with thermometer attached at crown of a furnace.

2.8.6 Heating Element
Ceramic heaters are used to heat the furnace. Every heater have 1500 Watts rating. Complete 9 heaters are joined in star way to obtained 500^{0}C to 600^{0}C furnace temperature.

2.8.7 Insulation Covering
For keeping away from heat exhaust in atmosphere, protection is essential and to accomplish the reason, ceramic cover is given at outer side of a furnace cylinder.

2.8.7 Other Components

Fig. 3. (a) Brass Nipple (b) Brass Valve (c) Blower (d) Carburizing Liquid Container

3 EXPERIMENTAL SETUP AND EXPERIMENTATION

Mild Steel (MS) cylinder is outermost portion of multipurpose furnace. This cylinder is made from 4.5mm thick MS sheet by using rolling and welding processes. Inside surface of a cylinder is coated by ceramic blanket to avoid the exchange of internal heat to the atmosphere. On the inner side of ceramic blanket, element bricks are arranged along the circumference and high alumina fire bricks are arranged at the base. Difference in both bricks is that high fire alumina bricks has high load bearing capacity than element bricks. Bricks are also use to avoid the heat loss. Slots are produce on the element bricks and heating coil is put into these slots. When supply started, the heating coil starts heating and this heat is use for the desire operation. For operation, the work piece is put under Retord which is put under furnace shell. Retord is made of material SS310 having melting point 1830^{0}C - 1950^{0}C and thermal conductivity is 14.2 w/mc. Cylinder door is made up of material MOS. Different accessories and masterpieces are mounded on the door for safety purpose and to improvement in efficiency. SS circular pipe is mounded under the door. This pipe is mounted to improvement in efficiency and heat exchangers principle works where to the one pipe's one end, atmospheric air is supplied with the help of blower, which takes heat from furnace exhaust hot air and get heated. After heating, this air comes outside from the other end of a pipe. Two other circular SS pipes are also mounted vertically on the door, one of them is used to supply the carburizing liquid for gas carbonizing procedure. After gas carburizing process the exhaust carbon monoxide gas is come outside by the other pipe. For opening and closing a door mechanism is used in which door is hold on the arm and this arm is balanced with the circular rod and circular rod is mounted on furnace shell. To operate this mechanism, the lever is used on which one roller is attached which help to lift and close the door.

3.1 Experimental Procedure

Different operations are done in multipurpose furnace like aluminum melting, carburizing, different heat processes like annealing, quenching, normalizing, tempering, hardening, etc. Gas carburizing required some additional process as compared to aluminum melting / heat treatment process. Experimentation is done for following two processes:

3.1.1 Aluminum Melting

For aluminum melting process, aluminum work piece is put in the Retord which is put into a furnace shell. Retord is act as a container. The process is started with electricity supply to heating coil through controller. Heating coil converts this electric supply into the heat. This heat is used for the different operations. Heat given by the heating coil is taken by the work piece as melting point of aluminum reaches, work piece starts to melt and when it fully turns into molten state then electricity supply is stopped. This molten state of aluminum is used for further applications [10].

3.1.2 Gas Carburizing

Furnace is started to reach a temperature of furnace at 850°C. The furnace door is opened and the sample of material is inserted in the record of gas carburizing furnace. Then temperature of furnace is set at 920°C. Socking of material sample starts at 950°C. At constant temperature of 920°C for 1 hour the heat treatment on material is carried out (1 hour is the soaking period). At the temperature of 850°C the flow of gas carburizing liquid started for carrying out gas carburizing process. Liquid carbon was the gas carburizing liquid. After that sample of material is put out from furnace and it is immediately put inside water for 15 minutes for quenching.

3.2 Observations

At 920°C, the various temperature readings recorded at different parts of a furnace are as follows:

Outlet Temperature of air heat exchanger:	235°C to 240°C
Door top portion temperature:	115°C
Door bottom portion temperature:	30°C to 340°C
Shell top surface temperature:	80°C to 185°C
Shell circumference temperature:	60°C to 65°C
Carburizing flame temperature:	700°C to 800°C

3.3 Calculations

3.3.1 Amount of Heat from Input Source

Industrial heating element is used to generate the heat source. It is take approximately an hour to achieve its highest loading capability.

This is supported by the Joule- Lenz's law: $E = I^2RT$

Where,

E - Electrical energy I - Circuit Current

R - Resistance of Circuit T - Maximum heating time

By Ohm's law; $V = IR$

Where V = Voltage across the circuit

Hence, $E= ((230)^2 \times 3600)/1.85 = 102940540.5$ Joules

Where, V = 230 Volt; R = 1.85 Ω; t = 3600 sec.

Butrate of heat flow: $Q = E/t$ =102940540.5/3600 = 28594.59 J/s.

3.3.2 Design Assumptions and Constant [11]

Convective coefficient of air (h_{air}) =800W/km^2

Time to heat (t) =1 hr.

Circuit Resistance (R) =1.85Ω

Thermal conductivity (brick) (kb) = 3 W/mk

Circuit Voltage (V) =230V

3.3.3 Design Data Assumptions [12], [13]

r_i=Inner Radius of Retord = 0.071m

r_1= Inner Radius of Bricks and Outside Radius of Retord = 0.147m

r_2= Inner Radius of Ceramic Insulation and Outside Radius of Bricks = 0.223m

r_3= Inner Radius of Furnace Wall and Outside Radius of Ceramic Insulation = 0.249m

r_4= Outside Radius of Furnace Wall = 0.254m

L= Length = 0.406m

K_1 = Retord's Thermal Conductivity = 14.2 W/mk

K_2 = Bricks Thermal Conductivity = 1.2 W/mk

K_3= Ceramic Insulation's Thermal Conductivity = 0.12 W/mk

K_4 = Mild Steel Sheet's Thermal Conductivity (Outer Sheet) = 45.3 W/Mk

h_h= Coefficient of Hot Fluid = 25 W/m^{2}k

h_c= Coefficient of Clod Fluid = 500 W/m^{2}k

T_i= Inside Temperature of Furnace = 900^{o}C = 1173 K (assumed)

T_4= Outside Temperature of Furnace = 60^{o}C = 333 K (assumed)

TABLE 2.
HARDNESS VALUES FOR DIFFERENT SAMPLES

Sample No.	Hardness Value(HRC)	Sample No.	Hardness Value(HRC)
1	52	13	67
2	55	14	59
3	55	15	60
4	58	16	61
5	64	17	68
6	57	18	62
7	59	19	62
8	59	20	65
9	67	21	69
10	59	22	61
11	62	23	69
12	62	24	61

T_{coil} = Temperature of heating coil = 1000°C = 1273K (assumed)
T_1 = Temperature at inside surface of Retord
T_2 = Temperature at bricks and ceramic interface
T_3 = Temperature at ceramic blanket and M.S. interface
R_1 = Resistance of Retord
R_2 = Resistance of bricks
R_3 = Resistance of ceramic blanket
$R_{4=}$ Resistance of mild steel
Q = Heat transfer

$$R_i = \frac{1}{A_i h_i} = \frac{1}{\pi\, D\, L\, x\, hi} = \frac{1}{\pi\ x\ 0.1424\ x\ 0.406\ x\ 25} = 0.22\ K/W$$

$$R_1 = \frac{1}{2\pi\, K1\, L}\ x\ \ln(r_1/r_i) = \frac{1}{2\pi\ x\ 14.2\ x\ 0.406} x \ln(0.147/0.071) = 0.02 K/W$$

$$R_2 = \frac{1}{2\pi\, K2\, L}\ x\ \ln(r_2/r_1) = \frac{1}{2\pi\ x\ 1.2\ x\ 0.406} x \ln(0.223/0.147) = 0.136 K/W$$

$$R_3 = \frac{1}{2\pi\, K3\, L}\ x\ \ln(r_3/r_2) = \frac{1}{2\pi\ x\ 0.12\ x\ 0.406} x \ln(0.249/0.223) = 0.3602\ K/W$$

$$R_4 = \frac{1}{2\pi\, K4\, L}\ x\ \ln(r_4/r_3) = \frac{1}{2\pi\ x\ 45.3\ x\ 0.406} x \ln(0.254/0.249) = 1.72\ x\ 10^{-4}\ K/W$$

$$Q_1 = T_{max} - T_i / (R_i + R_1) = 1000 - 920 / (0.22+0.02) = 333.34 W$$

$$Q_2 = T_{max} - T_4 / (R_2 + R_3) + R_4 = 1000 - 60/(0.136 + 0.3602) + 1.72 x\ 10^{-4} = 1893.74\ W$$

Heat Transfer, $Q = Q_1 + Q_2 = 333.34 + 1893.74 = 2227.08\ W$

3.3.4 Heat Exchanger Effectiveness

$$\varepsilon = \frac{T2 - T1}{T3 - T1} = \frac{240 - 25}{335 - 25} = \frac{215}{310} = 0.69$$

$$EWR = \frac{1000\ x\ We}{t}\ mg/min$$

Where

$$W_e = W_1 - W_2$$

W_e - Loss of weight (Electrode in grams)
W_1 – Initial electrode weight prior to machining (grams)
W_2 – Final electrode weight after machining (grams)
t - Machining time (minutes)

4 RESULT AND DISCUSSION

Total 24 samples are used for carburizing process. The required hardness is about 52-63 HRC. Out of 24 samples 17 are found in this range and 7 samples are rejected.

Fig. 5. Time series plot of Hardness Values.

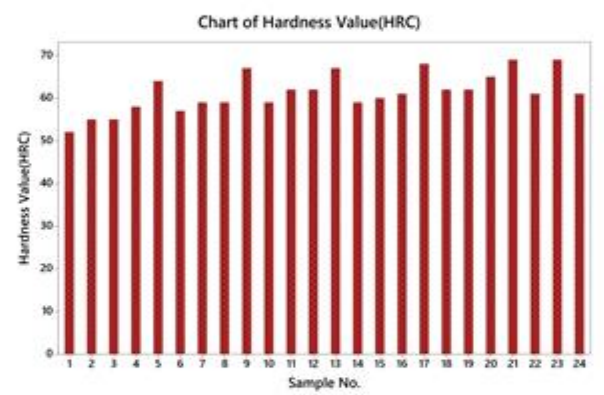

Fig. 6. Bar Chart of Hardness Values.

5 CONCLUSION

This attempt to develop a new multi-operational furnace and improving the efficiency of traditional furnace by performing multiple operations in one furnace is successfully accomplished. The furnace is designed to have minimum losses but certain heat losses are occurred during experimentation. The losses of heat inside a furnace are major due to open mouth of furnace and carburizing process. An energy loss during this process indicates inefficiencies that waste energy and increase the operation costs.

ACKNOWLEDGMENT

The authors wish to thank Principal, Priyadarshini College of Engineering, Nagpur, Maharashtra, India for providing facilities and constant support for execution of the project. Thanks are also due to the Workshop Superintendent, Priyadarshini

College of Engineering, Nagpur, Maharashtra, India for providing time to time valuable guidance for completion of the research work.

REFERENCES

[1] C. A. Bermúdez, J. Porteiro, L. G. Varela, S. Chapela, and D. Patiño, “Three-dimensional CFD simulation of a large-scale grate-fired biomass furnace,” Fuel Processing Technology, vol. 198, no. July 2019, p. 106219, 2020.

[2] O. G. Babatunde et al., “Development of a Novel Oven-Furnace,” Journal of Minerals and Materials Characterization and Engineering, vol. 05, no. 02, pp. 62–73, 2017.

[3] A. Adefemi, “Development of a 30Kg Aluminium Oil-Fired Crucible Furnace Using Locally Sourced Materials,” American Journal of Mechanics and Applications, vol. 5, no. 3, p. 15, 2017.

[4] T. Olukokun, A. Adekunle, I. Alabi, M. Aderonmu, and M. Kareem, “Development of an Indigenously Made Diesel Fired Crucible Furnace,” Proceedings of the 3rd International Conference on Energy Harvesting, Storage, and Transfer (EHST’19), pp. 1–8, 2019.

[5] M. Zhang and Q. Cheng, “Development of a heavy oil burner for aluminum melting furnace,” Proceedings of the 2017 IEEE International Conference on Information, Communication and Engineering: Information and Innovation for Modern Technology, ICICE 2017, pp. 151–154, 2018.

[6] N. R. Reddy and G. M. Reddy, “Friction stir welding of aluminium alloys - A review,” International Journal of Mechanical Engineering and Technology, vol. 7, no. 2, pp. 83–90, 2016.

[7] Y. Hashimoto, Y. Sawa, Y. Kitamura, T. Nishino, and M. Kano, “Development and validation of kinematical blast furnace model with long-term operation data,” ISIJ International, vol. 58, no. 12, pp. 2210–2218, 2018.

[8] Z. Yi, Z. Su, G. Li, Q. Yang, and W. Zhang, “Development of a double model slab tracking control system for the continuous reheating furnace,” International Journal of Heat and Mass Transfer, vol. 113, pp. 861–874, 2017.

[9] G. Kang, A. A. Cikmit, T. Tsuchida, H. Honda, and Y. sang Kim, “Strength development and microstructural characteristics of soft dredged clay stabilized with basic oxygen furnace steel slag,” Construction and Building Materials, vol. 203, pp. 501–513, 2019.

[10] T. Harada, H. Hirata, T. Arai, T. Toh, and T. Yamada, “Development of the molten slag reduction process -1 characteristics of closed type DC arc furnace for molten slag reduction,” ISIJ International, vol. 58, no. 10, pp. 1934–1942, 2018.

[11] R. K. Rajput, Heat and Mass Transfer, Vol. 1, S. Chand Publishing, 1999, p. 351-373.

[12] William D. Callister, Jr.,Materials Science and Engineering-An Introduction,Vol.1, 7th ed. John Wiley & Sons, Inc., 2007, p. 388-401.

[13] Marks' Standard Handbook for Mechanical Engineers, 11th ed., McGraw-Hill Education, 2006.