HEAT TREAT FURNACE OPERATIONS

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The subject of heat treatment furnaces is broad based and the intention of this paper is to cover some aspects of heat treatment operations and control. With my limited exposure to carburising and hardening operations, I would like to share my experiences in the use of furnaces in controlled conditions.

It is best to illustrate with the help of an example the various inter-relations between the factors that influence the process of heat treatment. Typically case carburising of bearing races in sealed quench furnaces is chosen as an example. Figure-1 shows the cause and effect diagram of the factors that influence case depth and homogeneity of products in seal quench operations.

Before proceeding into the details of case carburising operation, let me give you a small background of heat treat process at Tata Timken. Tata Timken manufactures case carburised tapered roller bearings. The heat treatment involved is case carburising of races and rollers. The process flow in heat treatment shop is as follows :

* Carburise races in sealed quench furnace and rollers in Rotary Retort Furnaces

* Check the case depth by Ms Technique. (Refer transactions of ASM Vol.37, 1946 page 27 for details.

* Harden the components by re-heating to hardening temperatures in Rotary Hearth Furnaces (for races) and mesh belt drop hardening furnace (for rollers)

* Temper the hardened component in the belt temper furnaces

* Check for hardnesses, micro-structure and de-carburisation of tempered components

The four main factors influencing case carburising operations are time, temperature, atmosphere and load per heat. Each of these factors needs to be discussed in depth to understand controlled operations.

Time of different elements of operations is easily controllable by use of timers or PLCs. Therefore, this is normally not paid attention to. Unfortunately the complexity of variables in heat treat is so high that some of the factors may influence the non-adherence of time leading to metallurgical defects. For instances;

* Malfunctioning of solenoids, proximity switches and another controls leading to delay in operations.

* Jamming of fixture and trays in furnaces causes disturbed mechanical movements.

* The cylinders seal if not maintained, can delay the drop of charge in the quench system

* The mal-function of the agitators and quench oil cooling system could lead to inadequate quench. The above is only some of the reasons why timely operations are not performed. The emphasis therefore, is to detail out maintenance schedules and adhere them strictly.

Temperature is the second factor that needs to be considered. Pyrometry or the science of temperature measurement should be detailed and followed up in every furnace to ensure compliance to temperature aims. Normally, it is the practice of set up thermo-couples in the furnaces and have controllers to control these around the aim temperature. The few possible details worth noting are :

* What is the amplitude of control i.e. at what temperature do the heaters go 'On and Off" around the set temperature.

* What is the product temperature ? This can be measured by the use of a hand held monitor on a calibrated standard thermocouple. The furnace should have ports for inserting the calibrated thermocouple at various locations so that the dispersion of the temperature within the chamber can be noted. Contact pyrometers can be used to check for insulation damage by sensing the skin temperature at various locations on the shell. If there are many zones of heating in the furnace the individual zones are to be checked for product temperatures.

The correction from deviation (difference between set and actual temperature) can be done by changing set points to match product temperature or by positioning the control thermocouples towards or away from the heat sources. I prefer to adopt the second method since the amplitude of control of controllers is specific for a specific set point and with the change of set point the temperature dispersion may worsen.

The condition of thermocouples, the protective sheathing, and the compensating leads to the controller are to be checked on a continual basis. The frequency of check would depend upon the severity of the atmosphere used in the furnace. Highly reducing atmosphere and very high temperature causes rapid deterioration of the sheath leading to exposure of thermocouple. Thus processes like carburising or hardening would demand a high frequency of check (fortnightly basis) as against a normalising tempering operation) Table-1A and 1B lists the upper temperature limits for various types of thermocouples and the type of protecting sheathing used in heat treat applications.

The next major consideration is the atmosphere in the furnace. The following are the details to be considered :

* Type of atmosphere generation (solid, liquid or gases)

* Source and quality of process fluids used for generating atmosphere

* Required quantums of fluids to generate desired atmosphere

* Monitoring mechanism of the fluid flows.

* Control mechanism of the atmosphere generated.

The detailed cause and effect leading to low case depth due to atmosphere is given in Figure-2. The discussions of atmosphere generation is best done by considering the following factors.

Selection of Fluids :

For case carburising operation, it would typically involve use of a carburising media with an enrichment gas and inert dilutant. Tata Timken decided to work with nitrogen-methanol-LPG system to generate the desired atmosphere. The process of carburising races demands very high carbon potential. In order to achieve this consistently without soot formation nitrogen-methanol was the only solution. Experiments were conducted to decide on the ratio of nitrogen-methanol to give a high carbon potential as a base and further enrich it with little dosages of LPG.

It is very important that the gas handling system are detailed to ensure consistent availability of fluids to the furnaces. Table-2 details the requirements of fluid handling system for nitrogen and methanol. Table-3 details the quality of methanol-LPG and nitrogen that is required for high consistency of case depth and homogenerity.

Mode of control

The carburising atmosphere generated in sealed quench furnaces can be controlled by any one of the following methods.

1. Dew point controller systems developed by Alnor and others are very useful to check and monitor the water vapour present in furnace atmosphere. By the use of lithium chloride crystals (which are hygroscopic in nature) the extent of moisture is detected and

furnace atmosphere also controlled by enriching atmosphere through use of a motorised valve which adds LPG according to the requirement.

2. A CO_2 infrared analyzer can be used to check the carbondioxide percentage available in the furnnce. Though CO_2 levels are less sensitive and therefore, difficult to control, it gives a good indication of the sealing of the furnace which might prompt checks for leakages if any, levels of CO_2 greater than 0.1% is a clear indication that furnace atmosphere is not rich and there is a definite leak in the furnace. Case carburising operations using fixed flow rates of carburising fluids could use the CO_2 measurement as a useful tool to ensure the upkeep of furnaces before carburising the loads.

3. Oxyprobe control systems are in vogue for the measurement and control of carbon potential. The Nernst equation is used to measure the partial pressure of oxygen and relate it to the carbon potential. The system works well on a well maintained furnace and use of lower carbon potentials. With higher carbon potentials the soot furnace on the probe leads to erroneous measurements of O_2 levels. In such cases the probe maintenance and regular flushing of air for burning off the probe is essential. If the furnaces are not maintained properly, the use of oxyprobe control may lead to disastrous results since there is no means to check the reason for lean atmosphere and the probe will regulate the atmosphere by pumping in more LPG which would further worsen the situation by sooting the furnace. It is therefore, essential to control both the carbon potential as well as the CO_2 levels within the furnace. There are oxyprobe control systems with in-built infrared analyzers which will monitor CO_2 levels on a real time basis and dictate the measurement of carbon potential base on CO_2 values.

4. The hot wire detector developed by CARBOHM, LEEDS and NORTHRUP or the ones developed by Tokyo Heat Treating Co, Japan is another simple method to detect the atmosphere in carburising furnaces. A thin piece of wire is placed in the furnace and its rate of carburising is a measure of carbon potential. The resistance of the wire changes due to increase of carbon content and this increased resistance is calibrated to carbon potential in a galvanometer wheatstone bridge. Care should be taken that while the wire is withdrawn from the furnace there are no martensitic transformations in the wire as this would lead to erroneous results.

The next major factor is the load per heat or the charge weight. A lot of work has been done to optimise operations in carburising to ensure maximum yield (throughput) from furnace and at the same time ensure uniformity of case depth in the charge. The other dimension is to restrict distortion of components in the charge.

The parameters to be considered are weight of components, effective volume of charge and surface area of the components. As a thumb rule for smaller components which are non-symmetric or complex in shape (simplest being a cylinder) the load per heat would depend on the surface area for the larger components it is the weight or volume that becomes the constraint.

A reduction in the magnitude of distortion (measured as out of roundness) and improvement in flatness of heat treated component was achieved by researchers in The Timken Co. by carburising under the following conditions:

* Carburising temperatures less than 927 degree C. Experiments were conducted at 885 degree C.

* A high carbon potential was used. The oxygen probe setting was 1185 mV to achieve good results.

* Load size was limited to 15.5 million square millimetres.

* High quenching temperatures of 120 degree C was used.

* Longer quench times of 20 minutes was used.

The conclusion of the series of experiments were the heat treat costs may be reduced by not investing size plugging the components and achieving distortion control by optimising parameters in carburising and hardening.

The above four factors are only few of the many interacting parameters influencing case carburising operations in sealed quench furnaces as shown in the cause and effect diagrams. Factors of significance not considered here are :

* Human resources in heat treat shop
* Mechanical and electrical maintenance of furnaces
* Establishing the process cycles and quenching parameters
* The appropriateness of steel chemistry and cleanliness

ACKNOWLEDGEMENTS

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REFERENCES :

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2. Solomon J. "Carburising" at Union Carbide Corporation

3. Communication with E Euvrard & J O. Wolfe, Timken Company

4. ASTM STP 470B "Manual on the use of thermocouple in temperature measurement".

TABLE 1 (A)
UPPER TEMPERATURE LIMITS FOR VARIOUS WIRE SIZES (0C)

THERMOCOUPLE TYPE	MATERIAL	NO.14 GAGE (1.63 MM)	NO.20 GAGE (0.81 MM)	NO.24 GAGE (0.51 MM)	NO.30 GAGE (0.25 MM)
T	CU (+), Constantan (-)	370	260	200	150
J	Fe (+), Constantan (-)	590	480	370	320
E	Ni 10% Cr (+), Constantan (-)	650	540	430	370
K	Ni 10% Cr (+), Ni 5% Al & Si (-)	1090	980	870	760
R	Pt 13% Rd (+), Pt (-)			1480	
S	Pt {10% Rd (+)}, Pt (-)			1480	
B	Pt (30% Rd), Pt 6% Rd (-V)			1700	

Table-1 (a) Recommended upper temperature limits for protected thermocouples

TABLE 1 (B)

Application	Protective Sheath Material
Annealing	
Upto 700°C	Black Steel
Greater than 700°C	Inconel 600
Carburising hardening	
Upto 815°C	Black Steel
Upto 1090°C	Inconel 600
Greater than 1090°C	Ceramic 600
Nitriding salt baths	Type 44655
Neutral	Type 44655
High speed	Ceramic

Table 1 (b) Recommended protective sheaths for various heat treating

TABLE - 2

	Nitrogen	Mathanol
Pressure supply (Kg/sq.cm)	2.1 (regulated)	3.5 (constant for uniform flow rates
Tank condition	Pressure vessel and piping designed to prevent pick up of moisture and dirt	Stainless steel tank blanketed with low pressure nitrogen to prevent contamination by atmospheric moisture

Table-2: Requirements of fluid handling systems for Nitrogen and Mathanol

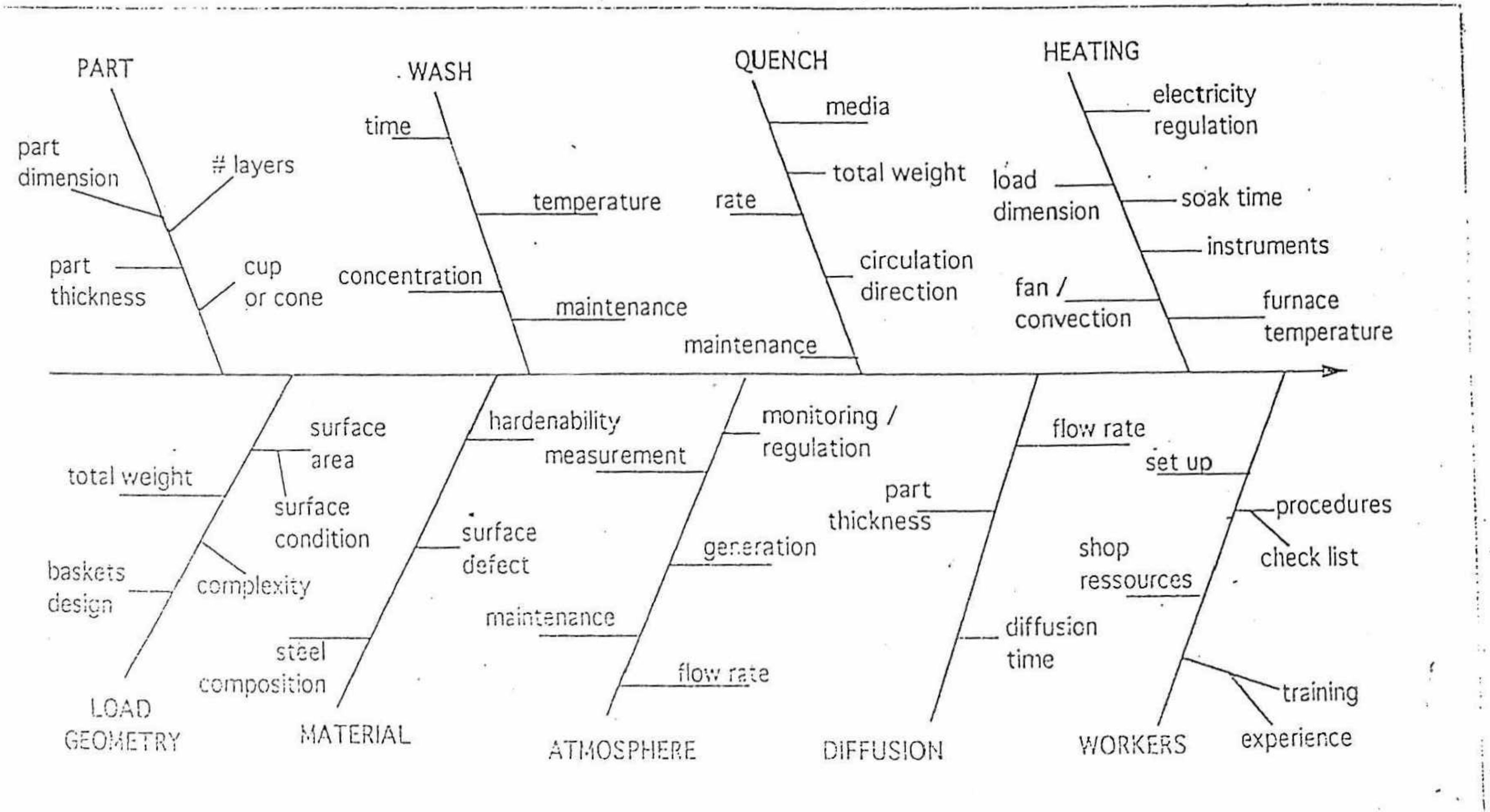
TABLE-3

Nitrogen	1.	Desired purity	99.995%	
	2.	Dew Point	less than 40oC	
Mathanol	1.	Chemistry	CH_3OH	99.85% by weight minimum
			Water	Less than 0.05 by weight
			Acetone	Less than 0.015 by weight
	2.	Completely miscible with water		
	3.	Cleanliness	- 10 micron (filtered)	
	4.	Nitrogen content	- Nil	
LPG	1.	LPG should be in gas phase prior to entry into furnace		
	2.	Total volatile sulphur (ppm) 25-35		
	3.	Unsaturates		
	4.	Range of composition (% by volume)		
		C3 Hydrocarbons	45-53	
		C4 Hydrocarbons	46-55	
		C5 Hydrocarbons	Nil	

Table-3: Quality requirements of process fluids

FIGURE 1

CAUSE AND EFFECT DIAGRAM FOR SEALED QUENCH OPERATIONS INFLUENCE ON CASE DEPTH AND HOMOGENEITY



<u>FIGURE 2</u>

DETAILS OF FACTORS INFLUENCING ATMOSPHERE IN SEALED QUENCH OPERATIONS