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Optimization of Heat Treatment Processes Using Taguchi's Parameter Design Approach

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ABSTRACT

The utilization of carburizing materials in engineering fields has undergone so many tremendous changes in engineering fields. Gas carburizing is one of the surface engineering techniques widely used in the process of heat treatment in all the engineering industries. Carburizing is a complex process; it involves a number of variables for the success of the carburizing process. Effective quality control is possible through carburizing the components under optimal conditions .The objective of the paper is to obtain an optimal setting of carburizing process parameters (carburizing temperature, soaking time, gas diffusion effect ,furnace air circulation) resulting in optimal values of the correct depth of the case in the surface of the components. Taguchi method is a powerful design of the experiment (DOE) tool for engineering optimization of a process. Analysis of variance (ANOVA) is used to study the effect of process parameters and establish correlation among the carburizing temperature, soaking time, gas diffusion effect, furnace air circulation.

Key Words: *Carburizing, Case Depth, Heat Treatment, Taguchi Method, Optimization.*

I. INTRODUCTION

Steel is an alloy of two major constituents iron and carbon. Carbon steel (plain-low) is graded by its carbon content as 0.1 % to 0.3% its called mild steel ,it cannot be hardened by direct heat treatment because of low strength of carbon content . Thermo chemical carburizing –case hardening and heat treatments of atoms in metals and alloys and a corresponding marked variation in physical, chemical and mechanical properties. Among the more important of these treatments are heat treatment processes such immersion hardening, induction hardening and case carburizing [child, 1980(1)]. Carburizing and case hardening are "thermo chemical" treatments, usually conducted at temperatures in the range 800-940^0 c in the first stage of "case –hardening". Quenching is followed by a low –tempering tempering. The heat treated employs a variety of processing media to achieve these objectives, including controlled gaseous atmospheres to a predetermined temperature .The furnace is flooded with a suitable gas such as methane, butane or propane. In carburizing, controlled level of carbon are introduced at the surface and allowed to diffuse to a controlled depth. Carburizing and case –hardening is applied to near-finished components and its enhancing to high-hardness, strength and wear resistant properties on surface in sufficient depth, and fatigue strength (2).In the gas carburizing process is that the original toughness and ductility remain unaffected even after the heat treatment [Rajan et.al,1994(3)].

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II. TAGUCHI METHOD

Optimization is a key step to improve the performance and to find the optimal process parameters based on the responses .There are several optimization tools such as the gradient search method, the FEM neutral, network method and Taguchi method(4). There is a unique statistical experimental design technique known as Taguchi's Robust Design method .The design of parameters using Taguchi's method is an off-line Quality control method. Offline Quality control methods are Quality and cost control activities conducted at the product and process design stages to improve product manufacturability and reliability and to reduce the product development and life time cost (Philip, 1988(5)).The method has also seen widely used in engineering analysis to optimize performance characteristics through design parameter settings. Parameter design can be used to make a process robust against sources of variation and hence to improve field performance. The Taguchi method uses a special design of orthogonal array to study the entire process parameter space with a small number of experiments. The Taguchi method is based on orthogonal arrays and analysis of variance to minimize the number of experiments and to effectively improve product quality (6-8).

The Taguchi method is a powerful tool for designing high quality systems based on orthogonal array experiments that provide much-reduced variance for experiments within optimum setting of process control parameters (9-11). Many of the researches have attempted to analyze and optimize. Single and multi performance responses of heat treatment process using Taguchi methodology. Among them multiple progressive tool (surnace (2010)) and utility concept (zhizharg (2008(12)) are used. This method combines the experimental and analytical concepts to determine the most influential parameter on the result response for the significant improvement in the overall performance. It employs signal-to-noise (S/N) ratio to analyze experiment data and conclude more information .The current study considered case depth as optimization criteria and also analyzed the influence of each heat treatment parameter on the quality of the research object. The optimal levels of process parameters can be estimated. In order to achieve carburizing steel components, a parameter optimization study is to be carried out in a gas-carburizing furnace by verification of results.

III. MATERIALS COMPOSITION

The work material used was C15 steel, carburizing-case hardening steel was carried out in a carburizing furnace. The following table shows the composition of the element present in C15 steel.

Table: 1 Chemical Composition

Element	C	Si	Mg	Cr	Ni
Wt%	0.15%	0.1%-0.35%	0.3%-0.6%	0.6%-1.1%	3.0-3.75%

At present, a number of steels are available for specific applications. In fact, the selection of suitable steel from an economic stand point has become an important function of a scientist or engineer (ASM metals Hand work, 1981).

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IV. CASE STUDY

The sample of diameter 15mm and length 250mm of A1S1 steels is 3.5 depths, 130kW methanol-acetone uni-therm gas carburizing furnace with oil quench. The process variables noted as holding time, carbon potential, carburizing temperature and quenching time which affect the hardness and case depth were selected for the Taguchi design. A L9 (3^4) orthogonal array design was adopted for experimentation for each steel material. Nine experiments were conducted by varying all the parameters, the details given below.

Table: 2. Parameters and Notations

S .No	PARAMETERS	NOTATIONS	UNIT	VALUE WITH RANGE
1.	Holding time	HT	Min	180-210
2.	Carbon potential	CP	mV	1110-1120
3.	Carburizing temperature	CT	℃	870-930
4.	Quenching time	QT	Min	20-30

The influence of these parameters (between low, medium and high) on surface hardness, case depth, and every case hardened component was taken to measure the surface hardness and case depth. The results of the L9 orthogonal array of gas carburizing process parameters and test results for A1SI 3310 material are noted below.

Table: 3 Experimental Details

Experiment	Holding time	Carbon potential	Carburizing temperature	Quenching time	HRA	HDN
01.	180	1110	870	20	79	0.8
02.	180	1115	900	25	80	0.7
03.	180	1120	930	30	80	0.7
04.	195	1110	900	30	81	0.9
05.	195	1115	930	20	79	0.9
06.	195	1120	870	25	79	1.0
07.	210	1110	930	25	81	0.8
08.	210	1115	870	30	82	0.9
09.	210	1120	900	20	79	1.0

The following table indicates that average effect of main parameters at a 3 factor level on surface hardness (HRA, HPN) and also carburizing temperature has an effect on surface hardness.

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Table: 4 Process Parameters

PARAMETER	LOW	MEDIUM	HIGH
Holding time	79.66	79.66	80.66
Carbon potential	80.33	80.33	79.33
Carburizing temperature	80.00	80.00	80.00
Quenching time	79.00	80.00	81.00

The percentage contribute of holding time 20%, carbon potential 20%, carburizing tempering 10% and quenching time 60% indicate that the quenching time has taken influence on surface hardness. The following shows that the influence of gas carburizing parameter: Holding time in the furnace has an influence (67%) on the case depth, as the percentage contributions of carbon potential, Carburizing temperature and quenching time are 9%,15% and 8%. The error is 1%.Then the case studies are concluded to: Time parameters have more influence on the quality of case hardened components, irrespective of the type of the material. The present analysis indicates the optimum process conditions to obtain high surface hardness and more case depth. Holding time 195-210 min; quenching time 30 min, Carbon potential 1110-1115mv, carburizes temperature 870-930°C. The confirmation of the experiment show that the observations are within a 95% confidence level. The error is the experimental analysis is very low, and hence Taguichi's techniques can be applied to determine the optimum process parameters of gas carburizing in order to achieve quality components. Micro structural and micro hardness studies were performed on selected specimens and it was determined that there were no defects in the carburized specimen.

Table: 5 Parameters Range

PARAMETER	LOW	MEDIUM	HIGH
Holding time	0.73	0.93	0.90
Carbon potential	0.83	0.83	0.90
Carburizing temperature	0.90	0.86	0,80
Quenching time	0.90	0.83	0.83

V. EXPERIMENTAL PROCEDURE

Design of experiment is a powerful tool for analyzing the influence of the process variables cover some specific variable, which is a un known function of these process variable. The major step in the taguchi method is the selection of the factors affecting the performance measures (13-15). The table shows the parameters and the corresponding levels chosen for the investigations. The multiple response characteristics including four heat treatment parameters (carburizing temperature, Soaking time, gas diffusion effect, furnace air circulation) are chosen on the output parameter to validate the effectiveness.

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Table: 6 Parameters and Levels

S .NO	PARAMETERS AND THEIR LEVELS
1.	Carburizing temperature^{0}c
2.	Soaking time(min)
3.	Gas diffusion effect mm/min
4.	Furnace air circulation

The selected factors and their levels are presented the table above. The performance measures selected for the experimentation were case depth and hardness. Analysis of variance is used to study the effect of process parameters and establish correlation among the soaking time and case depth with respect to the major-carburizing factor. Experimental results are provided to conform the effectiveness of Taguchi technique for carburizing of A1S1 3310. The standard experiment layout 3 level OA L9 (3^4) for factors are listed for this cases and shown in the following table.

Table: 7 Trial Number and Arrays

TRIAL.NUMBER	A(HTM)	B(HTM)	C(HTM)	D(HTM)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	3	2
5	2	2	1	3
6	2	3	2	1
7	3	1	2	3
8	3	2	3	1
9	3	3	1	2

Table-Experiment layout using L9 (3^4) orthogonal arrays. (HTM-Heat treatment parameter)

VI. VI. RESULT AND DISCUSSION

The objective of experiment is to optimize the case depth of C15 Steel parameters to get lower force values, smaller the better characteristics. From the following indicates that average effect of main parameters at a 3 factor level on surface case depth. From the Parameters Namely 1) Carburizing Temperature 2)Soaking Time 3) Carburizing Temperature 4)Air Circulation in GCF. The optimum process conditions will be by employing “higher the better (case depth in carburizing) strategy. (GCF-Gas carburizing furnace)

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VII. CONCLUSION

The following conclusions can be drawn from this study. Taguchi method is used to provide an efficient design of experiment technique to obtain simple, systematic and efficient methodology for the optimization of the process parameters. Taguchi's robust design method can be used to analyze optimal heat treatment parameters for the carburizing and case hardened steel described in the paper. The Taguchi method efficiently, obtains optimal heat treatment parameters for the plain low carbon steel, minimizes the number of experiments, and analyzers the influence of each heat treatment parameter on the experiment results and the contribution of individual parameters.

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