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Optimization of Heat Treatment Process for Internal Clutch by Using Taguchi Technique

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Abstract
Surface engineering and surface engineered materials find wide applications in engineering industries in recent years. Inconsistency in hardness and case depth has resulted in the further optimization of the process variables involved in surface hardening. In the present study, the following operating parameters viz. Carbon potential, holding position, furnace temperature, carburizing time, quenching medium, quenching temperature, quenching time, tempering temperature and tempering time were taken for optimization using the Taguchi and Factorial design of experiment concepts. From the experiments and optimization analysis conducted on **EN8** materials it was observed that furnace temperature and quenching time had equal influence in obtaining a better surface integrity of the case hardened components using gas carburizing. In the case of induction hardening process, power potential played a vital role in optimizing the surface hardness and the depth of hardness.
Keywords: Internal clutch, hardness, taguchi techniques, optimization, process variables.

I. INTRODUCTION

1.1-Surface Engineering

The engineering of surfaces of components to improve the life and performance of parts used in automobiles engineering is an active area of research. Suitable thermal/mechanical surface engineering treatments will produce extensive rearrangements 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 gas carburizing. [1]

Investigations indicate that in surface hardening processes, heat treatment temperature, rate of heating and cooling, heat treatment period, quenching media and temperature,[2] post heat treatment and pre-heat treatment processes are the major influential parameters, which affect the quality of the part surface hardened. This deals with the optimization studies conducted to evaluate the effect of various process variables in gas carburizing furnace and induction hardening.[3]

In this study, Taguchi's design of Experiment concept has been used for the optimization of the process variables of gas carburizing process and factorial design of experiment for the optimization of process variables of induction hardening process. Taguchi's L9 orthogonal array and 3^4 factorial arrays have been adopted to conduct experiments in gas carburizing and induction hardening processes respectively.

Automobile component which an internal clutch which require high fatigue resistance, is normally surface hardened by gas carburizing. Gas carburizing is carried out in retort type, sealed quench type and continuous pusher type furnaces. These furnaces are either gas fired or electrically heated. The gas carburizing temperature varies from 880^0 to 910^0 C the gas atmosphere for carburizing is produced from liquid or gaseous hydrocarbon methanol (CH_4O). The study of process parameters in metals during heat treatment has been of considerable interest for some years but there has been relatively little work on process variables during the surface hardening process since controlling parameters in gas carburizing is a complex problem. The major influencing parameters in gas carburizing are the holding time, carburizing temperature, carbon potential and the quench time in oil. The attainment of the correct combination of surface hardness and effective case depth requires the use of proper and optimized process variables. It is therefore desirable for industries/ researchers to explore the possibility of optimizing.

II. MATERIALS & METHODOLOGY

2.1 MATERIAL

The material selected for the present study is low carbon steel EN8. It was obtained in the form of 14.2 mm diameter rod. The composition of the raw material and after carburization was analyzed in optical emission spectroscope (OES). The results of the analysis along with the nominal composition are given in Table5.1. The raw sample conforms to the chemical requirements of EN8 specifications, as far as the constituents are concerned

The normal procedure followed in converting the raw material into a finished product is shown in Fig. (2.**1**)

Raw Material selection

↓

Machining of internal clutch

↓

Gas carburizing process

↓

Quenching

↓

Tempering

Fig: 2.1 Sequences of Operations in Gas Carburizing Process

2.2. METHODOLOGY

The methodology of heat treatment adopted for the present study is **Gas Carburizing Process** is a surface chemistry process, which improves the case depth hardness of a component by diffusing carbon into the surface layer to improve wear and fatigue resistance. The work pieces are pre-heated and then held for a period of time at an elevated temperature in the austenitic region of the specific alloy, typically between 880°C and 910°C. [4]

Figure 2.2 GAS CARBURIZING FURNACE

2.3. HEAT TREATMENT PROCESSES

2.3.1 Hardening

Hardening is performed to impart strength and hardness to alloys by heating up to a certain temperature, depending on the material, and cooling it rapidly.

2.3.2. Quenching

It is performed to cool hot metal rapidly by immersing it in brine (salt water), water, oil, molten salt, air or gas.

Quenching sets up residual stresses in the work piece and Sometimes results in cracks Residual stresses are removed by another process called annealing

2.3.3. Tempering

Tempering is applied to hardened steel to reduce brittleness, Increase ductility, and toughness. In this process, the steel is heated to lower critical temperature (200-300°C) keeping it there for about 15 - 25 minutes and then cooled slowly at prescribed rate. These processes increases ductility and toughness but also reduce hardness, strength and wear resistance marginally.

Increase in tempering temperature lowers the hardness.

2.4 HARDNESS OF INTERNAL CLUTCH

2.4.1 HARDNESS TESTING:

The heat treated specimens hardness was measured by means of Rockwell hardness tester. The procedure adopted can be listed as follows:

1. First the brale indenter was inserted in the machine; the load is adjusted to100kgf.
2. The minor load of a 10 kgf was first applied to seat of the specimen.
3. Now the major load applied and the depth of indentation is automatically recorded on a dial gage in terms of arbitrary hardness numbers. The dial contains 100 divisions. Each division corresponds to a Penetration of .002 mm. The dial is reversed so that a high hardness, which results in small penetration, results in a high hardness number. The hardness value thus obtained was converted into C scale by using the standard converter chart.[5]

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Fig.2.4 Rockwell Hardness Tester

2.5. INTERNAL CLUTCH

Hardness of a material is generally defined as resistance to permanent indentation under static or dynamic loads. Engineering materials are subjected to various applications where the load conditions and functional requirements may vary widely.[6]

In automobiles, clutch is an important assembly the major components subjected to twisting load. In order to improve the wear resistance characteristics and have high reliability, the components (internal clutch) are subjected to case hardening.

The major problem in case hardening is inconsistency in hardness and case depth obtained. The magnitude of hardness depends on the process variables of any surface hardening process. Hence, in the present research, process variable optimization study has been carried for obtaining higher surface hardness on the clutch material EN8 used in the internal clutch of the automobile.

Fig 2.5 Internal Clutch Sample

III. Experimental setup

Gas carburizing of selected materials have been done in a Unitherm Gas Carburizing Furnace (Fig. 2.2) where Methanol is used as carburizing medium. The specifications of Gas carburizing furnace and operating conditions with range are given in Table 4.1.

Table-3.1-Specifications and Operating Conditions of Gas Carburizing

Machine name	Gas Carburizing Furnace
Material Used	AISI – Low Carbon steel materials EN8
Diameter	14.2mm
Furnace Details	Methanol – Gas Carburizing Furnace of 3 m depth
Electrical rating	130 KW
Furnace Temperature	880 – 910°C
Quenching Time	10 – 20 minutes
Tempering Temperature	200 - 300°C
Tempering Time	15 - 25 minutes

3.2- Experimental Procedure

3.2.1 Gas Carburizing-Operating Conditions

In this investigation four factors have been studied and their low and high levels based on preliminary investigation and review of literature, the range of input parameters Which were finally selected is given. These values of process parameters of Gas carburizing were utilized for conducting design of experiments in Gas carburizing furnace machine of low carbon steel EN8, based on design of experimental process

Table 3.2. Gas Carburizing-Operating Conditions

SR.N0	FACTORS	NOTATION	LEVEL 1	LEVEL 2	LEVEL3
1.	Furnace temperature	A	880°C	895°C	910°C
2.	Quenching Time	B	10 min	15 min	20 min
3.	Tempering Temperature	C	200°C	250°C	300°C
4.	Tempering Time	D	15 min	20 min	25 min

IV. TAGUCHI DESIGN

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 offline 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 product development and lifetime costs.[7]

Parameter design can be used to make a process robust against sources of variation and hence to improve field performance. In Taguchi's concept, the product must be produced at optimal levels with minimal variation in its functional characteristics. Control and noise factors affect the product quality. The former can be easily controlled although noise factors are nuisance variables that are expensive to control.[8]

In order to achieve case hardened steel components, a parameter optimization study was carried out in a gas carburizing furnace by subjecting low carbon steel EN8 specimens to the gas carburizing process.

4.1 SELECTION OF AN ORTHOGONAL ARRAY

We Have Four Variables (Parameter) In Our Case with Three Levels

Hence, Degree Of Freedom = 1+4(3-1) =9

So, Minimum 9 Experiments are to be conducted .In this case array that can be used is L9 Orthogonal Array. The naming of array means the there are 9 runs for 4 factors, Contain 3 Levels. Our problem happens to fit inside of this array

4.2 Assigning Orthogonal Array for L9 Array

Experiment	Furnace Temp (Celsius)	Quenching Time (min)	Tempering Temp (Celsius)	Tempering Time (min)
1	880	10	200	15
2	880	15	250	20
3	880	20	300	25
4	895	10	250	25
5	895	15	300	20
6	895	20	200	20
7	910	10	200	20
8	910	15	200	25
9	910	20	250	15

V. ORTHOGONAL ARRAY FOR GAS CARBURIZING WITH TEST RESULTS AND S/N RATIO MATERIAL CALULATIONS.

A) Calculation for Maximum Hardness

EXPERIMENT							Maximum Hardness		
	T1	$T1^2$	T2	$T2^2$	T3	$T3^2$	SM1	ST1	SE1
1	31	961	31	961	31	961	2883.00	2883.00	0000
2	31	961	32	1024	32	1024	1003.00	3009.00	2006.00
3	31	961	34	1156	36	1296	1137.66	3413.00	2275.33
4	33	1089	36	1296	34	1156	1180.33	3541.00	2360.66
5	34	1156	36	1296	31	961	1137.66	3413.00	2275.33
6	31	961	31	961	31	961	2883.00	2883.00	0000
7	34	1156	35	1225	36	1296	1225.66	3677.00	2451.33
8	33	1089	34	1156	36	1296	1180.33	3541.00	2360.66
9	31	961	33	1089	34	1156	1068.66	3206.00	2137.33

B) Calculation For Larger the Better

EXPERIMENT	Calculation For Larger the Better		
	Ve1=Se1/1	Mean	S/N=-10*Log(1/(Mean*Mean)+variance)
1	00	31	44.74
2	1003.00	31.66	45.01
3	1137.66	33.66	45.79
4	1180.66	34.33	46.06
5	1137.66	33.66	45.79
6	00	31	44.74
7	1225.66	34	45.94
8	1180.33	34.33	46.06
9	1068.68	32.66	45.41

From the experimental result, the average effects of process variables under consideration on the obtainable surface hardness have been calculated and the same are presented in the table 3.

VI. CALCULATION FOR RESPONSE TABLE, FIRST PARAMETER & FIRST LEVEL:-

From the experimental result, the average effects of process variables under consideration on the obtainable surface hardness have been calculated and the same are presented in Table 4.7

The sample calculation for Average effect of Process variables on surface hardness is given below.

$$SP1{,}1 = \frac{44.74 + 45.01 + 45.79}{3} = 45.18$$

$$SP2{,}1 = \frac{44.74 + 46.06 + 45.94}{3} = 45.58$$

$$SP4{,}1 = \frac{44.74 + 45.79 + 45.41}{3} = 45.31$$

$$SP3{,}1 = \frac{44.74 + 44.74 + 46.06}{3} = 45.18$$

Table 6.1-Response Table

Level	Furnace Temp(Celsius) **A**	Quenching Time(min) **B**	Tempering Temp(Celsius) **C**	Tempering Time (min) **D**
1	45.18	45.58	45.18	45.31
2	45.53	**45.62**	45.49	45.23
3	**45.80**	45.31	**45.84**	**45.97**
Δ	0.62	0.31	0.66	0.78
RANK	**3**	**4**	**2**	**1**

From this we can say for obtaining Maximum Hardness **TEMERING TIME** is the most influential parameter

Table of the average SN value for each factor:-

Δ = Max – Min

Δ = 45.80 – 45.18

Δ= 0.62

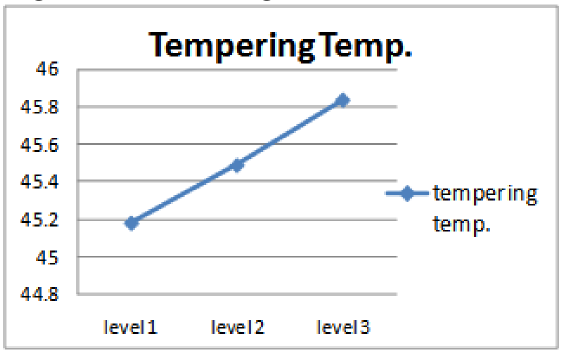
VII. RESULTS & DISCUSSION

7.1. Response Graph Method

Response graph method gives the output of interest to be optimized i.e., minimize, aximize, targeted, etc. The output can be more that one and also it can be quantitative or qualitative. [9, 10]

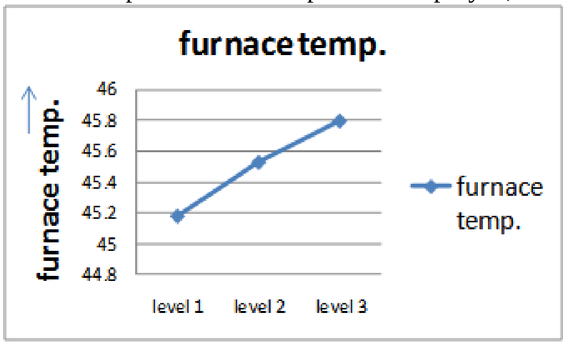
For getting maximum hardness following is the setting done A3B2C3D3 Furnace temp- 910°C
Quenching Time- 15 min
Tempering Temp- 300°C
Tempering Time- 25 min
Response graphs are drawn using Table **6.1**. Fig. (**7(a)-7(d)**) (Response graphs) shows the influence of process variables on the case depth for the Materials EN8.

From response graph 7 (a) indicates that Optimum tempering temp for the material internal clutch is below the lower temperature (200°C), process improves the hardness. The purpose is to relive internal stress to reduce brittleness and to make steel tough to resist shock fatigue.



7(a)

Response graphs 7 (b) indicates that preheating the material before subjecting to Gas carburizing process improves the hardness below the lower temperature (880°C). Even though, this process is employed to relieve the internal stresses, no remarkable micro structural changes occur during this process. Internal stresses are developed during machining and grinding. This pre-carburizing process removes these stresses. Further, it is observed that the extent to which the stresses can be relieved Depends on the temperature employed,



7(b)

Holding time and uniformity in cooling.

From response graph 7 (c) indicates that the internal clutch heated above the upper critical temperature at above 200°C the structure unchanged by gas carburizing process. It is then cooled by quenching it in a salt bath at minimum 20 min to maintain its hardness. It is observed that the extent to which the stresses can be relieved.

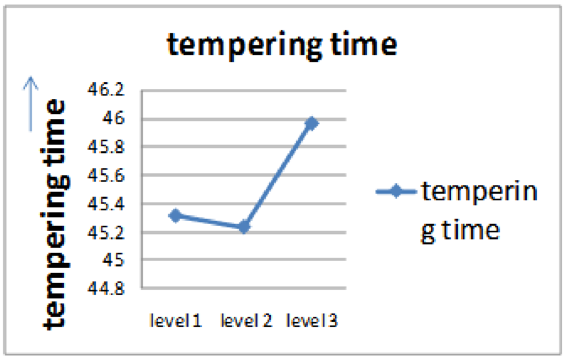


Fig 7(c)

From response graph 7(d) indicates that optimum quenching time for the material internal clutch is 10min in salt water, process improves the hardness The purpose is to relive internal stress to reduce brittleness and to make steel tough to resist shock fatigue.

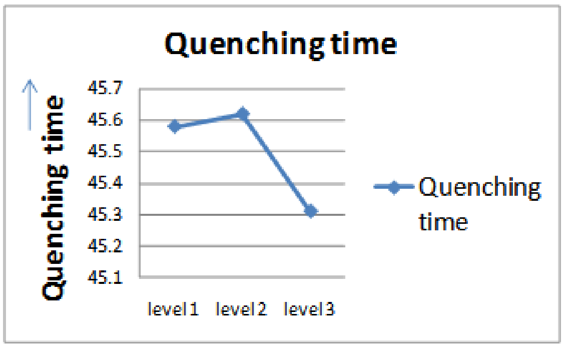


Fig 7(d)

7.2. Percentage contribution of each parameter on surface hardness

This analysis is carried out to determine the influence of main variables on surface hardness and also to determine the percentage contributions of each variable. Table **7.2.1** shows the results of percentage contribution of each variable.

Table 7.2.1. **Percentage contribution of each parameter on surface hardness**

Level	Furnace Temp(Celsius) A	Quenching Time(min) B	Tempering Temp(Celsius) C	Tempering Time (min) D
1	45.18	45.58	45.18	45.31
2	45.53	45.62	45.62	45.23
3	45.80	45.31	45.31	45.97
Δ	0.62	0.31	0.66	0.97
Contributions	**26.16%**	**13.09%**	**30.09%**	**33.00%**

From the above experimental analysis, furnace temperature is having a significant effect on obtainable hardness. The reason for this may be given as below. At higher furnace temperature, formation of water vapors is less. Water vapors are a strongly decarburizing gas but whether this decarburizing tendency will actually reveal itself in practice depends on a number of factors. The first is the concentration in which the water vapors are present and the second is the nature of the carburizing gases in particular gas mixture under consideration. There is perhaps, more contradictory evidence on this subject of the effect of water vapors in gas carburizing and in the heat treatment of steels than any other single item and it is quite clear that a lot more work remains to be carried out before an absolutely clear picture is obtained. It is possible that in small amount, water vapors actually has a beneficial effect on carburizing, an effect which seems to be catalytic in nature. However, the present study shows that higher furnace temperature **(910°C)** gives high hardness

In the present analysis, Optimum Gas Carburizing Process conditions to obtain higher surface hardness with more case depth are given in Table **7.2.2**

Table 7.2.2 Optimum Gas Carburizing Process conditions

Sr. No.	**Process Variables**	**Values with unit**
01	**Furnace Temp(Celsius)**	**910° C**
02	**Quenching Time(min)**	**15 Min**
03	**Tempering Temp(Celsius)**	**300° C**
04	**Tempering Time (min)**	**15 Min**

To check the optimum results obtained through Taguchi' DOE, confirmation trials are carried out and the results are tabulated in Table7.2.2. From the table it is clear that the predicted conditions for higher hardness and case depth suits well with the experimental results.

VIII. CONCLUSION

The present research is concerned with the optimization of process variables and identification of the root cause for the inconsistency in hardness in Gas carburized materials, e.g., internal clutch. After holding extensive consultation with the personnel's of all the departments in the industry in which this research has been carried out, it is concluded that preheating, carbon potential, holding position, furnace temperature, carburizing time, quenching medium, quenching temperature, quenching time, tempering temperature and tempering time are the influential variables responsible for the surface integrity of the components.

Analysis of variance is done for EN8. The results Tables **7.2.1** and optimum conditions for hardness (Table 6.1– Response graph and S/N ratio) indicate that the interaction between Furnace temperature and quenching time is having 25 - 30% influence on the hardness and . Further, the present optimization analysis shows that Signal to noise ratio method has also given the same optimal variable levels/best treatment combination levels with the Response Graph analysis.

Tempering time parameters have more influence on the quality of case hardened components, irrespective of the type of material.

Furnace Temperature and Quenching time have equal influence on the Surface integrity of the case hardened components in Gas Carburizing. The investigation reveals that the interaction effect between Furnace Temperature and Quenching time is 30%.

Optimum Gas Carburizing Process conditions as per the present test results to obtain Higher surface hardness with more case depth are preheating before gas Carburizing increases the obtainable hardness and case depth of the material.

The confirmation of the experiment shows that the observations are within a 95% confidence level. The error in the experimental analysis is very low, and hence Taguchi's techniques can be applied to determine the optimum process parameters of gas carburizing in order to achieve quality components.

Micro hardness studies were performed on selected specimens and it was determined that there were no defects in the carburized specimen.

The Taguchi method efficiently obtains optimal heat treatment parameters for the EN8 low carbon steel, minimizes the number of experiments, and analyzes the influence of each heat treatment parameter on the experiment results and the contributions of individual parameters.

In the heat treatment process of the EN8 low carbon steel, the optimal conditions for better hardness value are: Furnace temp- 910 Celsius, Quenching Time- 15 min, Tempering Temp- 300, Tempering Time- 25 min respectively.

In the heat treatment process of the EN8 low carbon steel, the contributions by percentage of hardness are Furnace temp- **26.16%**, Quenching Time- **13.09%**, Tempering Temp- **27.85%**, and Tempering Time- **33.00%** respectively.

The important sequences of optimal conditions for hardness are Furnace temp, Tempering Temp, Tempering Time and Quenching Time

REFERANCES

[1] Child, H.C., Surface hardening of steels", Oxford University Press, London, 1980.
[2] Schimizu N, Tamura I. An examination of the relation between quench-hardening behavior of steel and cooling curve in oil. Trans ISIJ 1978; 18: 445-50.
[3] Barbacki A, Mikolajski E. Optimization of heat treatment conditions for maximum toughness of high strength silicon steel.Int J Mater Process Techno 1998; 78: 18-23.
[4] J. Wunning, "Advances in Gas Carburizing Technique," *Haerterei-Technische Mitteilungen*, 23 (3) (1968), 101-109.
[5] Fee AR, Robert, and Edward SL. Mechanical testing of materials. ASM Handbook 1995; vol.8: pp.91-93
[6] ASM metals handbook: heat treating. 9th ed. Ohio: Metal Park 1981; vol. 4.
[7] Philip, J.R., Taguchi Techniques for Quality Engineering", McGraw Hill, New York, 1988.
[8] Dr.Genichi Taguchi, "Taguchi Methods, Design of Experiments", ASI Press.
[9] Schimizu N, Tamura I. An examination of the relation between quench-hardening behavior of Steel and cooling curve in oil. Trans ISIJ 1978; 18: 445-50.
[10] Barbacki A, Mikolajski E. Optimization of heat treatment conditions for maximum toughness of high strength silicon steel. Int J Mater Process Technol 1998; 78: 18-23.