An Optimization of Various Heat Treatment Process Parameters:To Improve The Surface Hardness of Mild Steel Product By Taguchi Method And Anova Techniques

Abhishek Nigam[1], Anand Swaroop Verma[2], Ashutosh Nigam[3]
[1, 2, 3] Department of Mechanical Engineering
[1, 2] Kanpur Institute of Technology, Kanpur , India
[3] Bhabha Institute of Technology, Kanpur , India3

Abstract- *The main purpose of this paper is to improve the mechanical properties by analyzing and detecting with the use of destructive testing methods. There are so many engineering material exist in this Universe. But here we are discussing about steel. So when steel is heated under control sequence of heating and cooling to change their physical and mechanical properties. After changing their properties we get the desired engineering applications. Whenever we undergo through heat treatment process on low carbon steel. This process follows to improve toughness, strength, ductility, hardness, tensile strength, and to relive internal stress capability which is developed in the material. Here the main intension of this paper is to acknowledge you about the effect of heat treatment (mainly quenching followed by tempering), the microstructure and the hardness of the low carbon steel were discuss in this theory. When we go through the different parameter which is used in this experiment for instance heat treatment temperature, Heat treatment duration of steel at the same temperature and the quenching low temperature. In this experiment we are trying to improve the result for the hardness values at different levels. So we have used technique which is called Taguchi method. Through this we try to do optimization of various process parameters. We have used standard method to find out the hardness of the treated and untreated samples.*

During our experiments, we have used nine workpieces of low carbon steel and all the nine pieces quenched at three different temperature (i.e. 870°C ,885°C and 900°C) for three different holding time(i.e. 3hr,3.3hr,3.66hr) along with three different quenching time(i.e. 20 min,30 min and 40 min). When we implemented this with Taguchi method, we came to conclusion that the optimum parameters for hardness were heat treatment temperature at 900°C for 3 hr of heat treatment duration and 40 min Quenching time with 0.4 % Carbon content. Also by the help of ANOVA techniques, we find that the parameter A (i.e. carbon content) is the most influential parameter with the contribution ratio of 49.30 % towards the improvement of hardness exhibited by the mild steel components.

Keywords- Heat treatment , Quenching, Tempering, Hardness, Microstructure, and Taguchi technique.[6]

I. INTRODUCTION

The process of heating and cooling of material is Heat treatment . It is possible to obtain the desirable mechanical properties for steel or alloys by heat treatment. In heat treatment temperature variation with time is basic parameter to alter mechanical property of the component. If this variation is proper so that phase transformation is according to part application requirement, because the basic requirement of mechanical properties is different for different environment.[1]

In this paper a grade of steel 45C8 has been taken for experiment purpose in highly stressed application and number of heat treatment processes has been carried out which impart the optimum value of mechanical properties. In these heat treatment processes a variation is made over temperature and time and optimum value has been selected. The most important heat treatments are Stress relieving, Annealing, Normalizing, Hardening and Tempering.

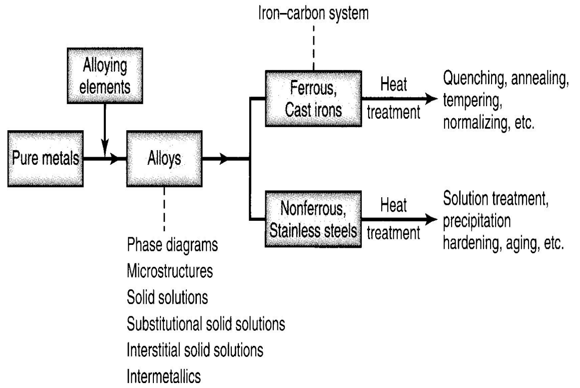

Figure 1. An outline of various Heat treatment processes for various materials.

II. MATERIAL DETAILS

As we are taking the samples of workpiece, which is to be tested to know the mechanical properties with the chemical composition as mentioned below [4]:

Table 1.

C	Si	Mn	P	S
0.10-0.45	0.15-0.35	0.65-0.90	0.30 max	0.30 max
Cr	Mo	V	Cu	Ni
0.25 max	0.045 max	0.045 max	0.30 max	0.25 max

III. HEAT TREATMENT OPERATION

1. ANNEALING

a) The specimen was heated up to a temperature of 950̊ C.
b) At temperature 950̊ C the specimen was held for 2 hour.
c) Then the furnace was switched off so that the specimen temperature will decrease with the same rate as that of the furnace the objective of keeping the specimen at 950̊ C for 2 hrs is to homogenize the specimen. The temperature 950̊ C lies above re-crystallization temperature. So that the specimen at that temperature gets sufficient time to get properly homogenized .The specimen was taken out of the furnace after 1 day when the furnace temperature had already reached the room temperature.[2]

2. NORMALIZING

a) At the very beginning the specimen was heated to the temperature of 950̊ C.
b) There the specimen was again kept for 2 hour.
c) Then the furnace was switched off and the specimen was taken out.
d) Now the specimen is allowed to cool in the ordinary environment i.e. the specimen is air cooled to room temperature. The process of air cooling of specimen heated above re-crystallization is called normalizing.

3. QUENCHING

This experiment was performed to harden the 45C8. The process involved putting the red hot specimen directly in to a liquid medium.

a) The specimen was heated to the temp of around 860̊ C and was allowed to homogenize at that temp for 2 hour.
b) An oil bath was maintained at a constant temperature in which the specimen had to be put.
c) After 2 hour the specimen was taken out of the furnace and directly quenched in the oil bath.
d) After around half an hour the specimen was taken out of the bath and cleaned properly.
e) Now the specimen attains the liquid bath temp within few minutes. But the rate of cooling is very fast because the liquid doesn't release heat readily.

4. TEMPERING

Tempering is the one of the important experiment carried out with the objective of the experiment being to induce some amount of softness in the material by heating to a moderate temperature range.

a) Firstly all the six specimens were heated to from 250̊ C to 750̊ C for 2 hour.
b) The hardness of all six specimens was calculated.
c) Now again all six specimens were heated to 860̊ C and after quenching in the oil bath then again heating to 250̊ C to 750̊ C for 2 hour.[3]

IV. PARAMETERS; WHICH IS TO BE OPTIMIZED

The parameters which are to be considered during the whole optimization process are carbon content, heating temperature, holding time and time of quenching; which affect the hardness of the metal to be heat treated used for the Taguchi design.[5]An orthogonal array was formed to design and optimize the required data responsible for the calculation of signal to noise ratio ,which is the important properties from the measurement point of view. Nine experiments were conducted by varying all of these parameters ; the details of which are listed below[11]:

Table 2.

S.No.	Parameters	Notations	Units	Range
1	Carbon content	CC	%	0.10-0.45
2	Heating temperature	HT	℃	870-930
3	Time of holding	TH	Min	180-240
4	Time of quenching	TQ	Min	20-40

V. METHODOLOGY

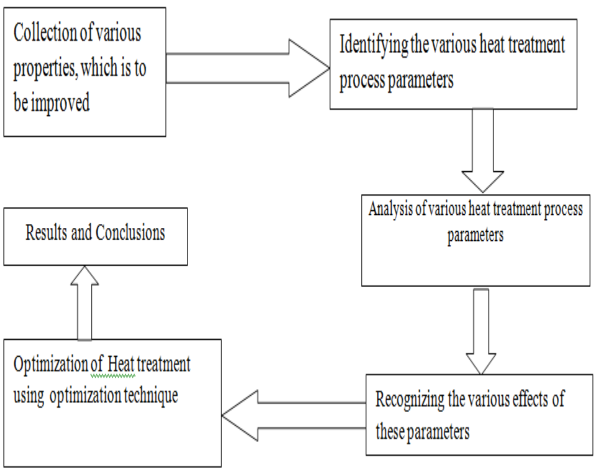

Figure 2. METHODOLOGY

VI. STEPS INVOLVE IN TAGUCHI METHOD

The use of Taguchi's parameter design involves the following steps:-

1. Forming the main function and recognizing its side effects.
2. Calculating the noise factors, testing condition and quality characteristics.
3. Identifying the objective function to be optimized.
4. Specify the control factors and their levels.
5. Selection of a suitable Orthogonal Array and formation of the Matrix.
6. Conduction of the Matrix experiment.
7. Examine the data; predict the optimum control factor levels and its performance.
8. Conduct the verification experiment.

VII. OPTIMIZATION OF PROCESS PARA- METERS TO IMPROVE THE HARDENING AND CASE DEPTH

The purpose of this paper is to fulfill the criteria of optimization under which the improvement in properties occurs. There are some proper steps by which the properties will be optimized are falls under this categories:

1. To make a list of parameter involved which are mostly responsible for the causes of changing properties.
2. Properties is mainly considered as the most important factor in rejection of a workpiece .
3. Based on the experimental conditions, collect the data related with heat treatment process which is collected by orthogonal array and parameter level.
4. Now optimize the all individual parameter at the optimized level by using the optimization techniques.
5. Verify the optimum settings result in the predicted improvement in the properties.
6. The main causes of rejection of workpiece are due to improper mechanical properties such as hardness and depth of casing. The process parameters of the heat treatment process can be listed as follows:

- Carbon Content (%)
- Heating Temperature (℃)
- Time of holding (Min)
- Time of Quenching (Min)

For each parameter during a process a range is decided between the different levels which optimize the parameter to a certain level and is acceptable in the foundry of an organization for the purpose showing the improvement in properties by heat treatment. The parameters, along with their ranges and different levels are carbon content ,heating temperature , time of holding and time of quenching are given in the following Table (a) .The parameters; which affect the hardness of the metal to be heat treated used for the Taguchi design. An orthogonal array was formed to design and optimize the required data responsible for the calculation of signal to noise ratio ,which is the important properties from the measurement point of view. Nine experiments were conducted by varying all of these parameters.[10]

Table 3. (a) Parameters ,which is to be optimized

S.No.	Parameters	Range	Level-1	Level-2	Level-3
1.	Carbon Content (%)-A	0.20-0.40	0.20	0.30	0.40
2.	Heating Temperature (℃)-B	870-930	870	885	900
3.	Time of holding (Min)-C	180-220	180	200	220
4.	Time of Quenching (Min)-D	20-40	20	30	40

VIII. MEASUREMENT OF QUALITY CHARACTERISTICS BY TAGUCHI METHOD

Surface hardness was selected as a quality characteristic to be measured. The larger the better number of surface hardness implies better process performance.[8]

As hardness to be maximized keeping the process parameters optimized so accordingly signal to noise ratio was calculated by considering "larger is better" criterion. S/N ratio was calculated by following Equation :

$$S/N = -10 \times \log_{10} [1/n. \sum_{i=1}^{n} (1/X_i^2)] .$$

Where S/N is performance statistics, n is the number of repetitions for an experimental combination; and "X_i" is performance value of the i-th experiment. In the current work, for any given experimental combination only one trial was carried out hence n=1 and the equation can be rewritten as

$$S/N = -10 \times \log_{10} [(1/X_i^2)] .$$

The S/N ratio corresponding to L9 orthogonal array are also included in Table 3. Then the mean S/N ratios at each level for various factors have been calculated.

The optimum levels were selected as the largest S/N ratio among all the levels of the factors. In order to evaluate the influence of each factor on the hardness value, the S/N ratio for each factor was computed. The S/N ratio for single factor can be calculated by averaging the values of S/N ratios at different levels.[9]

IX. A. FORMATION OF ORTHOGONAL ARRAY L9

Formation of an orthogonal array depends upon the number of control factors and interaction of interest. It also depends upon number of levels for the control factors of interest. Therefore with one control factor carbon content of two levels and other control factors Heating Temperature, Time of holding & Time of Quenching and orthogonal array is selected with 9 experimental runs and four columns. Taguchi has provided in the assignment of factors and interaction to arrays. The assigned L9 orthogonal array is shown in Table (b) and the experimental orthogonal array having their levels are assigned to columns is shown in Table (c).

Table 4. (b) Orthogonal Array L9

Trail No.	A	B	C	D
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

IX.B. EXPERIMENTAL ORTHOGONAL ARRAY L9

An experimental orthogonal array by the help of orthogonal array is to be formed as given in the table (c)

Table5. (c) Experimental Orthogonal Array L9

Trial No.	**A** Carbon Content (%)	**B** Heating Temperature (°C)	**C** Time of holding (Min)	**D** Time of Quenching (Min)
1	**0.2**	**870**	**180**	**20**
2	**0.2**	**885**	**200**	**30**
3	**0.2**	**900**	**220**	**40**
4	**0.3**	**870**	**220**	**30**
5	**0.3**	**885**	**180**	**40**
6	**0.3**	**900**	**200**	**20**
7	**0.4**	**870**	**200**	**40**
8	**0.4**	**885**	**220**	**20**
9	**0.4**	**900**	**180**	**30**

X. RESULTS OF EXPERIMENT & S/N RATIO

The result of this experiments is obtained by conducting one time for the same set of parameters using a single-repetition randomization technique .The hardness value of the surface of specimen that occur in each trial conditions were found and recorded. Therefore the conclusion derived by considering the utilization of various parameters and desired Hardness value, the best value chosen is Taguchi Approach for "Larger the better" which is 210 BHN. Larger the better S/N ratios were computed for each of the 9 trials and the values are given in Table (d):

Table 6. (d) Hardness Value and Signal to Noise (S/N) Ratio against Trial Number

Trial No.	Properties taken in Experiments				Hardness Value (BHN)	S/N Ratio
	A	B	C	D		
1	0.2	870	180	20	180	45.1054
2	0.2	885	200	30	192	45.6660
3	0.2	900	220	40	203	46.1499
4	0.3	870	220	30	195	45.8006
5	0.3	885	180	40	200	46.0205
6	0.3	900	200	20	205	46.2350
7	0.4	870	200	40	203	46.1499
8	0.4	885	220	20	207	46.3194
9	0.4	900	180	30	210	46.4443

XI.A. MEAN EFFECT PLOTS TABLE FOR S/N RATIO

Table 7. for the mean effects plots for S/N Ratio is as Follows:

Level No.	Carbon Content (%)-A	Mean S/N Ratio	Heating Tempera-ture (℃)-B	Mean S/N Ratio
1	0.2	45.6404	870	45.6853
2	0.3	46.0187	885	46.0019
3	0.4	46.3045	900	46.2764
Level No.	**Time of holding (Min)-C**	**Mean S/N Ratio**	**Time of Quench-ing (Min)-D**	**Mean S/N Ratio**
1	180	45.8567	20	45.8866
2	200	46.0169	30	45.9703
3	220	46.0899	40	46.1067

XI.B. MEAN EFFECT PLOTS FOR S/N RATIO

Following four types of graphs are represented from the subject point of view as shown in graph (a) and graph (b).

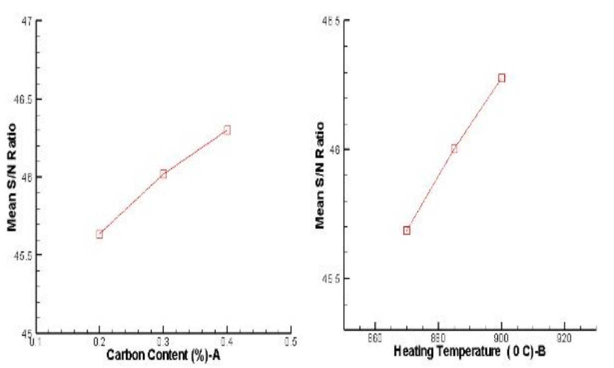

Figure 3. Graph (a) Mean S/N ratiov/s carbon content (%) and heating temperature (℃)

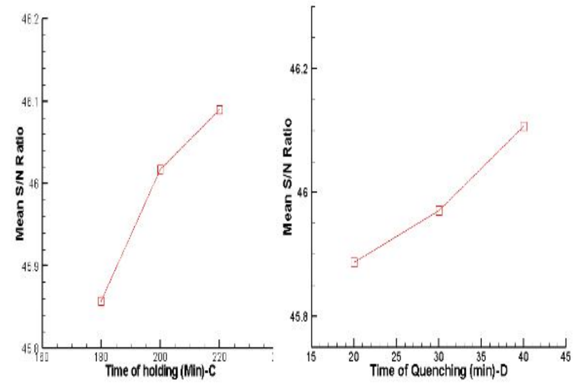

Figure 4. Graph (b) Mean S/N ratio v/s time of holding (min) and time of quenching (min)

XII. COMPUTATION SCHEME OF PARETO ANOVA FOR THREE LEVEL PARAMETERS

The general scheme of computation of Pareto ANOVA was given in the Table (e). Pareto ANOVA computation was done by using the S/N ratios of the process parameters to predict the optimal parameter level combination as well to determine the most influencing process parameter involved in this study.

Table 8. (e) General Scheme for Pareto ANOVA computation:

Parameters		A	B	C	D	Total
SUM	1	ΣA_1	ΣB_1	ΣC_1	ΣD_1	T= ΣA_1 + ΣA_2 + ΣA_3
	2	ΣA_2	ΣB_2	ΣC_2	ΣD_2	
	3	ΣA_3	ΣB_3	ΣC_3	ΣD_3	
SSD		S_A	S_B	S_C	S_D	$S_T= S_{A+} S_{B+} S_{C+} S_D$
Degree of Freedom		2	2	2	2	8
Contribution Ratio		$(S_A/S_T)*100$	$(S_B/S_T)*100$	$(S_C/S_T)*100$	$(S_D/S_T)*100$	100

XIV. CALCULATIONS

For Level 1 :

ΣA1=(45.1054 +45.6660 +46.1499)= 136.9213
ΣB1=(45.1054+45.8006+46.1499)= 137.0559
ΣC1=(45.1054+46.0205+46.4443)= 137.5702
ΣD1=(45.1054+46.2350+46.3194)= 137.6598

Similarly we can calculate the values for Level 2 and 3.

SA=(138.0561-136.9213)2+(138.9136-138.0561)2+(138.9136-136.9213)2=5.9923

Similarly we have calculated the values of SA,SB and SC for different parameters A,B and C respectively.

XV. CONCLUSION

1. Taguchi Approach

The optimum conditions for the parameter computed for the hardness of the desired workpiece are given below as-

Carbon Content (%)– level 3 – 0.4
Heating Temperature (℃)– level 3 – 900
Time of Holding (Min)– level 1 – 180
Time of Quenching(Min)– level 2 – 30

The optimized expected hardness of the surface is 210 BHN under the methods of non-destructive testing and Taguchi methods .This also reflect that by using Taguchi method the factor levels when optimized will result in increment of surface hardness and increase the yield percentage of the accepted casting product without any additional investment.

A usage of quality tools like Pareto chart is useful for finding the surface hardness in the daily operations of foundry. Quality of surface can be improved by aesthetic look, dimensional accuracy, better understanding of noise factor and interaction between variables, quality cost system based on individual product, scrap reduction, reworking of casting and process control.

2. ANOVA Approach

The Pareto ANOVA computation was performed for hardness and was given in Table V. From the Table V, it can be inferred that the process parameter A (Carbon Content) is the most influential parameter with the contribution ratio of 49.30 % towards the improvement of hardness exhibited by the mild steel components.

XVI. FUTURE SCOPE

The present method adopted to solve the optimization problem of heat treatment process is simple enough and is flexible in selection of objective functions for such manufacturing processes. During the solution of the problem, it has been found that the results obtained by the Taguchi method towards the exact solutions. This approach may be coupled to other optimization algorithms to get multistage multi-criterion optimization by Taguchi approach. Then this method will be able to show its importance in real life complex manufacturing problem solution. The use of ANOVA analysis is also done to find the satisfactory result for the parameter which mostly affects the hardness of the material.

REFERENCES

[1] Kalpakjain Serope and Schmid S.R., ”PRODUCTION TECHNOLOGY”.

[2] Rajan T.V; Sharma C.P. and Sharma, A., Heat Treatment Principles and Techniques.

[3] Krauss G., Steels: Heat Treatment and Processing Principles, ASM International, OH, USA, 1989.

[4] Metals handbook 9th ed., American society for metals, vol.9, 1985.

[5] Raymond A. and Higgins B., Properties of Engineering Materials. Hooder and Stonghton.

[6] S. K. Putatunda and P. K. Gadicherla ; Materials Science and Engineering A, 268(1999) 15-31.

[7] Effect of heat treatment on mechanical properties of mild steel -A. Adebayo and J.T. Stephen.

[8] Optimization of Heat Treatment Processes Using Taguchi’s Parameter Design Approach by- 1-V.K. Murugan, 2-Dr.P. Koshy Mathews(ISSN Online:2347-5188 Print: 2347-8772) .

[9] P. J. Ross: “ Taguchi Techniques for Quality Engineering “ , McGraw Hall, New York, 1988.

[10] ASM metals Hand Book, 1981.

[11] Zhen Song 40531165,University of Science and Technology Beijing, Dept. of M.S.E Work on “Effect of Heat Treatment on the Microstructure and Mechanical Properties of Steel”.