Optimization of Flame Hardening Process Parameters Using L9 Orthogonal Array of Taguchi Approach

S. Jeyaraj, K.P.Arulshri, K. P. Harshavardhan, P.S.Sivasakthivel

Abstract—**Flame hardening is a surface heat treatment process with the application of hot flames obtained from an oxy acetylene gas mixture. About 3000ºC temperature level of gas flame is exposed to work piece material, and bring it out into red hot stage or recrystallization temperature and suddenly quenched by water immediately. Due to these drastic micro structural changes, leads the increase of surface micro hardness. It is mainly influenced by surface temperature, stand-off distance and quenching time. This research article aims with studying the influences of process parameters of flame hardening process by the robust design method. The medium carbon steel specimens were hardened by flame hardening process by adjusting the process parameters. The primary process parameters such as surface temperature of specimen, stand-off distance (SOD) and quenching time were the primary process parameters were investigated experimentally by Taguchi`s approach. L9 orthogonal array was implemented for design of experimental trials based on parameters and its levels. Micro-hardness values of specimens were examined using Vickers micro-hardness tester with the payload of 100g. Optimization model has been developed for micro hardness on the basis of experimental results. The effects of process parameters were analysed by S/N ratio and ranked by order. The optimal parameters were obtained from the S/N ratio analysis has been authorized by confirmatory tests. It was found the greater micro hardness value 801 HV was obtained by the optimal parameters given by taguchi optimization. Such approach is economic one, reduction of experimental trails which will be very suitable for the heat treatment industries.**

Index Terms- **Flame hardening; micro-hardness; orthogonal array; surface temperature; standoff distance; quenching time;**

I. INTRODUCTION

Flame hardening is a process in which the surface of a material is heated to high temperatures with direct application of Oxy – Acetylene gas flame, followed by a water quenching process. A mixture of oxygen and acetylene is used for heating up of work pieces up to red-hot conditions. Flame hardening procedures are used in various Engineering applications to improve the mechanical properties of components.

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Flame hardening method additionally results in an increase in fatigue strength behaviours and most cost-effective hardening method. Lee et al. [1] investigated that the control of surface hardness, hardness depth and residual stresses are dependent on conditions such as surface temperature, cooling rate and exposed height from the water surface in flame hardening of low carbon 12Cr steel. As increase in cooling rate, hardening depth and hardness is additionally accrued.

Lee et al. [2] reported that the enviable residual stresses and hardness were obtained in between the temperature levels of 870˚ to 960˚c. Stress corrosion cracking, brittle fracture, fatigue failures are main associated failures while carrying out the flame hardening [3],[4],[5],[6] due to improper selection and control of thermal process parameters. Grum et al. [7] focused on increasing the hardness by mechanized flame hardening procedure, conversely the optimal process parameters were not considered. Previous experimental investigations were conducted by randomized manner.

Selection of process parameters also has not been in proper categorization. It is needed that to investigate the effects of process parameters by systematic and standardised procedures. In preceding studies design of the experimental approach was not followed to investigate the effects of flame hardening parameters. The significances of flame hardening parameters and its outcomes are not explored by taguchi optimization studies. Hence, the above mentioned aspects are the motivations for this experimental study to investigate the flame hardening procedures using taguchi approach by orthogonal array studies. In this investigation, parameters such as specimen temperature, standoff distance and quenching time were considered for experimental study. In this study, the Taguchi's approach was preferred to study the effects of major process parameters. L9 Orthogonal array was preferred for experimental design based on three parameters with three levels.

II. L9 ORTHOGONAL ARRAY

For the systematic approach of experimental work, Design of Experiment was used to make a robust design [13]. A robust design is made with a system of design tools to decrease variability in product or process, simultaneously guiding the performance towards an optimal setting. Taguchi's approach to robust design is one of the important methods. Taguchi method is based on performing evaluation or experiments to test the sensitivity of a set of response variables to a set of control parameters by considering experiments in orthogonal array [8, 9, 10 and 11] with an aim to attain the optimum setting of the parameters to be controlled. Table 1 shows the layout of L9 Orthogonal array.

Table 1 .L9 Orthogonal Array

Experiments Run order	P1	P2	P3
	Levels		
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

III. EXPERIMENTAL SETUP

A. Materials and method

The flame hardening experimental setup and the accessories are shown in fig 1. The flame torch is mounted on clamp holder and positioned in vertical. Oxy- acetylene gas cylinders were connected to the circuit to supply the gas mixtures to required quantity and pressure. A neutral type flame was employed for all experimental conditions. The test specimens made up of medium carbon steel (Compositions: C-0.56%, Mn-0.73%, Si-0.10%, S-0.048%, P-0.05%, Fe-98.5%) of size 25.4 x 25. 4 x 5mm^3 were employed for flame hardening treatment. Totally nine medium carbon steel specimens of above sized were taken for experimental work. A small hole was drilled in all specimens to insert the thermocouple end. The flame torch was mounted on the holder which is clamped in vertical stand. The standoff distance (S.O.D. - Distance between gas torch tip to the specimen) was attuned by an adjustable clamp on holder. Each specimen was located at the bottom of torch tip and the S.O.D. attuned to essential height of distance. The pressure of the Oxy- acetylene gas mixture set out from torch tip was maintained constantly and ignited by spark igniter. The burning high temperature flame was exposed to the specimen surface and heated up uniformly. A contact type thermocouple (K-type - 1200ºC) was employed to measure the specimen's temperature. After the attainment of specified temperature, specimens were quenched with injection of water to the stipulated time. A small water pump was used to supply the water for quenching with constant volume of discharge. A digital type stop watch was used to monitor the quenching time. The experiments were accomplished based on the run orders of L9 orthogonal array given in the table 2 for the experimental conditions.

Table 2.Experimental Parameters

Parameters	Level 1	Level 2	Level 3
A.Temperature -°C	750	850	950
B.Stand off Distance - mm	10	20	30
C.QuenchingTime [Sec.]	10	25	50

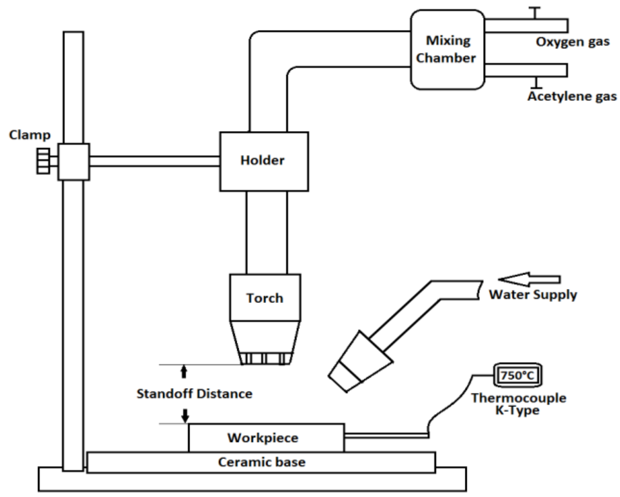

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Fig. 1 Experimental setup

B. Surface morphological studies and Micro hardness

Subsequent to the completion of experimental work, flame hardened specimens were polished for investigation of surface morphologies. The specimens were cleaned and polished through metallographical procedures. The degreased specimens were etched with Nital solution and undergone to microscopic investigations. A high transmission trinocular metallurgical microscope (KYOWA, Japan) integrated with CCD camera (WATEC, Japan) was employed to absorb the microstructures of specimens before and after hardening. The microstructures of specimens were engrossed in different magnifications. The micro hardness of the specimens was determined from Vickers micro hardness tester (SHIMADZU Corporation, Japan) with the pay load of 100gram force for 10sec of indentation. Average micro hardness of the specimen before hardening was about 242 HV.

Table 3. Experimental Trail

Trail No.	A	B	C	Micro Hardness HV
1	750	10	10	449.5
2	750	20	25	572.5
3	750	20	50	329
4	850	10	25	587.5
5	850	20	50	508
6	850	30	10	697
7	950	10	50	521
8	950	20	10	424
9	950	30	25	773.5

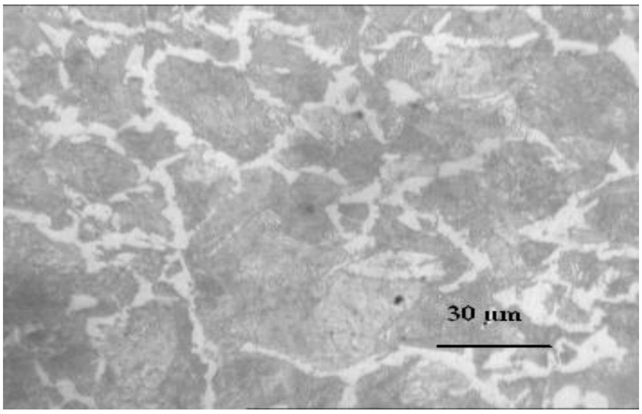


Fig. 2 (a). Before flame hardening 400x

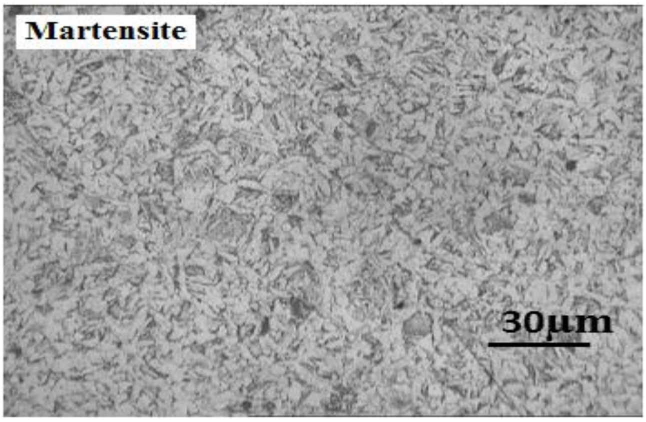


Fig.2.(b).After Flame hardening Magnification 100x

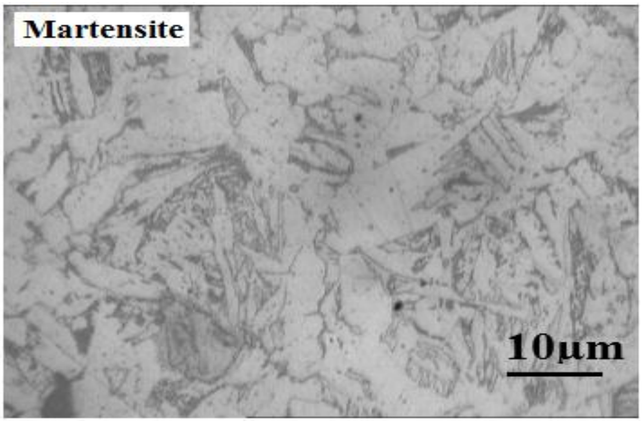
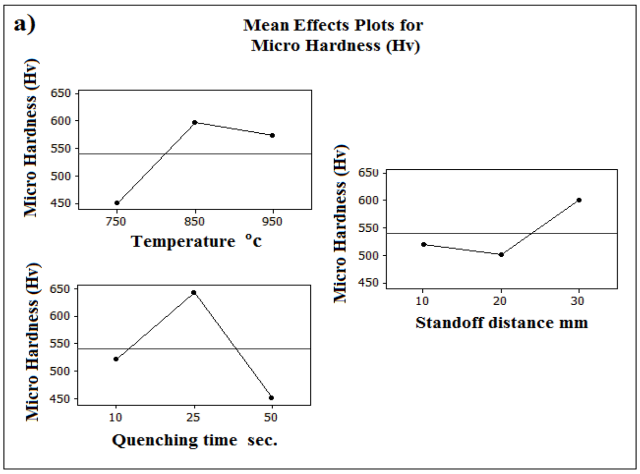


Fig.2 (c).After Flame hardening Magnification 400x

IV. RESULTS AND DISCUSSION

The microstructure of the specimen before flame hardening is shown in Fig.2 (a). Fig.2 (b) and (c) shows the microstructures after hardening for the trail no.9. It has been observed that the micro hardness of all specimens was found to be distorted after flame hardening. It is the evident from Fig. 2 (b & C) that the complete formation of martensite structure after hardening treatment. Micro hardness of the hardened specimens was speckled between 329 HV to 773.5 HV for the experimental trials. In order to analyze the main influences of process parameters on micro hardness, the taguchi technique study has been implemented. The Minitab 16 software was utilized to analyse the effect of process parameters by Taguchi's approach. The mean effects and S/N ratio plots for process parameters were shown in Fig.3.a &b.



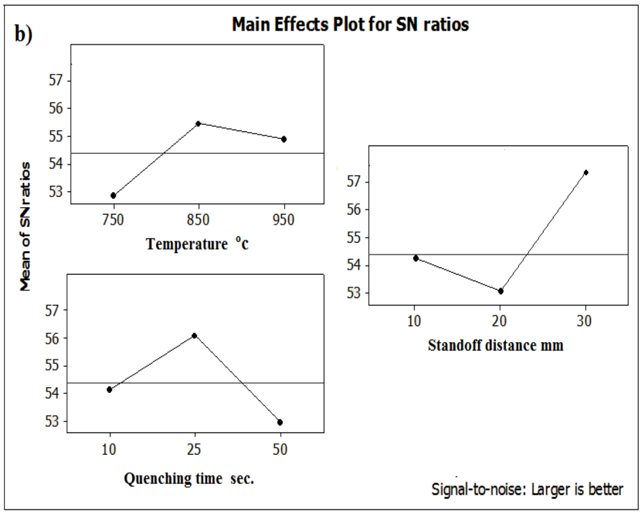


Fig. 3. a) Mean effect plots and b) S/N ratio plots for process parameters.

A. Consequence of Design of experiments

The design of experiments methodology is an imperative tool applied in investigation and modeling of process parameters and factors involved in an experimental study. It is used to analyze influence of various factor involved in an experimental process on the outcome. The outcomes of the experiment are also called response variables and the input factors are known as process variables. To get better results of experimental study the Analysis of variance terminology can be implemented to investigate the process variance and the significances of each factor to the response variables [12].

B. Analysis of S/N Ratio

It is the need to analyse the S/N ratio value from the experimental data to compute the average S/N response for each factor. From the mean S/N response value, the optimum Flame hardening conditions for each design parameters can be identified and the design parameters can be ranked according to their impact on the response parameter. The method stated previously followed in calculating the average S/N response value.

C. Determination of S/N ratio

In this experimental design, surface hardness is the response variable which needs to be maximized and hence larger the better characteristics was opted for this set of experimental investigation. The equation is given by,

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_{ij}}^{2}}\right) \qquad (1)$$

Here *n* is equal to 2 since the experimental work was replicated for two times. S/N ratio was calculated for the various combinations of experimental data and their corresponding values were put into a table 4.

Table 4: S/N Ratio

Trail No.	Micro Hardness HV	S/N Ratio
1	449.5	59.07
2	572.5	61.18
3	329	56.36
4	587.5	61.40
5	508	60.13
6	697	62.88
7	521	60.35
8	424	58.56
9	773.5	63.79

Table 5: Mean S/N response value for Flame Hardening

Parameter	Level 1	Level 2	Level 3	Max-Min	Rank
A -	58.87	**61.47***	60.9	2.6	**2**
B -	60.27	59.95	**61.01***	1.06	**3**
C -	60.17	**62.12***	58.94	3.18	**1**

The mean S/N ratio values of process responses are shown in table 5. From the response table, largest value of mean S/N ratio response was taken from each process parameter and marked with *. These marked levels are recognized as the optimum parameters to accomplish better micro hardness. It is evident from the S/N ratio response table that the optimum flame hardening conditions to achieve maximum micro hardness are A2- Temperature - 850°C, B3-Standoff distance- 30mm, C2-Quenching time- 25 Seconds from table 2.

C. Determination of S/N ratio

In order to conform, the optimum level of parameters for the attainment of maximum micro hardness obtained from S/N ratio analysis, confirmatory test was conducted. The optimal conditions obtained from taguchi optimization are given in table 6. By setting temperature-850°C, standoff distance-30mm and quenching time-25 seconds the confirmatory test was performed. As a result, maximum micro hardness of 801 HV was obtained from above set of optimal parameter conditions.

Table 6: Confirmatory test results

Sl. no.	Temp. °C	S.O.D mm	Quenching time Sec.	Obtained Micro Hardness HV
1	850	30	25	801

V. CONCLUSIONS

In general, selection of process parameters and its levels for experimental work is carried out by conventional methods such as trial and error method; prior work experience, handbooks and field expert are enormously tedious and time overwhelming method. The design of experiment (DOE) provides a robust design approach and it consents the minimization of experimental effort. Experimental outcomes are estimated based on statistical techniques and the influences of process parameters on experimental results can be measured. In this study, we investigated the flame hardening process parameters by DOE analysis of Taguchi's approach. The main influences of process parameters and its effects were analyzed thoroughly and the parameters were optimized for maximum micro hardness. The following observations have been observed from this study.

- The experiment trails were accomplished by adjusting the primary process parameters of flame hardening by robust design method.
- It is a new approach for flame hardening process by framing of experimental design by L9 orthogonal array to investigate the influences of process parameters.
- It was observed that the micro hardness of all specimens was increased after flame hardening process. The highest Micro hardness value is about 773.5 HV obtained from the trial 9 for the conditions of temperature 950°C, standoff distance 30mm and quenching time of 25 seconds.
- The least Micro hardness value is about 329 HV obtained from the trial 3 for the conditions of temperature 750°C, Standoff distance 20mm and quenching time of 50 seconds.
- Mean effect study and S-N ratio analysis were conducted to investigate the influences of process parameters.
- Through S/N ratio analysis it has been found that the micro hardness value mainly depends on the process parameters with the rank order of 1.Quenching time, 2.Temperature and 3.Standoff distance respectively.
- The results of mean effect plot were also closer to the optimal parameter levels obtained from the S-N ratio analysis.
- Confirmatory test was conducted for the optimal process parameters and maximum micro hardness obtained was about 801 HV.
- It is an essential to formulate a technique to analyze the influences of process parameters by a robust design method that would obtain specified level of end properties.

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