Taguchi Optimization and Flame Hardening Experimental Investigation on Eglin Steel

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Abstract. Flame hardening was one of the surfaces hardening methods to improve the substance behaviors. It was a rapid and economical method to harden the selected surface of the material. It is suitable for all types of steels, particularly wear resistant steel. The hardening of the material was achieved through heating the material and then followed by quenching process. Eglin steel was one of the wear resistant steel which was considered for the experimental work. After the surface of flame hardening of it, Brinell hardness was found through the input factors such as surface temperature, standoff distance (SOD) and quenching time. The Taguchi optimization was used to analyze the effect of flame hardening factors and it has provided the optimal solutions. The involvement factor was studied through the variance test.

1. Introduction
The flame hardening was operated at high temperature of flame of oxy-acetylene gas. Sometimes, propane gas was also used. The wear behavior was gradually increased. It was used in hardening the blades, rollers, gears, cam and automotive parts. It was one of the best methods to achieve high hardness with low cost. The knife quality of the steel was decide by forging and flame hardening processes [1]. The laser hardening of EN25 steel and its micro structure was studied [2]. The hardening of 1060 steel was discussed and its micro hardness has been improved [3]. The role of temperature and cooling rate was investigated in blaze hardening of chromium steel [4]. The mechanical behaviors were improved after quenching of steel in grinding process [5]. The hardening parameters have been optimized and its effects were reported in chromium steel [6-7]. The fast cooling rate was affecting the hardness of the material. The residual stresses of low carbon steel and its surface hardening factors were optimized [8]. The developed mathematical model and optimization was used...
to predict the hardness [9]. The austenite transformation, microstructure and hardness were reported on heat treated steel [10]. Many investigates based on the Taguchi technique, response surface methodology, and the variance analysis to predict the optimum performance of mechanical, wear, corrosion behaviour of composites and mechanical / structural analysis of parts of the system in the automobile industry [11-41].

The present experimental idea was discussed about the flame hardening of eglin steel and its factors were optimized with the aid of Taguchi technique.

2. Experimental methods

The experimental setup for flame hardening process was exposed in Fig.1. The flame torch, oxy acetylene cylinders, pressure regulators and temperature indicator were the main components of flame hardening method. The neutral flame which was contains equal amount of oxygen and acetylene. The thermocouple was used to determine the surface temperature of the work piece. The standoff distance between the work piece and nozzle was maintained. The high temperature of the flame was focused on the surface of the work piece. The work piece was immediately quenched when it has reaches the austenizing temperature. The eglin steel was contains different alloying elements such as carbon (0.3%), silicon (0.7%), manganese (1.6%), phosphorous (0.02%) and sulfur (0.01%). The experimental arrangement was revealed in Fig.1.

![Figure 1. Flame hardening set up](image)

3. Experimental outcomes and detailed discussion

The hardening was depends on intensity of flame, amount of heat applied, surface temperature and composition of materials. The Brinell with tungsten carbide ball indenter was used to measure the hardness after flame hardening process. The size of the plate specimen was 100 x 80 x 40 mm.

| Exp.No. | Temperature(°) | SOD (mm) | Quenching time (sec) | Hardness (HBW) |
|---------|----------------|----------|---------------------|----------------|
| 1       | 800            | 20       | 40                  | 440            |
| 2       | 800            | 30       | 50                  | 448            |
| 3       | 800            | 40       | 60                  | 445            |
| 4       | 900            | 20       | 50                  | 460            |
4. Taguchi method
The experimental design was carried out with respect to the orthogonal array (L9). The purpose of the experiment was to increase the hardness. Due to its condition, the larger the better criterion was used to determine the signal to noise ratio. The estimated SN ratio and mean was listed in Table 2 and 3.

Table 2. SN ratios for flame hardening

| Levels | Water pressure (bar) | Traverse speed (mm/min) | Abrasive flow rate (gm/mm) |
|--------|----------------------|-------------------------|----------------------------|
| 1      | 3000                 | 30                      | 75                         |
| 2      | 3500                 | 60                      | 150                        |
| 3      | 4000                 | 90                      | 225                        |

Table 3. SN ratios for flame hardening

| Level | Temperature | SOD | Quenching time |
|-------|-------------|-----|----------------|
| 1     | 444.3       | 463.3 | 477.3       |
| 2     | 470.7       | 477.3 | 476.0       |
| 3     | 507.3       | 481.7 | 469.0       |
| Delta | 63.0        | 18.3 | 8.3          |
| Rank  | 1           | 2    | 3            |

The Fig.2 was shown that the effects of SN ratio to the response such as hardness. The surface temperature, standoff distance and cooling time was the important factors for flame hardening. The experiment aim was to achieve the maximum hardness. It was gained at surface temperature of 1000ºC, standoff distance of 40mm and cooling time of 40 seconds. The hardness was increased due to the high temperature of oxy acetylene flame.
Figure 2. SN ratio graph for flame hardening
The role of flame hardening factor was determined through variance analysis and it was exposed in Table 4. It was clearly shown that the developed model was within accepted limit (P-Value is less than 0.05). From the table individual factor effect and combined factor effects were also determined. The surface temperature has the maximum value of F (60.96). Hence, the surface temperature was provided the highest role on Brinell hardness. It was validated through Pareto chart and it was shown in Fig. 3. From the chart, the combined parametric effects were also mentioned. The standoff distance was the second highest role factor on the response.

Table 4. Variance test for flame hardening

| Basis                  | DF | Adj. SS    | Adj. MS    | F-Value | P-Value |
|------------------------|----|------------|------------|---------|---------|
| Model                  | 6  | 6635.90    | 1105.98    | 24.86   | 0.039   |
| Linear                 | 3  | 3043.20    | 1014.40    | 22.80   | 0.042   |
| Temperature            | 1  | 2712.05    | 2712.05    | 60.96   | 0.016   |
| SOD                    | 1  | 190.72     | 190.72     | 4.29    | 0.174   |
| Quenching time         | 1  | 7.29       | 7.29       | 0.16    | 0.725   |
| 2-Way Interactions     | 3  | 74.07      | 24.69      | 0.55    | 0.694   |
| Temperature*SOD        | 1  | 29.17      | 29.17      | 0.66    | 0.503   |
| Temperature*Quenching time | 1 | 1.93      | 1.93       | 0.04    | 0.854   |
| SOD*Quenching time     | 2  | 1.93       | 1.93       | 0.04    | 0.854   |
| Error                  | 2  | 88.98      | 44.49      | ---     | ---     |
| Total                  | 8  | 6724.89    | ---        | ---     | ---     |

Figure 3. Parametric effects for flame hardening

5. Conclusions
The following conclusions are drawn from the above experimental study:

- The Flame hardening experimental investigation was conducted on eglin steel with the aid of high temperature flame of oxygen acetylene flames.
- The optimal solution of flame hardening was achieved through Taguchi technique.
• The maximum hardness was gained at surface temperature of 1000ºC, standoff distance of 40mm and cooling time of 40 seconds.

• The developed model was validated through variance analysis.

• From variance test and Pareto chart, the surface temperature was the essential role played on hardness.

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