Quality Improvement in Hot Dip Galvanizing Process Using Robust Design tools

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Abstract

This paper deals with the concept of quality engineering and robust design as one of the new practical methods for the improvement of galvanizing parameters design in order to obtain the best mechanical properties (hardness) by experimental design and robust design tools. By using Taguchi parameter design, three factors (controllable factors) were chosen, which are temperature, time, and withdraw speed, along with three levels for each factor to determine their effect on the hardness in galvanizing steel in order to obtain better quality levels. A L₂⁷(3³) orthogonal array was selected and used in this experiment.

Minitab software was used in design and data analysis to achieve the desired quality objectives. Results show that the best combination to achieve a desired hardness were (T=455 °C, t=4 min., and S=6 m/min ). The experiment also revealed that the temperature and time have the largest effect on the hardness. In addition, the optimum condition was verified during the optimization stage using central composite design.

Key words: Quality engineering, Taguchi design, Hot dip galvanizing coating, Orthogonal array, Robust design.

1. Introduction

Quality Engineering (QE) is an interdisciplinary science which is concerned with not only producing satisfactory products for customers but also reducing the total loss (manufacturing cost plus quality loss). Hence, QE involves engineering design, process operations, after – sales services, economics and statistics. Taguchi’s impact on the concept of quality control in the manufacturing industry has been far-reaching. QE system has been used successfully by many companies all over the world. Taguchi extensively uses experimental designs primarily as a tool to design products more robust (which mean less sensitive) to noise factors.
Robust Design is based on the principle of optimization in which the objective function is defined as the signal to noise ratio which will help in finding those values of the design parameters at which the response is least sensitive to the different effects of noise factors. Robust design method has wide applications in practice, it has some limitations. In particular, it can only be used for optimizing single response problems. Several methods have been proposed to resolve multiple response problems (Fowlkes & Creveling, 1995; and Summers, 2000).

Design of Experiment (DOE) sometimes known as experimental design, is a major concern for many organizations today. It is a powerful technique used for exploring new processes, gaining increased knowledge of the existing processes and optimizing these processes for achieving world class performance.

Experimental design was first introduced and developed by Sir Ronald Fisher (Shyam, 2002) in the early 1920s at the Rothamsted Agricultural Field Station in London. In his early applications, Fisher used experimental design to determine the effect of factors such as rain, fertilizer, sunshine, condition of soil..etc., on the final condition of the crop. Since that time, much more development of the technique has taken place in the academic environment, but not as many applications in the manufacturing environment. Taguchi, a distinguished electrical engineer and statistician, carried out extensive research on experimental design techniques in the early 1950s. He was successful in integrating the statistical methods into the powerful engineering process for process optimization problems. He also has developed and promoted a powerful methodology for solving product and process quality related problems in industry and recommended the use of orthogonal arrays (OAs) for studying the effect of a number of process parameters (design parameters) or factors on the process output performance (product quality characteristic). Orthogonal arrays assist an experimenter to study a large number of parameters (factors) in a limited number of experimental trials and thereby slash the experimental budget and resources (Shyam, 2002; and Antony, 2003).

Taguchi’s parameter and tolerance design are important tools for robust design. The fundamental principle of robust design is to improve the quality of a product by minimizing the effects of the causes of variation without eliminating the causes. This is achieved by optimizing the product and process design to make the performance minimally sensitive to the various causes of variations (Phdake, 1989; Bagch, 1993; and Fowlkes & Creveling, 1995).

The present paper deals with the improvement of galvanizing parameters design in order to obtain the best properties by experimental design and robust design tools.
2. Materials and Methods

2.1 Materials

2.1.1. Steel

Hot rolled steel according to standard (BS EN 10025-GRADE S235JR). The main dimensions of the used samples were (150×150×3 mm). The chemical composition of the steel is given in Table 1.

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage %</td>
<td>0.110</td>
<td>0.341</td>
<td>0.022</td>
<td>0.011</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

2.1.2. Alkaline Cleaner (Degreasing)

The concentration and temperature of alkaline cleaner solution illustrated in Table 2 were used in cleaning the surface of the samples.

<table>
<thead>
<tr>
<th>Alkaline</th>
<th>Concentration (g/l)</th>
<th>Temperature (ºC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOH</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Na₂CO₃</td>
<td>80</td>
<td>70</td>
</tr>
</tbody>
</table>

2.1.3. Hydrochloric Acid (Pickling)

Hydrochloric acid (HCl) was used in the cleaning process (Pickling stage), it was dilute solution of HCl (12%) with an organic inhibitor at room temperature.

2.1.4. Flux

An aqueous solution of ZnCl₂:2NH₄Cl at density 12 ºB was used in the process of (fluxing stage).

2.1.5. Zinc

Special High Grade (SHG) 99.99% of zinc was used in this study; the zinc bath composition is given in Table 3 according to standard (ASTM B6).

<table>
<thead>
<tr>
<th>Pb</th>
<th>Fe</th>
<th>Sn</th>
<th>Cd</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0020</td>
<td>0.0600</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.0007</td>
<td>Bal.</td>
</tr>
</tbody>
</table>
2.2 Experimental Procedure

2.2.1. Surface Preparation
The steel samples were initially degreased by immersion in an aqueous solution of NaOH and Na$_2$CO$_3$ for 30 minutes and rinsed with water. Subsequently, they pickled in a dilute solution of HCl with an organic inhibitor at room temperature for 30 minutes and rinsed with water. Then, the samples were fluxed in an aqueous solution of ZnCl$_2$:2NH$_4$Cl. Finally, they were dried for 10 minutes at 105 ºC and dipped into the molten zinc bath, then immediately quenched in water in order to preserve the structure existing at end of the galvanizing.

2.2.2. Hardness Measurement
The hardness of received specimens (without coat) and the hardness measurements after zinc coating were carried out with EQUOTIP as stated in ASTM A956, HB30 hardness tester based on dynamic predicated upon the principle of energy measurement.

2.2.3. Analytical Tools for Design of Experimental

The following tools can be used for the analysis of experimental results:
- Main Effects Plot
- Interactions Plot
- Contour Plot for Mean and S/N Ratio
- Surface Plot for Mean and S/N Ratio

Minitab software was used in this study for selecting the type of design to be used for running the experiment, to display all possible combinations of controllable factors and analyzing data representing the main and interaction relationships between them.

3. Case Study

The quality by design methods are used to improve the quality of products and processes. Improved quality results when a higher level of performance is consistently obtained. The highest possible performance is obtained by determining the optimum combination of design factors. The consistency of performance is obtained by making the product/process insensitive to the influence of the uncontrollable factor.

An investigation is carried out to find the near-optimum parametric combination of process variables in zinc coating with considerations of multiple performance characteristics to improve galvanizing steel hardness. The Taguchi L27 (3$^3$) orthogonal array-based experiment design is used in this study to optimize process parameters. The significance and percentage contributions of each
process variable are evaluated using the signal-to-noise (S/N) ratio, ANOVA, response curve. The study infers that Taguchi off-line quality control is a correct method for optimizing coating process variables with a minimum number of trial runs as compared with the full factorial design in the traditional surface-coating process.

In this study, the controllable factors are temperature (T) is represented by factor (A), immersion time (t)– represents factor (B), and withdraw speed (S) represents factor (C), were selected due to have a potentially affect coating hardness in galvanizing process. Table 4 shows all the Taguchi design parameters and level.

The experiments were carried out with three mixing parameters (controllable factors), temperature (A), time (B), and speed (C), each run (mix) is conducted four times and are indicated as (R1, R2, R3 and R4). Hence, a total of (27x4) =108 data values were used. After the data were collected from different mixtures and recorded in Table 5 signal to noise ratio, loss function, mean, standard deviation, and variance of each experimental run.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Factors</th>
<th>Response: Hardness</th>
<th>Mean (HB)</th>
<th>Standard Deviation</th>
<th>S/N (dB)</th>
<th>Loss Function ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temp (A) °C</td>
<td>Time (B) min</td>
<td>Speed (C) m/min</td>
<td>R1</td>
<td>R2</td>
<td>R3</td>
</tr>
<tr>
<td>1</td>
<td>445</td>
<td>4</td>
<td>2</td>
<td>122.7</td>
<td>121.9</td>
<td>122.0</td>
</tr>
<tr>
<td>2</td>
<td>445</td>
<td>4</td>
<td>4</td>
<td>118.8</td>
<td>117.8</td>
<td>117.0</td>
</tr>
<tr>
<td>3</td>
<td>445</td>
<td>4</td>
<td>6</td>
<td>125.5</td>
<td>125.3</td>
<td>125.0</td>
</tr>
<tr>
<td>4</td>
<td>445</td>
<td>5</td>
<td>2</td>
<td>112.4</td>
<td>112.3</td>
<td>112.0</td>
</tr>
<tr>
<td>5</td>
<td>445</td>
<td>5</td>
<td>4</td>
<td>113.6</td>
<td>113.3</td>
<td>114.0</td>
</tr>
</tbody>
</table>
4. Results and Discussion

Figure 1 show the lines of factors A, B, and C are not horizontal therefore, main effects are existing. Different levels of the factors affect the characteristic (SNR) differently. Larger values of signal to noise ratio are desirable, because maximizing the S/N ratio is equivalent to maximizing the hardness of galvanized steel. By comparing the slopes of the lines, we can compare the relative magnitude of the factor effects.

The greatest effects on signal-to-noise ratio are factors temperature and time respectively, whereas, the line of factor speed is semi- horizontal, so there is very small main effect present in this case.
Figure 1. Main Effects Plots for Signal-to-Noise Ratio (SNR)

It is clear from Figure 2 that there are interactions present. It shows that the effect of temperature at three different levels of time is not the same trend. This implies that there is an interaction between two process parameters. Figure 3 shows the effect of temperature and speed and Figure 4 shows that the effect of time and speed are almost the same. Moreover the lines are almost not parallel, which indicates that there is interaction between these two factors.

Figure 2. The Interaction Plot Between Temperature (°C) and Time (min)
The contour plots in Figures (5 and 6) indicate that the larger value of Mean and S/N ratio is obtained when temperature is set at high level and time is set at low level. The darker green regions indicate higher Mean and S/N values, therefore, the best region of interest appears at the lower right region of the plot.
Figure 5. Contour Plot for Mean Hardness (HB) vs. Temperature (ºC) ; Time (min)

Figure 6. Contour Plot for S/N Ratio vs. Temperature (ºC) ; Time (min)
It is clear from Figures (7 and 8) of 3D surface plots for Mean and S/N ratio, the hardness of galvanized steel increases when temperature is set at high level and time is set at low level.

Figure 7. 3D Surface Plot for Mean(Hardness) (HB)

Figure 8. 3D Surface Plot for SNR
5. Conclusion

Taguchi quality suitable method for optimizing zinc galvanizing variables with a minimum number of trial runs as compared with the design in the traditional zinc galvanizing process, the best combination to achieve optimum hardness were obtained when, temperature = 455 ºC, time = 4 min, and speed = 6 m/min.

In the main effects plot for S/N ratio, the greatest effect on signal to noise ratio are the temperature and time respectively however, speed has very small effect, from the contour and 3D surface plots, it can be concluded that the hardness of galvanizing process increases when temperature is set at high level and time is set at low level whereas. Finally, the experiment revealed that the temperature and time have the largest effects on the hardness of galvanized steel. As well as, the optimum condition was verified during the optimization stage using the central composite design.

Reference


