Multi-Objective Optimization of Resistance Spot Welding using MOORA technique

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Abstract
Resistance Spot Welding (RSW) is a process that is being used in industry for sheet joining purposes especially in the Automobile and Aerospace industry. The problems associated with RSW are tendency of alloying with the electrode resulting in increased tool wear, and subsequent deterioration of weld quality. More current and time lead to expulsion and overheating of the electrode affecting the weld quality and less value result in insufficient weld strength. The complicated behavior of this process must be analyzed to set the optimum parameters to get good quality weld. This paper presents an experimental investigation for optimization of RSW for AA6061 and Galvanized steel by using MOORA technique. The experimental studies were conducted under varying electrode force, welding current and welding time. Taguchi quality design concepts of L9 orthogonal array has been used.

Keywords: Resistance Spot welding, Galvanized steel, AA6061, MOORA.

Introduction
Resistance Spot Welding (RSW) is a high speed process, wherein the actual time of welding is a small fraction of second and it is one of the cleanest and most efficient welding process that has been widely used in sheet metal fabrication. The high speed of process, the case of operation and its adaptability for automation in the production of sheet metal assemblies are its major advantages. Over the last few years, the weight of automobiles has increased considerably due to the addition of safety related items, such as impact resistance bumpers and door impact beams, emission control equipment and convenience items, such as air conditioning. At the same time fuel consumption has increased significantly primarily due to emission control equipment[1-5].

Experimental Analysis and Methodology
AA6061 aluminum alloy sheets with a thickness of 2.5 mm and commercial galvanized steel of 3.0mm thickness were used as base alloys in this investigation. The sheets were cut to required size by shear-off machine, followed by surface grinding to remove oxides and scales. The dimensions of the AA6061 sheet and commercial GI are 80mm × 20 mm × 2.5 mm and 80mm × 20 mm × 3.5 mm respectively. The sheets were resistance spot welded in a 30 mm overlap configuration. The chemical composition and mechanical properties of the base alloys are presented in Tables below. The rolling direction of the material was kept parallel to the loading directions, and the joints were initially secured with the help of mechanical clamps. A non-consumable rotating tool made of high speed steel (HSS) was used to fabricate the lap joints.

![Figure 1: Dimensions of Lap shear tensile specimen](image)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Zn</th>
<th>Ti</th>
<th>Fe</th>
<th>Cu</th>
<th>Al</th>
<th>Mn</th>
<th>Si</th>
<th>Mg</th>
<th>C</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.35</td>
<td>0.20</td>
<td>0.10</td>
<td>0.04</td>
</tr>
<tr>
<td>AA6061</td>
<td>0.25</td>
<td>0.15</td>
<td>0.7</td>
<td>0.15</td>
<td>95.8</td>
<td>0.33</td>
<td>0.53</td>
<td>0.69</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
is the final preference. [3, 6, 7].

value is the best alternative among all since
is the weight of
is done from highest to lowest
assessment value is calculated using equation (iii) and ranked
and the sum of all the weights will be 1. The MOORA overall
percentage of weight is considered for UTS and bending stress
that the normalized assessment values were calculated. Equal
the output responses is done according to Equation (ii). After
optimization for RSW process. The normalization of
Now, MOORA optimization method is applied to find out the
Optimization using MOORA Technique

Multi objective optimization on the basis of the ratio
analysis method (MOORA)
The MOORA method (Multi objective optimization on the
basis of the ratio analysis) has been used to disregard
unsuitable substitutions by selecting the most appropriates an
also by collation the selection parameter. It is a decision
making method, where the objectives were restrained for
every pronouncement of outcomes from a set of available
alternatives. The MOORA method can be functional in
numerous forms of complex multi objective optimization
problems. In MOORA method the recital of the diverse output
responses is arranged in a decision matrix as specified in
Equation (i) [3, 6, 7].

\[ X = \begin{bmatrix}
    x_{11} & x_{12} & \cdots & x_{1m} \\
    x_{21} & x_{22} & \cdots & x_{2m} \\
    \vdots & \vdots & \ddots & \vdots \\
    x_{m1} & x_{m2} & \cdots & x_{mn}
\end{bmatrix} \]  

(i)

Where, \( x_{ij} \) is the performance measure of the \( i \)th alternative on
\( j \)th attribute, \( m \) is the number of alternatives, and \( n \) is the
number of attributes.

A ratio system will be formed by normalizing the data of
decision matrix which can be calculated by using the equation
(ii).

\[ x_{ij}^* = \frac{x_{ij}}{\left(\sum_{j=1}^{n} x_{ij}^2\right)^{1/2}} \]  

(j = 1, 2, …… n)  

(ii)

Table 2: Control Parameters & their levels

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode Force, N</td>
<td>A</td>
<td>250</td>
<td>280</td>
<td>310</td>
</tr>
<tr>
<td>Welding Current, kA</td>
<td>B</td>
<td>6</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Weld time, cycle</td>
<td>C</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 4: Orthogonal array L9 of the experimental runs and responses

<table>
<thead>
<tr>
<th>Expt. No.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>UTS(MPa)</th>
<th>Bending Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250</td>
<td>6</td>
<td>2</td>
<td>252.75</td>
<td>5537.61</td>
</tr>
<tr>
<td>2</td>
<td>250</td>
<td>8</td>
<td>4</td>
<td>180.00</td>
<td>3797.09</td>
</tr>
<tr>
<td>3</td>
<td>250</td>
<td>10</td>
<td>6</td>
<td>230.50</td>
<td>6830.89</td>
</tr>
<tr>
<td>4</td>
<td>280</td>
<td>6</td>
<td>4</td>
<td>250.75</td>
<td>5840.47</td>
</tr>
<tr>
<td>5</td>
<td>280</td>
<td>8</td>
<td>6</td>
<td>210.50</td>
<td>5269.28</td>
</tr>
<tr>
<td>6</td>
<td>280</td>
<td>10</td>
<td>2</td>
<td>241.75</td>
<td>5318.96</td>
</tr>
<tr>
<td>7</td>
<td>310</td>
<td>6</td>
<td>6</td>
<td>269.25</td>
<td>6689.74</td>
</tr>
<tr>
<td>8</td>
<td>310</td>
<td>8</td>
<td>2</td>
<td>231.50</td>
<td>7235.16</td>
</tr>
<tr>
<td>9</td>
<td>310</td>
<td>10</td>
<td>4</td>
<td>175.75</td>
<td>9732.71</td>
</tr>
</tbody>
</table>

Results and Discussions

Samples are prepared by using Taguchi’s experimental design
which is shown in Table 4. L9 orthogonal array was used as
design of experiment. The experimental results for the UTS
and bending stress are listed in Table 4. Typically, larger
values of all the responses are required for optimizing strength
of the welded joint. All the specimens are tested at the
universal testing machine with capacity of 600 KN universal
testing machine (UTM BSUT 60JD) and with a cross head
speed of 10mm/min and the values and graph are given in
Table 4.

Table 5 shows the normalized assessment values of
the responses and overall assessment value and their ranking
according to the highest value of the overall assessment value.
Where, \( x_{ij}^* \) represents the normalized value \( x \) which is a
dimensionless number which lies between 0 and 1 \( i \)th
alternative on \( j \)th attribute.
After that, the normalized value will be added for
maximization problem or subtracted in case of minimization
problems. In some cases, some of the attributes have more
importance than others, and to deliver even more importance
to these attributes, they are multiplied by their corresponding
weight. After the consideration of weight, the equation will
be:

\[ y_i = \frac{\sum_{j=1}^{g} w_j x_{ij}^* - \sum_{j=g+1}^{n} w_j x_{ij}^*}{\sqrt{\sum_{j=g+1}^{n} w_j x_{ij}^*}} \]  

(iii)

where, \( g \) is the maximized number of attribute, \( (n-g) \) is the
attributes to be minimized and \( w_i \) is the weight of \( j \)th attribute.
\( y_i \) is the normalized assessment value of the \( j \)th
alternative relating to all the attributes. After calculation of normalized
assessment value, ranking of \( y_i \) is done from highest to lowest
value to know the best alternate among the entire attributes.
Thus, highest \( y_i \) value is the best alternative among all since
ranking of the \( y_i \) is the final preference. [3, 6, 7].

Optimization using MOORA Technique

Now, MOORA optimization method is applied to find out the
optimal parameters for RSW process. The normalization of
the output responses is done according to Equation (ii). After
that the normalized assessment values were calculated. Equal
percentage of weight is considered for UTS and bending stress
and the sum of all the weights will be 1. The MOORA overall
assessment value is calculated using equation (iii) and ranked
according to the highest value of the overall assessment value.

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<td>Weld time, cycle</td>
<td>C</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

Where, \( x_{ij}^* \) represents the normalized value \( x \) which is a
dimensionless number which lies between 0 and 1 \( i \)th
alternative on \( j \)th attribute.
Table 5: Normalized Individual Assessment Values and Overall Assessment Value

<table>
<thead>
<tr>
<th>Run No.</th>
<th>UTS</th>
<th>Bending Stress</th>
<th>yi</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.3679</td>
<td>0.2864</td>
<td>0.0407</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>0.2620</td>
<td>0.1964</td>
<td>0.0328</td>
<td>3</td>
</tr>
<tr>
<td>3.</td>
<td>0.3355</td>
<td>0.3533</td>
<td>-0.0089</td>
<td>7</td>
</tr>
<tr>
<td>4.</td>
<td>0.3650</td>
<td>0.3021</td>
<td>0.0314</td>
<td>4</td>
</tr>
<tr>
<td>5.</td>
<td>0.3064</td>
<td>0.2726</td>
<td>0.0169</td>
<td>6</td>
</tr>
<tr>
<td>6.</td>
<td>0.3519</td>
<td>0.2751</td>
<td>0.0384</td>
<td>2</td>
</tr>
<tr>
<td>7.</td>
<td>0.3919</td>
<td>0.3460</td>
<td>0.0229</td>
<td>5</td>
</tr>
<tr>
<td>8.</td>
<td>0.3370</td>
<td>0.3743</td>
<td>-0.0186</td>
<td>8</td>
</tr>
<tr>
<td>9.</td>
<td>0.2558</td>
<td>0.5034</td>
<td>-0.1238</td>
<td>9</td>
</tr>
</tbody>
</table>

In the above table, it can be seen that by using the MOORA method for a particular values of input parameter in experiment no. 1 has the highest overall assessment value. Therefore, experiment no. 1 is an optimal parameter combination for RSW according to MOORA technique optimization. Hence factor setting of Electrode Force of 250 N, Welding Current of 6 kA and Weld time of 2 cycle is optimum for RSW of AA6061 and galvanized steel.

Conclusions

In this study, AA6061 and galvanized steel plates are used for experimentation through resistance spot welding process by optimizing three advanced optimization technique i.e. MOORA technique. Purposeful relationship between process parameters and three parameters (Electrode Force, Welding Current and Weld time) for RSW has been established using the optimization techniques. Based on experiment studies carried out Electrode Force of 250 N, Welding Current of 6 kA and Weld time of 2 cycle is optimum for RSW of AA6061 and galvanized steel. As the feed rate of parameters increases, the UTS decreases and the bending stress increases. Thus, this study opens up further scope of optimization of the resistance spot welding characteristics with a larger number of process parameters, along with their influences, for attaining a better weld superiority more rapidly.

Acknowledgments

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References


