Effects of Shot Blasting on Corrosion Properties after Electrodeposition and Fatigue Properties of Arc Welds in Automotive Steel Sheets*1

Hiroki Fujimoto*2, Koji Akioka and Masatoshi Tokunaga

Steel Research Laboratories, Nippon Steel & Sumitomo Metal Corporation, Futtsu 293–8511, Japan

In this study, we investigated the effect of shot blasting on the corrosion properties after electrodeposition and the fatigue properties of the arc welds in automotive steel sheets. The corrosion properties of arc welds after electrodeposition were significantly improved by shot blasting due to the removal of slag and fume, which can cause painting defects. Also, the fatigue strength of welded joints was enhanced by shot blasting, because the mean stress effect due to compressive residual stress improved the fatigue properties. These results suggest that shot blasting has the potential to reduce the thickness of arc welded steel parts in automobile chassis.  [doi:10.2320/matertrans.P-2017838]

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1. Introduction

There is an increasing demand for automobiles to reduce CO₂ emission to achieve global environment conservation. Recently, the application of high strength steel sheets to car bodies’ parts is becoming increasingly popular so that the weight of the body can be reduced by reduction in the thickness of steel sheets. On the other hand, reducing the thickness of steel sheets in car chassis’ parts by using high strength steel sheets is not as popular as in car bodies’ parts. This is because dominant negative factors for sheet thickness reduction in chassis parts are influenced by rigidity, corrosion resistance, and fatigue strength. As the aforementioned factors are primarily negatively affected by the sheet thickness reduction of chassis parts depending on the position of these parts, measures to cope with each of these factors are required. For instance, as steel sheet has a constant Young’s modulus, the sheet thickness reduction using high strength steel can merely lead to a decrease in rigidity. In parts in which rigidity is primarily negatively affected by sheet thickness reduction, it is difficult to take measures in the processing phase. In this case, it is necessary to take measures such as to modify the cross-section shape of parts in the design phase to assure the required rigidity with reduced sheet thickness. Conversely, there are many parts in which corrosion resistance and/or fatigue strength are primary factors that are negatively affected by sheet thickness. In this case, measures can be taken in the processing phase; hence, to date several methods for such measures have been studied.

Figure 1 shows an example of the chassis parts in a car that was driven for 13 years in a field test. The chassis parts are painted to prevent them from being rusted. Rust can propagate from arc welds as seen in Fig. 1. For this reason, in the chassis parts sheet thickness is determined in view of the expected loss of thickness due to corrosion. Accordingly, low corrosion resistance after coating in arc welds may be negatively affected during the determination of sheet thickness using high strength steel. It is reported that the main cause of poor corrosion resistance after electrodeposition of the arc welded part is coating defects due to slag which is oxide generated at the time of welding1). Since slag is hard to pass electricity, it is difficult to perform electrodeposition coating. In order to improve the corrosion resistance of the arc welds after electrodeposition, it is important to ensure defect free electrodeposition coating. Slag is formed from silicone and manganese in steel, e.g., welding wires and steel sheets, and oxygen in the shielding gas. Thus, a method is reported2,3) by which slag is reduced by decreasing the oxidative gases (CO₂, O₂) in the shielding gas to improve the corrosion resistance after electrodeposition coating. However, decreasing oxidative gases in the shielding gas causes an unstable arc, insufficient penetration, and uneven bead formation. Hence, extreme care should be taken when the aforementioned method is applied to chassis for which high reliability is required in the welds. Moreover, slag tends to decrease by reducing heat input, or reducing silicone or manganese in wires. However, these methods are not sufficient to completely improve the corrosion resistance.

In addition, the car chassis parts are subjected to repetitive stress while the cars’ are driven. Under repetitive stress, arc

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*2 Corresponding author, E-mail: fujimoto.fh2.hiroki@jp.nssmc.com
welds that are geometrically discontinuous are likely to become the most fragile. Therefore, excellent fatigue properties are also required for arc welds. Using steel sheets with high strength does not necessarily improve the fatigue strength of arc welded joints in automotive steel sheets\(^4,5\). Therefore, lack in fatigue strength of arc welds may hinder sheet thickness reduction when using high strength steel sheets. There are some previous studies such as tensile residual stress relief by local heat treatment\(^5\), shape control\(^6\) at the weld toe of beads by combined use with plasma arc welding, and the application of low-temperature transformation wires\(^7\).

In this paper, the potential of shot blasting to improve both corrosion resistances after electrodeposition coating and fatigue properties of arc welds in steel sheets for automobiles was investigated and analyzed. Although there are some cases\(^8\) in which shot blasting is applied to arc welds in thick steel plates for bridge construction to improve the fatigue strength, there are no cases, to the best of our knowledge, that have been reported in which shot blasting is applied to arc welds in thin steel sheets for automobiles. Conversely, in the hot-stamped press formed parts in domestic automotive parts production, shot blasting has been used since the beginning of 2000 to eliminate iron scales occurring on the surface of steel sheets during the heat treatment process of un-coated hot-stamped steel sheets\(^9,10\). Therefore, it is assumed that a similar method could find potential application in arc welded car parts without significant impacts on the precision of parts. This paper reports the results from the studies on how shot blasting affects corrosion resistance after electrodeposition coating and fatigue properties of arc welds using steel sheets for automobiles with tensile strength of 440 and 1500 MPa.

2. Experimental Procedure

The chemical compositions and the mechanical properties of steel sheets used in this study are shown in Table 1. These are un-coated hot-rolled steel sheets with 440 MPa grade tensile strength and un-coated hot-stamped steel sheets of 1500 MPa grade. The as arc welded test specimens and those that were subjected to shot blasting after arc welding were fabricated, and their corrosion resistance after coating and the fatigue properties are evaluated. The shape of the test specimens for corrosion resistance evaluation is shown in Fig. 2 (a). The test specimens for corrosion resistance evaluation were prepared by bead-on-plate welding performed on steel sheets of 2.3 mm thickness. The welding conditions are shown in Table 2. Moreover, shot blasting conditions and shot blasting methods are shown in Table 3 and Fig. 3. Shot blasting conditions capable of removing slag and fume in arc welds were preliminarily explored and

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Table 1 Chemical composition and mechanical properties of steel sheets (mass%).

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>C (mass%)</th>
<th>Si (mass%)</th>
<th>Mn (mass%)</th>
<th>P (mass%)</th>
<th>S (mass%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>440 MPa</td>
<td>0.10</td>
<td>0.05</td>
<td>1.14</td>
<td>0.019</td>
<td>0.003</td>
</tr>
<tr>
<td>1500 MPa</td>
<td>0.20</td>
<td>0.20</td>
<td>1.30</td>
<td>0.010</td>
<td>0.002</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>Y.S. (MPa)</th>
<th>T.S. (MPa)</th>
<th>El (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>440 MPa</td>
<td>304</td>
<td>462</td>
<td>37</td>
</tr>
<tr>
<td>1500 MPa</td>
<td>1130</td>
<td>1553</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 2 Arc welding conditions.

<table>
<thead>
<tr>
<th>(a) Corrosion test specimen</th>
<th>(b) Fatigue test specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (A)</td>
<td>94</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>20</td>
</tr>
<tr>
<td>Travel speed (cm/min)</td>
<td>50</td>
</tr>
<tr>
<td>Shielding gas</td>
<td>Ar+20%CO(_2) 20 ℓ/min</td>
</tr>
</tbody>
</table>

Table 3 Shot blasting conditions.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Atsuchi Tekko Co. BA-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast material</td>
<td>Steel beads (Diameter: 0.3 mm, HV 390–510)</td>
</tr>
<tr>
<td>Air pressure</td>
<td>0.35 MPa</td>
</tr>
<tr>
<td>Distance</td>
<td>200 mm</td>
</tr>
<tr>
<td>Blasted area</td>
<td>All surface of both sides</td>
</tr>
</tbody>
</table>

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Fig. 2 Shapes and dimensions of arc welded specimens.

Fig. 3 Shot blasting method.
established by utilizing a shot blasting device used for the removal of scales from hot-stamped steel sheets. In order to prevent deformation, shot blasting was uniformly applied to the entire surface of the specimens.

Electrodeposition coating was applied to the test specimens as arc welded and those as shot blasted after arc welding. The corrosion resistance after coating was evaluated in the two specimens. The test specimens were degreased and subjected to zinc phosphate treatment of the trication type using a powderized surface additive for surface preparation, before they were subjected to electrodeposition coating of the cation type. The electrodeposition coating thickness was targeted at 20 μm. Corrosion resistance after electrodeposition coating was evaluated in combined cyclic corrosion tests that comprised spraying with 5% NaCl solution salt water, drying, and wetting. The corrosion tests were performed at a wet time rate of 67% and 24 h was set as one cycle. The coating was stripped off and rust was eliminated after the corrosion tests of 120 cycles were completed. Moreover, as shown in Fig. 4, the corrosion depth for every section was obtained by measuring the sheet thickness, and maximum corrosion depth was determined. A point micrometer shown in Fig. 4 was used for the measurement.

The fatigue test specimens are shown in Fig. 2(b). The fatigue test specimens were prepared by lap fillet welding because there are many lap fillet welded joints in chassis parts. Steel sheets with thicknesses of 2.0 mm and grades of 440 and 1500 MPa were used. The welding conditions and shot blasting conditions are shown in Tables 2 and 3, respectively. Fatigue tests were conducted in pulsating plane bending load (stress ratio = 0) which is often the load mode of the chassis parts of the automobile. The fatigue tests were conducted under displacement control using a bending/torsion fatigue testing machine TB-10 from Shimadzu Corporation. In addition, residual stress on the surface of the arc welded steel sheets was measured. A model of XRD PSPC-RSF from Rigaku Corporation was used for the measurement of residual stress. Measurement regions were set to be 0.5 mm in diameter, and the residual stress in the orthogonal direction to the weld bead was measured.

3. Results and Discussions

3.1 Evaluation of corrosion resistance after electrodeposition coating

The appearance of the welded bead in the 440 MPa grade steel sheets after arc welding is shown in Fig. 5 (a). Slag was identified on the welded beads. Moreover, fume was identified in the surroundings of the weld beads. Figure 5(b) shows the appearance of the beads that were shot blasted after arc welding. Slag on the beads and fume around the beads was clearly eliminated.

Figure 6 shows the magnified photographs of the surface of the beads after electrodeposition coating. Coating defects due to slag was identified at the weld toe and at the top of the beads in the as welded beads. Meanwhile, neither slag nor coating defects were identified in the shot blasted beads. Figure 7 shows the cross sections at the weld toe of the beads after electrodeposition coating. Slag was identified at the weld toe of the beads in the as welded beads, and it was observed that the surface of bead was not completely covered by electrodeposition coating. Conversely, no slag was identified in the shot blasted beads, and the beads were identified as being completely covered by electrodeposition coating.

The appearance of the test specimens that were subjected to the combined cyclic corrosion tests of 120 cycles after electrodeposition coating is shown in Fig. 8. Severe corrosion was identified around the weld beads in the as arc-welded test specimens. In contrast, little corrosion was identified around the weld beads in the shot blasted test specimens. The measurement results of the maximum corrosion depth are shown in Fig. 9. Although the maximum corrosion depth in the arc welded case was approximately 1.1 mm on an average, the depth in the shot blasted case was approximately less than 0.2 mm on an average. Thus, shot blasting significantly improved the corrosion depth. The reason for this is assumed to be that the slag was removed by shot blasting and the electrodeposition coating defects was almost eliminated. It was confirmed that the cause of the deterioration of the corrosion resistance after the electrodeposition of the arc welded part was caused by the slag, as has been previously reported.

3.2 Evaluation of fatigue properties

The plane bending fatigue test results for arc welded lap fillet joints are shown in Fig. 10. The fatigue limit (cycle number of $10^7$ times) was 360 MPa in the as arc welded joints of 440 MPa grade steel sheets. In the case of as arc welded joints, the 1500 MPa grade steel sheets have fatigue properties approximately equivalent to those of the 440 MPa grade steel sheets. The fatigue limit of the 440 MPa grade steel sheets that are shot blasted after arc welding was 450 MPa, i.e., improved by approximately 25%. In addition, the fatigue limit load after shot blasting was somewhat higher with the joint of 1500 MPa grade steel sheets than the 440 MPa grade steel sheets. The cross sections of arc welds after the fatigue test are shown in Fig. 11. The joints that are as arc welded and those that are shot blasted after arc welding fractured at the bead toe in the position where stress concentrates; moreover, no difference was identified in the frac-
tured positions. In addition, no variation was identified in the shape of bead toes due to shot blasting.

To clarify why shot blasting improved the fatigue strength, the hardness and residual stress distributing on the top surface of the welds were investigated. Figure 12 shows the hardness distribution in the direction parallel to the surface of base metal at a depth of 0.1 mm below the surface of steel sheets. As the 1500 MPa grade steel sheets contain more alloy elements than the 440 MPa grade steel sheets, the HAZ portion (on the side of the positive value in distance) was hardened. In addition, due to shot blasting, the hardness slightly increased in the HAZ in 440 MPa grade steel sheets, little increase was identified in the hardness of the HAZ in the 1500 MPa grade steel sheets.

Figure 13 shows the residual stress distribution on the surface of the steel sheets measured by X ray diffraction. In the as welded specimen of 440 MPa grade steel, the residual stress at the bead toes (at the position of 0 mm in which the initiation position of fatigue cracks) was nearly 0 MPa. In
the shot blasted specimen, compressive residual stress of approximately 400 MPa was observed. The presence of compressive residual stress enhances fatigue strength due to the effect of reducing tension stress during fatigue test load. Therefore, it is assumed that the enhanced fatigue strength by shot blasting is dominantly affected by neither the variation in the shape of weld toes nor hardening. The fatigue strength is affected by applied compressive residual stress. Moreover, as seen from Fig. 10, in the high load, the difference in the fatigue life is small between the joints that are as welded and those that are shot blasted after welding. This is because a slight plastic deformation occurring at the weld toe of joints under high loading stress reduced the compressive residual stress. Furthermore, 1500 MPa grade steel sheets have higher fatigue strength after shot blasting than 440 MPa grade steel sheets. It is assumed that hard HAZ is difficult to cause plastic deformation; therefore, the high compressive residual stress endowed beforehand is unlikely to be reduced during fatigue tests.

The above-mentioned results from the corrosion resistance test and fatigue test after electrodeposition coating have revealed that the application of shot blasting to arc welds in steel sheets for automobiles significantly improve the corrosion resistance after coating and the fatigue strength. Application of the shot blasting increases the number of processing steps. However, especially when the shot blasting is applied together with high strength steel sheets, the static strength of parts, the corrosion resistance and the fatigue strength of welds are improved. Accordingly, it is considered that there is a possibility that application of shot blasting lead to a reduction in the thickness of the chassis parts where above mentioned condition are restricting factor of the sheet thickness.

4. Conclusion

In this study, we investigated the effects of shot blasting on the corrosion properties after electrodeposition coating and fatigue properties in arc welded joints in steel sheets for automobile. The results are as follows:

(1) According to the combined cycle corrosion tests, shot blasting after arc welding significantly improved the corrosion properties after electrodeposition coating.

(2) Improved corrosion resistance after electrodeposition coating of arc welded joints by shot blasting is attributed to the removal of slag, which is the cause of coating defects.

(3) Shot blasting enhanced the fatigue limit of arc welded joints in 440 MPa grade steel sheets by approximately 25%.

(4) In the case of as welded joints, the fatigue strength of arc welded joints is almost the same between 440 MPa grade steel sheets and 1500 MPa grade steel sheets. Conversely, the fatigue strength of those after shot blasting was higher in 1500 MPa grade steel sheets.

(5) Improved fatigue strength of arc welded joints by shot blasting is possibly derived from compressive residual stress provided for bead toes.

(6) The application of high strength steel sheets together with shot blasting enhances the static strength of components, as well as corrosion resistance and fatigue strength after electrodeposition coating of welds. It is considered that lighter chassis parts can be realized by reducing sheet thickness, which has been hindered by above properties.
REFERENCES