Technical Report

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Improvement of Corrosion Properties after Electrodeposition of Arc Welds in Automotive Steel Sheets by Shot Blasting

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Abstract

Steel chassis parts for automobiles are subjected to rust prevention treatment mainly based on cation electrodeposition coating. However, it is reported that there are many cases where arc welded parts are a bottleneck to performance. This report describes the results of corrosion resistance and fatigue property after electrodeposition coating in arc welded joints by shot blasting.

1. Introduction

There is an increasing demand for automobiles to reduce CO_2 emission to achieve global environment conservation. Recently, the application of high strength steel sheets to the cabin parts of car bodies is becoming increasingly popular so that the thickness of the sheet can be reduced while securing crash performance. On the other hand, the application of high tensile steel sheets to car chassis parts such as front and rear subframes, rear axle beams, lower arm and upper arm is not popular in car body parts. This is because not only the static strength but also the rigidity, corrosion resistance and fatigue strength are the major dominant restrictive factors in determining sheet thickness in chassis parts, and it is assumed that there are many cases where the reduction of thickness cannot be achieved by simply applying high strength steel sheets.

As the aforementioned restrictive factors to be taken into consideration vary depending on the positions of chassis parts, measures to cope with each of such restrictive factors are required. As for rigidity for instance, as the steel sheet has almost a constant Young's modulus regardless of its steel type, the sheet thickness reduction using high strength steel can merely lead to a decrease in the rigidity of parts, and exerts adverse effects such as deterioration in running stability and increase in vibration. In parts in which rigidity is the major dominant factor in determining sheet thickness, it is difficult to take measures in the processing phase, and it is necessary to take measures in the design phase. In this case, to assure the required rigidity by reducing sheet thickness, measures such as optimization of the cross-section shape of parts, reduction of sheet thickness of the parts that contribute less to parts rigidity, reinforcing the parts that contribute to rigidity greatly and so forth are taken. On the other hand, there are many positions where the corrosion resistance and/or the fatigue strength required for parts become dominant restrictive factors in determining sheet thickness. Recently, the importance of corrosion resistance has particularly increased, and hence, to date, to improve these properties, several methods have been studied not only in the design phase but also in the processing phase.

The general process of the production of automobile chassis parts is comprised of the processes of press-forming steel sheets, assembling them in the consumable electrode type gas-shielded arc welding method using solid wires, and providing electrodeposition coating for rust prevention. The pre-treatment line of electrodeposition coating consists of the processes of degreasing to remove oil and grease, surface control, zinc-phosphating treatment and water washing so as to form minute zinc phosphate crystal on the surface of a steel sheet so as to enhance the corrosion resistance of steel material and the adhesion properties of the coating film. In the subsequent electrodeposition coating process, in many cases, cation type electrodeposition coating is provided where the subject parts act as the cathode. The thickness of the coating film of the electrodeposition coating is 20–30 μm.[1]

Figure 1 shows an example of the chassis parts of a car that was driven for approximately 100 thousand kilometers for 13 years in Japan. In chassis parts, rust is generated at arc welds and corrosion propagates from the 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 in arc welds after coating may constrain the reductions in sheet thickness and weight. As the main cause of poor corrosion resistance of the arc welds after electrodeposition coating, coating de-

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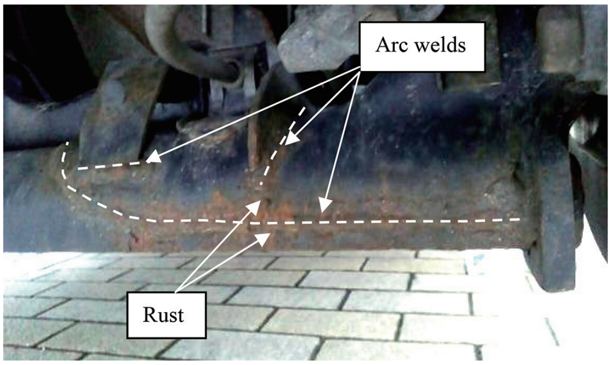


Fig. 1 Example of arc welds in the rear axle of the 13 year-old field tested automobile

fects due to slag generated at the time of welding, and the deterioration in coating film adhesion properties due to the adhesion of fume on the steel sheet surface can be listed.

In particular, the influence of the coating defect due to slag is reported to be large.[2]. Since it is difficult for slag, an oxide, to pass electricity, it is difficult to perform electrodeposition coating. In order to improve the corrosion resistance of the arc welds after coating, it is important to reduce slag. Major compositions of slag are silicone oxide and manganese oxide. These oxides are produced mainly from the silicone and manganese in welding wires and oxygen in the shielding gas used in welding. In domestic automobile manufacturers, CO_2, or a mixture of Ar and CO_2 of approximately 20% (with the addition of a minute amount of O_2 as necessary) is popularly used as the shielding gas. O_2 in CO_2 also forms oxides. Thus, a method to improve the corrosion resistance after electrodeposition coating is reported in which slag is reduced by using Ar as the main shielding gas, and decreasing the amount of oxidative gases (CO_2, O_2) to below 5%, and by reducing the formation of slag accordingly.[3–5]

However, decreasing oxidative gases in the shielding gas added intentionally to stabilize the arc is likely to cause an unstable arc, which tends to cause insufficient penetration and unstable bead formation. Hence, extreme care should be taken when the aforementioned method is applied to the chassis for which high reliability is required. Moreover, slag tends to decrease by reducing heat input, or reducing deoxidizing elements such as silicone and manganese in welding wires. However, if these elements are decreased excessively, there arises the problem of a growing risk of deterioration in weld quality such as the generation of blow holes due to insufficient deoxidization of weld metal and deterioration in mechanical properties.

In addition, as the car chassis parts are subjected to repetitive stress while the cars are driven, high fatigue reliability is also required. Under repetitive stress, arc welds that are geometrically discontinuous are likely to become the most fragile. Therefore, excellent fatigue properties are also required for arc welds. When the steel sheet strength increases, the fatigue strength of base metal (fatigue strength of flat and smooth sheet without stress concentration) also increases. However, as the fatigue strength of arc-welded joints does not increase all the time,[6, 7] the lack in fatigue strength of arc welds may hinder sheet thickness reduction. Therefore, the means to improve the fatigue strength of arc welds such as tensile residual stress relief by local heat treatment,[7] shape control at the weld toe of beads by combined use with plasma arc welding,[8] and the application of low-temperature transformation welding wires[9] have been studied.

In this paper, as a means to improve the corrosion resistance and fatigue properties of arc welds after electrodeposition coating in automotive steel sheets, the potential of shot blasting was investigated and analyzed. Although there are some cases reported in which shot blasting is applied to arc welds in thick steel plates for bridge construction to improve the fatigue strength,[10] no cases, to the best of our knowledge, have been reported in which shot blasting is applied to arc welds in thin automotive steel sheets of about 2 mm in thickness to improve the corrosion resistance and fatigue properties of arc welds after electrodeposition coating.

On the other hand, in the domestic automotive parts production of press-formed parts, shot blasting has been used since the beginning of 2000 to eliminate iron scales occurring on the surface of steel sheets during the hot-stamping process of un-coated hot-stamped steel sheets.[11] Therefore, it is considered that a similar method can find potential application in arc-welded car parts without significant impacts on the precision of parts. This paper reports the results of the studies on how shot blasting affects corrosion resistance and fatigue properties of arc welds after electrodeposition coating using automotive steel sheets with a tensile strength of 440 MPa grade and 1 500 MPa grade.[12]

2. Experimental Procedure

In this experiment, un-coated hot-rolled steel sheets of 440 MPa grade and 1 500 MPa grade un-coated hot-stamped steel sheets were used. The chemical compositions and the mechanical properties of the steel sheets used in this study are shown in **Table 1**. The as-arc-welded test specimens and the test specimens that were subjected to shot blasting after arc welding were prepared, and their corrosion resistance and the fatigue properties after electrodeposition coating were evaluated. **Figure 2** (a) shows the shape of the test specimens for corrosion resistance evaluation. The test specimens for the evaluation of corrosion resistance were prepared by bead-on-plate welding performed on steel sheets 2.3 mm in thickness under the welding conditions as shown in **Table 2**. A direct-pressure type shot blasting device was used, and the steal beads were shot under the conditions as shown in **Table 3**, and the shot blasting method is shown in **Fig. 3**. The shot blasting conditions were preliminarily explored and established so as to be capable of removing slag and fume in arc welds. In this study, in order to suppress deformation, shot blasting was uniformly applied to the entire surface of the test specimens on two sides.

Electrodeposition coating was applied to the as-arc-welded test specimens and the test specimens shot-blasted after arc welding, and corrosion resistance after coating was evaluated in the two types of test specimen. The test specimens were degreased and subjected to

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

Steel grade	C	Si	Mn	P	S
440 MPa	0.10	0.05	1.14	0.019	0.003
1 500 MPa	0.20	0.20	1.30	0.010	0.002

Steel grade	Y.S. (MPa)	T.S. (MPa)	El. (%)
440 MPa	304	462	37
1 500 MPa	1 130	1 553	8

Y.S.: Yield strength, T.S.: Tensile strength, El.: Elongation

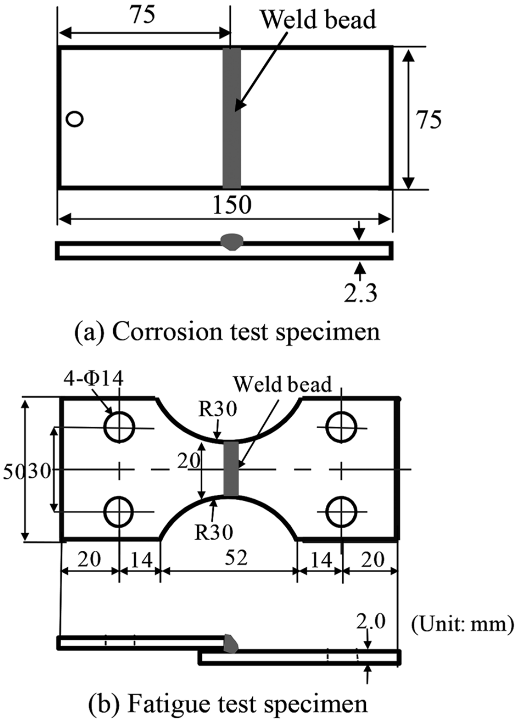


Fig. 2 Shapes and dimensions of arc welded specimens

Table 2 Arc welding conditions

	(a) Corrosion test specimen	(b) Fatigue test specimen
Current (A)	94	135
Voltage (V)	20	23
Travel speed (cm/min)	50	
Shielding gas	Ar+20%CO_2 20 l/min	
Wire	NSSW YM-24T (diameter: 1.2 mm)	

Table 3 Shot blasting conditions

Machine	Atsuchi Tekko Co. BA-1
Blast material	Steel beads (diameter: 0.3 mm, HV 390–510)
Air pressure	0.35 MPa
Distance	200 mm
Blasted area	All surface of both sides

zinc phosphate treatment of the trication type using powdered surface additive for surface preparation before they were subjected to electrodeposition coating of the cation type. The target electrodeposition coating thickness was 20 μm on the plain surface, and the test specimens were baked at 175°C. Corrosion resistance after electrodeposition coating was evaluated in combined cyclic corrosion tests that were comprised of spraying 5% NaCl solution salt water, drying and wetting. The 24 hour with wetting time ratio of 67% was set as one cycle. The coating was stripped off and rust was eliminated after a corrosion test of 120 cycles was completed. As shown in **Fig. 4**, the corrosion depth at 10 points in each of 5 sections 10 mm in width was obtained by measuring the sheet thickness, and the maximum corrosion depth was determined. A point micrometer as shown in Fig. 4 having the front edge diameter of 0.3 mm was used for the measurement.

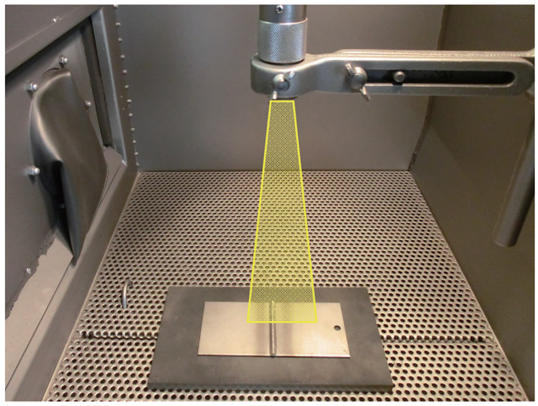


Fig. 3 Shot blasting method

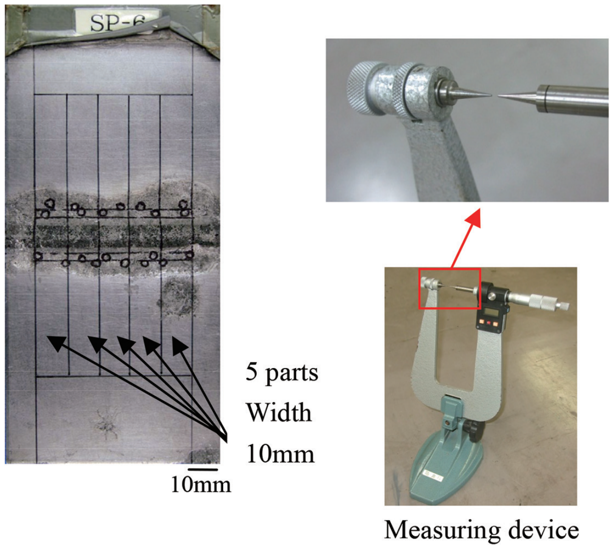


Fig. 4 Method of measuring maximum corrosion depth

Figure 2 (b) shows the shape of fatigue test specimens. Fatigue test specimens were prepared by lap fillet welding because there are many lap fillet welded joints in chassis parts. Steel sheets with a thickness of 2.0 mm and steel grades of 440 MPa and 1 500 MPa were used. The welding conditions and the shot blasting conditions are shown in Tables 2 and 3, respectively. Pulsating fatigue limit tests (bending load R=0), a loading mode for automobile chassis,[5] were conducted for the as-arc-welded test specimens, and the shot-blasted arc-welded test specimens. Tests were conducted in displacement control mode using a bending/torsion fatigue testing machine TB-10 from Shimadzu Corporation.

3. Result of Experiment and Discussion

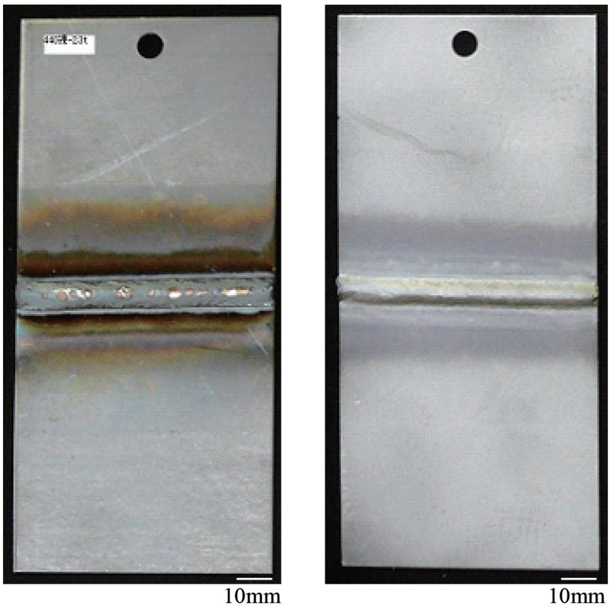
3.1 Evaluation of corrosion resistance of arc weld

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 weld bead and at the boundaries between the bead and the base metal (weld toe of bead), and fume was identified in the surrounding of the weld bead. Figure 5 (b) shows the appearance of the test specimen that was shot-blasted after arc welding. Slag on the bead and the fume on the base metal were clearly eliminated.

Figure 6 shows the results of the observation by scanning electron microscope (SEM) of the neighborhood of the weld bead after zinc phosphate treatment. On the surface of the as-arc-welded test specimen, zinc phosphate crystal in a lamella pattern was observed, and a number of transparent parts without crystal were observed. Meanwhile, on the surface of the shot-blasted test specimen, granulated zinc phosphate crystal was formed evenly and tightly without transparency. This difference was attributed to the presence or absence of fume adhering to the base metal surface, and it was considered that the surface treatability of zinc phosphate was improved by removing the fume by shot blasting, and the adhesion properties of electrodeposition coating were improved accordingly.

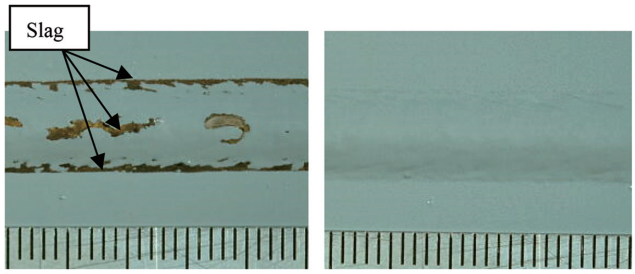
Figure 7 shows the magnified photographs of the surface of a weld bead after electrodeposition coating. On the as-arc-welded test specimen, coating defects were identified on the bead and at the bead toe to which slag adhered. On the other hand, no coating defects were identified on the shot-blasted test specimen. **Figure 8** shows magnified photographs of the cross sections at the toe of the beads after electrodeposition coating. Slag was identified at the toe of the bead in the as-welded bead. Where slag is identified, electrodeposition coating scarcely exists. On the other hand, no slag was identified in the shot-blasted bead, and it was confirmed from the section that the bead surface was completely covered by an electrodeposition coating with the target thickness of approximately 20 μm.

The appearance of the test specimens that were subjected to the combined cyclic corrosion test of 120 cycles after electrodeposition coating is shown in **Fig. 9**. Severe corrosion accompanied by coating film blisters around the bead was identified in the as-arc-welded test specimen. In contrast, little corrosion was identified around the weld bead in the shot-blasted test specimen. The measurement results of the maximum corrosion depth of the 440 MPa grade steel sheet and 1 500 MPa grade steel sheet are shown in **Fig. 10**. Although the maximum corrosion depth in the as-arc-welded case was approximately 1.1 mm, the depth in the shot-blasted case was below approximately 0.2 mm. Thus, by shot blasting, the maximum corrosion depth was decreased to below 1/5, and shot blasting significantly decreased the corrosion depth. The reason for this is assumed to be that the slag was eliminated by shot blasting and the electrode-



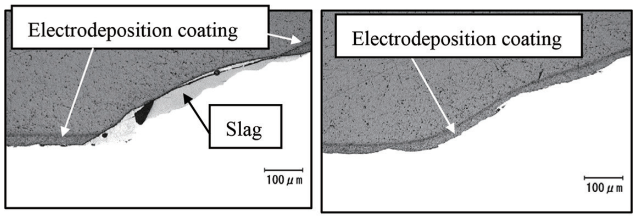
(a) As welded specimen (b) Shot blasted specimen

Fig. 5 Surface of the arc welded specimens (440 MPa steel)



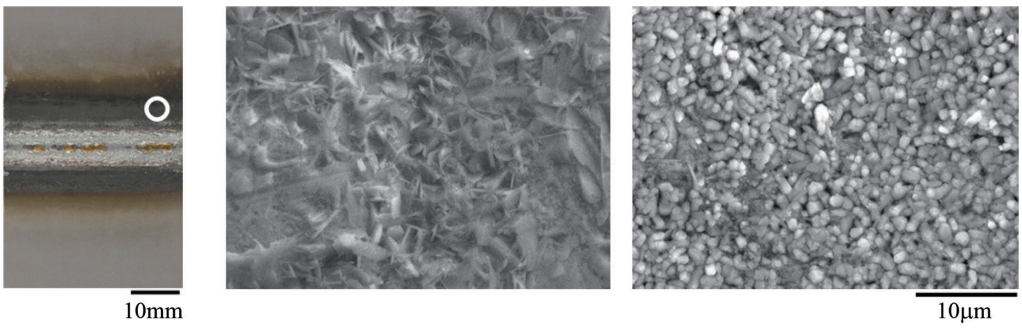
(a) As welded specimen (b) Shot blasted specimen

Fig. 7 Surface of the arc welds after electrodeposition (440 MPa steel)



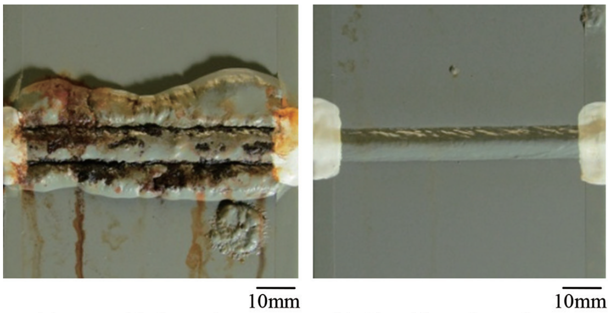
(a) As welded specimen (b) Shot blasted specimen

Fig. 8 Cross section of toe of arc welds after electrodeposition (440 MPa steel)



Observation point (a) As welded specimen (b) Shot blasted specimen

Fig. 6 Surface of the specimens after phosphate coating (440 MPa steel)



(a) As welded specimen (b) Shot blasted specimen

Fig. 9 Surface of the electrodeposition coated specimen after combined cyclic corrosion test of 120 cycles (440 MPa steel)

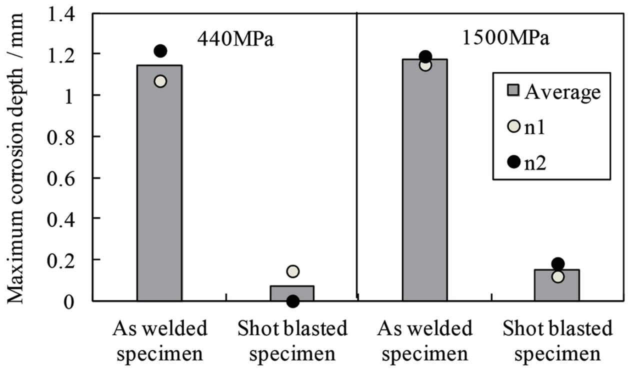


Fig. 10 Maximum corrosion depth after a combined cyclic corrosion test of 120 cycles

position coating defects were almost eliminated and the adhesion properties of electrodeposition coating were improved by removing the fume in the neighborhood of the bead. The elimination of slag that causes coating defects is considered to be the major factor of improvement in corrosion resistance after electrodeposition coating.

3.2 Evaluation of fatigue properties of arc weld

Results of the pulsating plane bending fatigue test for arc-welded lap fillet joints are shown in **Fig. 11**. The fatigue limit was 360 MPa in as-arc-welded joints of the 440 MPa grade steel sheets. In the case of as-arc-welded joints, the 1 500 MPa grade steel sheets have fatigue properties approximately equivalent to that of the 440 MPa grade steel sheets. The fatigue limit of the joint of the 440 MPa grade steel sheets that was shot-blasted after arc welding was 450 MPa, i.e., improved by approximately 25% by shot blasting. In addition, the fatigue limit load after shot blasting was somewhat higher with the joint of the 1 500 MPa grade steel sheets than the 440 MPa grade steel sheets. This is considered to be the influence of the compressive residual stress provided to the weld joint surface by shot blasting, and it was assumed that, particularly in the case of the 1 500 MPa steel sheets, as the heat affected zone (HAZ) where fatigue crack is generated is hard, the compressive residual stress provided beforehand is unlikely to be reduced during fatigue tests.[12)]

Based on the above results, it was clarified that the corrosion resistance and the fatigue strength of arc welds after electrodeposition coating are greatly improved by shot blasting. Application of the shot blasting increases the number of processing steps by one. However, particularly when the shot blasting is applied together with high strength steel sheets, not only the static strength and the fatigue strength of flat and smooth parts of the sheet, but also the corrosion

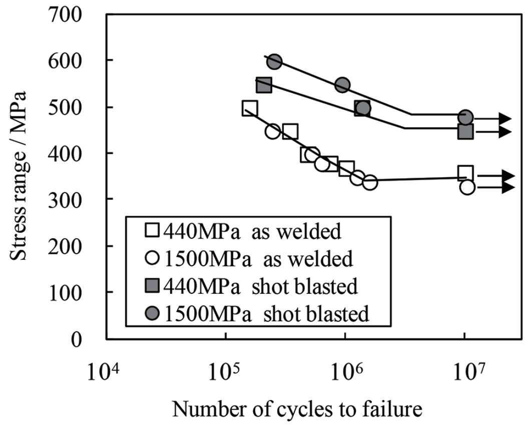


Fig. 11 Fatigue test results of arc welded specimens with and without shot blasting

resistance and the fatigue strength of arc welds after electrodeposition coating are improved. Although, in applying shot blasting to actual chassis parts, verification of the suitability of shot-blasting material, shot-blasting conditions pursuant to respective parts configurations, and the post-shot-blasting material removal method and so forth are required, the application of shot blasting may lead to the reduction in the weight of chassis parts and the enhancement of car products marketability.

4. Conclusion

With the intention of improving the properties of arc welds of automobile chassis parts, we investigated the effects of shot blasting on the corrosion resistance properties and fatigue properties after electrodeposition coating in arc welded joints in automotive steel sheets. The results are as follows:

(1) According to combined cycle corrosion tests, shot blasting after arc welding significantly improved the corrosion resistance properties after electrodeposition coating, and the maximum corrosion depth was decreased to below 1/5 as compared with the one without shot blasting.

(2) Corrosion resistance after electrodeposition coating of arc welded joints improved by shot blasting is considered to be 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 the 440 MPa grade steel sheets by approximately 25%. Moreover, the fatigue strength of as-arc-welded joints is almost the same between the 440 MPa grade steel sheets and the 1 500 MPa grade steel sheets. The improvement in fatigue strength after shot blasting was slightly higher in the 1 500 MPa grade steel sheets.

(4) The application of high strength steel sheets together with shot blasting enhances the static strength and the fatigue strength of the flat and smooth part of the base metal as well as corrosion resistance and fatigue strength of arc-welded joints after electrodeposition coating. Therefore, this technology may contribute to the reductions in thickness and weight of parts, which have been hindered by corrosion resistance and fatigue strength.

References

1) Sugisaki, K.: Electrodeposition Coating for Automobile. Journal of The Surface Finishing Society of Japan. 53 (5), 293–298 (2002)

2) Takahashi, M., Uchihara, M., Sakoda, A., Ueki, M., Niisato, B.: Corrosion Resistance of Gas Shielded Metal Arc Welds with E-coat —1st Report: Investigation of Corrosion Mechanism of Weld Zone with E-coat—. Transactions of Society of Automotive Engineers of Japan. 28 (2), 143–148 (1997)
3) Uchihara, M., Takahashi, M., Sakoda, A., Taka, T., Nakata, J.: Improvement of the Corrosion Resistance of Gas Metal Arc Weld with E-coat by Newly Developed Shielding Gas. Materia Japan. 36 (4), 388–390 (1997)
4) Yamamoto, S., Suzuki, S., Ando, S., Kataoka, T., Ueda, S., Nakazawa, T.: Development of Corrosion Resistance and Fatigue Strength Improvement Welding Technology of Chassis Parts (Report 2). Preprints of the National Meeting of JWS. 2015, p.304–305
5) Kasai, R., Suzuki, R.: The Improvement Method of the Performance of Electro Deposition Coating and Corrosion Resistance in Arc Welding Joint for Automobile. Preprints of the National Meeting of JWS. 90, 2012, p.88–89
6) Uchihara, M., Kurita, M., Taka, T.: Effects of Metallurgical Properties on Fatigue Limit of Arc-welded Sheet Steel. Tetsu-to-Hagané. 86 (5), 336–342 (2000)
7) Osawa, K., Shiozaki, T., Urabe, T., Yoshitake, A., Saito, T., Kabasawa, M.: Improvement of Fatigue Properties of Fillet Lap Joints by Applying. Quarterly Jounal of the Japan Welding Society. 17 (2), 319–325 (1991)
8) Matsushita, M., Kataoka, T., Ikeda, R., Ono, M., Yasuda, K.: Development of Plasma-Arc Hybrid Welding Technology (Report 2). Preprints of the National Meeting of JWS. 80, 2007, p.14–15
9) Toyama, K., Magara, S., Koibuchi, K.: Application of Low Transformation Temperature Welding Wire to Structures of Vehicle Chassis. Preprints of the National Meeting of JWS. 72, 2003, p.F39–42
10) Yamada, K., Ojio, T., Torii, A., Baik, B., Sasaki, Y., Yamada, S.: Influence of Shot Blasting on Fatigue Strength of Out-of-plane Gusseted Specimens under Bending. Journal of Structural Engineering. A. 54A, 522–529 (2008)
11) Nakajima, S., Kanie, E., Ozawa, M., Endo, T., Okazaki, T.: Development of Die Quenching Technique for Impact Beam. Sokeizai. 43 (12), 31–35 (2002)
12) Fujimoto, H., Akioka, K., Tokunaga, M.: Effects of Shot Blasting on Corrosion Properties after Electrodeposition and Fatigue Properties of Arc Welds in Automotive Steel Sheets. Journal of the Japan Society for Technology of Plasticity. 58 (675), 299–303 (2017)

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