INFLUENCE OF WELDING CONDITIONS ON NUGGET FORMATION IN SINGLE-SIDED RESISTANCE SPOT WELDING PROCESS



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ABSTRACT

This paper describes the single-sided resistance spot welding (SSSW) process which is expected to be a productive welding technology for joining stamped sheet panels to hollow parts for auto bodies. To obtain guidelines for making a good weld with SSSW process, the influence of welding parameters and set-up conditions of the specimen upon nugget growth were investigated experimentally. In addition, a numerical study was carried out to establish the mechanism of nugget growth in the SSSW process. Since deflection of parts during welding is one of the features of the SSSW process, this report focuses on the influence of electrode force and the stiffness of the specimen upon nugget formation. In addition, the effect of electrode geometry was examined.

IIW-Thesaurus keywords: *Assembling; Computation; Finite element analysis; Manufacturing; Resistance spot welding; Resistance welding.*

1 INTRODUCTION

In the field of automobile development, high stiffening and weight reduction of auto bodies have been proposed in order to improve crashworthiness and fuel efficiency. Therefore, hollow parts such as bended pipes or hydro-formed parts are being more widely used in order to reduce weight and to improve stiffness.

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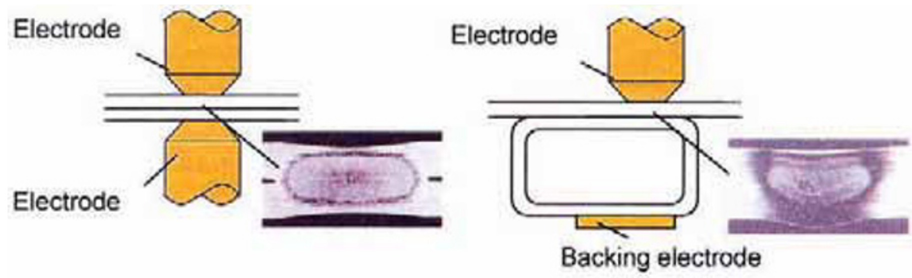
To join these hollow parts and sheet panels together, welding processes that allow us access from one side are needed. Single-sided resistance spot welding (SSSW) without backing support is considered to be one of the productive technologies [1-4].

Figure 1 shows schematic representations of conventional direct resistance spot welding (RSW) and single-sided resistance spot welding (SSSW). In the conventional RSW, a point of weld is forced with two electrodes from both sides. On the other hand, in the SSSW process, a point of weld is forced with an electrode from one side and a backing electrode is placed at another optional position on the hollow parts. As a result of electrification between the electrode tip and the backing electrode under proper welding conditions, a weld nugget will grow at the interface of the hollow part and the sheet placed under the electrode tip.



a) Direct SSW **b) Single-sided RSW (SSSW)**

Figure 1 – Welding process of direct RSW and SSSW

However, it was revealed that there was a limit to the number of parts to which the SSSW process can be applied. It was recommended that lower sheets have a certain amount of stiffness [1].

For example, in our preliminary trial shown in Figure 2, a steel sheet (1.0 mm thick) could be welded to a square, sectioned steel pipe (2.0 mm thick) by the SSSW process. On the other hand, joining a steel sheet (1.0 mm) to a stamped part (1.0 mm) by the SSSW process was difficult; a sound, welded nugget, grown to an ideal position and size, was hardly formed in any condition. Those cases suggest that the parts deflection is the major influencing factor on weldability in the SSSW process.

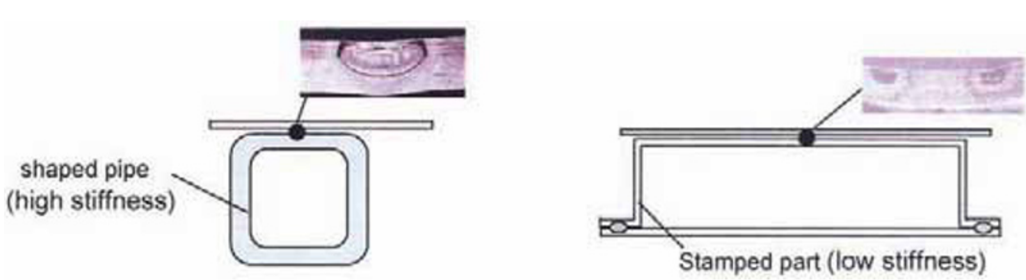
A study on nugget formation in low stiffness parts by SSSW is so far inadequate. Much knowledge remains to be gained on this subject. In this report, to obtain guidelines for making a sound nugget in combination with two thin steel sheets in the SSSW process, the influence of welding parameters, the set-up conditions of the specimen and the electrode geometry of the nugget growth were investigated experimentally [5]. Furthermore, to discuss the mechanism of nugget growth in SSSW, distribution of current density and contact condition between electrode and sheets were calculated by CAE analysis.

2 EXPERIMENTAL PROCEDURE

Coupon specimens of mild steel with chemical compositions as written in Table 1 were prepared. They measured 30 mm wide, 120 mm long and 1.0 mm thick.

Figure 3 shows the schematic image of our experiment. Full-rapped specimens are supported with two backing electrodes located under both sides of the specimen. The specimens are clamped on the backing electrode. Since deflection of the specimen is an influencing factor in nugget growth during the SSSW process, electrode displacement during welding, known as electrode tip movement, is measured. The level of upper sheet surface without load is defined as the level, and the direction of tip movement for the lower side is indicated as positive (+) in graphs.

The current type used is a DC inverter. In this report, the electrode tip side is the positive pole and the backing electrode is the negative pole. The experimental conditions are shown in Table 2 and the geometry of the electrodes used in this experiment is shown in Figure 4. To avoid buckling distortion of the specimen by electrode force, low electrode forces were set for this study.



a) Joining high stiffness parts and sheet panel **b) Joining two sheet panels**

Figure 2 – Difference in weldability depending on shape

Table 1 – Chemical compositions of material used (mass%)

	C	Si	Mn	P	S
JSC270D	0.001	0.01	0.15	0.01	0.009

Table 2 – Welding conditions

	Condition A	Condition B	Condition C
Electrode force ***F*** (N)	196	490	
Span of backing electrode ***d*** (mm)	50		20
Deflection of specimen during the weld	*small*	*large*	*small*
Welding time (ms)	366		
Electrode type	R, DR	R, DR, CF	R, DR

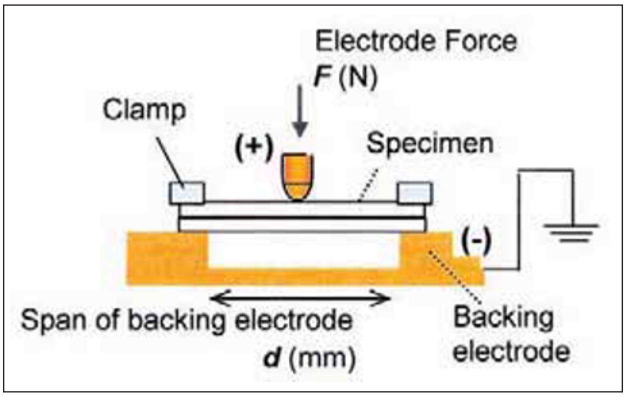
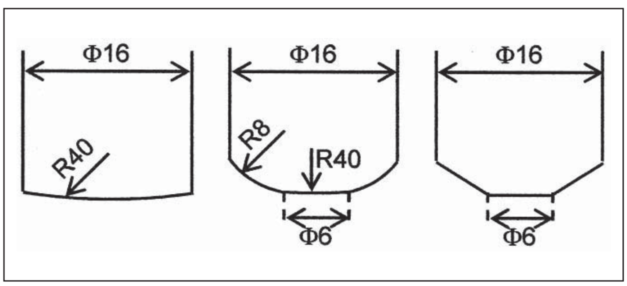


Figure 3 – Schematic of experimental procedure



a) R type b) DR type c) CF type

Figure 4 – Schematics of electrode's geometry

Three types of electrode, single-radius (R) type, double radius (DR) type and centre flat (CF) type were used. The DR type electrode used in this experiment is one of the standard electrodes used by Japanese automotive companies. To investigate the effects of electrode geometry, single R type electrodes which had the same radius (R40) and flat type electrodes which had the same diameter (Φ6) were used in this report.

In this report, conditions A, B and C as referred to later in this paper concern the conditions described in Table 2.

In the area of resistance welding, shunt current sometimes becomes a problem. As described above, two specimens are clamped together on a backing electrode several dozen mm from weld point, and shunt current may easily occur in such conditions. That is to say, shunt current may pass through from the upper sheet to the lower sheet at the clamped area. In this report, only in the case we discuss phenomena using CAE analysis, insulators were inserted between upper and lower sheet under clamps.

Because of shunt current, welding under the conditions of this experiment might have been more difficult than under industrial conditions, if we undertake the welding of only one point by SSSW. However, most auto parts have numerous welding points. Because the disposition of welding points affects shunt current, the case study depends on the design of the part.

3 RESULTS AND DISCUSSION

3.1 The effect of the deflection of the specimen on nugget growth

Figure 5 shows the influence of electrode force ***F*** on nugget diameter at the interface of two sheets with span ***d*** kept constant. Electrode tip movement under each condition with 6.0 kA is shown in Figure 6. Under condition A (lower electrode force condition), the nugget formed at lower current and the nugget diameter was larger. The histories of electrode displacement are also different and condition A also gave a smaller deflection.

Shown in Figure 7 is the nugget diameter under the different conditions of backing electrode span ***d*** with constant electrode force. A larger nugget formed under the short span condition. Figure 8 shows the electrode tip movement at 6 kA. The welding condition of small span, which formed a larger nugget, also gave a small deflection.

Both results mentioned above (Figure 5 and Figure 7) show that a larger nugget formed under small deflection conditions. This might suggest that the condition

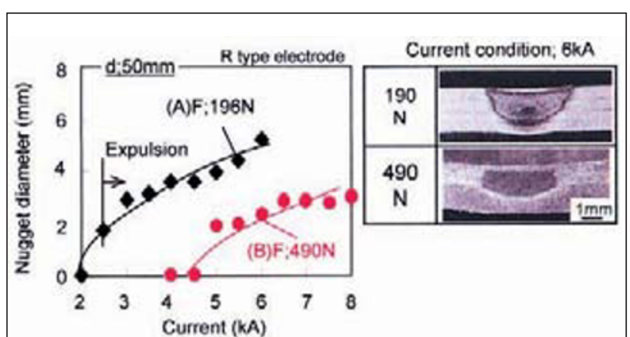
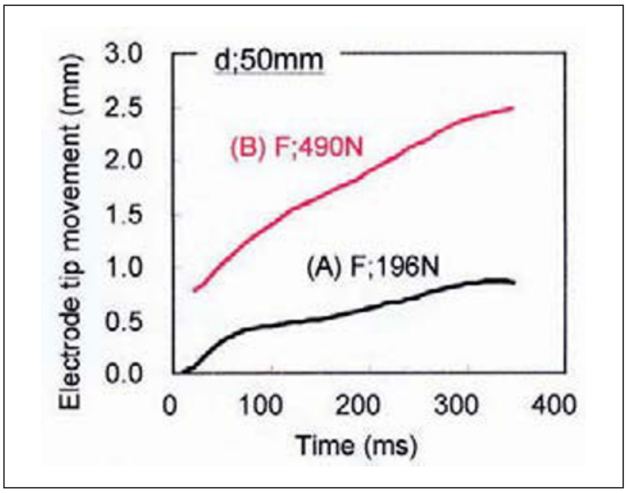


Figure 5 – The influence of electrode force *F* on nugget diameter under condition A: 196 N, 50 mm, and condition B: 490 N, 50 mm



Current condition: 6.0 kA.

Figure 6 – Electrode type movement under each condition

which does not cause large deflection of a specimen is better for the SSSW process.

There are two different ways to reduce deflection of a specimen. One is to increase stiffness by shortening the span ***d***. The other is to reduce the electrode force ***F.*** Thus, in order to choose the better approach of the two, weldability under two different conditions which gave almost the same deflection was compared.

The results of this experiment are shown in Figure 9 and electrode tip movement under these two conditions is shown in Figure 10. As demonstrated in the result, the deflections under condition A: 196 N, 50 mm, and condition C: 490 N, 20 mm, are almost equal. In this case, shunt current at clamped area was blocked with insulators between two sheets.

Although their deflections were almost equal, conditions A and C gave different results. Under condition A, with small electrode force and long backing electrode span, the nugget grew at lower current. However, in condition A, expulsion also occurred from upper sheet surface at low current.

To discuss these differences in the results of conditions A and C, nugget growth was simulated by CAE analysis of SSSW. CAE software used for this report is

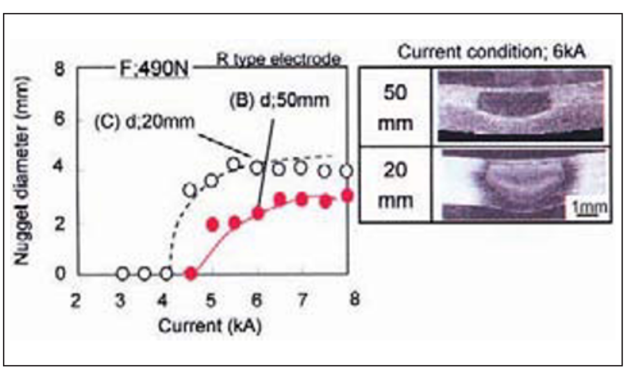
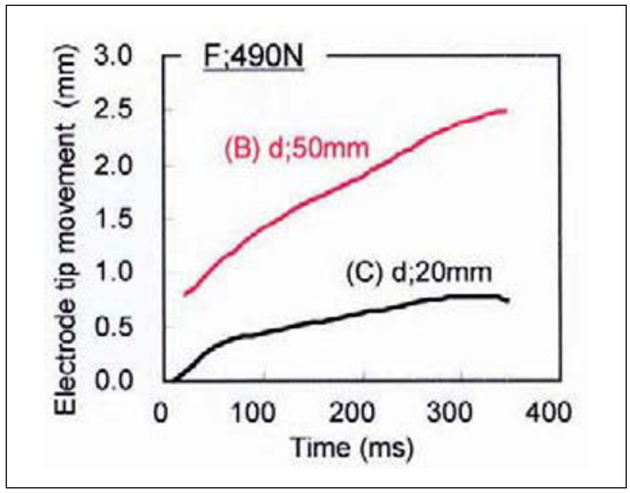


Figure 7 – The influence of span *d* on nugget diameter under condition B: 490 N, 50 mm and condition C: 490 N, 20 mm

the finite element simulation, based on the incrementally-coupled electrical – thermal-mechanical modelling techniques [6].

Conditions of CAE analysis are shown in Figure 11. 3-D models were employed here to simulate the process in conditions A and C.



Current condition: 6.0 kA.

Figure 8 – Electrode type movement under each condition

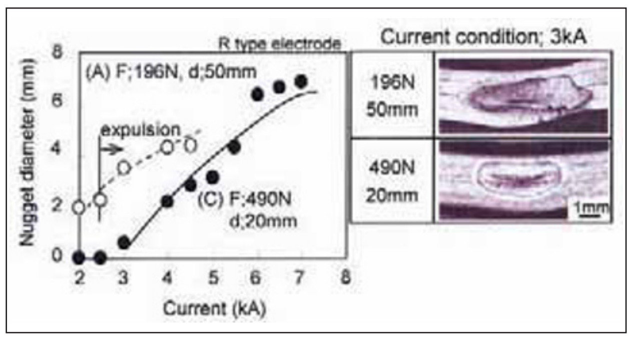
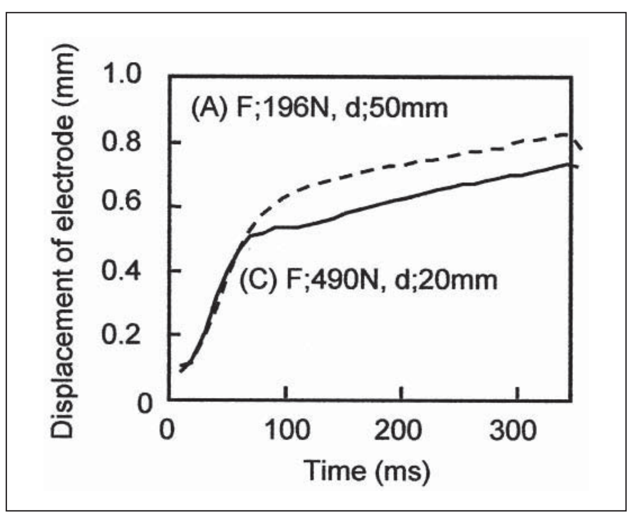


Figure 9 – The influence of electrode force and span on nugget diameter under condition A: 196 N, 50 mm, and condition C: 490 N, 20 mm



Current condition: 3.0 kA.

Figure 10 – Electrode type movement under each condition

Figure 12 shows the results of CAE analysis in conditions A and C. The figures in the upper row show contact pressure at electrode / sheet 1 interface and at sheet1 / sheet 2 interfaces. The figures in the lower row show distribution of current density. Though their deflection during welding was almost equal as shown in Figure 10, their conditions of contact pressure were quite different.

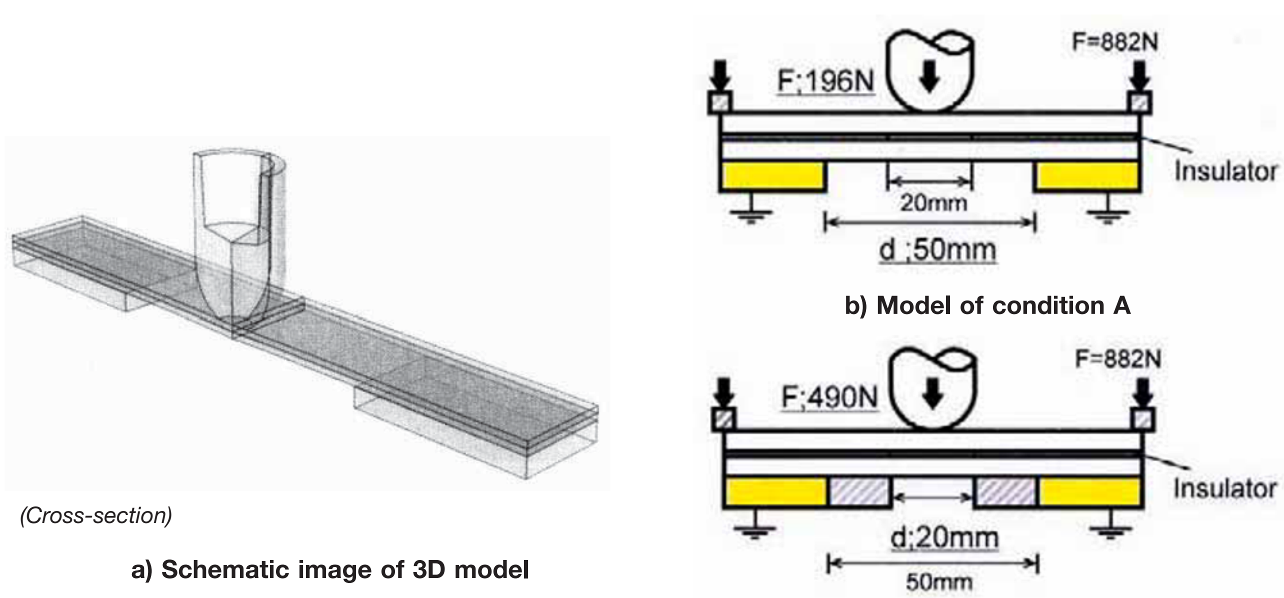
In condition A (low pressure – low stiffness), the contact area is limited to a narrow area as compared with condition B. As a result, current density is high which would explain why the nugget can grow at a lower current in condition A. However, in condition A, the current density between the electrode and the upper sheet was also higher than that of condition C. It suggests that expulsion from the upper sheet occurred at low current.

It is considered that adjusting an optimum welding current is difficult in such conditions (low electrode force and low stiffness of parts). Based on these results, welding conditions with higher parts stiffness and higher electrode force like condition C seem to be more suitable for the SSSW process from the viewpoint of industrial applications.

3.2 The effect of electrode geometry on nugget growth

In order to choose the proper electrodes for making a sound nugget with the SSSW process, weldability tests were carried out by using some electrodes with a different geometry.

Nugget formations with two types of electrode, single-R (R) type and double-R (DR) type, were compared under two different conditions of deflection of specimen, because deflection of specimen has influence on nugget growth in SSSW.



a) Schematic image of 3D model

b) Model of condition A

c) Model of condition C

Figure 11 – FE models of SSSW

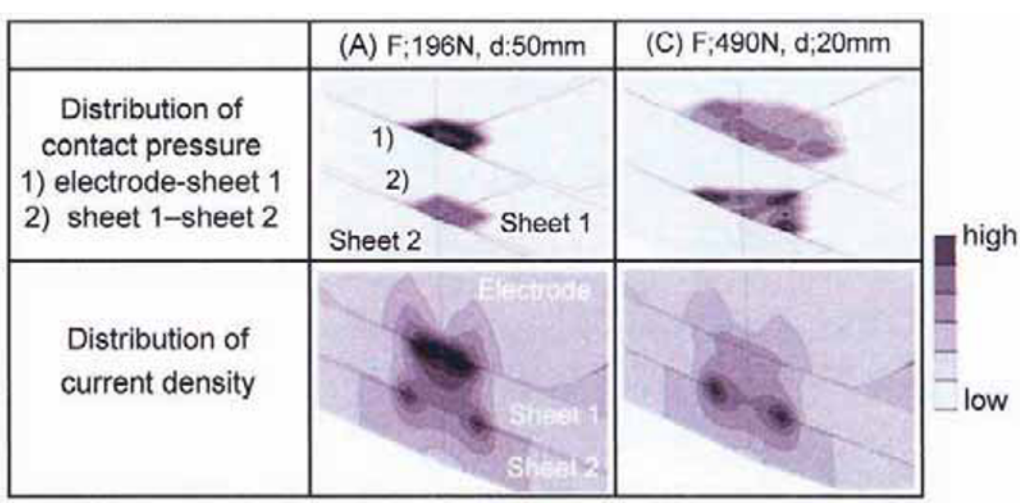


Figure 12 – The results by CAE of SSSW in conditions A and C (3 kA – 16 ms)

In this experiment, electrode pressure ***F*** was kept in 490 N. Span ***d*** under condition C was 20 mm and span ***d*** under condition B was 50 mm. Electrode tip movement under each condition is shown in Figure 13. Condition B gave a larger deflection of specimen.

Figure 14 shows the diameters of nuggets welded with each electrode under condition C which causes a small deflection. In this condition, there is less difference in nugget diameters between two types of electrodes. In contrast, as shown in Figure 15, when the deflection of specimen is large, only single-R type electrode could make a nugget at the interface of two sheets, while double-R type electrode gave small separate melted zones in the upper sheet.

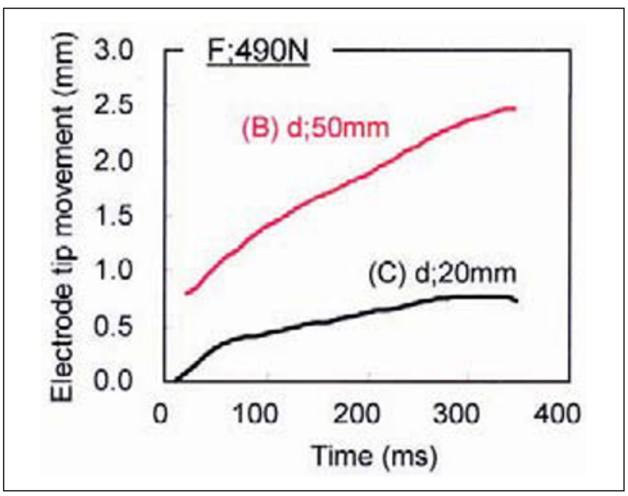
These results suggest that single-R type electrode is suitable for welding parts which deform largely in the SSSW process.

To discuss the mechanism of those results, nugget growth was simulated by CAE analysis. Figure 16 shows current distribution by CAE analysis in each condition. In condition C, where deflection of the specimen is small, current was concentrated in the area under the centre of the electrode and at the interface of two sheets.

In Figure 16, the lower figure shows the results of condition B, for which the DR electrode was unable to give a sound nugget. The result shows that the current concentrated at the electrode edge due to the large deflection of the specimen. The simulated results explain the experimental results well.

As further investigation on the effect of the electrode's shoulder, weldability using centre flat type (CF type) electrode was evaluated. Figure 17 shows the result of the nugget formation in condition C, that nugget could be formed with DR electrode. As shown in the lower photo of Figure 17, cross-sections show that small, separated, melted zones formed with CF type electrode, even though the specimen's deflection was limited. This result suggests that a curvature is required in the tip of the electrode to concentrate current to proper point in the SSSW process.

The effect of electrode geometry has been discussed from the viewpoint of the electrode contact in the early stage of welding. However, the contact position between an electrode and an upper sheet can sometimes change during welding. Figure 18 shows the result under condition A: 196 N, 50 mm. In this case, contact position seems to change during welding.



Current condition: 6.0 kA.

Figure 13 – Electrode type movement under condition B: 490 N, 50mm, and condition C: 490 N, 20 mm

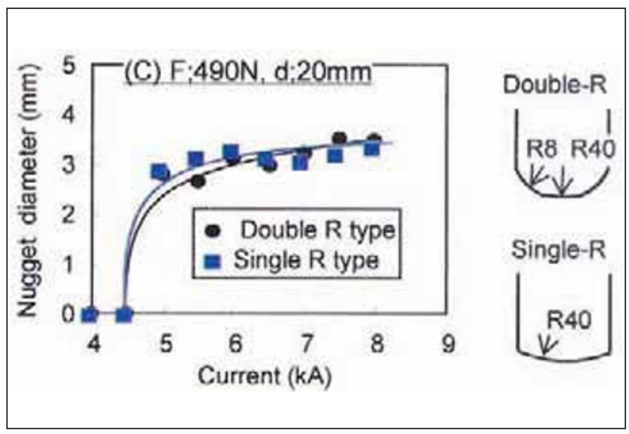


Figure 14 – The influence of electrode geometry on nugget growth under condition C: 490 N, 20 mm

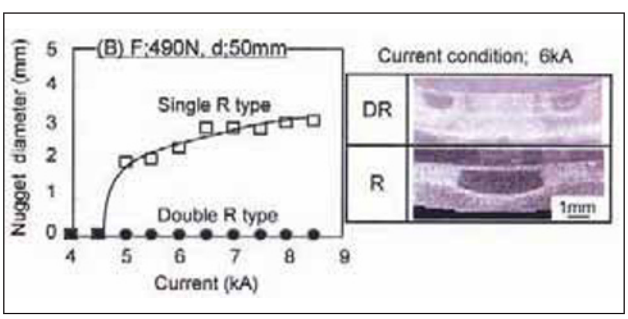
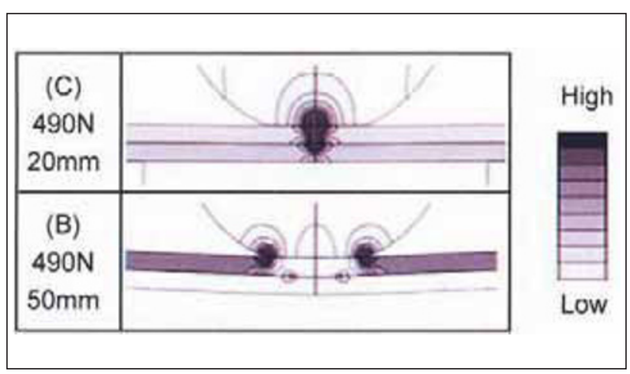


Figure 15 – The influence of electrode geometry on nugget growth under condition B: 490 N, 50 mm



6 kA - 67 ms, Double-R type electrode was used.

Figure 16 – Current density calculated by CAE analysis under condition A: 490 N, 20 mm, and condition C: 490 N, 50 mm

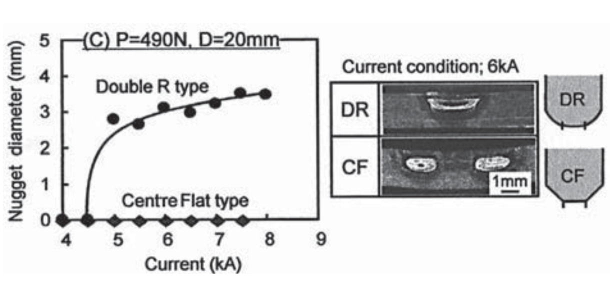


Figure 17 – The influence of electrode geometry on nugget growth under condition C: 490 N, 20 mm with DR-type and CF-type electrode

There was no difference in nugget diameters at low current between the DR type and R type electrode. On the other hand, at high current, the diameter of the nugget welded with DR type electrode increased significantly.

From these results, it is probable that there is a difference in the contact point of the electrode to the upper sheet, between low and high current conditions due to the difference in deflection of the specimen. Figure 19 reveals a history of electrode tip movement and cross-sections during welding using DR type electrode at 5 kA and 8 kA. For both currents, no displacement occurred at the beginning of welding, therefore only the top of the electrode seems to be in contact with the upper sheet at this time.

A difference in deflection was observed after 50 ms. The deflection with 8 kA increased, largely due to the softening of specimens caused by the heat input during welding, and finally, the deflection with 8 kA was twice as large as that with 5 kA.

From a cross-sectional view, there were imprints of the electrode's shoulder on the upper sheet welded under the conditions of 8 kA and 333 ms, while there were not any imprints on the welds of 50 ms and 167 ms.

This suggests that the contact position of the electrode to the upper sheet shifted from the top to the shoulder of the electrode in the later stage of welding with 8 kA using DR type electrode. In this case, current would be concentrated in the centre in the early stages and a nugget formed there. After that, the concentrating point of current seemed to separate and move to the outside of the nugget, where the shoulder of the electrode contacts strongly. Then the nugget grew additionally in the final stage of welding when using DR type electrode.

In the case of using single R type electrode, the contact area will spread gradually during welding and current density will drop with it. Therefore, the nugget will not grow in the later stage of welding.

The results of our study show that the influence of electrode geometry on nugget growth in the SSSW process can be discussed from the viewpoint of the electrode's contact position. R type electrode is considered a proper geometry for the SSSW process. However, the

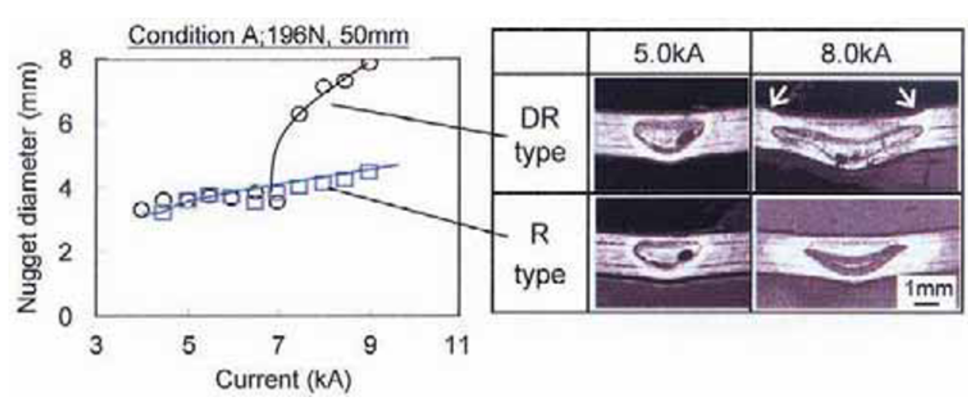


Figure 18 – The influence of electrode geometry on nugget growth under condition A: 196 N, 50 mm

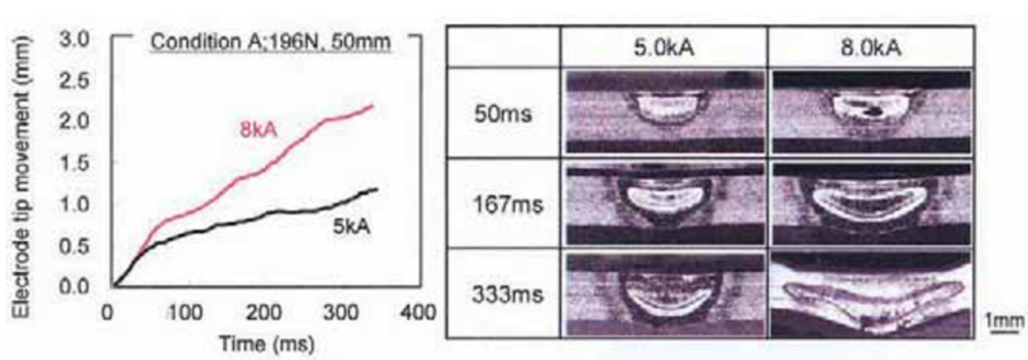


Figure 19 – Electrode tip movement and cross-sections of a welded joint during a short period with DR-type electrode

effect of radius and wear of electrode should be investigated for practical application (especially in the case of welding coated steel sheet).

4 CONCLUSIONS

To obtain guidelines for the SSSW process, the influence of parts deflection and electrode geometry on nugget growth were investigated. The SSSW process, without a direct backing electrode, causes deflection of the welded area. The deflection causes the difficulty in nugget formation. The summary of our interpretation of the results is explained as follows:

1. Lowering electrode force is one of the conditions for reducing the deflection. However, the low electrode force could bring about expulsion at the surface of the weld. Increasing the stiffness of parts is the best approach to make a good weld with the SSSW process.

2. The contact point between an electrode tip and an upper sheet also affects nugget growth. To produce a requested size nugget formed in the proper position, contact between the shoulder of the electrode tip and upper sheet at the early stage in welding should be avoided.

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