

Development of Short Pitch Resistance Spot Welding Technology

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ABSTRACT

In order to reduce the pitch used in resistance spot welding, it is necessary to quantify the phenomenon of shunting, or short-circuiting of current flow. A technology for predicting the state of current flow using a three-dimensional spot welding simulation was therefore developed. Test results showed that predicted spot weld diameter values when current shunting occurred, corresponded well with measured values. Using this method, it was shown that it was possible to realize sufficiently sized spot welds in short-pitch resistance spot welding by increasing input energy to compensate for heat loss caused by the short-circuiting of the welding current. In addition, an application study of short pitch spot welding showed that a reduced weld pitch of 15 mm in high stress regions reduced peak stress in the weld, making the use of thinner steel sheets possible.

1. Introduction

In response to environmental issues, automotive manufacturers are today actively engaged in developing technologies which increase fuel efficiency and thus reduce CO₂ emissions. In the area of the vehicle body, continuous joining processes using laser welding and adhesives are being employed to reduce sheet thickness and achieve weight savings while still realizing joining strength. However, this increases cost, and the time necessary for the welding process in comparison to resistance spot welding (RSW), a discontinuous joining method.

RSW is a joining method in which an electric current is applied through adjoining metal sheets that are held under pressure by the electrodes. Joule heat (resistive heating) is generated by the transmission of current between opposing electrodes and by the corresponding contact resistance at the interface between the work piece and electrode surfaces, and by the specific resistance of the metal materials through which current is passed. Subsequent melting and joining occurs at the surfaces. If it were possible to reduce the pitch between these spot welding points, the strength of the join would increase proportionally with increase in the area of the joints. However, when the pitch between welds is reduced, a phenomenon termed shunting occurs, in which the current is short-circuited by contiguous welding points (Fig. 1). This results in insufficient heat being generated in the area to be welded, making it challenging to realize the necessary size in the welding point (termed the “nugget diameter” below) to satisfy strength standards. Because

of this, it is common to employ a pitch of around 30 mm between spot welds.

In order to realize RSW using a pitch of around 15 mm (short-pitch RSW), it was necessary to elucidate the phenomenon of shunting. A method was therefore developed to predict shunting using a three-dimensional spot welding simulation. Using this method, it was determined that the heat loss due to shunting could be compensated for, by increasing the input energy. The study also showed that it was possible to set welding conditions that would satisfy nugget diameter standards even when conditions such as the thickness, combination, or properties of the sheets differed. This paper will report on these results.

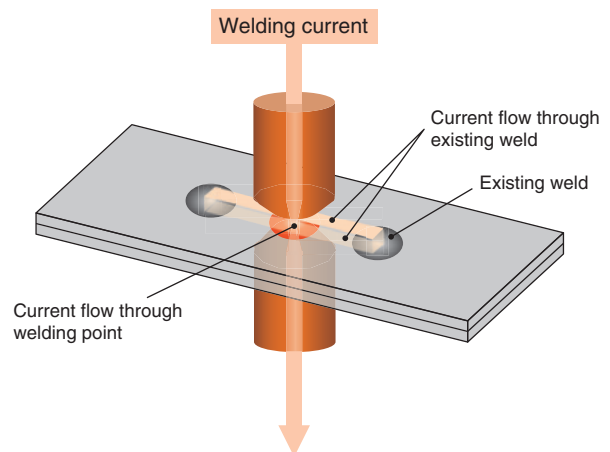


Fig. 1 Phenomenon of current shunt

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2. RSW Simulation

2.1. Conditions for Study using RSW Simulation

Because the shunting that occurs as a result of short-pitch RSW is a phenomenon that occurs in an infinitesimal range, measurement of the phenomenon in tests represents a challenge. A simulation was therefore used in order to conduct a current path analysis. Spot welding simulation software available on the market is normally used to conduct simulations of nugget formation, and therefore involves analysis of two-dimensional axial symmetry models, making it unable to calculate the phenomenon of shunting. The three-dimensional model shown in Fig. 2 was therefore formulated using a spot welding simulation software, capable of three-dimensional analysis, developed by Nippon Steel & Sumitomo Metal Corporation. Analyses were conducted using this model. A 1/4 model was used based on considerations of symmetry and calculation speed. Contact resistance at the interface between the steel sheets is an important parameter in RSW, and was set with consideration of the effect of contact pressure and the properties of the steel sheets (yield stress, resistivity, and the temperature-dependence of these parameters)⁽¹⁾. Two sheet combinations were employed for comparison: a mild steel with a lower specific resistance, which was considered would have a significant effect on shunting (Combination A); and a 590 MPa high-tensile steel with a high specific resistance (Combination B). Details of the materials and the spot welding conditions are shown in Table 1.

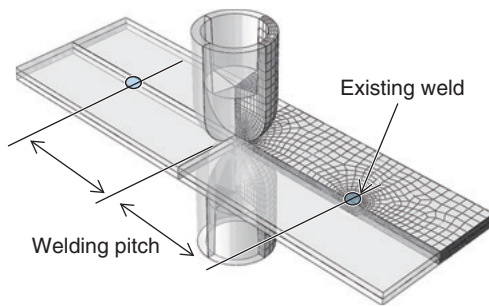


Fig. 2 Analysis model by CAE

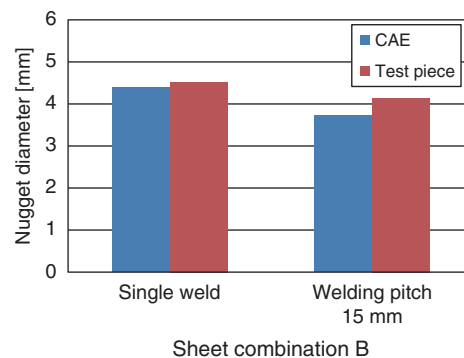
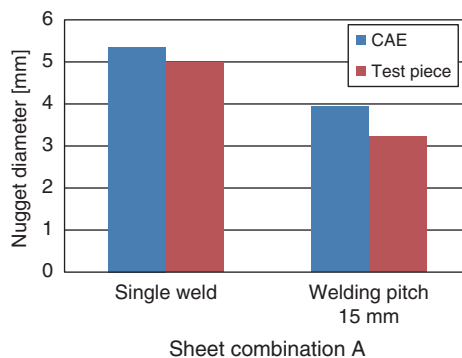


Fig. 4 Results by analysis and experiment of spot welding (nugget diameter)

Table 1 Spot welding conditions

Sheet combination	A	B
Material	JSC270D	JSC590R
Thickness	1.4 mm	1.0 mm
Electrode force	3.5 kN	3.5 kN
Welding current	7.8 kA	6.2 kA
Welding time	17 cycles	12 cycles
Existing weld diameter	5.2 mm	4.5 mm
Welding pitch	Single weld, 15 mm	

2.2. Verification of Analytic Accuracy of RSW Simulation

First, the analytic accuracy of the simulation was verified. Figure 3 shows the shape of a nugget as determined using the simulation and in a test. The upper frames in each case show simulation results, and the lower frames show test results. Images from the simulation and the test show that in going from a single weld point, for which shunting does not occur, to a welding pitch of 15 mm, results in a reduction in the nugget diameter due to the effect of shunting.

Figure 4 shows simulation and test results for nugget diameter. The tendency for the nugget diameter to decline

Sheet combination	Method	Single weld	Welding pitch 15 mm
A	CAE		
	Test piece		
B	CAE		
	Test piece		

Fig. 3 Results by analysis and experiment of spot welding (cross-sectional images)

due to shunting matches in the simulation and test results for both sheet combinations, indicating that it is possible to use the simulation in evaluations.

2.3. Results of Study of Shunting using RSW Simulation

Figure 5 shows simulation results for the distribution of current density during welding of Combination A. Figure 5(a) shows results for a single weld point, for which shunting does not occur, while Fig. 5(b) shows results for a welding pitch of 15 mm. Under the conditions shown in Fig. 5(b), because the current is flowing via the intermediary of the nugget, the current density increases in areas other than the welding point, indicating that shunting is occurring. Figure 6 shows simulation results for the amount of shunting in Combination A. In the case of the single welding point, 100% of the current flows to the welding point [Fig. 6(a)], while in the case of the 15 mm welding pitch, an average of approximately 67% of the current flows to the welding point, indicating that approximately 33% of the current is shunted.

Figure 7 shows the relationship between the amount of time that the current is applied, and the amount of current flowing through the welding point. The amount of current flowing through the welding point declines with time, indicating the amount of shunting increases during the initial three cycles. However, after three cycles the amount of shunting declines. This phenomenon is thought to occur because, up to the third cycle, the heating of the welding point increases its resistance, thus restricting the flow of current through the welding point. It is considered that the current flows more easily after the third cycle because the area in which the current flows, increases with increasing nugget diameter, and the resistance of the welding point declines.

The use of the simulation made it possible to visualize

and study the phenomenon of shunting during welding, which is not possible to measure in tests. In addition, it was also possible to study the amount of change in shunting produced by changes in conditions, such as material properties, sheet thickness, and welding conditions.

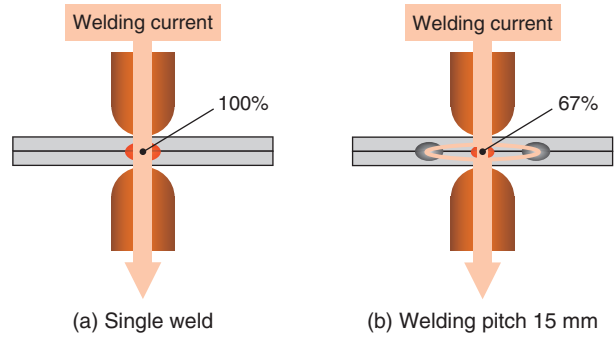


Fig. 6 Measurement of current shunt by CAE

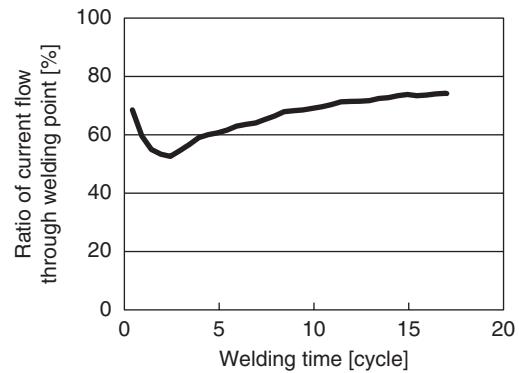


Fig. 7 Relationship between welding time and current shunt

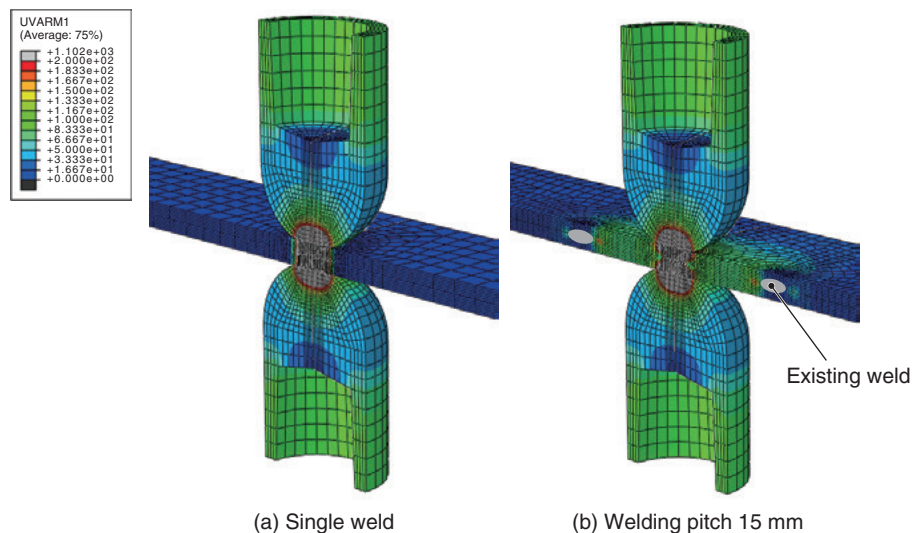


Fig. 5 Results of current density distribution by CAE

3. Method of Setting Welding Conditions

3.1. Study of Method of Compensation via Input Energy

It was conjectured that by increasing input energy in relation to the loss of heat generation resulting from shunting, it would be possible to satisfy nugget diameter standards, as for example, those stipulated by the Japanese Industrial Standards⁽²⁾. Figure 8(a) shows a schematic diagram of the current waveform for direct current. The area of the section shaded in yellow is input energy. A variety of methods of increasing input heat can be considered: increasing the input current [Fig. 8(b)], increasing the length of time for which the current is input [Fig. 8(c)], or a combination of the two suffice. The present research conducted a study of both increased welding current and increased welding time methods, using simulations and tests.

Table 2 shows the sheet combination and basic welding conditions. In order to study the effects of increased welding current and increased welding time, welding current and welding time were varied under the basic welding conditions (Fig. 9). Figure 9(a) shows results for

Table 2 Spot welding conditions

Sheet combination	JSC270D
Thickness	1.4 mm
Electrode force	3.5 kN
Welding current	7.6 kA
Welding time	14 cycles

increased welding current; results for single weld points are shown as black, and results for a weld pitch of 15 mm are shown as grey. The solid lines show CAE results, while the round points show test results. A decline in nugget diameter due to the effects of shunting under the same current conditions can be observed. However, increasing the welding current, increases the nugget diameter, and enables weld size equivalency to that of the single point weld. In Fig. 9(b) are results for increased welding time, and saturation can be observed from the 14th cycle onwards. The Joule's law equation [Equation (1)] also shows that current, I , has a significant effect on increasing the amount of heat produced, Q . This relationship also suggests the

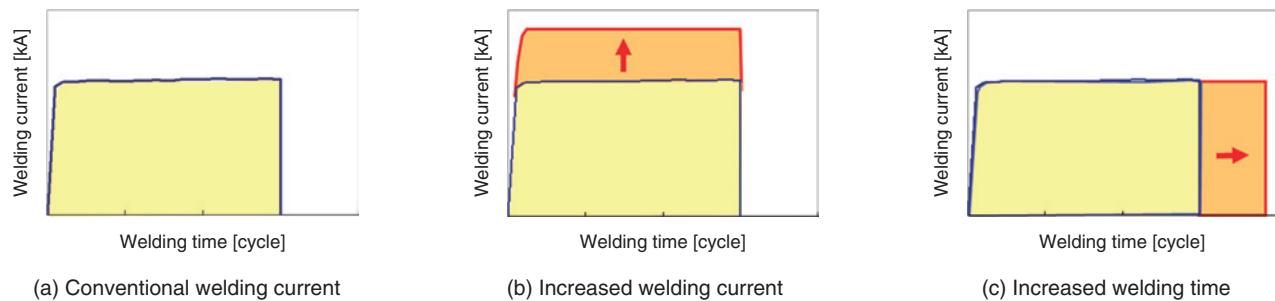


Fig. 8 Current waveform

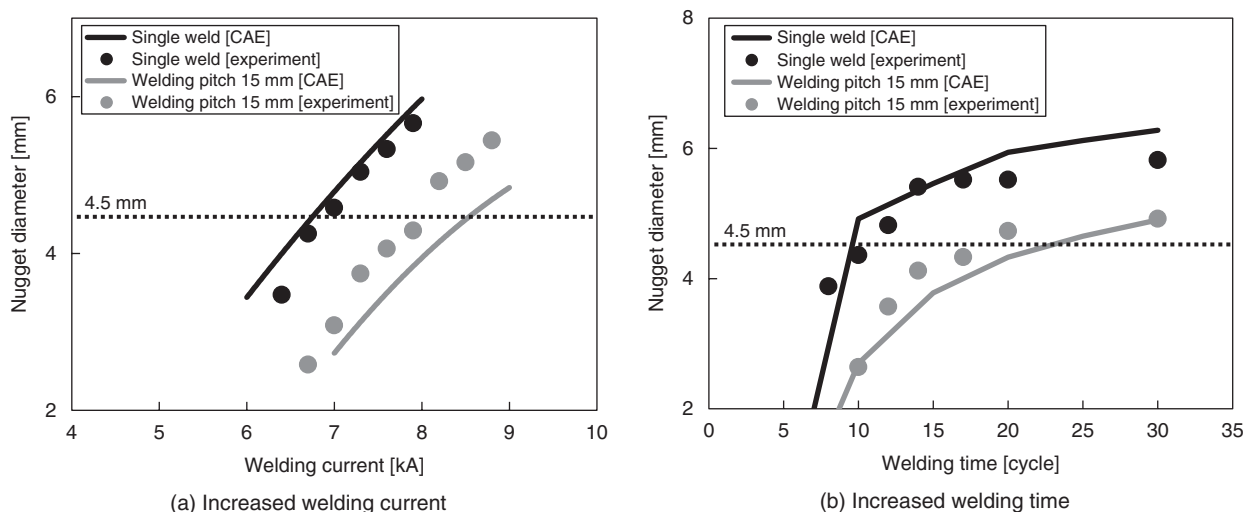


Fig. 9 Influence of welding current and welding time on nugget diameter

Table 3 Spot welding conditions

Sheet combination	JSC270F	JSC590R	JSC590R
Thickness	0.7 mm	1.4 mm	1.4 mm
Sheet size	30 mm × 100 mm		
Electrode force	3.5 kN		
Welding time	18 cycles		
Welding pitch	Single weld, 15 mm		

effectiveness of increasing current. In addition, increasing the welding time on an actual production line would have an effect on the number of welds that could be made in the process, further suggesting that increased current would be the more effective method of compensating for the loss of heat generation.

$$Q = R \times I^2 \times t \quad (1)$$

Q : Joule heat [J]

R : Resistance [Ω]

I : Current [A]

t : Time [s]

3.2. Study of Short-pitch Resistance Spot Welding Conditions using Sheet Combinations Employed in Actual Vehicles

A simulation analysis was conducted using representative three-sheet spot welding for sheet combinations in general use in vehicle bodies. Table 3 shows the sheet combination and welding conditions, and Fig. 10 shows the welding results.

Comparing single weld points and 15-mm pitch weld points of diameter 4.5 mm and larger, it was predicted that a 2.0 kA welding current increase for the close pitch joints would yield equivalent weld size to that of single point welds.

Tests were conducted based on the simulation results.

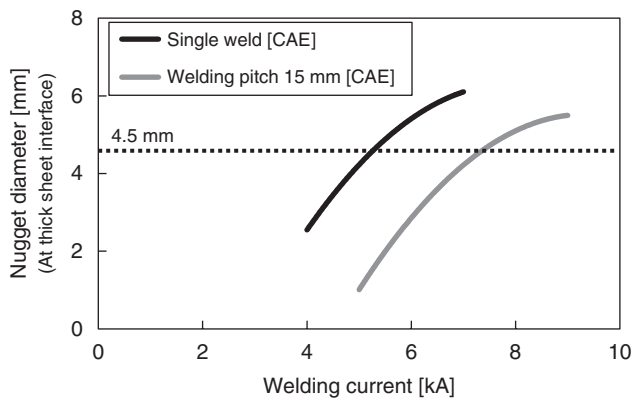


Fig. 10 Influence of short-circuit on nugget diameter by CAE

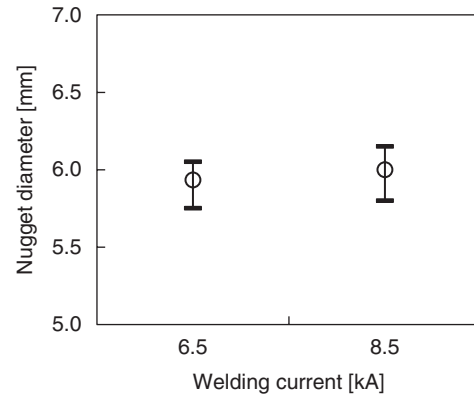


Fig. 11 Influence of short-circuit on nugget diameter by experiment

For the single weld point, 6.5 kA was set as the welding current that would satisfy the nugget diameter standards. For the 15-mm pitch welds, the welding current was increased by 2.0 kA to 8.5 kA. Tests were conducted under these conditions, and Fig. 11 shows the test results. The nugget diameter for the 15 mm-pitch welds is almost equivalent to the nugget diameter for the single weld.

These results demonstrate that the simulation is able to make predictions for actual sheet combinations, including differing sheet thickness and material properties in three-sheet welds.

Conventionally, sheets of the same combination have been joined under the same welding conditions, but in the case of short-pitch RSW, the effect of shunting due to the welding pitch, the sheet combination, and the welding conditions makes it necessary to optimize the welding conditions in order to satisfy nugget diameter standards.

4. Application to Actual Vehicle

A study was conducted in order to determine which areas of an actual vehicle short-pitch RSW would be effectively applied. A CAE analysis was conducted, focusing on areas in which spot welding discontinuities were prone to occur under strength and durability conditions due to the stress concentration. Figure 12 shows the structure of the front damper housing. Figure 13(a) shows

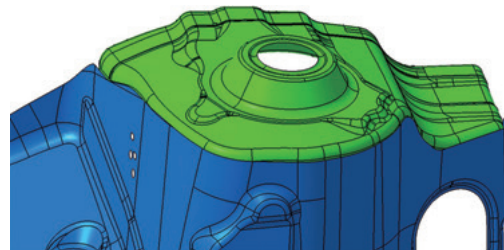


Fig. 12 Front damper housing structure

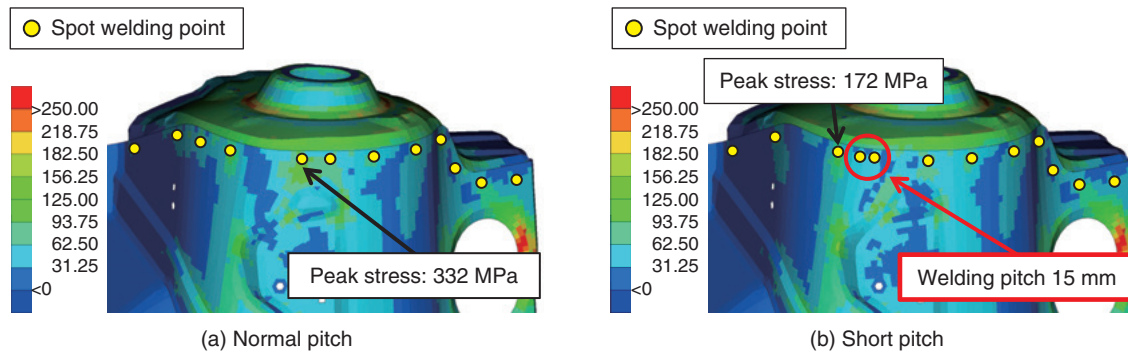


Fig. 13 Stress distribution

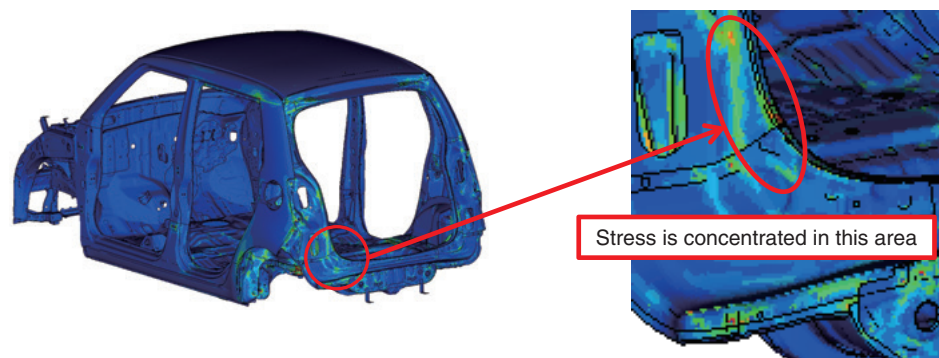


Fig. 14 Result of stress analysis by torsion test

the stress distribution in the structure with input from the damper. The input is particularly strong at the corners of the structure. A maximum stress of approximately 332 MPa is generated on the welding points used in conventional RSW. The use of short-pitch RSW in the corners of the damper housing disperses stress, reducing the maximum stress on the spot weld points by 48% [Fig. 13(b)]. Consequently, even if the sheets were reduced in thickness (to achieve a weight savings of approximately 13%), the stress target of 250 MPa at the spot weld points would be satisfied. This study changed the position of the welding points, but did not change the number of welding points. It would, therefore, be possible to achieve weight savings and reduce material costs through sheet thickness reduction, without increasing process costs associated with additional welding points.

In an entire vehicle body, stress concentrates particularly in the corners of the door openings and the tailgate, which are large open sections. Figure 14 shows the results of a stress analysis using a torsion test with input to the left rear damper. In the future, studies will be conducted concerning application of short-pitch RSW to areas of this type.

5. Conclusion

The development of a short-pitch RSW technology produced the following outcomes.

(1) Using a three-dimensional resistance spot welding

simulation, the phenomenon of shunting was elucidated, and it was shown that the amount of shunting could be predicted even when sheet thickness, sheet combination, material properties, welding conditions, and other parameters differed.

- (2) The study showed that heat loss due to shunting in short-pitch RSW could be compensated for, by appropriately inputting energy. In addition, it was demonstrated that it was possible to set welding conditions in order to realize a stable nugget diameter even when sheet thickness, sheet combination, material properties, and other parameters differed.
- (3) In order to test the applicability of the method to vehicle bodies, short-pitch RSW was used in the areas of the body in which stress becomes high under the conditions employed in strength and durability tests, and it was verified that peak stress was reduced and that sheet thickness could be reduced in those areas.

This technology will first be applied in the 2014 model year FIT, following which its use will be successively expanded. It is believed that its use will contribute to the realization of weight savings.

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