ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 10 (2011) 2775–2781

Engineering Procedia

International conference on the mechanical behavior of materials

Expulsion Reduction in Resistance Spot Welding by Controlling of welding Current Waveform

In Sung Hwang[a], Mun Jin Kang[a], Dong Cheol Kim[a*]

[a] *Advanced Welding & Joining Department, Korea Institute of Industrial Technology, 7-47 Songdo-Dong, Incheon, 406-840, Korea*

Abstract

There is a welding problem such as expulsion in resistance spot welding of high strength steel. This is due to overheating induced by increase of total heat input. Recently, many studies are carried out to solve the problems using electrode force control and current control. In this study, we tried to achieve expulsion reduction through controlling welding current. Steel sheet coated by Al-Si that has strength of 1500MPa was selected as a base material. The control results were compared with conventional welding method. Also, it is characterized how the variation of the heating and cooling by pulse current waveform control have an effect on expulsion.

Keywords: Advanced high-strength steel; Resistance spot welding; Weldability; Welding lobe; Shear tension strength; Nugget width

1. Introduction

In the vehicle industry, to enhance the fuel efficiency by reducing the weight of the car body, the application of advanced high-strength steels (AHSS), is being increased[1-3]. Many structural members can be made significantly lighter by using AHSS sheets and reducing their thicknesses.

With the application of AHSS sheet to the car body, a new problem on the weldability, and the study on resistance spot welding which occupies almost part of assembly process of car body in the car manufacturing line has become an important issue.

Resistance spot welding (RSW) is a welding process that joint sheet metal pieces together by applying pressure and passing a large current through localized area while the sheets are fixed together. Resistance

* Corresponding author. Tel.:+82-32-850-0218; fax:+82-32-850-0210.
E-mail address:dckim@kitech.re.kr.

 doi:10.1016/j.proeng.2011.04.461

spot welding power supply type is divided into traditional single-phase alternating current (AC) system and inverter direct current (DC) system. The former has been widely used in assembling car bodies and the application of inverter DC resistance welding equipment has been increased due to its less usage of welding current and wider welding lobes [4-6]. Furthermore, the inverter DC welding method has the advantage of low electrode wear.

In this paper, the inverter DC resistance spot weldability of 1500MPa hot-forming steel for car bodies was evaluated, and pulse current waveform control was introduced in order to reduce the expulsion rate. The control result was evaluated using welding lobe.

2. Experimental material and procedure

The resistance spot welding experiments were performed using an inverter DC RSW equipment. Table 1 shows the details of the welding equipment used in this study. The resistance spot welding equipment use direct current rather than alternating current. The electrodes were dome-type with electrode face diameter of 6mm. Table 2 shows the range of welding process parameters. One cycle of welding time means 1/60 second.

The material used in this study was 1.2mm thick steel sheet of NHPA-1500 (Al-Si coated) and its chemical compositions are listed in Table 3. Table 4 indicates the mechanical properties of NHPA-1500 steel sheet.

Table 1
Welding equipment details

Input voltage	440VAC
Switch frequency	1kHz
Maximum welding current	40 kA
Welding current type	Direct current
Maximum electrode force	500kg$_f$/cm^2

Table 2
Welding conditions

Parameter	Condition
Weld current (kA)	3~9
Weld Time (cycles)	6~24
Electrode Force (kg$_f$/cm^2)	400, 500, 600

Table 3
Chemical composition of base metal (Weight, %)

C	Si	Mn	P	S	Fe
0.23	0.26	1.24	0.015	0.002	Bal.

Table 4
Mechanical properties of base metal(NHPA-1500)

Yield strength(MPa)	1,280
Tensile strength(MPa)	1,530
Elongation (%)	8

To evaluate weldability, shear tension strength test and macro-section test were carried out. For the shear tension strength test, Shimadzu Corporation's Universal Tester, which can cover up to 30 tons of loads, was used. For the macro-section test, on the other hand, the nugget width was measured after etching of weld test specimen.

A welding lobe is a graph indicating the evaluation of the resistance spot weldability that shows an appropriate welding range by changing two factors while fixing one factor of resistance spot welding process parameters such as electrode force, weld time, and weld current. In this paper, the weld current–time lobe diagram was used with the electrode force fixed. The horizontal axis was set as the weld current, and the vertical axis as the weld time. Figure 1 shows an example of the weld current-time welding lobe. The lower limit of welding current, the left boundary line of the welding lobe, was set to 9.4kN (minimum acceptable shear tension strength by AWS D8.1M:2007) while the upper limit, the right boundary line, was set depending on whether or not expulsion occurred.

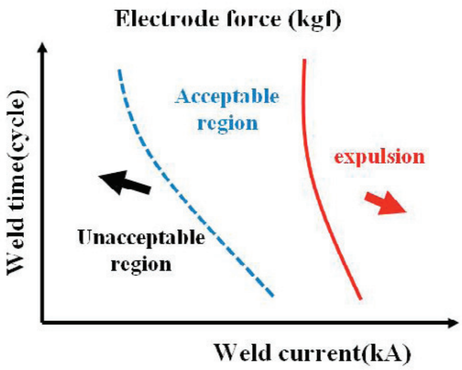


Fig.1 Example of a current/time welding lobe

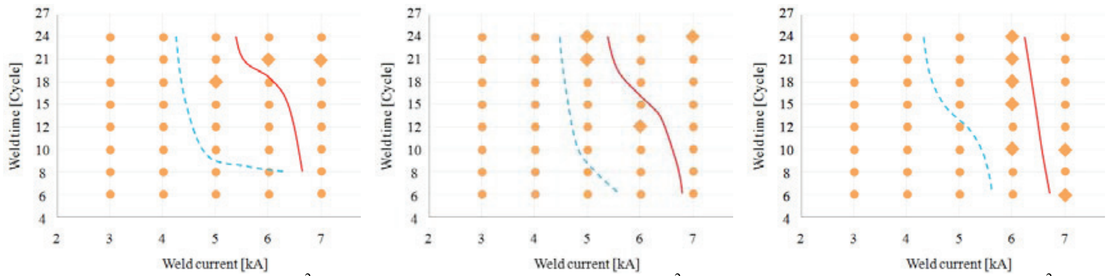
3. Experimental result and discussions

Fig. 2 shows welding lobes for 1.2mm NHPA-1500 steel sheet, which were obtained through shear tension strength tests on NHPA-1500 steel sheet using inverter DC spot welding machine.

In addition to suitable welding conditions, fracture modes were added to the welding lobe. In the welding lobe, round and diamond shapes are seen. The former represents an interfacial fracture mode while the latter stands for a plug fracture mode. Here, the interfacial fracture is a fracture type in the melting part while the plug fracture is a base metal-broken fracture type. In general, if a plug fracture occurs, it means that the melting part is stronger than the base metal.

In Fig. 2, acceptable shear tension strength has been observed at about 2kA of the current range. The acceptable current range stayed almost the same in all electrode force conditions. This result is different from general spot welding phenomenon that the increase of welding electrode force requires the increase of welding current to compensate for reduction of resistance heating due to decrease of contact area.

It appears that an increase in electrode force had little effect on the resistance heating of 1500 MPa steel sheet using DC spot welding current. According to the welding lobes, the inverter DC spot welding process showed a narrow acceptable welding current range because of much expulsion.



(a) Electrode force :400 kgf/cm^2 (b) Electrode force:500 kgf/cm^2 (c) Electrode force:600 kgf/cm^2

Fig. 2 Welding lobes for 1.2mm NHPA-1500 steel

Fig. 3 shows weld nugget width at the weld time of 18cycles and the electrode force of 500kgf/cm^2. As the welding current increases, weld nugget width also increases.

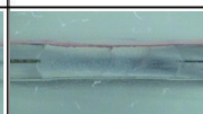
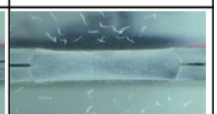
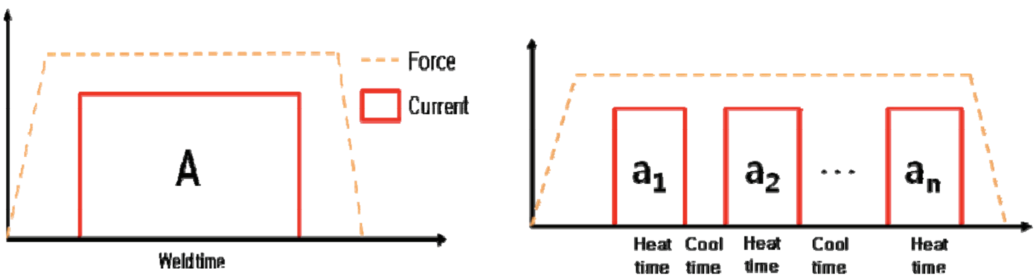
Current	3kA	4kA	6kA	7kA
Macro				
Nugget width	0mm	2.3 mm	4.5 mm	5.5 mm

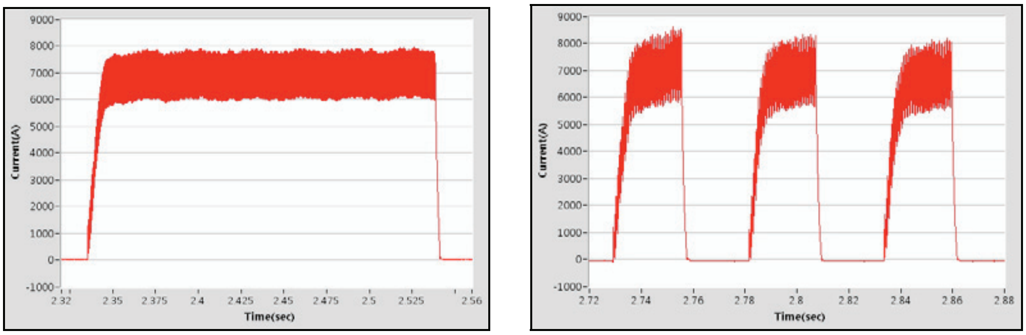
Fig. 3 Weld nugget width for 1.2mm NHPA-1500 steel.

In order to increase the acceptable welding current range, pulse current waveform control was introduced. Fig. 4(a) shows a conventional inverter welding current form and Fig. 4(b) is a current waveform of pulse type. Fig. 5 shows examples of real welding current wave forms.



(a) Conventional welding current form (b) Pulse welding current waveform

Fig. 4 Schematic diagram of inverter DC spot welding current waveform.



(a) Conventional welding current form (b) Pulse welding current waveform

Fig. 5 Inverter DC spot welding current waveform measured from real welding systems

The pulse welding current waveform consists of two parts. One is heating part and the other is cooling part. In order to determine optimum heat time and cool time, several spot welding tests were performed. Table 3 shows welding parameter conditions.

Test No.1 is a conventional DC inverter welding current condition. In this experiment, welding electrode force was fixed at 400kgf/cm^2, weld peak current 7kA, and cool time 4ms. As a result, the heat time of pulse was changed.

Table 3

Spot welding conditions for pulse current waveform control

No	Weld time (heat time + cool time)	One pulse time	
		Heat time	Cool time
1	300ms(18cycles)	DC	DC
2	420ms (300ms+120ms:30 pulses)	10ms	
3	360ms (300ms+60ms:15 pulses)	20ms	
4	340ms (300ms+40ms:10 pulses)	30ms	4ms
5	330ms (300ms+30ms:8 pulses)	40ms	
6	324ms (300ms+24ms:6 pulses)	50ms	

Fig. 6 shows the effect of heat time on weld strength for 1500MPa steel. In Fig. 6, heat time of 10ms and 20ms shows no expulsion but heat time of 30ms, 40ms, and 50ms shows expulsion. This experimental result shows that too much heat time produced expulsion easily and reduction of weld strength. From the Fig. 6, the heat time of 20ms was optimal condition.

To verify that the pulse welding current waveform control is useful, resistance spot welding of NHPA-1500 steel sheet was performed using inverter DC spot welding machine with weld current waveform control. Welding conditions were as follows. Welding electrode force was fixed at 400kgf/cm^2, cool time 4ms, and heat time 20ms. The weld time and weld current were changed. Fig. 7 shows the welding lobe which was obtained through shear tension strength test on NHPA-1500 steel sheet. Fig. 7 shows increase of acceptable welding range compared with Fig.2 (a). The conventional DC welding current type and the new pulse welding current type were same lower limit of welding current of about 5kA. However, acceptable maximum current limit of 7kA for pulse welding current control was obtained compared with 6kA or less for conventional DC current type. This test result showed that the intercycle cooling time of pulse welding current made spot welds less prone to expulsion at higher welding current.

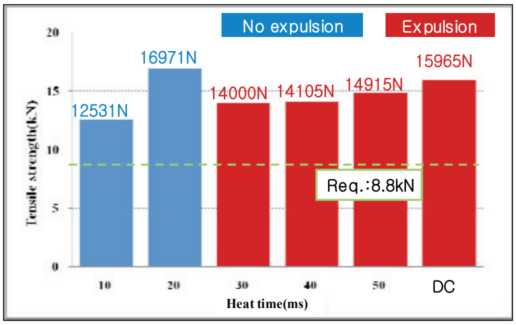


Fig. 6 Shear tension strength plot as a function of weld current waveforms

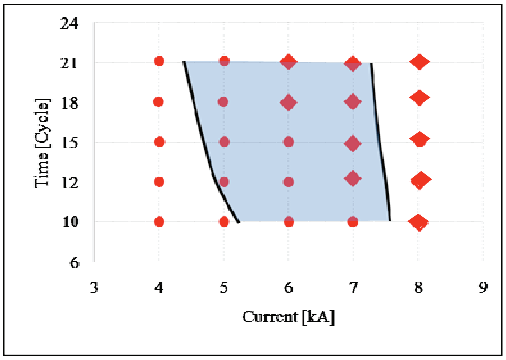


Fig. 7 Welding lobe for NHPA-1500 when using pulse welding current waveform

4. Conclusions

This study has evaluated the resistance spot weldability of 1500MPa steel sheet using conventional inverter DC spot welding system. In addition, pulse welding current rather than conventional DC current was introduced and its spot weldability was evaluated. The following results have been obtained:

1) The welding lobes for inverter DC spot welding of 1500MPa steel sheet have been determined. Acceptable shear tension strength was observed at about 2kA of welding current range.
2) The acceptable current range stayed almost the same in 3 electrode force conditions(400kgf/cm2,500kgf/cm2, 600kgf/cm2).
3) Pulse type welding current waveform control showed that it could reduce weld expulsion and increase acceptable welding current range.

Acknowledgements

The authors thank Ministry of Knowledge Economy, Republic of Korea, for financial supporting to this study.

References

[1] M. Suehiro, J. Maki, K. Kusumi, M. Ohgami, T. Miyakohi, Properties of aluminum-coated steels for hot-forming, Nippon Steel Technical Report, No.88, 2003, pp. 16-21.

[2] M.D. Tumuluru, Resistance spot welding of coated high-strength dual-phase steels, Welding Journal, Vol.85,No.8,2006, pp. 31-37.

[3] V.H. Lopez-cortez, F.A. Reyes-valdes, Understanding resistance spot welding of advanced high-strength steels, Welding Journal, Vol.87,No.12,2008, pp. 36-40.

[4] M. Y. Lee, The high strength steels for light car body and welding technology, Journal of KWS, Vol. 22, No. 3, pp. 214-218

[5] Sree. H. L, Soumitra A, Spot weldability of advanced high strength steels using AC and MFDC power sources, Sheet Metal Welding Conference XI, 2004, pp. 11-14.

[6] B.M. Brown, A comparison of AC and DC resistance welding of automotive steels, Welding Journal, Vol.66,No.1,1987, pp. 18-23.