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Inverter DC resistance spot welding of magnesium alloy AZ31

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ABSTRACT

Purpose: The welding lobes of AC resistance spot welding and inverter DC resistance spot welding for the magnesium alloy sheet AZ31 were compared and analyzed.

Design/methodology/approach: Using the welding lobe in terms of electrode force, weld time, and weld current which are process variables of the resistance spot welding, optimal welding conditions were determined. The lower limit of the range of the optimal welding condition was decided by minimum shear tension strength for the magnesium alloy sheet AZ31, and the upper limit was decided by whether an expulsion occurs or not.

Findings: It was found that the range of the optimal welding condition of the inverter DC resistance spot welding was larger than the AC resistance spot welding and that the nugget width of inverter type resistance spot welding was larger in the same welding condition.

Research limitations/implications: A comparison was between the welding lobes for AC and inverter DC resistance spot welding of magnesium alloy sheet AZ31.

Practical implications: In this study, by comparing the range of the acceptable welding condition of the resistance spot welding between AC type and inverter DC type power supplies, the effect of the types of power supplies on welding lobes could be confirmed.

Originality/value: This study compared the characteristics of the resistance spot welding between the AC type and inverter DC type power sources. It was confirmed that the range of acceptable welding conditions of the inverter DC resistance spot welding was larger than AC type.

Keywords: Welding; Magnesium sheet metal; AZ31; Spot welding; Welding lobe

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Recently, the use of light materials has been the mainstream in automobile industry in order to improve fuel efficiency and reduce exhaust fumes by decreasing weight [1-2]. In terms of light materials, magnesium alloys have been preferred. If magnesium alloys are used for car body, however, there will be a problem in welding [3-4]. In particular, resistance spot welding which is performed in most car body assembly processes is critical.

In terms of density, magnesium alloys are two-thirds of aluminum alloys and one fifth of steel alloys. In fact, they have the lowest density among current alloys [3,5]. Among light materials, however, they are relatively high in terms of strength. In addition, magnesium alloys are superior in terms of electric conductivity, heat conductivity, processability, fatigue under high temperature and impact characteristics [5,7,9]. Because they are about 60-70% of steel alloys in terms of specific resistance, however, they generate less joule heating. Furthermore, since magnesium alloys are more than twice higher than steel alloys in terms of coefficient of linear expansion, there is a high possibility of contract pore [3-4,10].

Resistance spot welding is a welding process which passes weld current after making the two base metal surfaces face each other. The base metal is welded by the heat caused by contact resistance at the contact surface and specific resistance at the base metal [1,4]. Resistance spot welding can be divided into Silicon Controlled Rectifier (SCR) AC resistance welding and inverter DC resistance welding [2].

The SCR AC resistance welding makes output current through the phase control of single-phase power. In addition, large current is amplified through a transformer and imposed to a base metal. Because commercial power sources are used as they are, control period is relatively long (60 Hz:16.6 ms). Because a current discontinuity occurs due to AC phase control, in addition, it is necessary to take some time in imposing current in order to generate sufficient Joule heating for melting. This process increases weld time and power consumption. In addition, peak in output current can cause a bad impact on weldability [1,3].

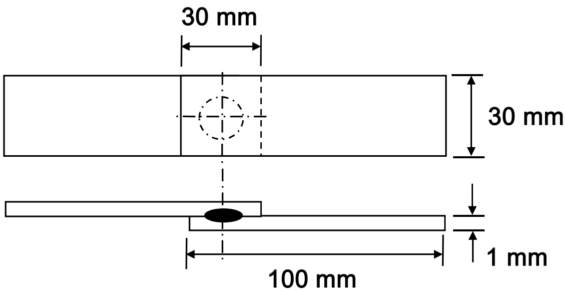


Fig. 1. Schematic illustration of Experimental setup

The inverter DC resistance welding controls current using high-speed switching elements. DC current is imposed to a base metal after installing a rectifier in the transformer output port. With a short control period, the inverter DC resistance welding makes precise current control possible. So, it can reduce power consumption by adjusting current frequency [2]. Table 1 describes the specifications of SCR AC resistance welding and inverter DC resistance welding equipment used in this paper.

In this paper, the resistance spot weldability of magnesium alloy AZ31 has been tested. In addition, SCR AC resistance welding and inverter DC resistance welding were compared in terms of characteristics and allowed welding range.

2. Experiments

2.1. Experiments setup

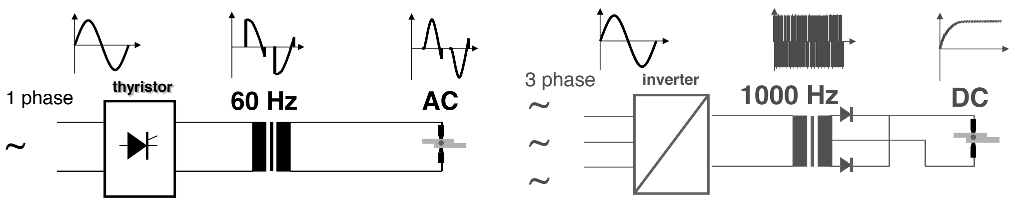
The conditions to test resistance spot weldability of AZ31 are shown in Table 2. Table 3 states the mechanical properties of the base metal [6-8]. Figure 1 shows the shape and dimensions of specimen.

2.2. Weldability evaluation

In this paper, the resistance spot weldability of AZ31 has been tested. The strength of spot weld joints has been assessed with a shear tension test. Also, nugget width has been estimated through a macro section test. Based on the results of these tests, a welding lobe has been acquired.

A welding lobe is an indicator on resistance spot weldability. The allowed welding range is obtained by fixing one factor and changing two remaining factors among electrode force, weld time and weld current. In this paper, weld current-weld time welding lobe has been used. After fixing electrode force, the horizontal and vertical axes were set to weld current and weld time respectively. Fig. 2 shows the example of weld-current-weld time welding lobe. The lower limit (left line) of welding lobe has been set to 1.3 kN (permission shear tension strength). On the contrary, the upper limit (right line) was set depending on whether or not expulsion occurred [1-2].

Table 1.
Resistance spot welding machine specification

Parameter	SCR AC	Inverter DC
Input Voltage	440 V	440 V
Frequency	60 Hz	1 kHz
Maximum Current	40 kA	35 kA
Maximum Electrode Force	1.000 kg_f	400 kg_f
Current Waveform		

3. Results and discussion

3.1. Shear tension strength

Table 4 states the result of the shear tension tests of SCR AC resistance welding and inverter DC resistance welding. As weld current increases, shear tension strength increases. Expulsion may take place at abnormal weld current. Under expulsion conditions, shear tension strength is very high. However, the conditions for expulsion are not decided with effective weld because expulsion occurs by exposing the melted metal to the outside of the weld part at welding [2]. Hence, the increase and decrease in shear tension strength are not constant at expulsion. Weld time also increased as shear tension strength increased. However, the increase was not strong unlike weld current. Therefore, it has been confirmed that weld current is more influential on shear tension strength.

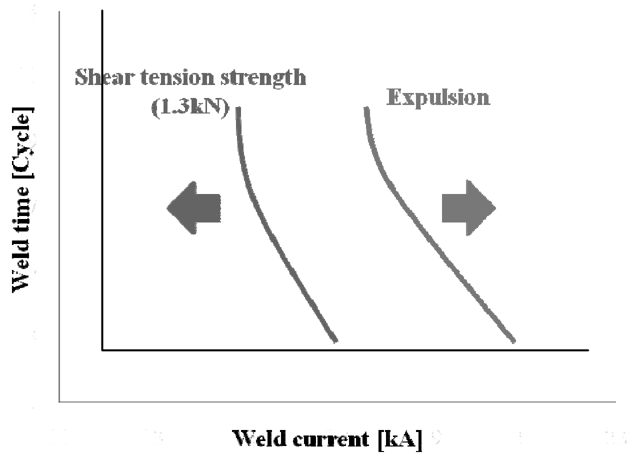


Fig. 2. Weld current-weld time welding lobe

Table 2.
Experiments setup

Base metal	Magnesium alloy AZ31 (Thickness 1.0mm)
Welding current	11~19 [kA]
Welding time	3, 5, 7, 9, 11 [cycle]
Electrode force	200 [kg_f]

Table 3.
Mechanical properties of AZ31

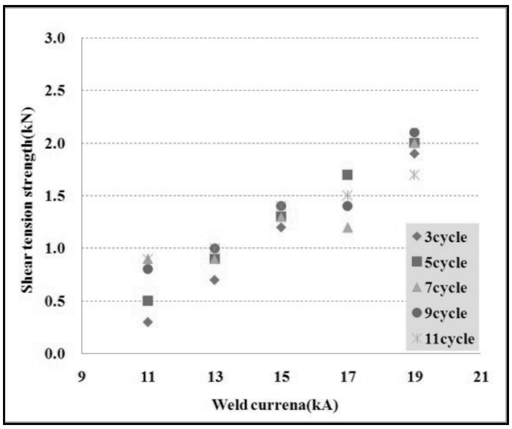
Tensile strength	255 N/mm^2
Yield strength	150 N/mm^2
Elongation	21.0%

Table 4.
Experimental results - Shear tension strength

Electrode force	SCR AC	Inverter DC
200 kg_f	see below	see below

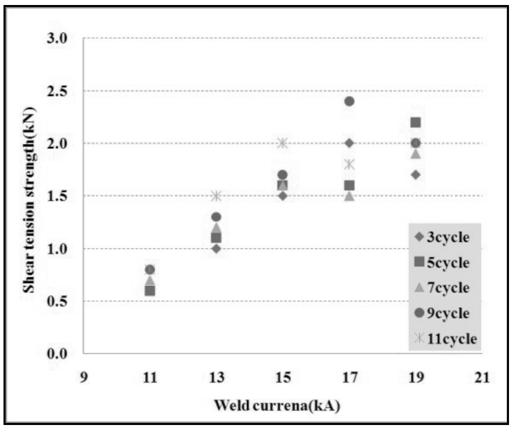
SCR AC

Time (cycle)	11 kA	13 kA	15 kA	17 kA	19 kA
11	0.9	1.0	1.4	1.5	1.7
9	0.8	1.0	1.4	1.4	2.1
7	0.9	0.9	1.3	1.2	2.0
5	0.5	0.9	1.3	1.7	2.0
3	0.3	0.7	1.2	1.4	1.9



Inverter DC

Time (cycle)	11 kA	13 kA	15 kA	17 kA	19 kA
11	0.8	1.5	2.0	1.8	2.0
9	0.8	1.3	1.7	2.4	2.0
7	0.7	1.2	1.6	1.5	1.9
5	0.6	1.1	1.6	1.6	2.2
3	0.6	1.0	1.5	2.0	1.7



* Blue mark: Over the minimum shear tension strength
* Red mark: Expulsion

In terms of shear tension strength, inverter DC resistance welding was higher than SCR AC resistance welding because of constant and stable current output. Due to constant current output, heat input is stable. Unlike SCR AC resistance welding, inverter DC resistance welding doesn't have pause period in terms of current output so that it is more efficient in terms of heat input. So, inverter resistance welding can impose higher heating than SCR AC resistance welding even though same power sources are used [1].

If expulsion was compared between SCR AC resistance welding and inverter DC resistance welding, no big difference has been observed, which means that there is a critical point of heat input for expulsion. Under expulsion conditions, shear tension strength does not constant. However, higher shear tension strength is found, compared to the non-expulsion conditions. Therefore, some studies have attempted to increase shear tension strength in the weld part by reducing expulsion.

3.2. Nugget shape and size

Table 5 states the results of macro section tests on SCR AC resistance welding and inverter DC resistance welding. Fig. 3 shows the comparison graph of nugget size. The results were the same with those under the shear tension test. In general, shear tension strength and nugget width either increase or decrease together. As weld current increases, nugget width increases as well. Generally, the allowed nugget width of the weld part is over 4√t mm (t:thickness). The allowed nugget width of the base metal in this paper is over 4mm. At over 15 kA, over 4 mm of nugget width is observed. Even under expulsion conditions, allowed nugget width is found. However, because nugget width generatesexpulsion even though it satisfies requirements, it would not be a good weld part [1-3].

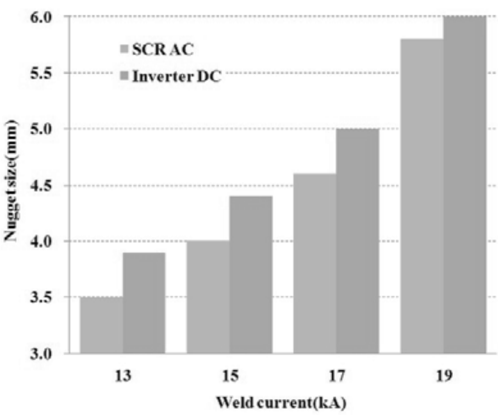


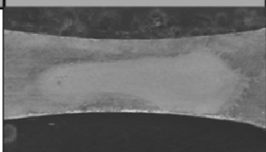
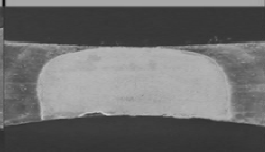
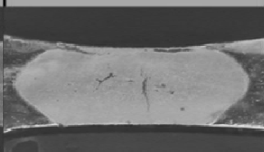
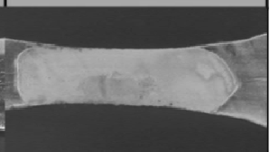
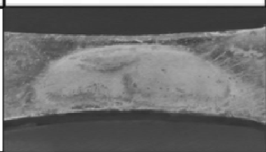
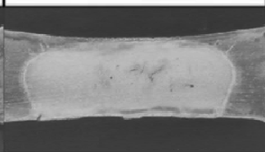
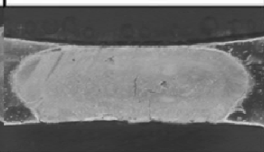
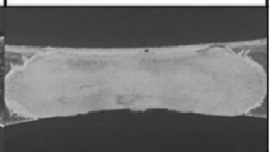
Fig. 3. Nugget size comparison

In terms of nugget shape, crack and pore have been found in both SCR AC resistance welding and inverter DC resistance welding. The crack and pore in the weld part have a influence on the properties of base metal. Magnesium alloys have high coefficient of linear expansion. So, the weld part rapidly expands at welding and quickly cools down. Then, a blank in the expanded space becomes pore [6].

Both crack and pore have a bad impact on the weld part in terms of strength and fatigue life. In general, electrode force has been increased after welding in order to reduce crack and pore [3]. Regarding the shape of the weld part, large deformation is found in the weld part. This kind of deformation occurs when the weld part is pressed after Pressure and heat input take place at the same time. The deformation worsens as heat input increases.

Table 5.
Experimental results - Nugget shape and size

200 kg_f/cm^2, 9 cycle

Current [kA]	13	15	17	19
SCR AC				
Nugget [mm]	3.5	4.0	4.6	5.8
Inverter DC				
Nugget [mm]	3.9	4.4	5.0	6.0

* Blue mark: Over the minimum nugget size
* Red mark: Expulsion

In terms of nugget width, inverter DC resistance welding was larger than SCR AC resistance welding because of higher heat input efficiency as shown in the shear tension test.

3.3. Lobe diagram

Table 6 describes the welding parts of both SCR AC resistance welding and inverter DC resistance welding.

The welding lobe is decided with shear tension strength and expulsion. And it marks the fracture shape in welding lobe. The fracture shape in the resistance spot welding can be divided into two categories; interfacial fracture and button fracture. Interfacial fracture refers to fracture on the surface of the weld part, which occurs when the weld part is weaker than weld metal. On the contrary, button fracture means fracture of weld metal while the weld part remains intact. Button fracture occurs when the weld part is stronger than weld metal [1-2]. Interfacial fracture mostly occurs in both SCR AC resistance welding and inverter DC resistance welding. Button fracture generally occurs under expulsion conditions. In general, button fracture is preferred in the industry. Therefore, it has been attempted to increase heat input by reducing expulsion in many studies.

In the allowed welding range, button fracture occurs on the inverter DC resistance welding only. In other words, inverter DC resistance welding is more efficient than SCR AC resistance welding in terms of heat input [2].

Fig. 4 compares welding lobe between SCR AC resistance welding and inverter DC resistance welding. A wider allowed welding range was observed in the inverter DC resistance welding. It had lower allowed welding range than SCR AC resistance welding. In other words, the inverter DC resistance welding is more efficient than SCR AC resistance welding in terms of heat input under the same conditions. In case of upper limit, SCR AC resistance welding showed higher welding range at over 5 cycles. According to the results of shear tension test and macro section test, SCR AC resistance welding show lower weldability under the same conditions. Therefore, because SCR AC resistance welding is less efficient than inverter DC resistance welding in terms of heat input, the welding range up to the critical point of heat input increases, which also means that inverter DC resistance welding is more efficient than SCR AC resistance welding in terms of heat input.

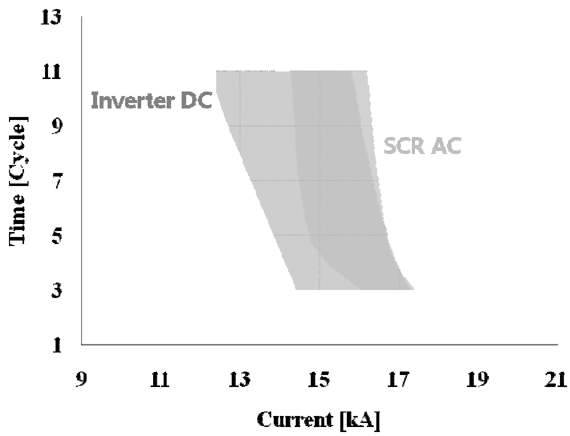


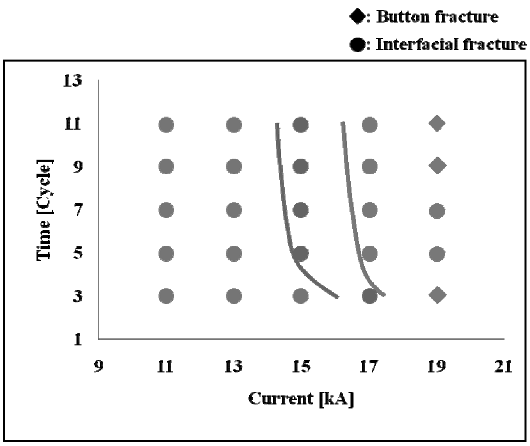
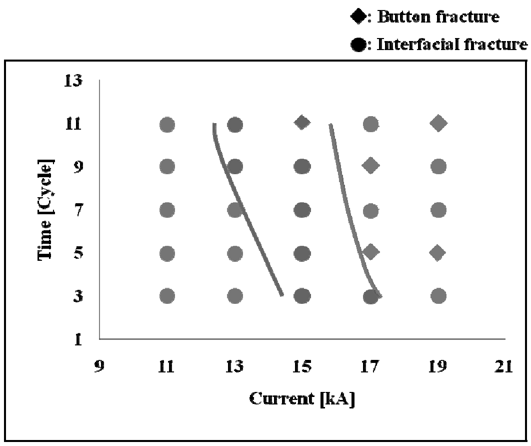
Fig. 4. Welding lobe comparison

4. Conclusions

In the magnesium alloy AZ31, SCR AC resistance welding and inverter DC resistance welding have been compared in terms of weldability. Also, welding lobe has been acquired. Then, the following results have been obtained:

1) Both shear tension strength and nugget width of the weld part increased in proportion to weld current and weld time.

Table 6.
Experimental results - Welding lobe

Electrode force	SCR AC	Inverter DC
200kg$_f$/cm^2		

* Blue mark: Over the minimum shear tension strength
* Red mark: Expulsion

2) Under the same conditions, inverter DC resistance welding was bigger than SCR AC resistance welding in terms of shear tension strength and nugget width.
3) Pore and crack were found in the weld part in both SCR AC resistance welding and inverter DC resistance welding. It appears that it is necessary to perform a study to reduce pore and crack.
4) Inverter DC resistance welding was broader than SCR AC resistance welding in terms of allowed welding range. The former had lower current range. However, the current range for expulsion is almost same in both inverter DC resistance welding and SCR AC resistance welding.
5) It has been confirmed that inverter DC resistance welding was more efficient than SCR AC resistance welding in terms of heat input and weldability through shear tension strength, macro section and welding lobe.

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