**International Journal of Mechanical Engineering and Applications**
2023; 11(5): 113-124
http://www.sciencepublishinggroup.com/j/ijmea
doi: 10.11648/j.ijmea.20231105.12
ISSN: 2330-023X (Print); ISSN: 2330-0248 (Online)

# Research on the Improvement of Weldability in Resistance Spot Welding of 6-Series Aluminum Alloys

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## To cite this article:

Lihui Zhong, Yuanbo Guo, Suhong Ji, Lijun Han. (2023). Research on the Improvement of Weldability in Resistance Spot Welding of 6-Series Aluminum Alloys. *International Journal of Mechanical Engineering and Applications*, *11*(5), 113-124. https://doi.org/10.11648/j.ijmea.20231105.12

**Received**: October 12, 2023; **Accepted**: November 8, 2023; **Published**: November 30, 2023

**Abstract:** Aluminum alloy RSW is influenced by the low melting point and high thermal expansion rate of aluminum alloy materials. During the welding process, the electrode cap surface is prone to erosion, which affects the continuous welding number and welding quality of RSW. It is a difficult problem in the industry that restricts the application of aluminum RSW. This article studies the factors affecting the weldability of resistance spot welding (RSW) of aluminum alloy materials, including plate materials, electrode specifications and materials, equipment structure and welding control methods, electrode connection methods, welding process specifications, etc., and identified possible ways to enhance the weldability and weld quality of aluminum alloy spot welding. Through the experimental study, it was further explored that the comprehensive performance capability of aluminum alloy RSW can be improved by setting appropriate welding parameters for the electrode with R100mm arc at the front end for the flat aluminum plate which has been pickled and passivated.

**Keywords:** Al Alloy RSW, Electrode, Surface Erosion, Welding Parameters, Welding Nugget, Peltier Effect

## 1. Introduction

With the development trend of lightweight and electrification in automobiles, more and more lightweight materials are applied to automobile production, such as aluminum alloy, magnesium alloy, carbon fibre, etc., of which the most widely used material is aluminum alloy. For the connection of aluminum alloys, SPR, Clinch, FDS, RES and other connection processes are commonly used. RSW is a preferred welding process method in the manufacturing field due to its high welding efficiency, low production cost, strong equipment versatility, and good production integration.

Due to the low melting point of the aluminum alloy material, the welding of the thermalexpansivity is high, the surface of the aluminum plate material is easy to oxidize, and it is easy to produce defects such as welding porosity and cracks in the welding process. Welding process, copper electrode and aluminum plate at high temperature, aluminum-copper metal interface is easy to generate poor conductivity AL2Cu and AL4Cu9 and other brittle intermetallic compounds [1, 2], which leads to the surface of the copper electrode is prone to electrode erosion phenomenon, affecting the welding quality and welding life [3-5].

In this paper, the main factors affecting the welding ability of aluminum alloy spot welding are studied to determine the methods to improve the welding ability.

## 2. Factors Affecting Weldability in Spot Welding of Aluminum Alloys

The weldability of aluminum spot welding is limited by a number of factors, including:

### *2.1. Selection of Al. Alloy Sheet Materials and Surface Treatment Process*

Aluminum alloy spot welding is suitable for 4-series, 5-series, 6-series, or aluminum alloy profile welding, of which 6-series aluminum is often used in automotive manufacturing. Compared to the 5-series, 6-series plate with magnesium, silicon and other alloying elements, with high strength, corrosion resistance and good processing performance [3], with better spot welding performance, can be used as a priority in automotive manufacturing of welding materials; at the same time, we should consider the surface treatment of the material, can be removed through pickling passivation of the aluminum plate surface of the grease and oxidized layer, the formation of a thin layer on the surface, dense, stable and uniform Passivation film to ensure the stability of the surface resistance, more conducive to ensuring the stability of the welding and quality of aluminum alloy spot welding. The entire pickling passivation process is divided into: degreasing oil, washing, pickling to remove the oxide layer, washing, passivation, cleaning and drying stages. As shown in Figure 1 is the picture of the parts before and after pickling passivation.

(a) before passivation (b) after passivation

***Figure 1.*** *Picture of Al. Alloy Plate Before and After Acid Cleaning and Passivation.*

### *2.2. Design Rules for RSW. Al. Alloy*

Considering the high welding current of spot welding of aluminum alloy materials and the influence of welding shunt on the quality of welded joints in the design of welded joints, therefore, in the product design, in order to reduce the influence of shunt on the welding, the spacing of welded joints should be kept at least 6 times the size of the diameter of welded cores. Usually we set the distance between two welding joints at about 40mm.

### *2.3. Equipment Selection*

Spot welding equipment mainly includes welding control cabinet and spot welding tongs.

In the welding control of spot welding, aluminum alloy spot welding usually adopts the adaptive control method of pressure monitoring in the equipment control. When the weld nugget expands, the pressure received by the clamp arm sensor will be transmitted to the control system in time, and the formation process of the weld nugget will be determined through the monitoring of the welding pressure. Moreover, the welding current or welding time is adjusted to ensure the finishing heat input and the quality of the welding process.

A spot welding clamp consists of a transformer, a drive system and a clamp body. For the design of the clamp, in addition to consider the transformer capacity to meet the aluminum alloy 3-5 million amperes of welding heat, but also to consider the aluminum alloy spot welding needs of high pressure and the rapid response to pressure ability. Therefore, the clamp drive system is usually used in the way of electric cylinder drive, electric cylinder output pressure of 8 KN. due to the need to bear a higher welding pressure, in order to avoid deformation of the welding clamp arm and electrode rod in the welding process, to ensure that the alignment of the welding electrodes, the clamp body should be used in high strength and rigidity of the material, usually for the 7 series of aerospace aluminum, and the electrode rod should be used in the end of the thicker structure. In addition, aluminum spot welding cooling water flow to reach 16L/min, because the aluminum spot welding current is large, the need for a larger flow of cooling water to ensure that the welding transformer, electric cylinders, welding clamps, upper and lower electrodes and the control cabinet inverter cooling to ensure the stability of the welding and the service life of the equipment.

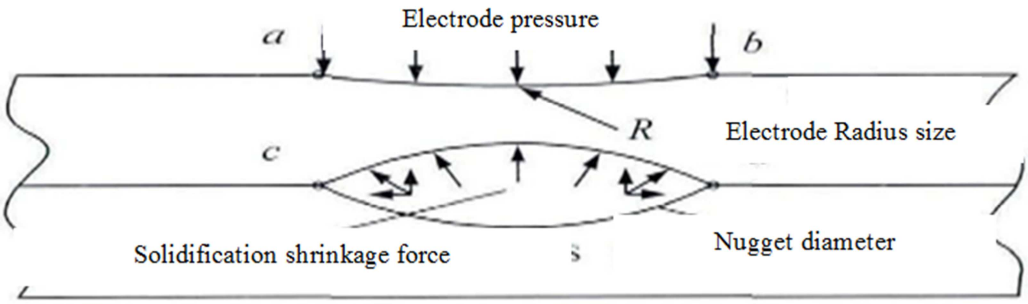
So the reasonable design and selection of aluminum alloy spot welding equipment is also very important.

### *2.4. Design of Fixtures*

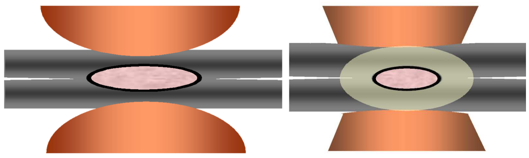
During the fixture design, taking into account the welding current is large, in order to reduce the shunt, to avoid the impact of the magnetic field of the welding process on the welding of aluminum alloys, positioning blocks and connectors to be used in anti-magnetic materials, usually using anti-magnetic stainless steel. Clamping cylinder swing arm and support is made of aluminum, and increase the insulating pad at the bottom of the fixture on the proximity switch selection of anti-strength magnetic switch. Through the reasonable design of the fixture and material selection to reduce the heat loss of aluminum alloy spot welding to ensure the quality of welding.

### *2.5. Welding Electrode Materials and Specifications*

There are many kinds of materials for electrode caps, and the commonly used welding electrode is chromium-zirconium copper. For aluminum alloy spot welding, through the reasonable control of the zirconium and chromium content in the electrode can obtain better spot welding ability. The shape of the electrode cap also affects the weld quality, the front arc size is different, resulting in different axial and radial tensile forces on the nucleus of the welded joint in the formation process, as shown in Figure 2. The use of electrodes with a suitable R angle at the front end is more conducive to obtaining higher current density and weld nugget quality under the same welding conditions. Aluminum alloy commonly used welding electrode diameter of 19-20mm, front arc R75-R150mm, will be more conducive to aluminum alloy spot welding surface oxide discharge, reduce the welding process electrode adhesion phenomenon.




(a) Nugget force diagram

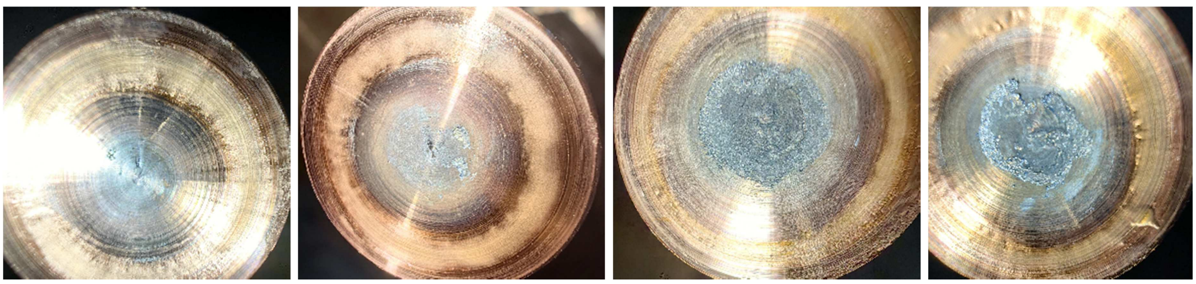


(b) Steel plate softening zone (c) Al. plate softening zone

***Figure 2.*** *Stress Diagram of Nucleus Formation.*

### *2.6. Welding Polarity*

Due to the Peltier effect, the melting core of the weld joint for spot welding of aluminum alloys is shifted towards the positive pole during the welding process for plates of the same thickness. Due to the higher current input, the tendency of the molten core offset of aluminum spot welding is more obvious. During the welding process, the erosion degree of the positive and negative electrode cap surfaces is different, the positive electrode erosion is more serious, with the increase in the number of points is also more and more obvious. Figure 3 below shows the comparison of the erosion status of positive and negative electrode caps after continuous welding of different points, and it can be clearly seen that the positive electrode erosion is serious.

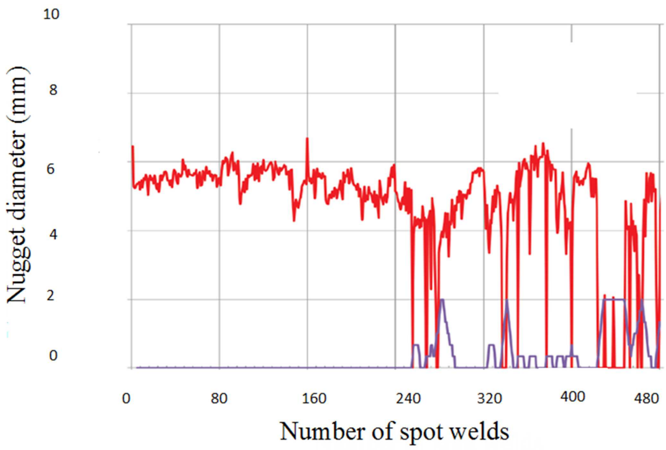


a. Negative 24 points b. Negative 48 points c. Positive 24 points d. Positive 48 points

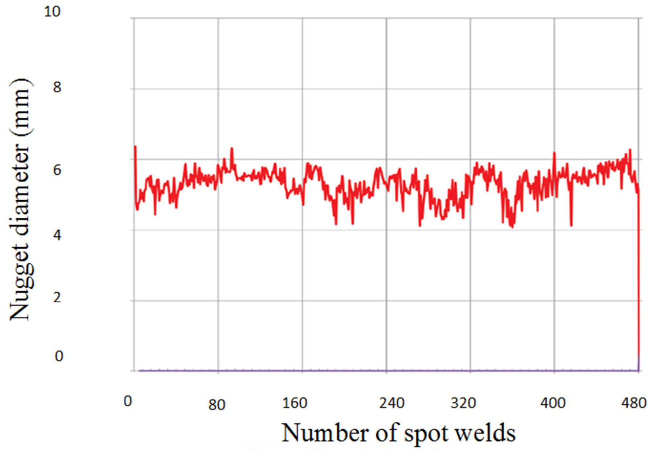
***Figure 3.*** *Erosion state of positive and negative electrode caps.*

As shown in Figure 4b below, the diameter of the welded joints welded by the alternating change of electrode polarity is basically around 6 mm, which is more stable than that of the single-polarity welded joints Figure 4a.

It can be seen that by controlling the alternating change of welding polarity of the welder, the uneven erosion phenomenon of the positive and negative electrodes can be overcome to improve the welding quality of the welded joints and prolong the life of the electrodes.




(a) Single polarity welding




(b) Positive and negative polarity transformation

***Figure 4.*** *Comparison of Welding with Different Power Poles.*

### *2.7. Welding Process Specification*

While many of the above factors are defined during product design and manufacturing program development, another key factor, "process specification", has a large impact on the spot welding quality and weld life of aluminum alloys. Appropriate welding process specifications (including welding current, welding pressure, welding time, cooling time, etc.) can greatly improve the weldability of aluminum alloy spot welding. In this paper, the research on process specifications, through experimental research and data analysis, to recognize the influence rule of different process specifications on the welding capacity and welding quality.

## 3. Research on Process Specifications

### *3.1. Test Input*

#### *3.1.1. Welding Materials*

Composition of TL091 is shown in Table 1.

***Table 1.*** *Composition of TL091 (wt. %).*

| Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
|---|---|---|---|---|---|---|---|---|
| 0.88 | 0.2 | 0.09 | 0.08 | 0.69 | 0.02 | 0.01 | 0.02 | The rest |

#### *3.1.2. Electrode (Size and Performance)*

In this experiment, an electrode cap with a diameter of 20 mm and an arc of R100mm at the front end was used. The material is chrome zirconium copper electrode, the composition of the electrode material is shown in Table 2, and the drawing of the electrode cap is shown in Figure 5.

***Table 2.*** *Performance Index of EC.*

| Cr | Zr | Cu | Hardnes s HB | Electrical conductivity %IACS |
|---|---|---|---|---|
| 0.98% | 0.08% | The rest | 137 | 87 |

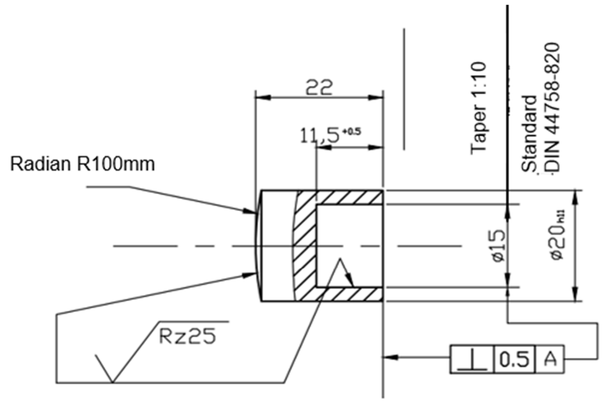



***Figure 5.*** *Drawing of electrode cap.*

### *3.2. Carry out Experiment*

#### *3.2.1. Material Plate Thickness: 1.15+2.2mm*

The combination form of plates and electrode connection method is shown in Figure 6;

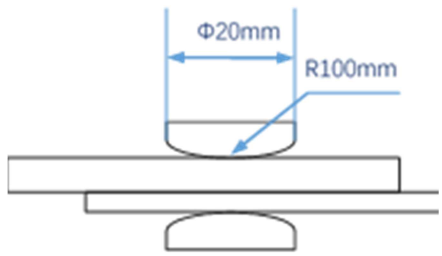



***Figure 6.*** *Material combination diagram.*

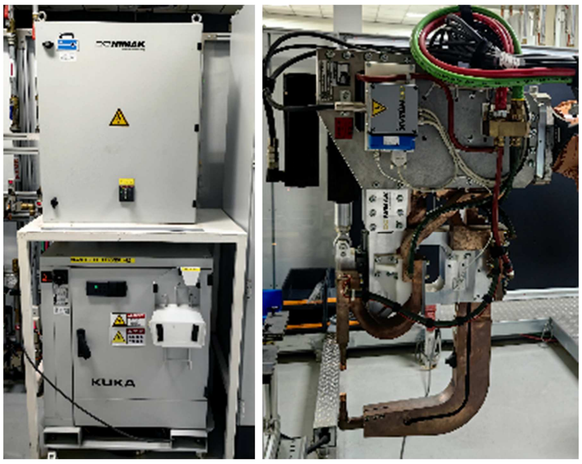



***Figure 7.*** *Automatic Spot Welding Equipment.*

### *3.2.2. Equipment Type*

Shown in Figure 7.

***Table 3.*** *Welding equipment parameters.*

| Equipment | Brand and model | Equipment parameter |
|---|---|---|
| Welding robot | KUKA R270 | Robot load 270KG |
| Welding gun | NIMAK C8000 | $F_{max}$: 8000N |
| Welding controller | HWH MF 1000 | $I_{max}$: 60KA |
| EC dresser | Braeuer | Electrode, ¢20, Radius 100mm |

### *3.2.3. Media Input*

Water flow rate: The water flow rate of the transformer and electrode arm is 6min/L+6min/L; The water cooling flow rate of the inverter is 6min/L.

Temperature: 15-25 degrees Celsius.

Pressure; inlet pressure: 5-7bar; return pressure 0-2bar.

### *3.2.4. Spot Welding Distance*

The distance between spot welding points is 40mm, and the distance between the welding points and the edge is 20mm.

As shown in Figure 8.

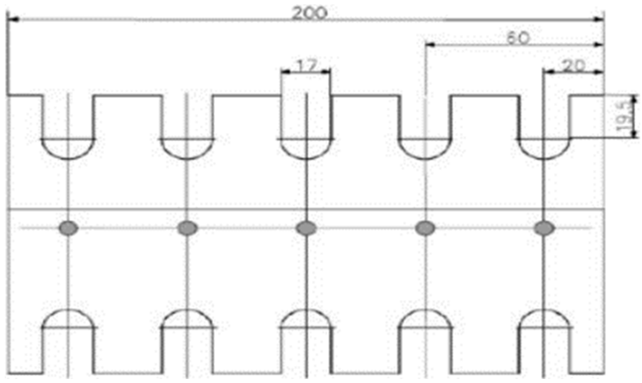



***Figure 8.*** *Spot welding distance.*

### *3.2.5. Welding Parameters*

After experimental research, preheating time, preheating current, welding tempering selection of the above parameters can be more stable welding quality. On the basis of keeping the above parameters unchanged, we adjusted the variables "welding current" and "welding pressure", which have the greatest influence on the welding process, and analyzed the corresponding welding capacity and welding quality trends under different parameters.

The parameters of welding current, preload and welding pressure were set as variables a and b respectively, as shown in Table 4.

***Table 4.*** *Welding Parameters.*

| Name | Parameter | Name | Parameter |
|---|---|---|---|
| Welding preheating time | 30ms | pre-pressure /Welding pressure | b KN |
| welding preheating current | 15KA | Welding current (R100mm) | a KA |
| Weld time (R100mm) | 100ms | Current decreasing time | 300ms |

The welding current was increased from 35KA to 50KA with a gradient of 2.5KA, and the welding pressure was increased from 2KN to 8KN with a gradient of 0.5KN to observe the continuous welding capability and the quality of the welded joints.

## 4. Test Result

### *4.1. Testing Methods*

After the experiment, chisel inspection, metallographic testing, and ultrasonic testing were used to observe the quality of welding joints under different welding specifications.

### *4.2. Testing Standards and Indicator Requirements*

The testing standards are based on VW's weld joint quality testing standard for PV6723/VW01105-2/3 (VW standard). Where the diameter of the weld nugget $d_L \geq 5\sqrt{t}$, and "t" is the minimum plate thickness of the weld material. The minimum diameter of the weld nugget for this test combination was calculated to be standardized at 5.36 mm.

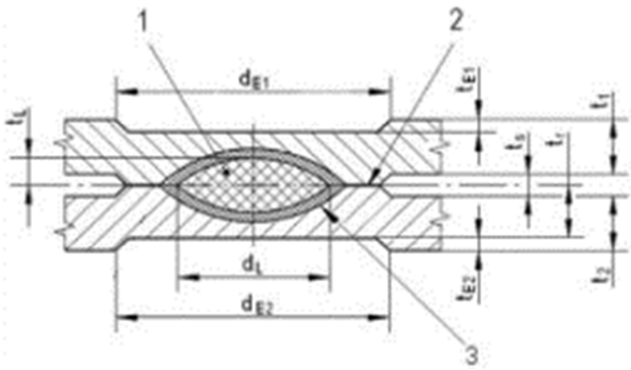



***Figure 9.*** *Schematic diagram of weld nugget.*

### *4.3. Inspection Results*

#### *4.3.1. Analysis of the Influence of Welding Pressure on the Diameter of Weld Nuggets*

Conduct destructive chiseling inspection on spot welds and observe the trend of changes in the diameter of weld nuggets under different welding currents and pressures, as shown in the Figure 10.

From the above welding nugget diameter trend can be seen, under the same conditions of welding current, with the increase of welding pressure, the overall welding nugget diameter shows a decreasing trend.

For 1.15+2.2mm thickness of double-layer aluminum plate:

1. Welding current of 32.5KA, no matter how to adjust the elding pressure, the welded points which meet requirements of the weld nugget diameter cannot be obtained.
2. Welding current of 37.5KA, in the small pressure, due to the contact resistance, welding heat can ensure that the welding nugget molding, that is, can be obtained to meet the standard requirements of the diameter of the weld nugget; but when the pressure increases, the diameter of the weld nugget of the welded joint is gradually becoming smaller, higher than the quality of the weld nugget of the 4.2KN can not be obtained after the qualified.
3. Welding current greater than 42.5KA above, welding pressure in the range of 2-7KN, can be obtained to meet the standard requirements of the weld nugget diameter.

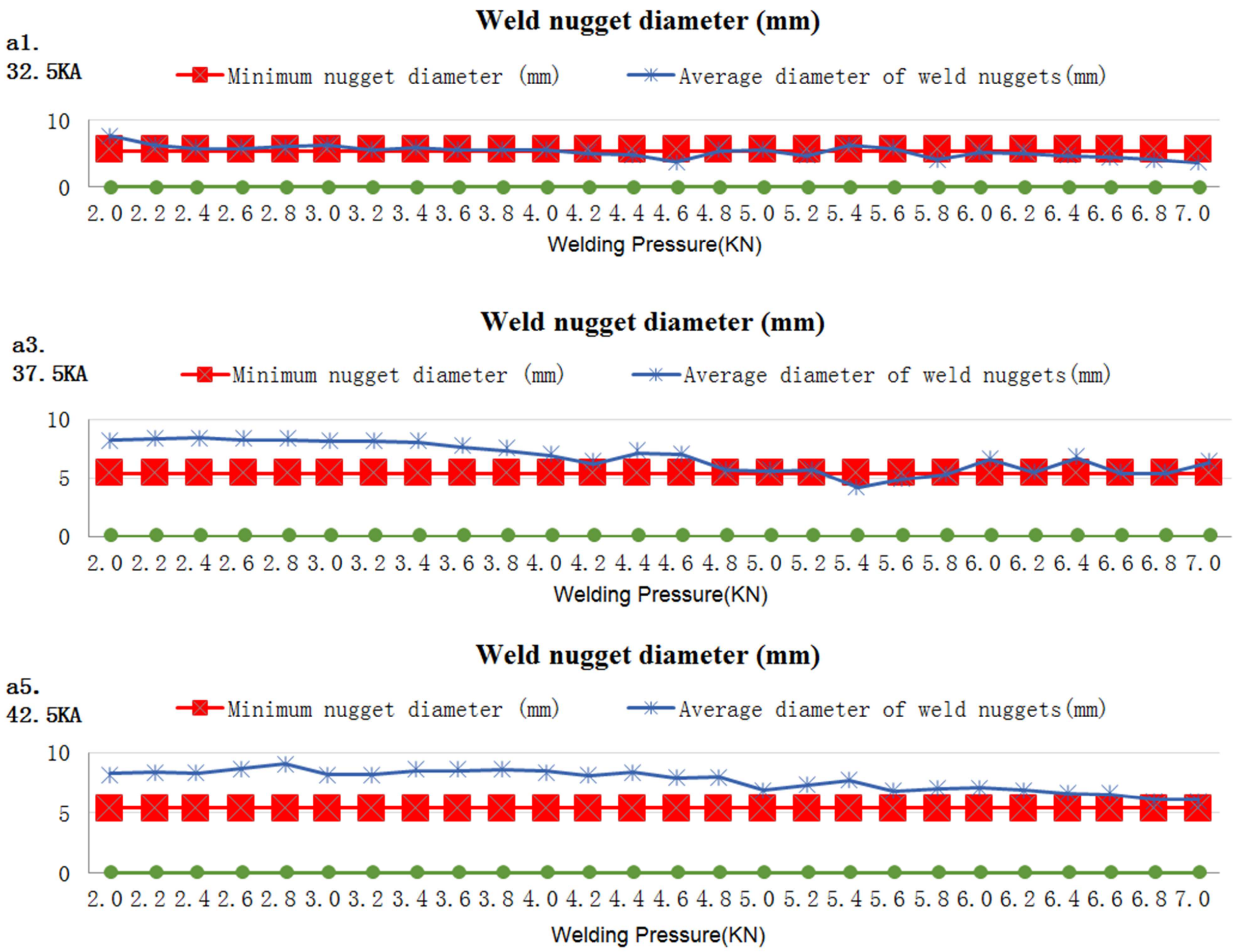



***Figure 10.*** *Weld nugget diameter at different welding currents and pressures.*

#### *4.3.2. Effect of Welding Pressure on Weld Nucleus Cracks*

Aluminum alloy thermal conductivity and linear expansion coefficient differences are more obvious, resulting in uneven heat distribution in the welding process and different post-weld cooling shrinkage capacity, resulting in larger spot welding weld deformation, welding cracks are easily produced during welding [4-6].

In addition to the welding nugget diameter to meet the requirements, we also need to confirm the internal metallographic detection status of the welded joint. When the current is 42.5KA, when the welding pressure is too small, the welded joint will appear adhesion phenomenon. Under the parameters of 42.5KA current and 3.8KN welding pressure for continuous welding, as shown in Figure 11, when welding to 12 o'clock, the surface of the welded joint begins to appear the phenomenon of adhesion, and the surface of the welded joint will appear different degrees of welding cracks, as shown in Figure 12.

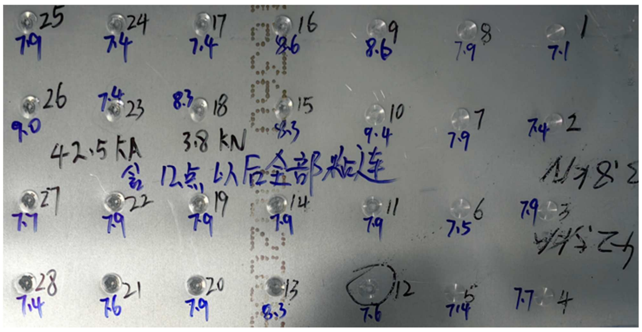


***Figure 11.*** *Surface state of welded joints.*

***Figure 12.*** *RSW cracks.*

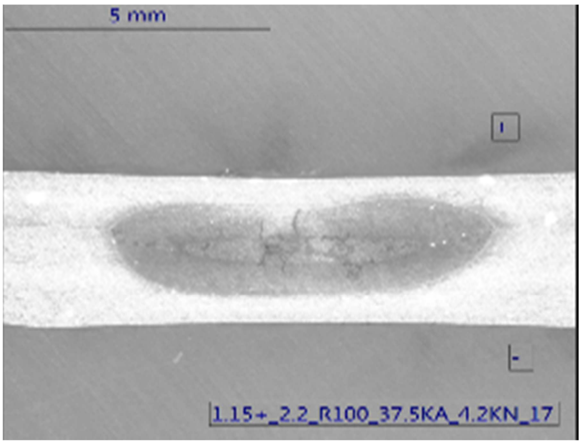



***Figure 13.*** *Metallographic inspection status of RSW under different welding pressures.*

Current setting 42.5KA, respectively, 3.8KN and 6KN pressure spot welding weld joints for metallographic testing, found in the same welding current specification, when the pressure is too small weld internal penetration cracks, as shown in Figure 13.

Therefore, the welding process specification range corresponding to this plate combination should be reduced, and it is concluded that under 42.5KA current, the welding pressure should be higher than 4KN to obtain qualified welded joints.

#### *4.3.3. Analysis of the Influence of Continuous Welding Ability of Welding Points*

After determining the welding process specification interval, we proceeded to analyze the continuous weldability of spot welding. Under the same specification, observe the effect of electrode connection method on the continuous welding ability of aluminum alloy spot welding.

Aluminum alloy, due to the high welding current, there is a Peltier effect when welding, that is, the phenomenon of melting nugget offset [10-15]. For the same plate thickness, the weld nugget forms in greater proportion on the positive pole, as shown in Figure 14. As shown in Figure 15, electrode erosion sticking occurred in Figure 15a after 20 points of continuous welding, whereas in Figure 15b, electrode erosion occurred after 13 points of continuous welding. Observing the metallographic pictures under the two electrode connection methods, it can be clearly seen that the way of connecting the positive electrode to the thin plate is more conducive to mitigating the phenomenon of molten nucleus shift and enhancing the continuous welding capability of aluminum alloy spot welding, in Figure 16.

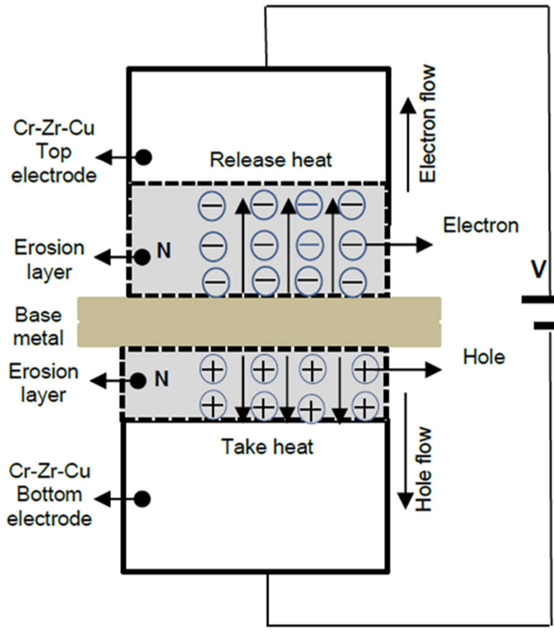
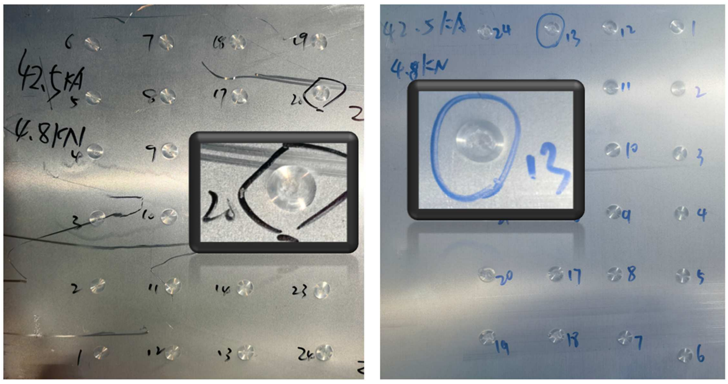


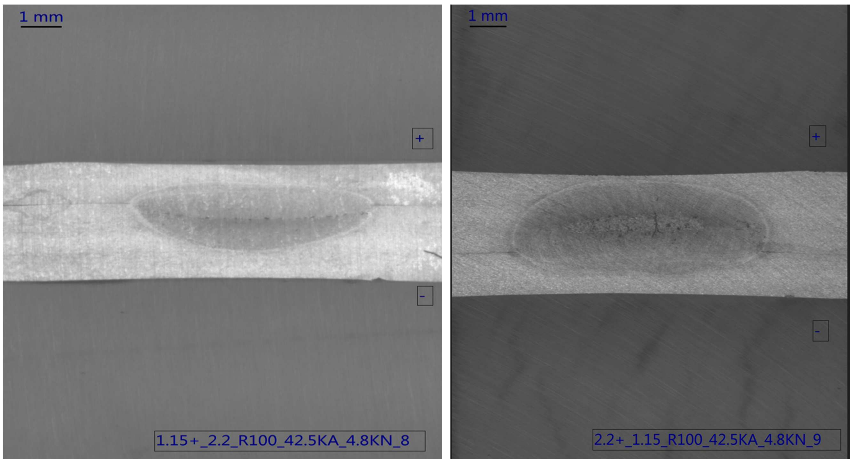

***Figure 14.*** *Peltier model of resistant spot welding for Aluminum alloy.*

The oxide film on the surface of aluminum alloy can lead to uneven contact between the electrode and the workpiece, leading to Cu Al alloying erosion on the electrode surface [7], The baking of the material surface also contributes to the improvement of welding ability [8]. In addition to the influence of material surface state on welding ability, welding parameters are also key factors affecting welding ability.



a. Thin plate to positive electrode b. Thick plate to positive electrode

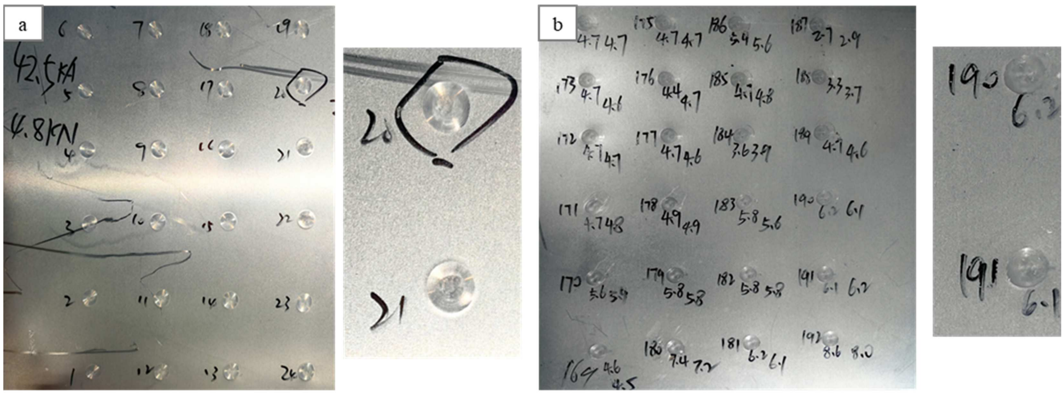
***Figure 15.*** *Picture of continuous welding of spot welding points under different electrode connection methods.*




a. Thin plate to positive electrode b. Thick plate to positive electrode

***Figure 16.*** *Metallographic images of spot welding joints under different electrode connection methods.*

After determining the electrode connection method, we conducted continuous welding under low pressure of 4KN and high pressure of 7KN respectively. At a low pressure of 4KN, the electrode erosion phenomenon on the surface of the spot weld begins to occur after 20 consecutive welding points; However, under high pressure of 7KN, there was no erosion phenomenon in the continuous welding of 200 points, indicating that under the same current, the continuous welding ability of spot welding joints under high pressure is stronger. The surface state of the welded joint after welding is shown in Figure 17.




a. 42.5KA, 4.8KN b. 42.5KA, 7KN

***Figure 17.*** *Continuous Welding State of Welding Points under Different Welding Pressures.*

In order to ensure the quality of welding points, destructive chiseling inspection was conducted on spot welds at 4KN and 7KN, respectively, to observe the stability of the size of the weld nuggets. 24 points of 4KN continuous welding have been tested and the quality of the welding points meets the standard requirements.

Among the 200 consecutive welding points at 7KN, 3 out of the first 60 welding points have a smaller nugget diameter. A total of 47 out of 200 solder joints have smaller nuggets, so the pressure range of the overall specification still needs to be reduced. The quality inspection records of the weld nuggets after welding are shown in Figure 18.

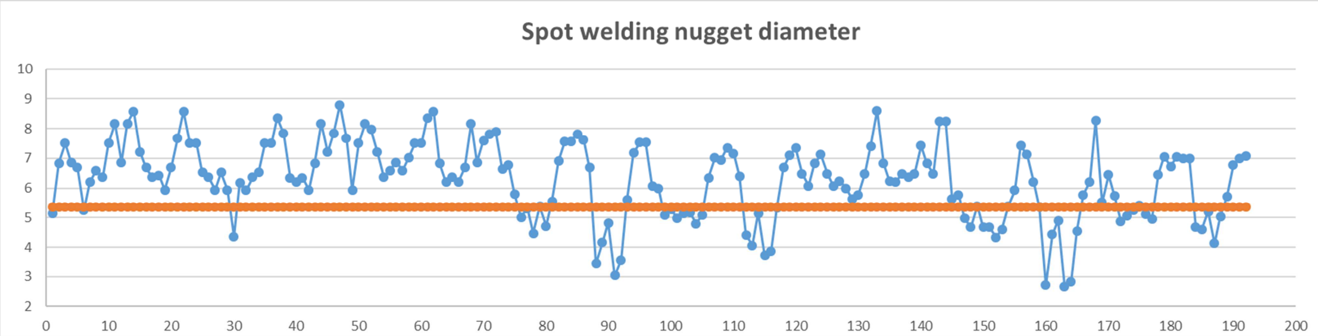



***Figure 18.*** *Nugget diameter of continuous welding RSW (mm).*

After the above experimental analysis, it is finally concluded that the recommended welding pressure range for RSW is between 4 and 6.5KN at 42.5KA. The green marking range area shown in Figure 19.

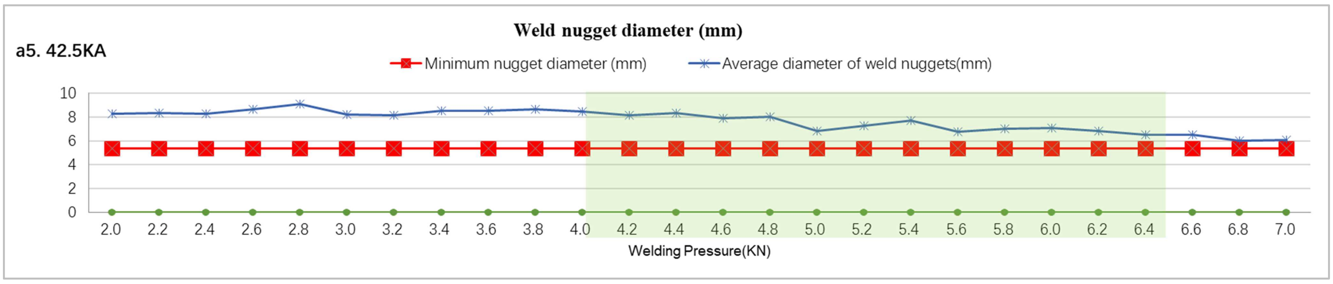



***Figure 19.*** *Welding Process Specification Interval at 42.5KA.*

### *4.3.4. The Influence of Electrode Arc Size and Electrode Connection Method on the Strength of RSW*

The morphology of aluminum alloy spot welding electrodes also has an impact on welding performance. There have been studies in the industry that have shown that using multi ring dome electrodes can improve welding ability. This experiment used conventional electrodes with a diameter of 20mm, and electrodes with R100 and R150 radians were used for welding [9]. Use different electrode connection methods to continuously weld 3 points. Conduct tensile tests on the welded joints and compare the trend of welding strength changes. The results are shown in Table 5.

Through this experimental analysis, it was found that using R100mm arc shaped electrodes can achieve higher welding joint strength and reduce welding heat input compared to R150 arc shaped electrodes. The connection method of welding electrodes has no significant difference in the shear resistance of the solder joint. However, when using the same material, the method of connecting the thin plate to the positive electrode can achieve higher continuous RSW ability.

***Table 5.*** *Shear strength under different electrode specifications and connection methods.*

| No. | Plate 1 thickness (mm) | Electrode polarity Plate 1 | Plate 2 thickness (mm) | Electrode polarity Plate 2 | radius (mm) | Current (kA) | Pressure (kN) | Fmax (N) | Rm N/mm$^2$ | Fmax average (N) | Rm average N/mm$^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | 1.15 | + | 2.20 | - | R100 | 42.5 | 5.8 | 3761.6 | 74.6 | | |
| 1.2 | 1.15 | + | 2.20 | - | R100 | 42.5 | 5.8 | 3362.8 | 66.7 | 3505.9 | 69.5 |
| 1.3 | 1.15 | + | 2.20 | - | R100 | 42.5 | 5.8 | 3393.3 | 67.3 | | |
| 2.1 | 1.15 | - | 2.20 | + | R100 | 42.5 | 5.8 | 3173.9 | 63.0 | | |
| 2.2 | 1.15 | - | 2.20 | + | R100 | 42.5 | 5.8 | 3606.6 | 71.6 | 3549.2 | 70.4 |
| 2.3 | 1.15 | - | 2.20 | + | R100 | 42.5 | 5.8 | 3867.0 | 76.7 | | |
| 3.1 | 1.15 | + | 2.20 | - | R150 | 42.5 | 5.8 | 3257.2 | 64.6 | | |
| 3.2 | 1.15 | + | 2.20 | - | R150 | 42.5 | 5.8 | 3582.8 | 71.1 | 3434.4 | 68.1 |
| 3.3 | 1.15 | + | 2.20 | - | R150 | 42.5 | 5.8 | 3463.2 | 68.7 | | |

Using the same arc electrode R100mm, adjusting different welding pressures, tensile tests were conducted on three sets of test specimens after welding under the same other specifications. Comparing the tensile results, it was found that the shearing force of RSW decreased with increasing pressure. see Figure 20.

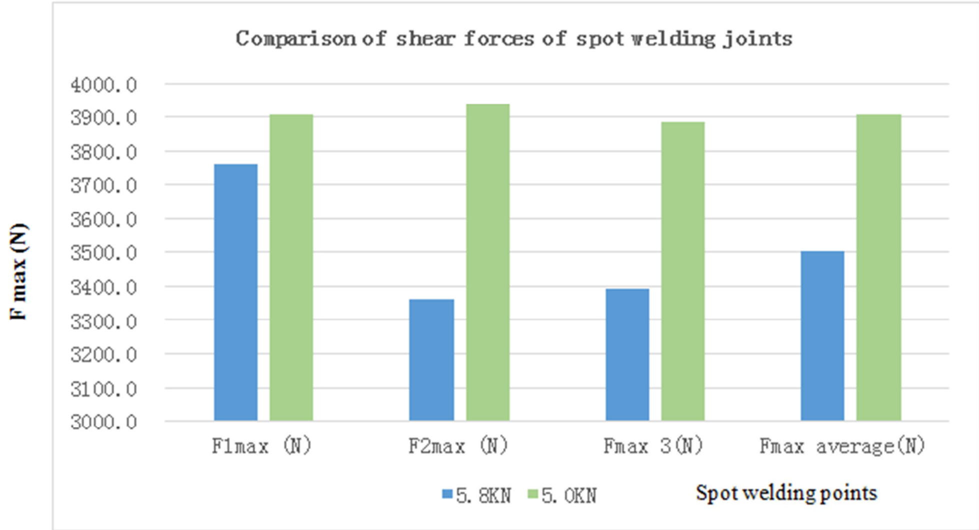



***Figure 20.*** *Welding Process Specification Interval at 42.5KA.*

### *4.4. Process Specification Range*

According to the above test methods, the welding current was set from 30KA to 50KA, taking 2.5KA as a gradient for experimental analysis and inspection, and the effective process specification range of 1.15+2.2mm for the combination of the two layers of plates was finally determined as shown in Figure 21.

We will divide the overall interval into four parts, with red indicating the unqualified welding area, which means that the quality of the welding points cannot meet the requirements; The gray color represents the unstable welding zone, which means that the compliance rate of the welding nugget size cannot meet the requirements; The light green color represents the restricted welding capacity area, which can obtain qualified welding points. However, due to the limited number of continuous welding points and high electrode consumption, this specification can be considered for application at specific beats; Dark green is a good welding process specification area, which can achieve good welding quality and strong welding ability, and is recommended for application in process production.

| number | Material combination (mm) | a. welding current (KA) | b. Welding pressure (KN) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2-2.5 | 2.6-3.0 | 3.1-3.5 | 3.6-4.0 | 4.1-4.5 | 4.6-5.0 | 5.1-5.5 | 5.6-6.0 | 6.1-6.5 | 6.6-7.0 | 7.1-7.5 | 7.6-8.0 |
| 1 | 1.15+2.2 | 35KA | | | | | | | | | | | | |
| 2 | 1.15+2.2 | 37.5KA | | | | | | | | | | | | |
| 3 | 1.15+2.2 | 40KA | | | | 3.6 | | 4.6 | | | 6.5 | | | |
| 4 | 1.15+2.2 | 42.5KA | | | | | 4.1 | | 5.1 | | 6.5 | | | |
| 5 | 1.15+2.2 | 45KA | | | | | | 4.6 | | 5.6 | | | 7.5 | |
| 6 | 1.15+2.2 | 47.5KA | | | | | | | | 5.6 | | 6.6 | | 7.6 |
| 7 | 1.15+2.2 | 50KA | | | | | | | | | | 6.6 | 7.1 | 7.6 |

Remarks:

| | |
|---|---|
| A | Welding point are qualified |
| B | Continuous welding capacity< 20 points ,welding point are qualified.The electrode is erosion. |
| C | Continuous welding ≥ 20 points, welding points are qualified, no erosion; |
| D | Unstable welding quality |
| A | Not applied |
| B | Conditional application.It can be considered to be used under certain rhythm conditions (such as a single welding of 5-10 points for one grinding) |
| C | Application.Can achieve high welding quality and welding ability |
| D | Not applied |

***Figure 21.*** *Scope of Welding Process Specification.*

Select two sets of process parameters within the specified range of the above experimental research to compare the continuous welding ability of spot welding points. It was found that the specification 1 in the dark green area can be continuously 128 points, and there is no adhesion on the surface after welding. The welding points meet the quality requirements through ultrasonic, metallographic, and destructive testing. Although specification 2 in the light green area can also meet the welding quality requirements, the continuous welding capacity is only 20 points. As shown in Figures 22, 23, 24, this experiment also demonstrates that setting the optimal process specifications can greatly improve the welding ability of spot welding.

## 5. Conclusion

Al. alloy RSW has a severe erosion phenomenon on the electrode cap of the positive pole of the power supply. By controlling the alternating changes in the welding polarity of the welding machine, the uneven erosion phenomenon of the positive and negative electrodes can be overcome, and the welding quality of the welding point can be improved and the electrode life can be extended.

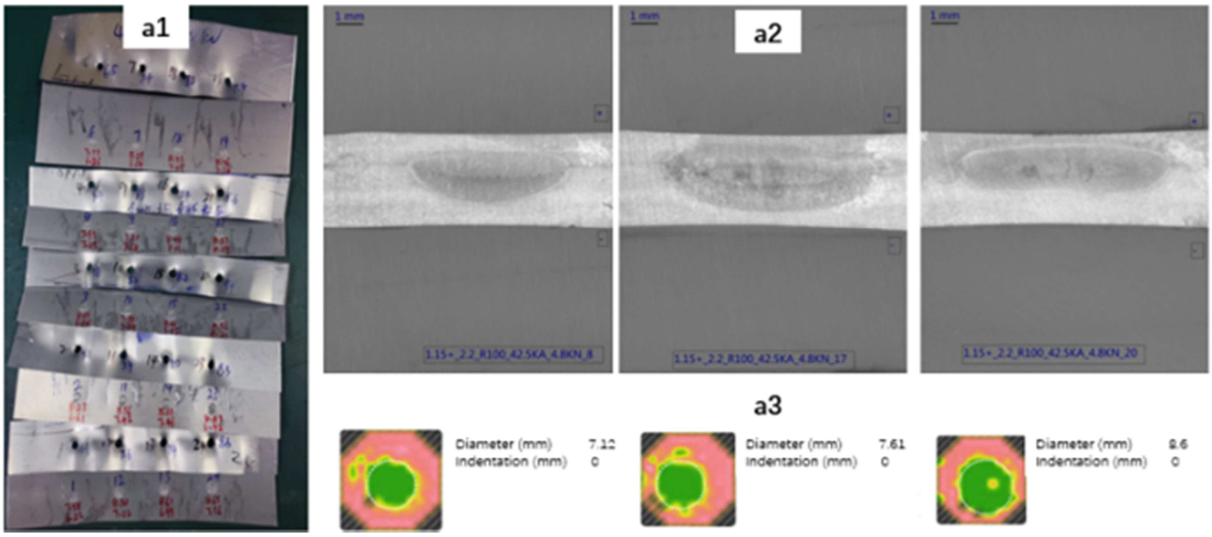
Under the same welding specifications, the electrode arc R100 mm relative to R150 mm can obtain a larger weld nugget diameter, so the electrode size will affect the input of welding current and welding energy consumption.

For different material combinations with different plate thicknesses, the connection method of positive and negative electrodes has little effect on the strength of RSW, but it has an impact on the welding ability of RSW. When using the same material, placing the thin plate at the positive end of the power supply can obtain more welding points, which leads to stronger welding ability.

For the same plate combination, when the welding current is the same, as the welding pressure increases, the diameter of the weld nugget decreases. When the pressure is too small, cracks are prone to occur on the surface of the weld joint.

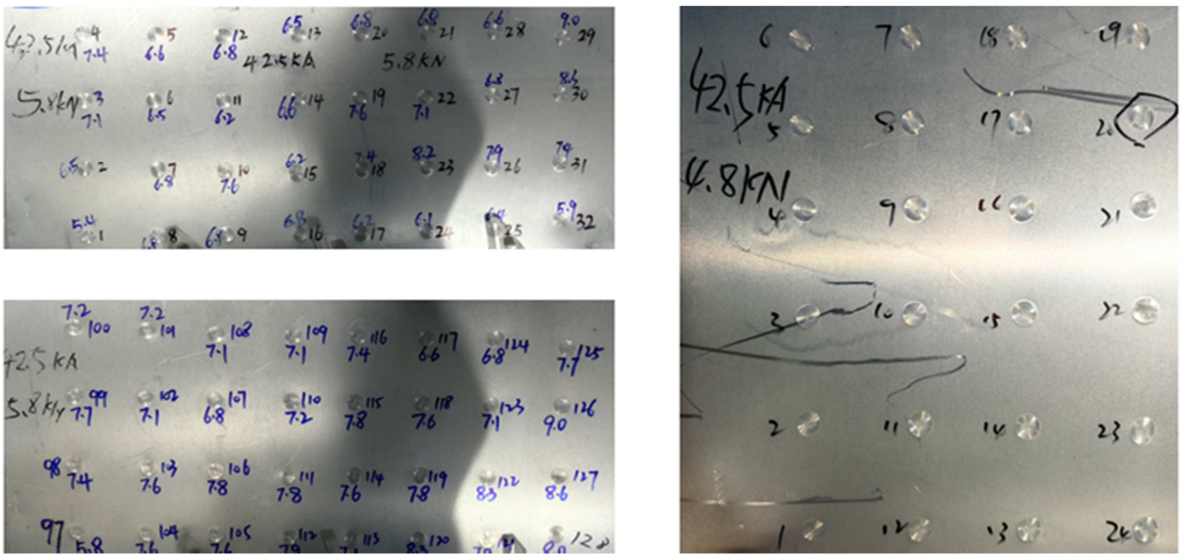
Compared to low pressure and low current welding specifications, high pressure and high current specifications are more conducive to reducing welding cracks and porosity, enhancing the stability of welding quality, and increasing the number of welding points.

Adopting reasonable welding specifications can greatly increase the number of welding points for Al. alloy RSW, improve welding quality, reduce electrode consumption, and reduce production and manufacturing costs.




a. 42.5KA, 5.8KN, 100ms; b. 42.5KA, 5KN, 100ms

***Figure 22.*** *Surface state of RSW points under different welding process parameters.*



a1. Destructive weld nugget inspection; a2. Metallographic examination; a3. Ultrasonic inspection

***Figure 23.*** *Quality status of spot welding points (Process Parameter 1).*

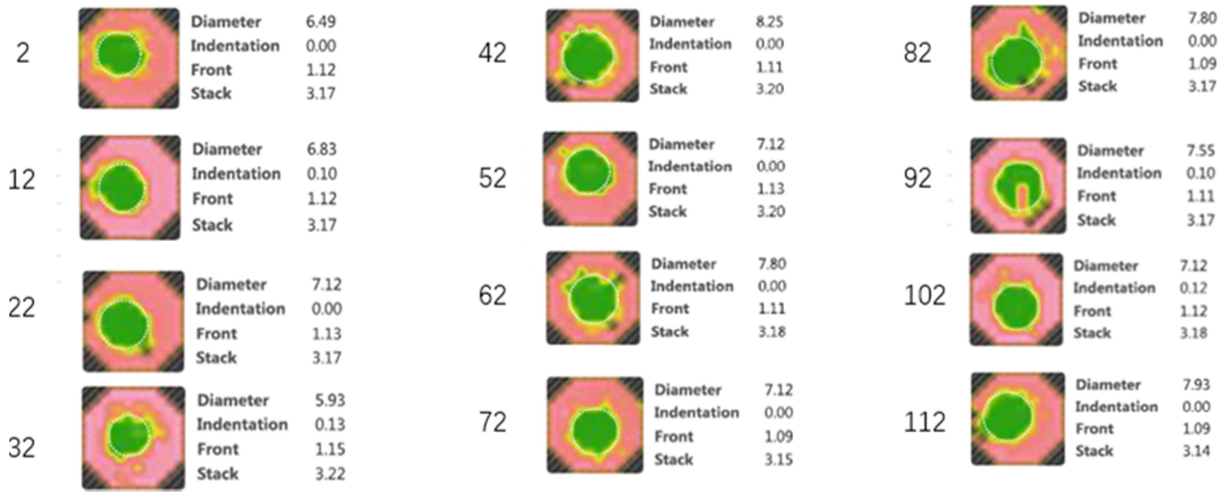



***Figure 24.*** *Ultrasonic inspection of spot welding points (Process Parameter 2).*

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