Optimization of the electrode processing methodology for spot welding of aluminium

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Resistance spot welding, aluminium alloys, electrode life, electrode processing method.

1. Introduction

Resistance spot welding [1] is an innovative, widespread and very economically viable welding process in the sheet metal processing industry. Over one billion resistance-spot-welded joints are executed every day, mainly in sheet metal processing and in automobile construction (body shell construction).

In earlier years, numerous investigations were conducted into the resistance spot welding of aluminium with regard to weldability, strength behaviour and electrode wear [2 – 6]. According to the current status, it is primarily the short electrode life (total number of weld spots which can be achieved with one electrode pair including the processing of the electrodes) or tip life (number of weld spots which can be achieved without processing the electrodes, e.g. milling) which prevents the widespread utilisation of the resistance spot welding of aluminium in fabrication. However, refinements relating to the aluminium materials, particularly due to the application of conversion coats and to optimisation measures with regard to the electrode processing, are highlighting potentials for utilising resistance spot welding in fabrication to an increasing extent once again. However, an improvement in the previously inadequate electrode life with high process reliability is imperative in this respect.

Within the framework of a research project which was promoted by German Federation of Industrial Research Associations (AiF) and was entitled "Development of a suitable electrode processing method for the resistance spot welding of aluminium materials" [7].

2. Experimental

In the tests we used the non-hardenable Al-alloy AW 5182 (AlMg4.5Mn) in the sheet thicknesses t = 1.5 mm with the TiZr conversion coat and a dry lubricant.

The welding tests were performed with an X100 Panther servo-motor spot welding gun from Düring. The X-shaped gun, working range: 400 mm, supplies a maximum electrode force of 8 kN and has a nominal power of 250 kVA (medium-frequency technology). The cooling water quantity per electrode arm is 4 l/min at a supply temperature of 20°C. The six-axis KR200 robot from KUKA serves to move the welding gun (Figure 1a). The series welds were executed on sheet metal plates with dimensions of 400 x 500 mm. The spot spacing was 30 mm.

2.1. Grinding and polishing devices

The grinding installations built in a stationary position work at speeds from 2,000 rpm to 10,000 rpm. Various grinding tools can be inserted into the drive head using the drill chuck (Figures 1b and 1c). The rotational movement is produced by a compressed air motor. The pressing force of the grinding tool on to the electrode caps is approx. 50 N. The grinding installation on Figure 1c offers the possibility of carrying out axial and radial rotations at the same time.

2.2. Grinding tools

Commercially available tools and tools close to practical needs were used in order to produce the various surface roughness during the processing of the electrode caps. On the one hand, P60 to P120 fan grinding rolls were utilised. Rolls made of non-woven materials in various roughness (fine, medium and coarse) served to produce finer grinding patterns. Combined rolls, so-called fan rolls made of non-woven materials, were used as well. The different grinding media produced roughness from $R_Z = 2.5$ µm to $R_Z = 15$ µm.

2.3. Milling devices

The milling devices from AEG Schweißtechnik (Fig. 1d) and Lutz Precision are built in a stationary position in the working range of the robot. The drive is provided by an electric motor at a speed of 350 rpm. The milling head with the milling blade is secured on the milling device using a bayonet catch. The jigs have a linear height compensation system. It is thus ensured that, with a varying electrode cap length, the milling removal is equal at the top and at the bottom. Milling heads for electrode cap diameters of 20 mm and 16 mm are used. The convexity radius is R100 mm with Ø 20 mm and Ø 16 mm.

3. Criteria for determining the end of the tip life

The end of the tip life is regarded as having been reached if:

a) the spot diameter drops below $dP < 5\times\sqrt{t}$

b) the quality capability index drops below the CpK value < 1.67 [8]

In the evaluations to which reference is made for the comparisons of the individual passes, three CpK curves are defined:

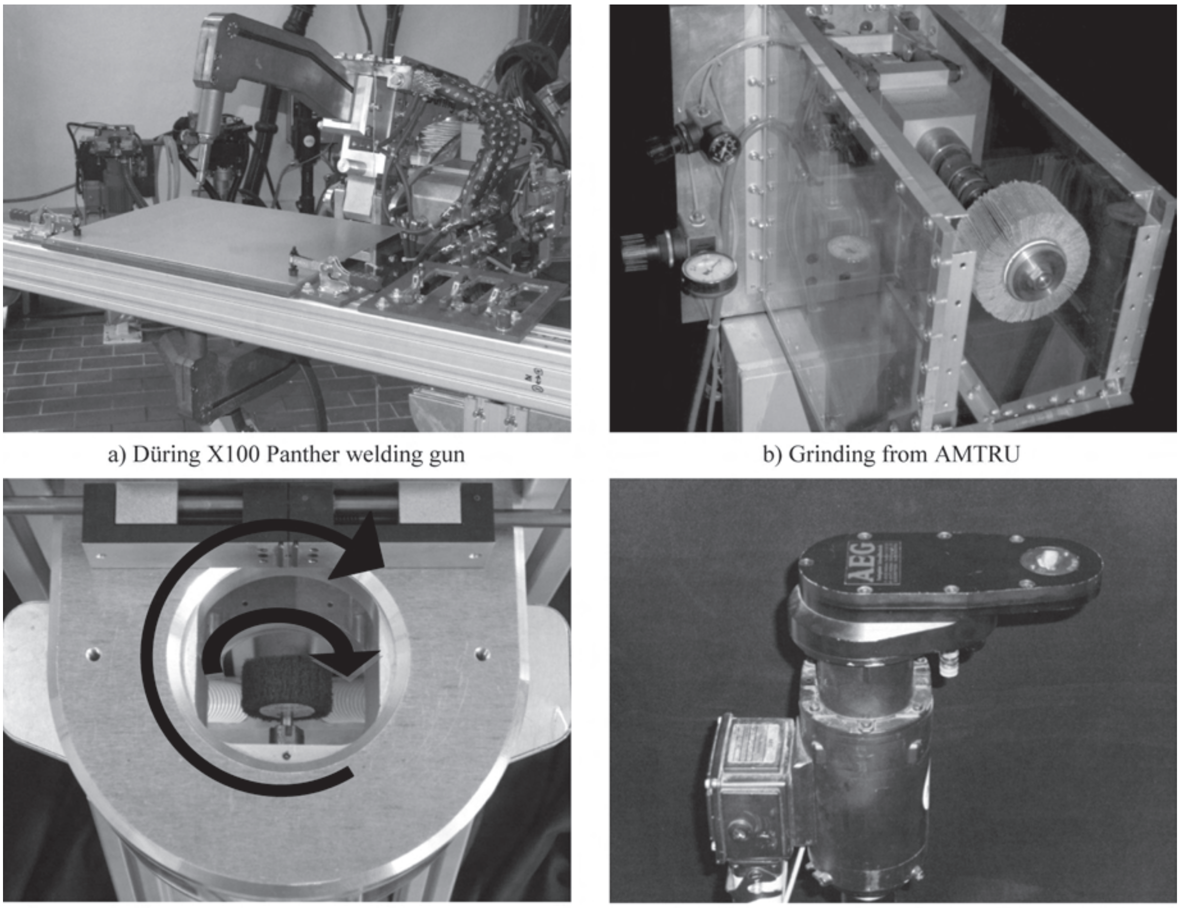
- CpK1 curve (red) ≙ CpK value calculation as from the 1st weld spot
- CpK15 curve (pink) ≙ CpK value calculation as from the 15th weld spot
- CpK6×√t curve (green) ≙ CpK value calculation as from the 1st weld spot

Spot diameters which are over $6\times\sqrt{t}$ are entered as $6\times\sqrt{t}$.

The processing methods were assessed according to the following criteria:

1. Fulfillment of the minimum CpK value;
2. Electrode life;
3. Number of spots at which processing takes place (processing interval);
4. Surface quality of the weld spots.

(CpK > 1.67), he weights this criterion with 50 %. For him, the remaining criteria (electrode life, processing interval and surface quality) have an importance of 20 % or 15 %. On the other hand, User B (for example) attaches great significance to the longest possible electrode life and weights this criterion with 50 %. Correspondingly, the other criteria (fulfillment of the minimum CpK value, processing interval and surface quality) have a lower importance.



a) Düring X100 Panther welding gun

b) Grinding from AMTRU

c) Grinding from PTM

d) Electrode milling device

Figure 1. Views of the utilized testing devices.

Table 1. Assessment of the processing methods according to different weighting figures.

		A		B		C		D		E	
Criterion	P	W	P x W	W	P x W	W	P x W	W	P x W	W	P x W
Fulfilment of the minimum CpK	0…4	0.5	**0…2**	0.2	**0…0.8**	0.2	**0…0.8**	0.2	**0…0.8**	0.25	**0...1**
Electrode life	0…4	0.2	**0…0.8**	0.5	**0…2**	0.15	**0...0.6**	0.15	**0...0.6**	0.25	**0...1**
Processing interval	0…4	0.15	**0...0.6**	0.15	**0...0.6**	0.5	**0…2**	0.15	**0...0.6**	0.25	**0...1**
Surface quality	0…4	0.15	**0...0.6**	0.15	**0...0.6**	0.15	**0...0.6**	0.5	**0…2**	0.25	**0...1**
Total number of points	0…4		**0…4**		**0…4**		**0…4**		**0…4**		**0…4**
Main focal point			**CpK**		**Elec.**		**Proc.**		**Qual.**		**Av.**

Abbreviations: P = number of points, W = weighting

For each criterion, assessment points from 0 to 4 (not sufficient to excellent) were awarded and total numbers of points were established. Since the users make different assessments of the importance of the criteria, the processing variants were marked with five varying percentage distributions of the criteria (A to E) in addition (Table 1). For example, if User A attaches great significance to fulfilling the process capability

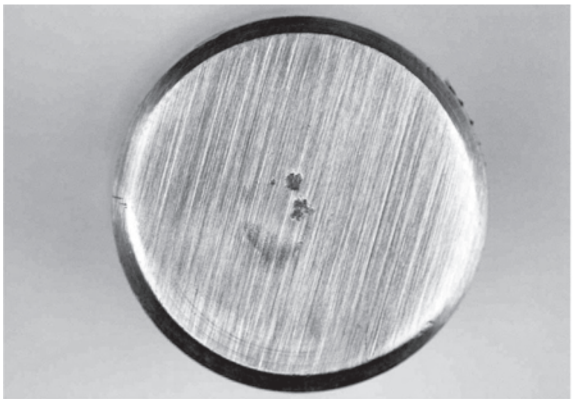
4. Results

Multiple series spot welds with 30, 40, 50 and 60 spots were executed with the Al alloy AW5182 (t = 1.5 mm) in order to highlight how the electrode life is influenced by electrode caps which exhibit pick-up phenomena and are processed. Polishing with fine non-woven material, grinding with P80 and subsequent milling were utilized as the processing methods.

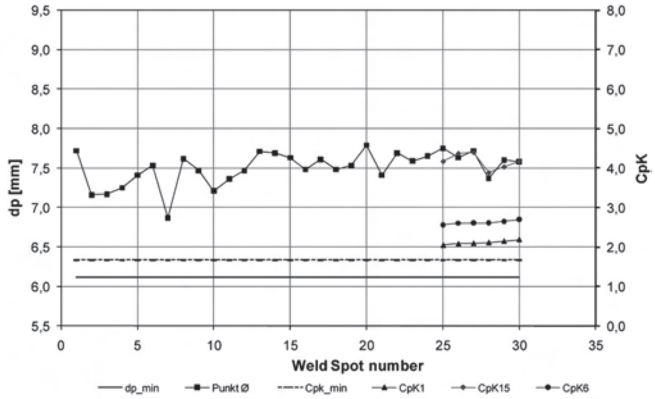
Polishing with a roll made of fine non-woven material after 30 spots is recommended as a suitable method for ensuring a high surface quality, a long electrode life and good process stability. The electrode exhibits only very slight pick-up phenomena and the pick-up residues can be removed completely to the greatest possible extent (Fig. 2). The polishing operation can be carried out at least 35 times without dropping below the minimum CpK value or dPmin. This corresponds to approx. 1,050 welds. Only then is a milling operation (removal: 0.2 mm) necessary in order to restore the electrode geometry. Theoretically, this would result in an electrode life of 30,000 weld spots. However, electrode processing at an early stage may be disadvantageous for series fabrication since the fabrication process must be interrupted for the electrode processing.

If even more stringent optical demands are made on the weld spot surface (e.g. no pick-up phenomena whatsoever on the electrode and no surface cracks), it is recommended to carry out processing by means of polishing after 15 welds.

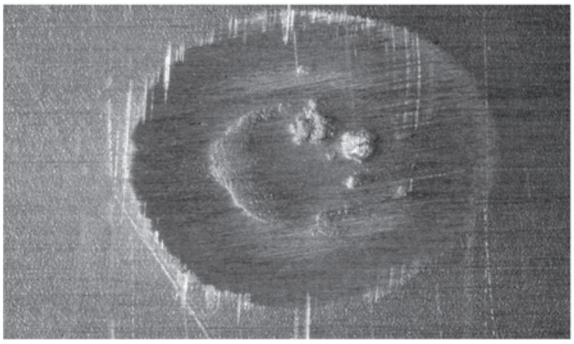
The disadvantage of interval grinding (e.g. with a P80 fan grinding roll) is the greater change in the geometry which leads to a reduction in the current density after processing the electrode several times. After 14 grinding operations, it is possible to recognize a significant impairment of the process stability and the value drops below the minimum CpK value. The calculated electrode life is approx. 6,000 weld spots.



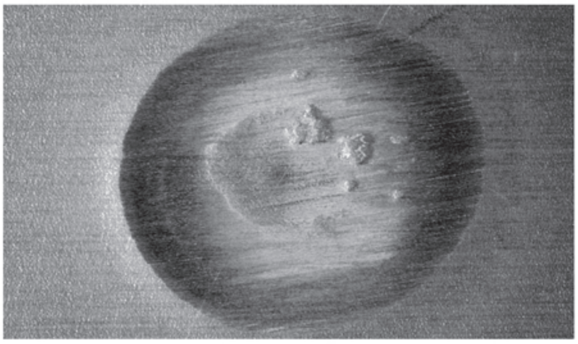
a) Slight erosion phenomena on the working face of the electrode surface after 35 intervals



b) Course of the spot diameters and the CpK values depending on the number of weld spots in the case of interval polishing with fine non-woven material after 30 spots (35th welding series)



c) 1st spot, 35th interval



d) 30th spot, no change in the surface marking

Welding parameters and boundary conditions: $F_E = 7.5$ *kN*, $t_S = 160$ *ms*, $I_S = 37.5$ *kA*, $D_{El} = 20$ *mm, roughness = 4.0 µm*

Fig. 2 View of the electrode and sheet surfaces after 35 welding series with an interval of 30 weld spots - grinding medium consisting of fine non-woven material from AMTRU.

Table 2. Assessment of the processing method consisting of polishing with “Non-woven, fine” with an interval number of 30 spots.

		A		B		C		D		E	
		W	P x W	W	P x W	W	P x W	W	P x W	W	P x W
Criterion	P										
Fulfillment of the minimum CpK	4.0	0.5	**2**	0.2	**0.8**	0.2	**0.8**	0.2	**0.8**	0.25	**1**
Electrode life	4.0	0.2	**0.8**	0.5	**2**	0.15	**0.6**	0.15	**0.6**	0.25	**1**
Processing interval	1.0	0.15	**0.15**	0.15	**0.15**	0.5	**0.5**	0.15	**0.15**	0.25	**0.25**
Surface quality	4.0	0.15	**0.6**	0.15	**0.6**	0.15	**0.6**	0.5	**2**	0.25	**1**
Total number of points	13		**3.55**		**3.55**		**2.5**		**3.55**		**3.25**
			CpK		Elec.		Proc.		Qual.		Av.

The great advantages of milling are the very good surface quality and process stability of the weld spots since the electrode geometry remains constant and pick-up phenomena can be eliminated completely. The electrode life is in the range of 2,000 spots in the case of milling at an early stage (removal: 0.1 mm per operation). Due to newly developed milling heads which permit removal values in the range of 1/100 mm (minimal milling), it is possible to increase the numbers of spots to as much as 10,000. Table 2 shows the reached assessment points according to different weighting figures for polishing with “non-woven, fine” with an interval number of 30 spots.

In the case of numbers of spots between 40 and 50, preference should also be given to polishing in so far as the user focuses on the process stability and the electrode life. During all the test series, polishing achieves high numbers of points with regard to the process stability criterion (3.6 points out of max. 4). The disadvantage is that the surface quality of the weld spots becomes ever worse with an increasing number of intervals and distinct fusion phenomena and cracks on the sheet surface arise there after five intervals. The process stability and the surface quality are slightly worse in the case of grinding.

If the user attaches significance to the best surface quality, milling is advantageous since the electrode working face can always be machined off completely subject to corresponding milling parameters. However, this is at the expense of the electrode life in so far as conventional milling is carried out.

Table 3. Ranking of the processing methods for the aluminium alloy AW5182 (1.5 mm).

	Criterion							
	Fullfillment CpK		Electrode life		Processing interval		Surface quality	
1.	P. 30	3.6	P. 30	3.6	M. 100	3.3	P. 30	3.6
2.	Mm. 30	3.6	Mm. 30	3.6	P. 50	2.5	Mm. 30	3.6
3.	G. 30	3.5	G. 30	3.5	P. 60	2.5	G. 30	3.3
4.	Mm. 40	3.4	P. 40	3.3	Mm. 30	2.5	Mm. 40	3.2
5.	P. 40	3.2	Mm. 40	3.1	Mm. 40	2.5	M. 30	3.1
6.	P. 50	3.1	P. 50	3.0	Mm. 50	2.5	M. 40	2.9
7.	M. 100	3.1	G. 40	3.0	P. 30	2.5	Mm. 50	2.8
8.	Mm. 50	3.0	P. 60	2.8	G.30	2.4	P. 40	2.8
9.	M. 30	3.0	G. 50	2.7	P. 40	2.4	M. 100	2.7
10.	M. 40	3.0	Mm. 50	2.3	G. 40	2.3	M. 50	2.5
11.	G. 40	2.9	M. 30	2.1	G. 50	2.3	P. 50	2.4
12.	M. 50	2.9	M. 40	2.1	M. 40	2.2	G. 40	2.4
13.	G. 50	2.7	M. 100	2.0	M. 50	2.2	G. 50	2.2
14.	P. 60	2.7	M. 50	1.6	M. 30	2.1	P. 60	1.9

4,0-3,6 excellent; 3,5-3,1 very good; 3,0-2,6 good; 2,5-2,1 satisfactory; 2,0-1,6 sufficient

Remarks: P.xx: polishing after xx spots
G.xx: grinding after xx spots
M.xx: milling after xx spots
Mm.xx: minimal milling after xx spots

In a ranking, Table 3 shows the positions of the different processing methods depending on the various criteria. On the basis of this final assessment, preference should be given to the P.30 variant (polishing after 30 spots) for the resistance spot welding of aluminum. This variant is rated highest in relation to the fulfillment of the minimum CpK value, the electrode life and the surface quality of the welding series.

Milling at low removal rates (e.g. MM.30) should be recommended as a second processing method. The great advantage of milling is that, subject to the choice of suitable milling parameters, the electrode working face can be manufactured in a completely clean and bright form (without any pick-up residues). This variation possibility in the removal rates does not exist in the case of the grinding media.

5. Summary and outlook

The results highlight that the resistance spot welding of aluminum alloys is possible with good process reliability if the electrode is processed with low removal at an early stage. In the event of stringent requirements on the surface quality of the weld spots, approx. 30 spots are possible with the Al alloy AW5182 (t = 1.5 mm, passivated TiZr). If processing is carried out at the earliest possible stage, the pick-up residues on the electrode are removed completely and hardly any erosion points form. With this method, several thousand weld spots are possible with one electrode pair. More extreme pick-up phenomena arise thereafter but do not exert a negative influence on the spot diameter. 60 weld spots are even possible if less stringent requirements are set on the surface qualities of the weld spots. However, intermediate milling must then be carried out between the processing cycles in order to eliminate the more extreme pick-up phenomena completely. This reduces the electrode life. The remaining residues on the electrode surface only affect the appearance of the weld spot. Due to the knowledge and results obtained from the project, fundamental prerequisites have been created for the widespread utilization of the resistance spot welding of aluminum alloys in series fabrication.

GSI mbH, NL SLV München has many years of experience in the field of the resistance spot welding of lightweight construction materials and supports users and fabrication plants, also with these latest research results, during the introduction and implementation of innovative lightweight construction materials.

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Calendar of international and national events /

Calendarul manifestărilor ştiinţifice şi tehnice internaţionale şi naţionale

2013			
07-09 Oct.	3rd IIW European-South American School of Welding	Salvador, Bahia, B razil	http://www.3schoolofwelding.com.br/
7-10 Oct.	NDT in Canada 2013 & International Workshop on Smart Materials and Structures, SHM and NDT for the Energy Industry	Calgary, Alberta, Canada	http://events.cinde.ca and http://www.cansmart.com
27-29 Oct.	2013 CWA Conference	Niagara Falls, ON, Canada	http://www.cwaevents.org/canweld
30 Oct. – 2 Nov.	World Conference on Acoustic Emission, WCAE-2013	Shanghai, China	http://www.wcacousticemission.org/whats_new.php
5-7 Nov.	43rd International Conference and NDT Exhibition - NDE for Safety / Defektoskopie 2013	Olomouc, Czech Republic	http://cndt.cz/nde_for_safety2013/
18-21 Nov.	FABTECH 2013 - Metal forming, fabricating, welding and finishing event	Chicago, United States	http://www.fabtechexpo.com/
29 Nov.	International Symposium on SHM and NDT	Lyon, France	http://lva.insa-lyon.fr/symposium2013
2014			
25-28 Febr.	iCT 2014 - International Conference on Industrial Computed Tomography	Wels, Austria	http://www.3dct.at/cms2/index.php/en/welcome
7-10 Apr.	IIW International Congress	Delhi, India	http://www.iiwelding.org
10-13 Jun.	The 19th Beijing ESSEN Welding / Cutting Fair	Beiling, China	http://www.beijing-essen-welding.com
13-18 Jul.	67th IIW Annual Assembly and International Conference	Seoul, Korea	http://www.iiwelding.org