JOINING OF THIN SHEETS FROM AL ALLOY EN AW 6016 BY CAPACITY DISCHARGE WELDING

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Abstract

The use of aluminum for car bodywork is a new trend in the automotive industry. But joining of aluminum carries a number of problems, such as pores, cracks and other internal defects. For joining of thin sheets, pressure welding is mainly used in the automotive industry. For example, spot resistance welding (RSW) or capacity discharge welding (CDW) can be used. The paper describes the influence of the parameters of CD welding on the size of the weld nuggets and the quality of the joint from the aluminum alloy EN AW 6016.

Keywords: CD welding, capacitor, RSW, Al alloy, welding parameters

1. INTRODUCTION

Aluminum and its alloys are currently a very attractive option for manufacturers. Some car manufacturers use up to 20 % aluminum alloys. The Super Light Car (SLC) project envisages up to 56 % aluminum alloys in the material concept. The main advantages of aluminum over steel are lower weight, excellent corrosion resistance, better recyclability (up to 95 % of total in-car) and good dent resistance. On the other hand, aluminum is more expensive than steel, with oxides forming on its surface causing wear on the die [1,2].

In particular, the resistance spot welding (RWS) method is used in the automotive industry for thin sheet joining. Joining of aluminum and its alloys by RWS is difficult and presently complies. Welding heat input is determined primarily by welding parameters. The RSW parameters significantly influence the mechanical properties, macrostructure, and microstructure of the weld joint [3]. Microstructure and mechanical properties of weld joints are effected by surface texture of electrode tip [4]. For proper setting of welding parameters (current, electrode force and time), the electrode - sheet contact resistance should be known. At the beginning of welding, the electrode - sheet contact resistance is done by oxide layer on surface. Removing of oxide layer improve weld quality. The oxide layer can be removed by pickling in 60 °C NaOH (concentration 10 - 30 %), or glass blasting [5,6]. Other way is using of high and short current pulse during capacity discharge welding.

Capacity discharge welding is preferably used for projection resistance welding of modern materials, such as in other ways difficult-to-weld surface-treated high-strength materials or aluminum and its alloys. During welding at conventional AC or DC sources the work take place with multiple current pulses that are taken directly from the mains supply network and lead to an asymmetrical network load. During capacity discharge welding is used just a single, short and high current pulse (up to 1000 kA), which is supplied via a transformed capacitor discharge. The welding time is usually less than 20 ms.

It is assumed with CD welding that the course of the welding current is mainly influed by the design characteristics of the machine (the capacitance of the capacitors, the translation ratio of the transformer and the inductance of the welding current circuit). In this conception the variation of the welding parameters is only possible to a limited degree via the charging voltage of the capacitors. The solution can be in the new multi-capacitor source (MCS) system [7].

The electrical system of a capacitor discharge machine (CD machine) influences the welding behaviour. Whilst the operator is only able to affect the welding process via the charging voltage of the capacitors, and therefore via the energy fed to the joining process, it is ultimately the resistance and inductance of the machine, as well as the capacitance of the capacitor bank - the basic variables - that determine the current progression. Whilst the capacitance is installed in the machine as a compact module, the overall resistance and inductance comprise multiple main components. The transformer variables and the inductance of the secondary circuit have the greatest influence.

According to a widely-held opinion, welding parameters cannot be transferred from one CD machine to another. This drawback arises due to the unknown basic variables of the machines and heavily simplified designated welding parameters, which are limited almost exclusively to the specification of energy E and peak current I_P [7].

With four capacitors connected in parallel, it is possible to specifically influence the course of the welding current. This enables welding process control. To perform a quality joint, it is necessary to know in detail the course of the welding process and the influence of the individual parameters on the shape and size of the weld.

2. MATERIALS

As base material is used sheet from Al alloy EN AW 6016 T4 (EN AW AlSi1.2Mg0.4) with thickness 1.5 mm. The chemical composition according to the manufacturer is given in **Table 1**, mechanical properties in **Table 2**. Electrode tips were milled to a radius of curvature 150 mm, ø d = 16 mm. Material A2/2 - CuCr1Zr were used. Chemical composition of the cap is: Cu = 98.98 wt. %, Cr = 0.9 wt. %, Zr = 0.12 wt. %.

Table 1 Nominal chemical composition of Al alloy EN AW 6016 (wt%) [8]

Fe	**Si**	**Mn**	**Cr**	**Ti**	**Cu**	**Mg**	**Zn**	**others**	**Al**
Max 0.5	1 - 1.5	max 0.2	max 0.1	max 0.15	max 0.2	0.25 - 0.6	max 0.2	total 0.15	rest

Table 2 Mechanical properties of Al alloy EN AW 6016 T4

$R_{p0.2}$ (MPa) **(T4)**	R_m (MPa) **(T4)**	A_{min}, L_o = 50 mm (%) **(T4)**
80 - 140	170 - 250	24

3. EQUIPMENT

PrimKoM-P18 - MCS (KAPKON) was used for welding (**Figure 1**), which is a "O" frame condenser welding machine and new multi-capacitor source (MCS) system (parameters: maximum energy = 17.5 kWs, capacitor capacitance = 20 500 µF, maximum peak current = 210 kA, maximum force = 18 kN), which is equipped with the PrimusKE welding control (HWH). Control unit offers numerous measuring channels through which to measure the relevant process variables with a scanning frequency of 20 kHz. With four connected in parallel, it is possible to specifically influence the course of the welding current. This system technology now enables process control tailored to the joining task. For example, a capacitance change can take place without mechanical reconnection, or peak currents increased or reduced. The "O" frame is more advantageous than the classic "C" frame (up to 40 %) in terms of machine stiffness, process stability, magnetic field size and distribution, and thus reduction of bypass effect.

PrimKoM-P18 - MCS it is equipped with four capacitors (main A = 58 % of C_{ges} and B = 30 % of C_{ges}, auxiliary G = 8 % of C_{ges} and H = 4 % of C_{ges}) with different capacities (12300 + 5740 + 1640 + 820 µF), which can be combined in any way. Thus, the device is capable of up to 4 pulses. Another parameter that characterizes the welding process is the time when another capacitor should start to discharge after the first (or next) pulse.

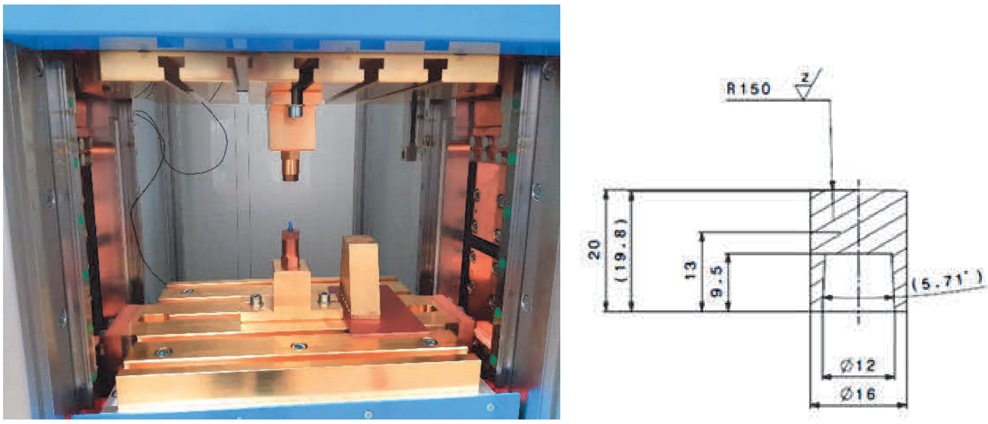


Figure 1 The detail of welding source PrimKoM-P18 - MCS with „O“ frame (left), schema of used electrode tip (right)

4. EXPERIMENT

Three capacitors, H, A and B, were used for welding, which means 3 pulses. The first pulse is the so-called cleaning pulse. During the first pulse, the oxides are removed from the sheet surface. The other two pulses are for melting the material. Welding parameters are shown in **Table 3**. The electrode force was 7 kN in all cases. If only 2 pulses were used (without the use of a cleaning pulse), the welds were significantly smaller and had an irregular lens shape. The first cleaning pulse was set to energy E = 0.496 kWs (H capacitor = 1100 V) for all welds. The time between the first and second pulse was also constant, t_{H-A} = 2 ms.

Table 3 Set welding parameters (Al alloy EN AW 6016)

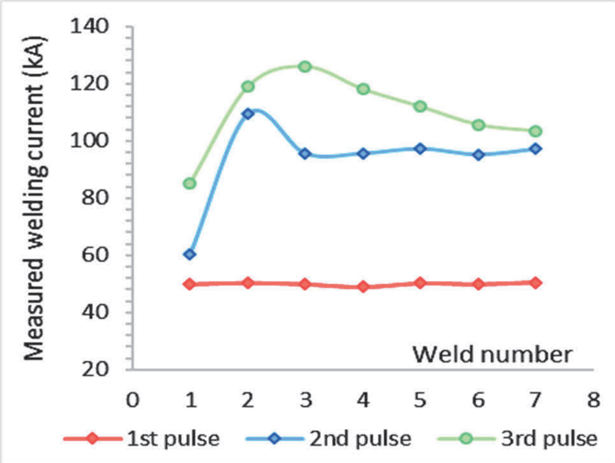
Number of weld	**Capacitor H**		**Capacitor A**		**Capacitor B**	**Total E** (kWs)
	E (kWs)	***t*** (ms)	***E*** (kWs)	***t*** (ms)	***E*** (kWs)	
1	0.496	2	0.918	6	1.406	2.820
2	0.496	2	3.673	6	2.324	6.493
3	0.496	2	2.812	4.5	2.324	5.632
4	0.496	2	2.812	5.5	2.324	5.632
5	0.496	2	2.812	6.5	2.324	5.632
6	0.496	2	2.812	7.5	2.324	5.632
7	0.496	2	2.812	8.5	2.324	5.632

First, a suitable amount of energy was sought for the second and third pulses (welds 1 and 2). Then, the time between the second and third pulses t_{A-B} was changed between 4.5 and 8.5 ms. The energy of the other pulses (welds 3 to 7) has already been set constant for all welds.

Metallographic cross sections for optical microscopy were made. Welds were evaluated for the size of the weld nugget d (mm) and internal defects (porosity, cracks, inclusions). The minimum weld diameter should be 3.5 $\cdot\sqrt{t}$ = 4.3 mm.

5. RESULTS AND DISCUSSION

The measured maximum welding parameter values are given in **Figure 2**. At the values of spot welds 3 to 7, the decrease in welding current I (kA) of the third pulse is only due to the prolonged time. This is also reflected in the power values P (kW). The measured diameters of the weld nuggets diameters are in **Table 4**.



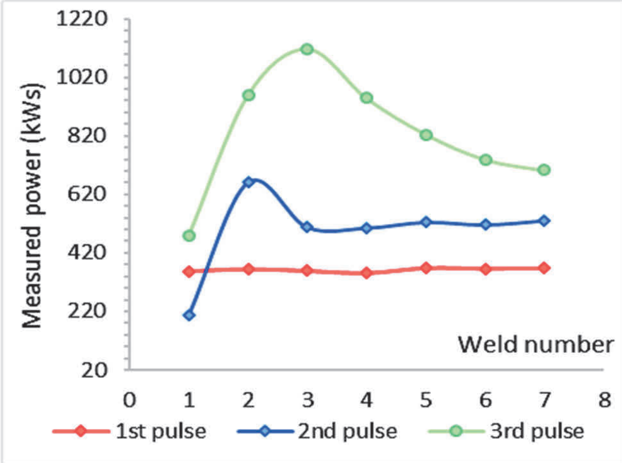
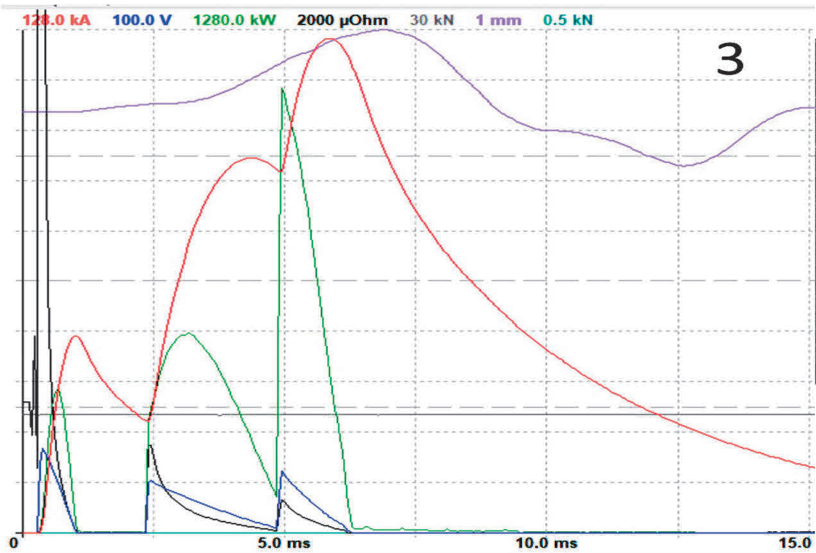


Figure 2 Measured maximal values of welding parameters for all pulses: currend *I* (kA) (left) and power *P* (kW) (right)

Weld number 3 had too short a time between 2nd and 3rd pulse (**Figure 3** left). The electrode was welded to the plate. After the electrodes were removed, the weld nugget was torn off (**Figure 3** right). On the circumference of the weld there is a depression, which is visible on some macros of welds.



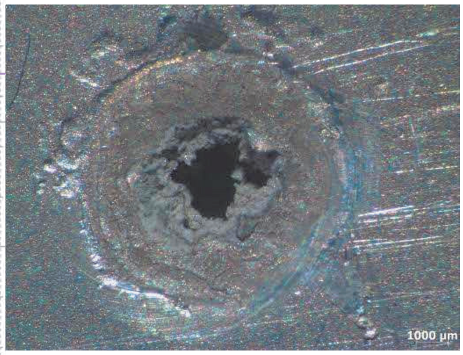


Figure 3 The course of welding parameters for weld No. 3 (left) and torn weld nugget (right); (welding current - red line, power - green line, resistivity - black line, voltage - blue line, electrode displacement - purple line)

Courses of welding parameters for all joins are on **Figure 4**. For the spot 1, the current peaks (also power peaks) for all pulses are too low. There is not enough energy to good weld. Weld nugget is small and narrow (**Figure 5**). The energy of capacitors A and B was set higher (spot 2). There are pores in weld nugget and deep depressions around the circumference of the weld (along the perimeter of the electrode contact surface). These places are notches (stress concentrators). Set energy values are too high. For spot 3, the energy of capacitor B was the same, but capacitor A was energy set lower. The time between 2nd and 3rd pulse was set shorter (**Figure 3)**. Whole energy was too high, the weld nugget was torn out. For all other welds, the capacitor energy was set to the same value, only the welding time was changed. **Figure 4** shows the increasing distance between individual current peaks. As time increases between pulses 2 and 3, the depression of the molten material disappears gradually at the edge of the weld as well as the amount of internal defects. On the macro-section of the weld 4, in addition to melting on the sheet metal surface, a large number of pores and cracks on the weld lens can be seen.

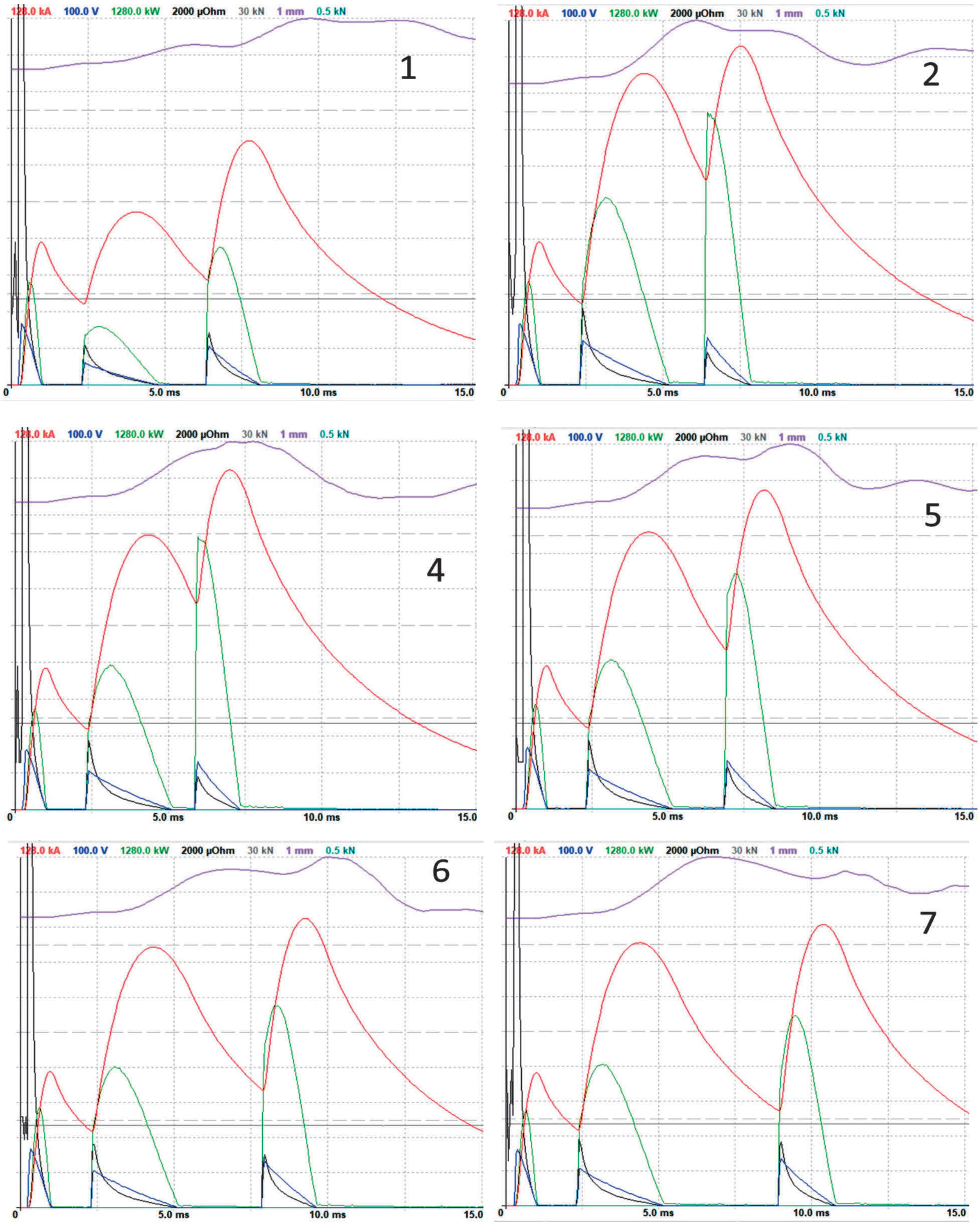


Figure 4 Courses of welding parameters (welding current - red line, power - green line, resistivity - black line, voltage - blue line, electrode displacement - purple line)

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The relevant parameters of the welding area can be reduced by consistent utilisation of the process sequence. The initial pulse is decisive for the metal evaporation. The current must increase very strongly and the pulse must have a certain minimum energy content. Otherwise any other variation will result in hardly any changes. Thus, only a value for the initial pulse needs to be found at the beginning of the parameter search, which can then remain constant. Thus, only the ignition delay and the energy content for the press pulses need to be determined [7].

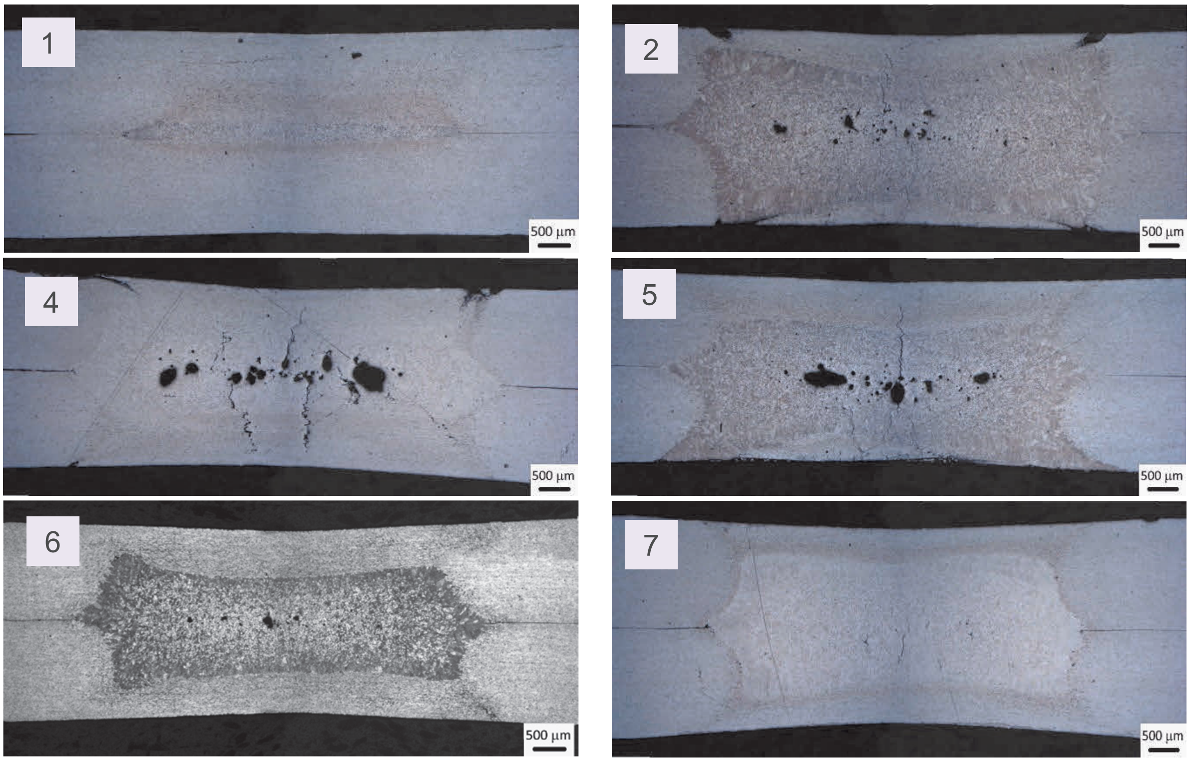

Figure 5 Macro - sections of spot welds

The effect of welding parameters on the size and shape of the weld nugget can be seen from the individual weld macro-sections (**Figure 5**). For welds 4 to 7 (where constant energy was set) with increasing time between the second and third pulse the number of pores and cracks decreased. For welds 5 to 7, there was no depression around the circumference of the weld. All spot welds complied with the minimum diameter nugget condition d_{min} = 4.3 mm (**Table 4**).

Table 4 Diameters of weld nuggets *d* (mm)

Number of weld	1	2	3	4	5	6
Diameter *d* (mm)	4.9	7.5	6.6	6.7	5.1	6.1

6. CONCLUSION

The aim of the paper was to show the possibility of joining hardly weldable material such as EN AW 6061 by the method of capacity discharge welding. The results show that the possibility of using three pulses, energy regulation and time between them leads to good spot weld.

- Due to the presence of difficult to melt oxides (high transition resistance) on the sheet metal surface, it is preferable to use a small first pulse as a cleaning pulse (auxiliary capacitor H).
- With constant pulse energy setting, the actual welding current (ie the actual energy) decreases by increasing the time between pulses.
- Increasing the time between pulse 2 and 3 leads to a reduction in internal defects such as pores and cracks.

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