

# Consolidation of materials by pulse-discharge processes

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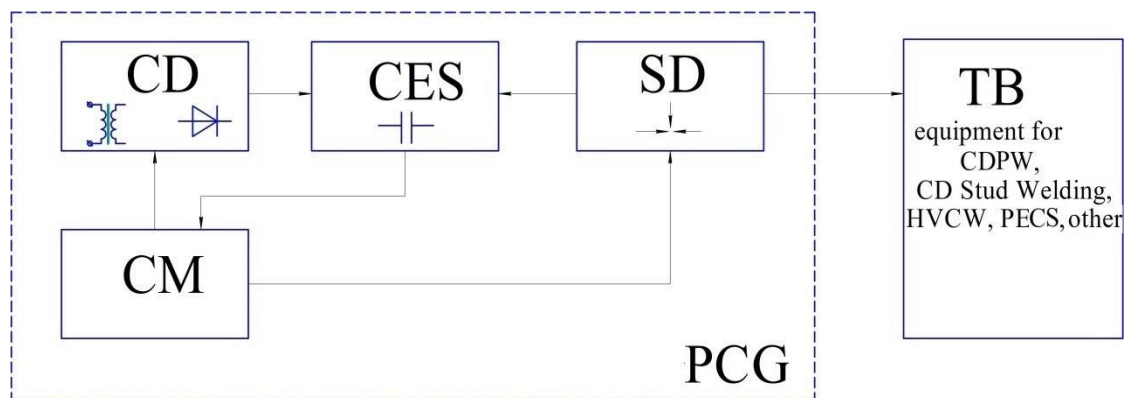
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**Abstract.** The article presents the research and the analysis of the pulse-discharge processes of capacitor discharge sintering: CD Stud Welding, capacitor discharge percussion welding (CDPW), high-voltage capacitor welding with an inductive-dynamic drive (HVCW with IDD), pulse electric current sintering (PECS) of powders. The comparative analysis of the impact parameter is presented.

## 1. Introduction

Pulse discharge processes are widely used to produce permanent joints of heterogeneous materials. Common for them is the technological use of the pulse-discharge equipment allowing implementing the thermal and physical impact on the processed unit [1].

The block diagram of the pulse-discharge equipment includes a charging device, capacitive energy storage, a switching device and a technological block. Common for all the types of processing is a pulse current generator (PCG), and technological block includes the instrument and the equipment typical for a particular type of processing (Fig.1).



**Figure 1.** A block diagram of the pulse-discharge equipment: CD - charging device; CES - capacitive energy storage; SD - switching device; CM - control module; PCG - pulse current generator; TB - technological block; CDPW – capacitor-discharge percussion welding; CD Stud Welding - welding pulsed arc; HVCW – high-voltage capacitor welding; PECS - pulse electric current sintering of powders.

To improve the reliability of welded joints of rod elements made of non-ferrous metals with the main part of the metal structure, it is necessary to reduce the width of the fragile part by generating

local heat and mechanically impacting the contact area. These requirements are met by the sintering methods with storing the accumulated energy in the capacitor banks: the CD stud welding technology, capacitor discharge percussion welding (CDPW) with a spring drive in air or in vacuum, high-voltage capacitor welding with an inductive-dynamic drive (HVCW with IDD).

Comparative analysis of rod elements welding methods allowed to summarize the area of their use [2-4].

## 2. Experimental results and discussion

The stud welding technology involves the starting of the impulse arc by a capacitor banks discharge due to the tearing off of the metal component from the flat part and further convergence of the surfaces caused by a press mechanism. The diameter of the welding rod elements does not exceed 12 mm.

The following technological methods of the CD Stud Welding has been developed: stud welding by a discharge of the capacitor banks (CD), by a short electric arc with a short production cycle (SC), by an electric arc (ARC) [2]. The methods vary by the duration of the arc burning,  $(1\div5)\cdot10^3$  ms,  $(3\div500)\cdot10^3$  ms and  $(100\div2000)\cdot10^3$  ms respectively.

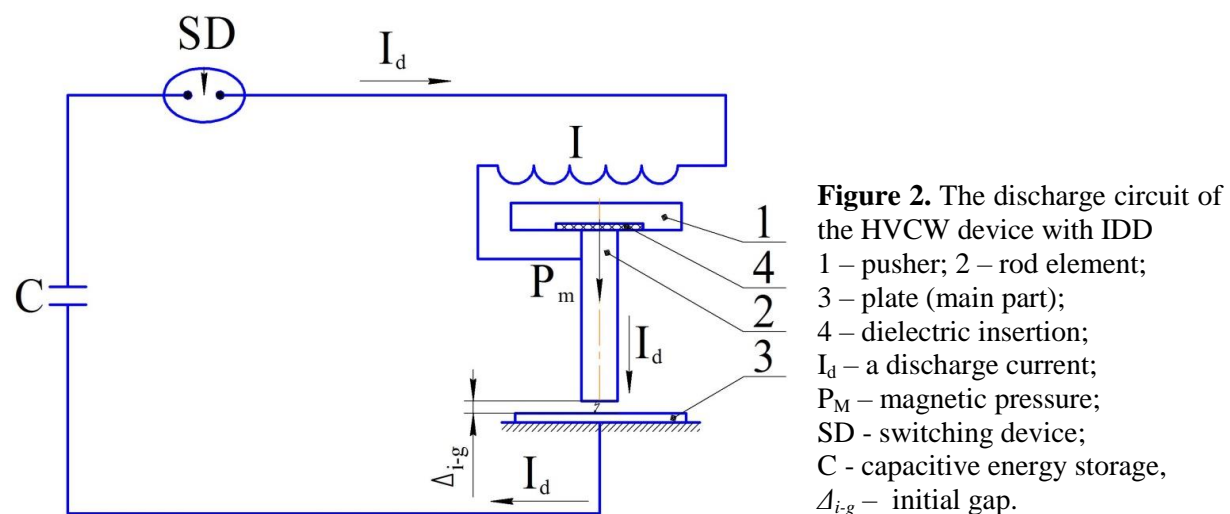
In the SC and ARC methods, the end of the metal component has a tapered shape, and protective gases or flux fings are used for protection of the weld pool from the environment.

In the CD method the end of the rod element has a cylindrical protrusion.

Capasitor discharge percussion welding (CDPW) is used for the welding of the rod elements less than 6 mm in diameter. The process includes a capacitor banks discharge into the welding components and their convergence caused by a spring mechanism. During the discharge, an arc is forming between the surfaces and burning in the metal fumes. The duration of the burning depends on difference between pressures of metal fumes and of spring mechanism. When the sping drive overcomes the metal fumes pressure, the rod element sinks into the molted weld pool, simultaneous crystallization occurs and the weld joint is formed in the liquid phase.

Experimental studies of CDPW in vacuum, with the pressue of aluminium components to steel sheets of 0.133 Pa to 0.00133 Pa showed that duration of arc burning increased at constant current and equals 3 ms to 20 ms [2,3]. The increase in duration leads to intensification and decrease of matal fumes pressure comparing to air enviroment, reduction in rod element damping against the metal plate and larger displacement of metal from the welding zone.

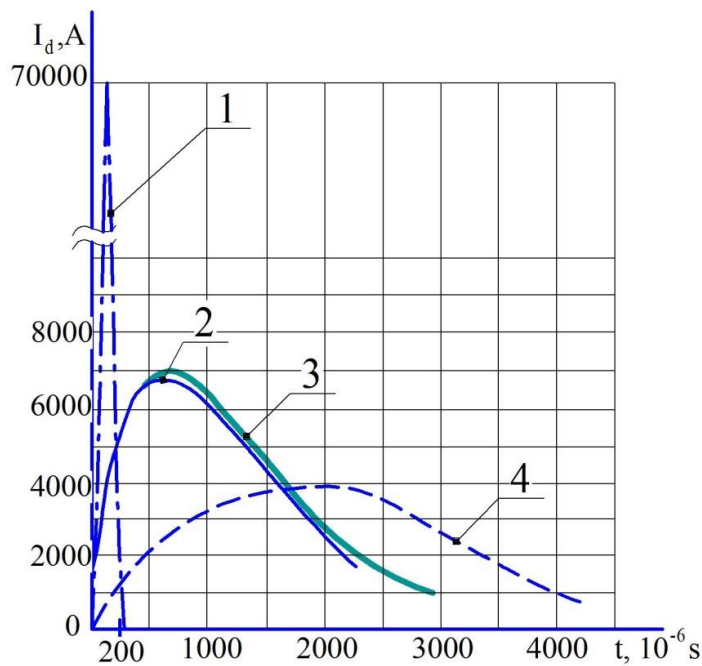
The process of high-voltage capacitor discharge percussion welding with an inductive-dynamic drive (HVCW with IDD) has been developed for welding of the rod elements to the main parts in homogeneous and heterogeneous combinations with diameter of 6 mm to 25 mm. [4] The scheme of the process is presented in Fig. 2.



During the discharge of the capacitor banks the current  $I_p$  flowing down the coils of the inductor  $I$  generates an alternating magnetic field which induces eddy currents in the pusher 1. Interaction of the eddy currents in the pusher 1 with the magnetic field of the inductor leads to generation of the magnetic pressure  $P_m$ , and so the mechanical impact on the rod element 2 occurs.

An inductive-dynamic drive (IDD) [1,4] is connected in series with the welded parts 2 and 3 into the generator circuit in order to synchronize the mechanical and thermal pulse loads.

IDD consists of a flat inductor with a pusher in the working area of it. Duration of the current discharge depends on the number of turns of the inductor and amounts to 100 to 500 ms. Comparative analysis of dependences of the welding current on the time of its occurrence in different capacitor discharge sintering methods is presented in Figure 3.



**Figure 3.** Graph of  $I=f(t)$  stud  $d=6\text{mm}$  alloy AMg3 with steel sheets:  
1 - HVCW device with IDD;  
2 – CDPW in the atmosphere;  
3 – CDPW in vacuum;  
4 – CD Stud Welding.

The dependences  $I=f(t)$  2, 3, 4 relate to the strict parameters of the modes of resistance welding exposure.

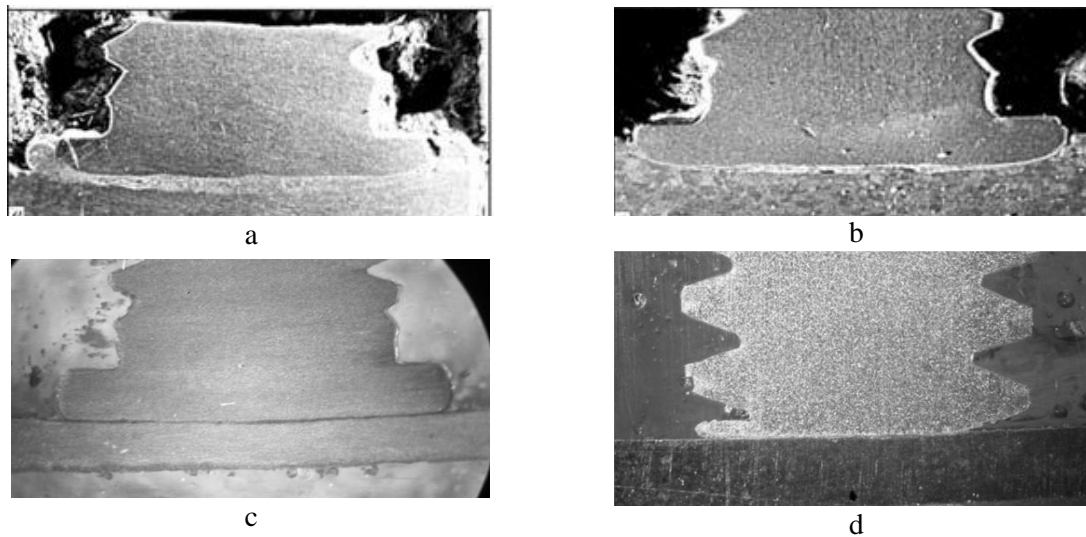
Using for the HVCW with IDD process the high-frequency pulse current generators with natural frequency ( $f$ ) of 100 kHz to 200 kHz and forging force of the IDD ( $P_m$ ) about  $105\text{ N/mm}^2$  to  $106\text{ N/mm}^2$  allows super-rigid processing modes, position 1.

The macrostructure of welded joints of aluminium rods with steel plates is shown in Fig. 4.

The thickness of the crystallized metal in the joint area is less in result of CDPW in vacuum than in result of CDPW in the atmosphere (Fig. 4 a,b), as evidenced by studies [3].

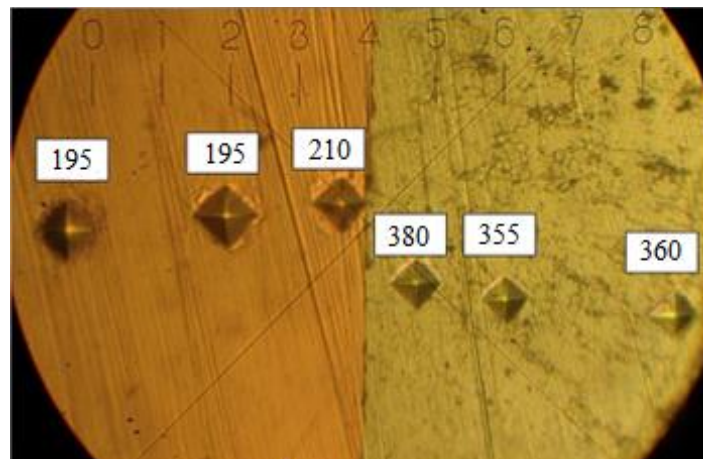
The width of the crystallized metal area formed with the use of CD Stud Welding technology occupies an intermediate position comparing to that of CDPW in the atmosphere and CDPW in vacuum (Fig. 4, c).

In the HVCW with IDD process there is no crystallized metal in the joint area due to a small amount of molten metal and its total displacement out of the welding zone due to the super-rigid welding mode.



**Figure 4.** Macrostructure of welded joints of aluminium rods with steel substrate (x16): (a) CDPW in the atmosphere; (b) CDPW in vacuum (0,00133 Pa); (c) CD Stud Welding; (d) HVCW device with IDD.

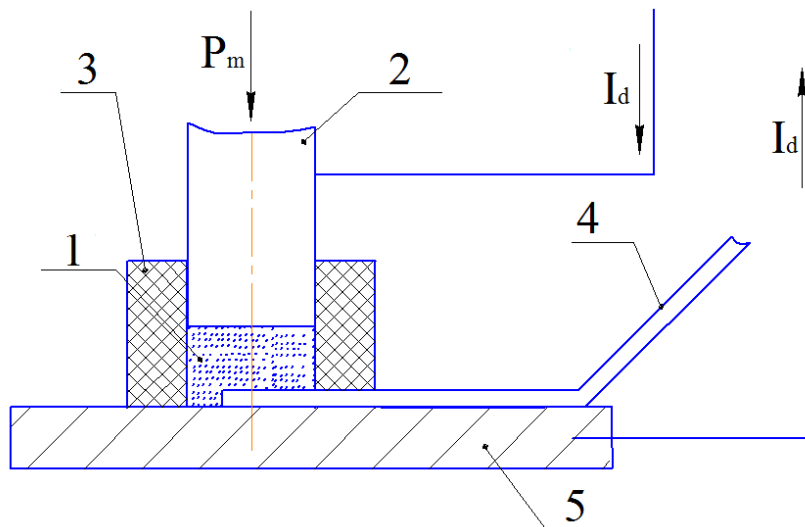
Figure 5 presents the microstructure of welding joint of M1 copper alloy C01 with B63 alloy. It has been established that the border between the joining areas of dissimilar alloys is typical for high-speed welding of metals in the solid phase; there is a distinct line of border – the area of “setting”. Microhardness in the welding zone is elevated, which is typical for pulse welding methods such as magnetic pulse welding and explosion welding.



**Figure 5.** Microstructure of a zone of welding joint of M1 copper alloy C01 with an alloy B63, x485.

By changing the value of initial gap  $\Delta i-g$ , the inductance of a plane inductor and the mass of the IDD pusher, it is possible to adjust the duration of the heat  $W_h$  and force  $W_m$  impact. Analysis of the experimental data showed that the maximum strength of welded joints is at the ratio of energy for heating and mechanical impact  $W_h/W_m$  equal  $2/3$ . When the  $W_h/W_m$  ratio is less than  $2/3$  there are pollution and lack of fusion observed in the welding zone. When  $W_h/W_m$  ratio is higher than  $2/3$ , the joint area is formed by overheated and crystallized metal.

HVCW devices with IDD are successfully used for pulse electric current sintering (PECS) of powders, particularly for the welding of the output circuit of electrochemical protection, Figure 6 [5-7].



**Figure 6.** The welding of the output circuit of electrochemical protection  
 1 – powder; 2 – electrode punch; 3 – dielectric matrix; 4 – wire of electrochemical protection; 5 – the body of the pipe;  $I_d$  – discharge current;  $P_m$  – magnetic pressure

In order to create powerful current pulses the battery of high-voltage pulse condensers with capacity of 150  $\mu\text{F}$  to 600  $\mu\text{F}$  is used, which provides intensive energy discharge through the electrode punch 2 in the powder composition 1. Connection of an IDD in series to the electrode-powder-pipe system provides the synchronization of dynamic pressure  $P_m$  with the thermal effect  $I_p$ , which allows increasing the density of the powder composition [6, 7].

The input energy spent on the thermal and physical impact amounts to 3000 to 7000 J. The duration of the current  $I_p$  flowing through the electrode punches and through the powder does not exceed 300ms.

## References

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