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Original Research Article

Analysis of resistance welding processes and expulsion of liquid metal from the weld nugget

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ARTICLE INFO

Article history:
Received 29 March 2017
Accepted 21 August 2017
Available online

Keywords:
Expulsion from welding nugget
Resistance spot welding
Resistance spot welding process controller

ABSTRACT

The article presents the process of resistance welding in relation to the expulsion of liquid metal from the weld nugget. The research-related tests involved the synchronic recording of welding process parameters such as welding current and voltage as well as electrode force and travel. The phenomenon of expulsion was filmed using a high speed camera. The tests aimed to determine the most effective parameter as regards the detection of expulsion as well as the accurate determination of the moment of expulsion in relation to the above-named parameter. During the tests it appeared that the most favourable parameter was the force of electrodes. The tests required the precise synchronisation of the recording of process parameters with the recording of images (using the camera). The uncertainty of expulsion time determination was estimated at 0.1 ms. The research-related experimental tests were focused on the possibility of eliminating expulsion by stopping (blocking) the flow of welding current.

In the case of expulsion, the process of welding was continued with a delayed second current pulse. The force signal, on the basis of which the expulsion detection was performed, was analysed using a dedicated controller which implementing the algorithm of discreet differentiation.

The tests were performed using an inverter welding machine having an internal transformation frequency of 10 kHz. In this study, SORPAS software-aided FEM analysis was performed to analyse the possibility of the effective reduction of the expulsion phenomenon.

1. Introduction

The phenomenon of expulsion in resistance welding is disadvantageous in nature as regards the aesthetics of joints and welded components as well as their strength. Due to the short duration (current flow) and large dynamics of resistance welding processes, the phenomenon of expulsion is difficult to eliminate [1,2].

The expulsion phenomenon was analysed using SORPAS software. The results of numerical calculations suggested the possibility of the expulsion elimination [3–5]. A pause in the

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http://dx.doi.org/10.1016/j.acme.2017.08.003
1644-9665/

welding current flow for approximately 1.2 ms before expulsion detection would allow – the elimination of this negative phenomenon. It is a good direction for further research.

A manner used for detecting expulsion using the travel of electrodes was described, among others, in publication [6]. In turn, forces affecting the weld nugget and conditions triggering expulsion were described in publications [7,8]. The influence of expulsion on properties of joints was discussed in publication [3]. The authors emphasised that joints having a greater imprint left by electrodes (caused by expulsion) were characterised by the lower capability of absorbing energy (failure energy) in comparison with joints having the same (or even smaller) weld nugget diameters, made during properly performed welding processes.

The phenomenon of expulsion is disadvantageous and undesirable. The elimination of this phenomenon would make it possible to improve the quality of welded joints and to reduce costs of production. Available scientific publications do not contain information enabling the successful detection and elimination of expulsion.

The phenomenon of expulsion was analysed, using a high-speed camera, paying special attention to the monitoring of parameters being characteristic of resistance welding, i.e. welding current and voltage, electrode travel and force [6,9].

The research was aimed at the determination of possibilities of detecting the expulsion phenomenon on the basis of characteristic parameters as well as the accurate determination of the moment of expulsion occurrence.

2. Testing station

The testing station for measurements with using high-speed camera is presented in Fig. 1, whereas the components of the measuring system are shown. Resistance welding parameters were recorded using a LogWeld 4 measuring system, designed and made at Institute of Welding, Gliwice, Poland, and provided with a synchronisation system featuring a Phantom high-speed camera made by the Vision Research company. Images were recorded at a speed of 10,000 fps.

Special emphasis was given to the developing of fast and delay-free electronic module synchronising welding current and voltage as well as electrode travel and force recorded by the LogWeld4 device featuring the high-speed camera. The maximum measured delay during synchronisation did not exceed several tenths of ns (nanoseconds).

While recording performed using the high-speed camera, the lightning of the area being recorded was of a great importance (due to the fact that the quicker the recording of the image, the shorter the time of exposure) [7,8]. Because of the fact that there should not be excessive light, particularly during the occurrence of strong flash accompanying expulsion. For this reason, two reflectors equipped with Fresnel lenses of luminous flux over 50,000 lm each, were installed at a distance of 50 cm away from the area being recorded.

The synchronisation of both recording processes was of crucial importance. The precise determination of the initial moment of resistance welding process recording and of the beginning of filming also enabled the precise determining of the moment of expulsion formation.

The uncertainty of the determination of the beginning of the recording of parameters in relation to the LogWeld 4 measuring device and the camera was also determined. The identified uncertainty amounted to ± 100 μs.

3. Test results

The test results are presented in Figs. 2–4. The technological tests included the measurements of welding parameters, i.e. welding current and voltage, electrode travel and force. The parameters were measured with special measurement device LogWeld 4 (Fig. 1) dedicated to resistance welding. This device can calculate additional parameters such as course momentary power, dynamic resistance and energy supplied to the weld. The device also has many useful features used for the analysis of recorded parameters (present value or a value for a given period of time, etc.).

Fig. 2a presents the recorded waveforms and courses (of welding current and voltage as well as electrode force and travel) in four separate *windows* (recorded using the LogWeld 4 device, Fig. 1a). Such a presentation enables the analysis of the above-named waveforms/courses, e.g. the reading of momentary (instantaneous) values using the cursor. The waveforms/courses present the effect of double expulsion. The phenomenon (of expulsion) is not visible in the current waveform as current is stabilised, yet the remaining waveforms/courses, i.e. of voltage as well as of electrode force and travel, contain

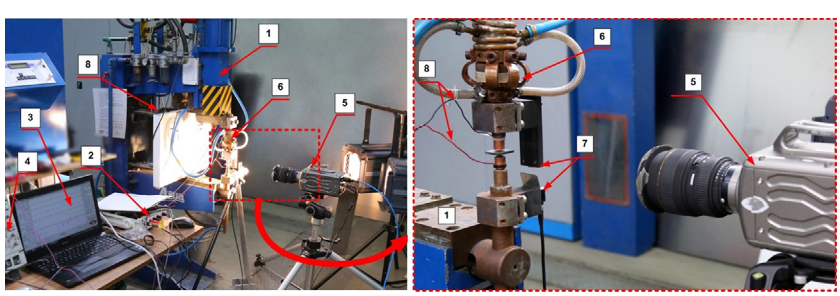

Fig. 1 – Testing station: (1) DC resistance welding machine, (2) LogWeld 4 measurement system, (3) PC for the graphic presentation of waveforms, (4) oscilloscope, (5) high-speed camera, (6) head with the sensing element for welding force measurement, (7) laser displacement sensor, (8) cables for measuring welding voltage, (9) current measurement sensor.