MONITORING OF RESISTANCE SPOT WELDING BY AE

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Abstract

Resistance spot welding is frequently used welding method in a mass production like: electric industry, production of white goods and production of body assembly in automotive industry. Selected welding parameters often cause excessive input, that assure better reliability of full penetrating welds even in the case of deviations of sheet thickness, surface conditions and deviations of electrode tips due to heat and mechanical damage influences. Excessive energy inputs lead to excessive heating of welded material that can cause unwanted expulsions and electrode tips damages. It shows up that in such cases we get unwanted surface appearance of welded pieces at excessive energy consumption with negative environmental influence and more expensive process. This is way users want different sensors systems to monitor and control the welding process to attain optimal conditions. The research was conducted with welding inverter that is as a rule used in robotized RSW particularly in automotive industry. Research results confirm possibility to evaluate RSW process state based on analyses of continuous AE signals during current flow. Continuous signal were analyzed in time and frequency domain.

Keywords: resistance spot welding, AE measurement, continuous emission, PZT sensor,

1. Introduction

Resistance spot welding (RSW) is a method which has been widely used in automotive industry for decades for the welding of metal tin sheets. In terms of use and control, it is a relatively direct production process. Numerous researches can be found in literature which were carried out with the purpose of monitoring and controlling this process in order to achieve adequate weld quality. They were based on destructive and non-destructive methods; the established methods of the former are the peel and the chisel tests, while the latter includes visual inspection, thermal conductivity measurement, and ultrasonic testing.

The main techniques of control and monitoring of RSW are:

- Electrical Parameter Limits:

Electrical properties of the process (primarily the current) can be monitored during welding. The majority of the available commercial welding controllers include high/low current alarm systems and other in-built control systems operating based on the electrical parameter limits. However, this information will enable only a decision-making operation if substantial changes occur during the RSW process.

- Dynamic Electrical Parameter monitoring:

Dynamic Electrical Parameter Monitoring uses the voltage and/or current record of the welding process as a feedback control parameter. However, due to the sensitivity of the welding electrical parameters to various types of steel, the generic system development becomes more difficult. The conventional method of process control by measuring voltage and current and calculating electric power and electrical resistance can only be applied under ideal conditions. The robust and reliable current sensor enables remote measurement and is perfect for industry use, but surface or metal contamination can lead to under-strength or under-sized welds even with constant voltage and current values [1].

- Ultrasonic testing of welded joints:

Ultrasound inspection with a PZT sensor integrated in the welding electrode was already performed [1,2]. This technique provides information on the size of the weld nugget, the condition of the electrode as well as on the final welding result.

- Nugget expansion:

By measuring thermal expansion of the weld nugget based on electrode movement, the RSW quality of the weld can be monitored. This technique was used to evaluate weld quality as well as to monitor the closed-loop process [1]. It proved to be efficient with robust and precise welding devices; however, when measuring small-scale movements between 10 and 100 μm, this technique would not be the best choice for general use in a production environment.

- Acoustic Emission:

Acoustic Emission is a passive technique for detecting signals occurring in the material exposed to thermal changes and mechanical strain. The key benefit of the AE technique is that the AE signal is transmitted through the material and the welding electrodes to remote areas where the sensors are safely protected from the effects of welding.

Almost all welding processes involve dynamic phenomena which have different characteristic sound sources. As a result, numerous researchers were soon attracted to the field of acoustic emission to evaluate the process of resistance spot welding.

According to documented sources, researches have been performed on all characteristic phases of welding: during the welding process itself, immediately after welding, and during the loading of the weld [3-5]. The basic aim of monitoring the AE during the process of welding, during the cooling process, or during the testing of the welds is to obtain useful information on the quality of the weld and the adequacy of the selected welding parameters.

2. Experimental system

Experiments were conducted on a portable RSW gun with jaw crank action (of the Nimak CSN type) with a pneumatic generation of clamping force and the Bosch Rexroth BT 6000 inverter source.

For the RSW process, specimens of standard dimensions (b x l = 30x105 mm), according to the DIN 50124 standard, were used for the one-spot welding joint with a lap joint of e = 30 mm. The weld pieces were made of mild steel sheet DC01(EN 10027-1), δ = 1.5 mm. Welding was performed by using copper electrodes with a diameter (d) of 7.5 mm, welding force (F) of 3.5 kN, and welding time (t_w) of 200 ms. The welding current (I_w) varied between 4.5 kA and 8.5 kA with a rate of 0.5 kA.
To detect acoustic emission, a contact PZT broadband sensor AE2045S, a product of Vallen Systeme GmbH, was used. The wideband sensor makes it possible to measure ultrasonic waves in a frequency range between 200 and 2500 kHz. The measuring sample rate was set to 2.5 MHz. The sensor was connected to AMSY5 (Vallen Systeme GmbH), AE measuring device, via the AEP4 pre-amplifier, as shown in Fig. 1. AE voltage signal was amplified, filtered and transformed into a digital signal by means of modification elements in the ASIPP acoustic signal pre-processor. The digital signal was fed to a unit determining signal parameters. ASIPP also enables signal squaring and transient recording of the digital form of the AE time signal. The AMSY5 unit is connected to a personal computer, which makes it possible to analyse the measured AE signals in the VISUAL AE and VISUAL TR modules.

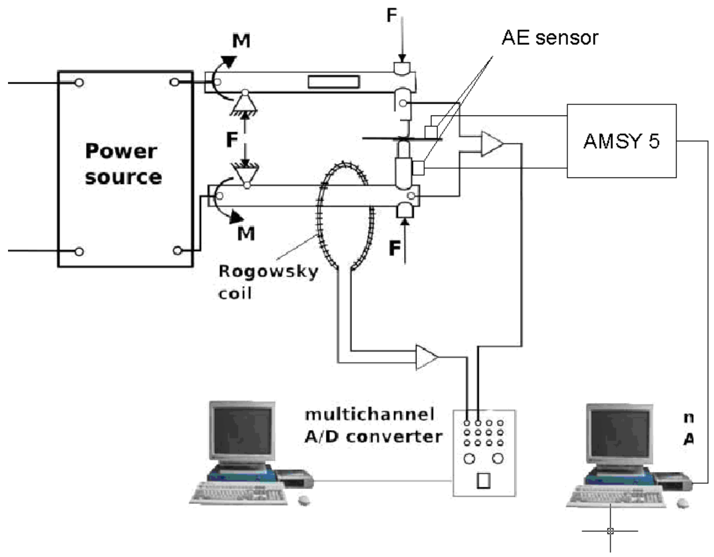


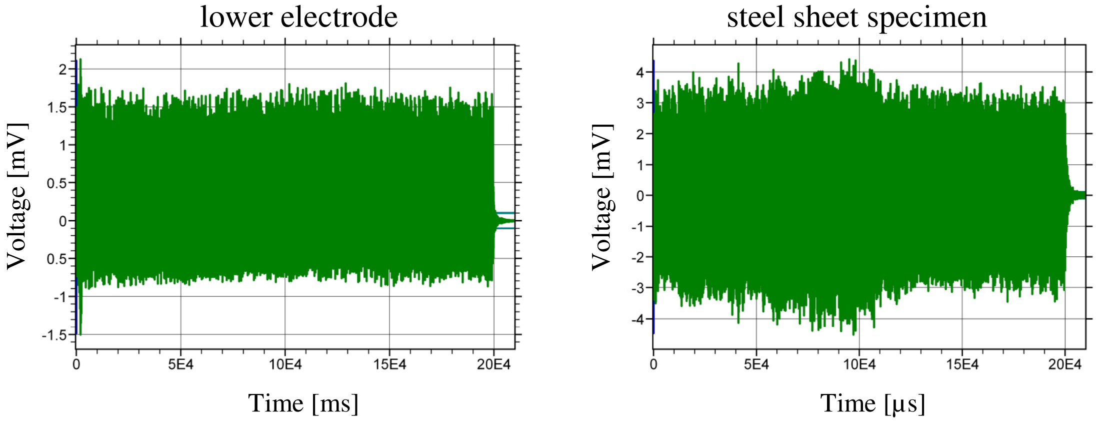
Fig. 1: Experimental set-up

,The Rogowsky coil was used to measure the welding current. The electrical resistance of the welding joint was calculated based on the measured welding current and voltage. The advantage of the Rogowski coil, compared to other current transducers, is that almost all current transducers have an iron- or ferrous-based magnetic core which limits the amount of the electric current that can be measured (saturation flux density of the core is exceeded) as well as the bandwidth due to a magnetic iron loss at high frequencies.

3. Experimental results

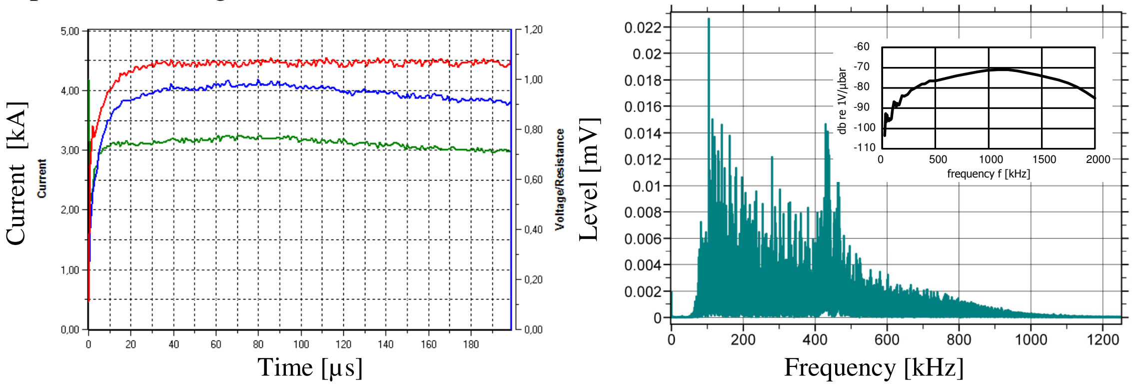
The resistance spot welding process consists of the following phases: the set-down of the electrodes, the squeeze, the current flow, the hold time or forging, and the lift off. During each of these phases, various types of acoustic emission signals are produced as a consequence of different physical phenomena occurring in various RSW phases [5-7]. Individual signal elements may differ significantly or they can be completely excluded from the welding process in which various materials, thicknesses and welding parameters are applied.

During the current flow, continuous acoustic emission signals can be measured (Fig. 2). By comparing the Fig. 2a and 2b, we find that the deviation in the amplitude of the AE voltage signal measured on a steel sheet is higher than that of the signal measured on the lower electrode. During resistance spot welding without expulsion, relatively uniform voltage and current values were obtained (Fig. 3a). The frequency spectrum (fig. 3b) of the AE signal indicates strong lower frequencies of approximately 100 kHz. These are followed by frequencies of approximately 430 kHz. The frequency characteristic of the AE sensor with very flat response is added to the frequency spectrum.



a) b)

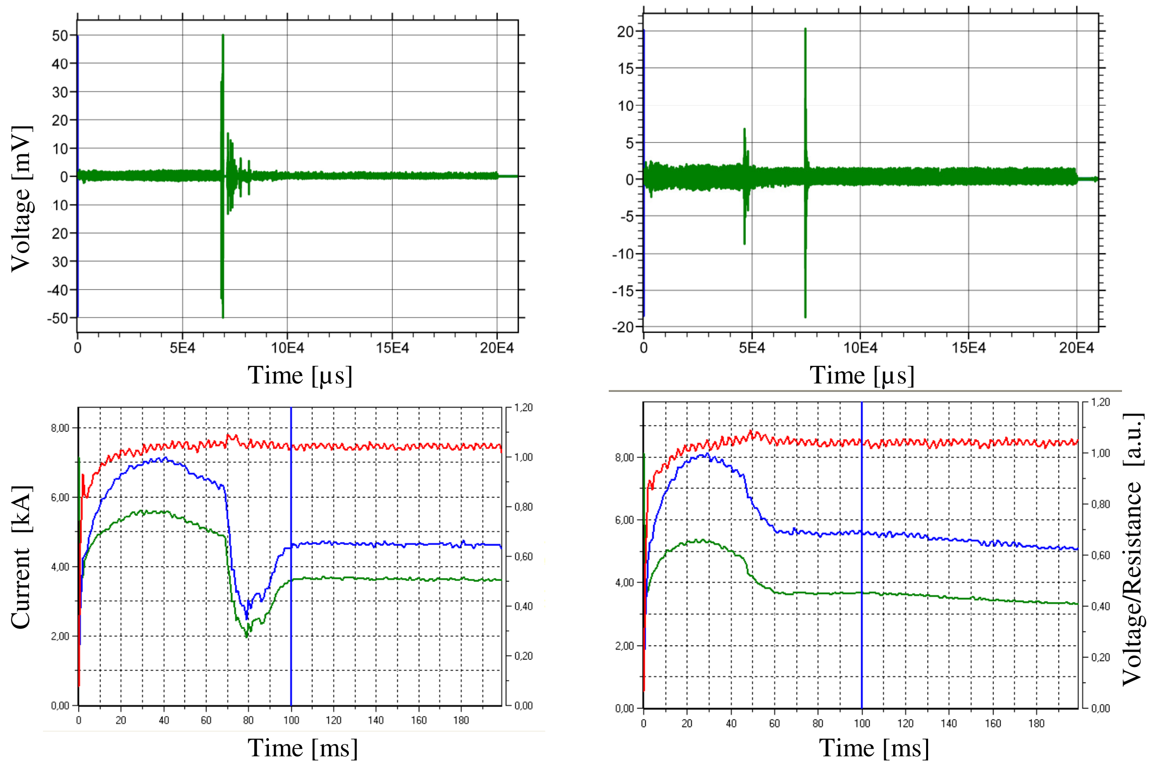
Fig. 2: AE waveform measured simultaneously on lower electrode and on a steel sheet specimen during current flow.



a) b)

Fig. 3: a) welding current (red line), voltage (blue line) and resistance (green line) during RSW and FFT spectrum of AE continuous signal shown on Fig. 2a

During the current flow, plastic deformation, friction, nugget expansion, melting and expulsions produce AE signals. The signals occurring during the expulsion of the material are usually of a higher amplitude and can be clearly distinguished from the signals produced by other factors during the current flow through the weld piece [8].
We would want to avoid the expulsion of the material as it removes the base of the material from the welding spot and spatters the welding sheet and the electrodes Expulsions are connected to over heating of material, higher consumption of electrical energy, lower strength and lower corrosion resistance of welded joint.
Nevertheless, when using systems without feedback control, expulsion is tolerated for production-oriented reasons. With a used welding device, expulsion was reduced by regulating the voltage (Fig.4) to compensate reduction in electrical resistance. Expulsion corresponds to a rapid increase in acoustic emission and a strong decrease in the measured voltage and electrical resistance. However, the expulsion of the material need not entail a strong voltage decrease (Fig. 4b). In the experiments conducted, acoustic emission measurement proved to be the most reliable indicator of expulsion during the RSW process.
During RSW of DC01 mild steel sheets, no strong acoustic emission was detected after welding that could be attributed to microstructure changes during the cooling of the weld joint or to cracking.



I_w = 7,5 kA I_w = 8,5 kA

Fig. 4: Acoustic emission signal waveform with welding current, voltage and resistance at, t_w = 200 ms.

The frequency spectrum varies throughout the duration of the acoustic emission signal in the welding process, as shown in Fig. 5. The frequency spectra are given for indicated individual time intervals (10,5 ms) of AE voltage signal before and after the expulsion of the material. There is a noticeable change in the frequency spectrum in the interval 30 ms before the expulsion. Frequencies in the frequency range between 400 and 450 kHz are less prominent.

Fig. 6 shows mean, standard deviation and kurtosis of positive values of continuous AE voltage signal during current flow for time intervals of 102 μs. Values are calculated for defined time periods of 6 ms and are represented as dots. Kurtosis K characterizes the relative peakedness or flatness of a distribution compared with the normal distribution. Kurtosis is defined as

$$K = \left(\frac{n(n+1)}{(n-1)(n-2)(n-3)} \sum \left(\frac{x_i - \bar{x}}{s} \right)^4 \right) - \frac{3(n-1)^2}{(n-2)(n-3)} \qquad (1)$$

where s is sample standard deviation. Positive kurtosis indicates a relatively peaked distribution while negative kurtosis indicates a relatively flat distribution.

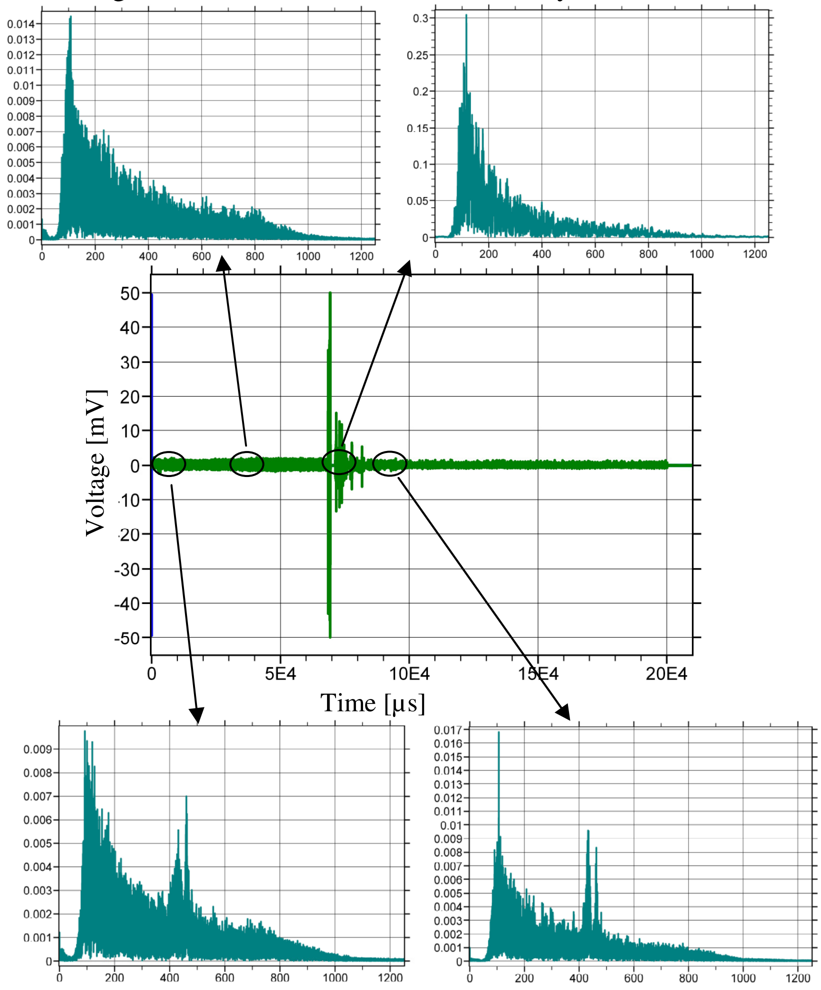


Fig. 5: Frequency spectrum of continuous AE signal during current flow, I_w = 7,5 kA, t_w = 200 ms.

Continuous AE signal during RSW can be divided into tree time periods:

- time period before expulsion
- expulsion of the material
- time period after expulsion

In a time period before expulsion a trend of increasing of mean and standard deviation and very unsteady values of kurtosis can be noticed. A trend of increasing of mean and standard deviation is approximately 20 ms before expulsion changed into trend of decreasing. Decreasing of mean and standard deviation is connected with decreasing of kurtosis of the signal that offers to predict the expulsion of the molten material during RSW. The characteristic values are very unsteady during the time period of expulsion, which is marked with a pattern on Fig. 6. After the expulsion the characteristic values becomes lower and more steady. Mean, standard deviation and kurtosis of the voltage signal of AE offers insight into RSW process state and prediction of expulsion of the material during RSW. The accuracy of the prediction can be improved with simultaneous consideration of additional characteristics of AE signal like FFT.

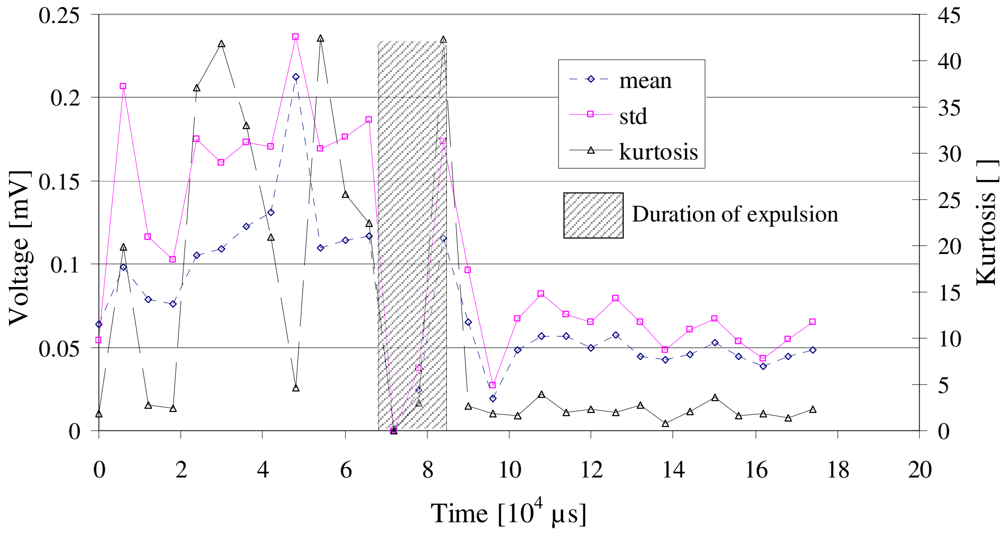


Fig. 6: Characteristic values of continuous AE signal during current flow, I_w = 7,5 kA, t_w = 200 ms.

4. Conclusion

The results of the research on the acoustic emission during the resistance spot welding process of DC01 uncovered the possibilities of optimising the welding parameters and predicting the quality of the weld. Based on the research conducted, we can conclude that the analysis of the acoustic emission signal provides useful information on nugget formation. The measurements showed that the AE outbursts are a stronger indicator of expulsion than the electrical and/or mechanical parameters measured. Furthermore, the frequency spectrum of the continuous signal occurring during current flow is also a potential feedback control parameter. The prediction of the expulsion during RSW can be improved with regard of other characteristic values of AE signal like mean, standard deviation and kurtosis of the short signal periods in defined time intervals. With simultaneous calculation of signal frequency spectrum and mentioned characteristic values the expulsion of the material can be predicted in a very short time interval before its occurrence.

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