ACOUSTIC EMISSION IN RESISTANCE SPOT WELDING

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1. INTRODUCTION

Beside testing of materials, which is the primary and main field of application of acoustic emission (AE), welding is one of those fields of application which have proved AE to be a universal method of testing /1, 2, 3/. AE investigations have been carried out in almost all welding processes, in all their characteristic stages which are directly or indirectly related to weld quality.

If in resistance spot welding, formation of a single weld spot is observed, it can be noticed that this is an extremely short technological process. To fabricate a workpiece, as a rule, several weld spots should be welded in short periods of time. These facts dictate a somewhat different approach to the application of AE than the usual one, including fusion welding processes.

Beside basic characteristics of AE and a critical survey of results obtained in investigations in resistance spot welding, the article gives a description of an approach to an analysis of AE signals obtained, which was chosen at the Faculty of Mechanical Engineering ,University of Ljubljana. At the end of the article, a survey of the results obtained and our vision of chances for further investigations are given.

2. BASIC CHARACTERISTICS OF AE

2.1. *Sound apparition*

AE is a term used to denote sound apparition due to macroscopic or microscopic changes in a solid body. Such changes occur due to local instabilities, when a partial of the accumulated energy transforms into sound energy /4/. The sound pressure generated $P_0(t)$ propagates generally in the form of spherical waves, which can be, in the distance l_x, registered as pressure $P_x(t)$. A sound sensor located at a body boundary transforms sound pressure into a voltage signal $U_x(t)$ which gives us information on an event provoked by the initial sound impulse Figure (1).

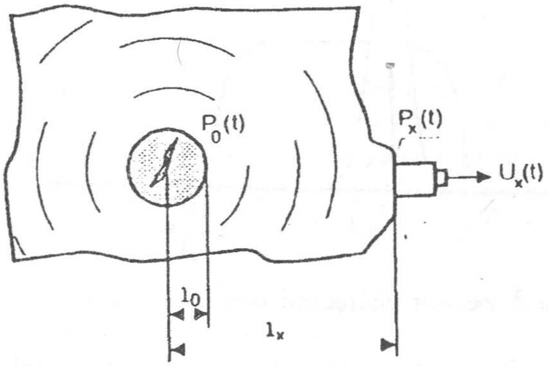

Figure 1. Sound detection.

In testing of materials, where the object of observation are changes at the level of crystal grain boundaries, the magnitude of generated sound frequencies can be assessed, e.g. for steel:

- specific density: $\rho \cong 10$ Kg /dm ^{3}
- modulus of elasticity: $E = 10^5\ N/mm^2$; shear modulus: $G \cong E/2.5$
- characteristic grain size: $d = 10^{-5}$ m

hence it follows:

sound velocity: $c = \sqrt{E/\rho} \cong 10^3$ m/s

time of grain discharging: $t = d/c \cong 10^{-8}\ s$

sound frequency: $f = 1/t \cong 100\ MHz$

The energy released in discharging, where shear deformation is approximately 1%, is, however:

$$W = \frac{G.\varepsilon.d^3}{2} \cong 10^{-9} J$$

2.2. *Instrumentalities used in AE analysis*

The first and basic instrumentality is a sound sensor which can be of a narrowband type or broadband type /3, 4/. The narrowband sensor reacts only to sound frequencies in the vicinity of γ_o and the broadband one to the sound in the width of frequency spectrum between γ_i and γ_s Figure (2).

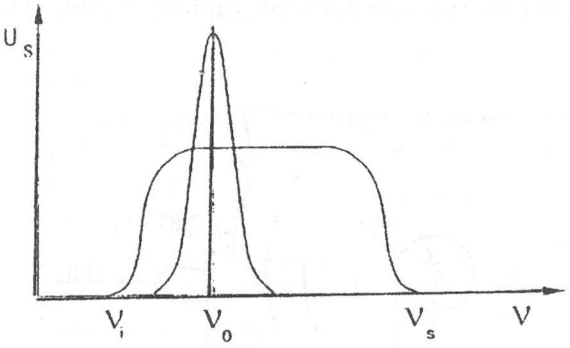

Figure 2. Sensor characteristics.

The voltage signal obtained on sensor terminals is very weak, therefore, it should be amplified by a preamplifier in the shortest possible distance from the sensor. A further data handling and an analysis of the signal record follow. The whole coupling is called an AE detector. Structural elements of the detector used in a welding laboratory of the Faculty of Mechanical Engineering in Ljubljana are as follows:

- amplifier with filter: it additionally amplifies the signals filtered (from 10 to 10^3 times),
- discriminator: it assigns to each impulse above a certain level U_d a uniform voltage signal Figure (3),
- counter: it subtracts the number of signals above the level set E,
- ratemeter: it transforms the frequency of the signals assigned into direct voltage, i.e. it shows AE activity.

Coupling of the elements used of the instrumentalities for AE detection in resistance spot welding is shown in Figure (4).

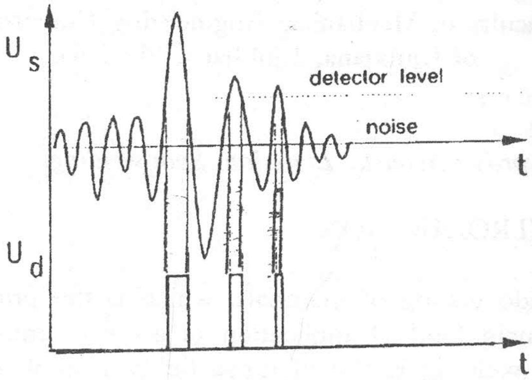

Figure 3. Principle of discriminator operation.

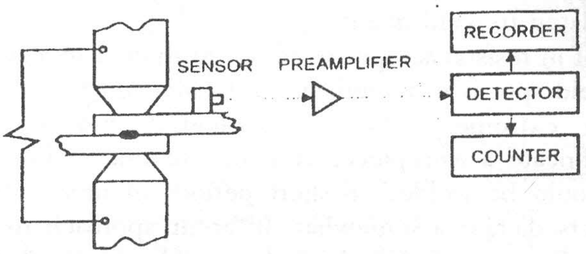

Figure 4. Block schematic diagram of instrumentalities for AE detection.

3. AE SIGNALS IN RESISTANCE SPOT WELDING

When monitoring a welding process by means of AE detection, one is interested in those phenomena which are related to weld spot quality. These phenomena generate "useful" signals, which means that they carry information from which it is possible to draw conclusions on growth and quality of a weld spot. Among these phenomena, the following can be numbered: volume dilatations of the weld spot, expulsion, structural changes and crack appearance in the area of the weld spot. During the welding process, there are also disturbing signals, which in AE detection should be avoided. Among these signals, we number environmental disturbances, electric network disturbances, murmur of cooling liquid, and electrode blows /6/.

With regard to generation of sound signals in the workpiece, the welding cycle in resistance spot welding can be split into the following stages, Figure (5):

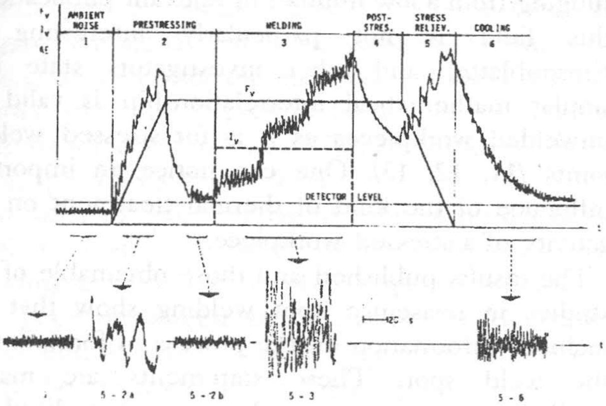

Figure 5. Characteristic AE signals in different stages of welding.

1. Prior to welding: a sensor can be mounted on the electrode or on the workpiece which is clamped in a fixture being insulated against the machine Figure (4). In the first case of sensor mounting, an extremely loud noise is obtained due to cooling water flow; in the latter case, the ambient noise is essentially weaker. The detector should be set a little above the upper level of the ambient noise Figure (5-1).
2. Prestressing - drawing nearer of the electrodes and application of preliminary pressure: the sensor reacts at the very beginning of the electrode movement, most of all to the electrode blow against the workpiece Figure (5-2a). The ambient noise is much stronger after the queeze of the workpieces and the electrodes than before welding Figure (5-2b).
3. Welding: when electric current flows, the sensor gives a strong signal, and the cumulative AE increases rather regularly Figure (5-3). There is no delimitation between the contribution of physical changes at the weld point and the contribution of electromagnetic influences on the sensor to the total AE activity.
4. Poststressing - holding of the electrodes: beside the "useful" signals due to changes in the weld, which are themselves due to cooling, there is also an environmental noise which is being transmitted through the machine and the electrodes which are still in contact with the workpiece Figure (5-4).
5. Stress relieve - electrode return: the signal registered by the sensor is of a similar shape and intensity as the that of the electrode blow Figure. (5-5).
6. Free cooling: if the workpiece is clamped in a fixture which is sound insulated against the machine, the sensor detects only "useful" signals of the events in the area of the weld spot and of the heat-affected zone Figure (5-6). In this final stage of cooling, it is possible to detect, by an experiment, in an almost undisturbed way, the AE activity which largely depends on the kind of material used and also on the welding parameters applied.

In monitoring the resistance welding processes by AE detection, special care should be taken of disturbing signals, which have nothing to do with formation and cooling of the weld spot. The level of the detector should be set above the level of a continuous ambient noise. It is also wise to eliminate from the analysis the strong signals caused by electrode approaching and electrode return.

4. CRITICAL SURVEY OF THE INVESTIGATION RESULTS

4.1. *International level*

Pioneering research work in the field of AE in resistance spot welding has been carried out by Gordon D. Sherer and Earl B. Schwenk of the Battel Northwest Institute /7/. They have established that with the growth of the number of AE impulses during welding, the weld nugget is generally growing as well, and consequently the carrying capacity of the weld spot is increasing. In their later investigations, the same authors have studied the influence of a surface condition on AE and have established that an oxide layer is a strong source of AE during welding /8/.

K.H. Kock, H.D. Steffens, and H.S. Crostak have studied results of AE during welding of workpieces made of various steel grades and results of tension-shear tests /9/. They have established that for different kinds of materials, there are different degrees of dependence between AE and the strength of the weld spot, and that for a known material it is possible to predict, by means of AE detection, limit characteristics of the weld spot (stick, optimum, burnt) and to assess the carrying capacity of the welded joint, Figure (6).

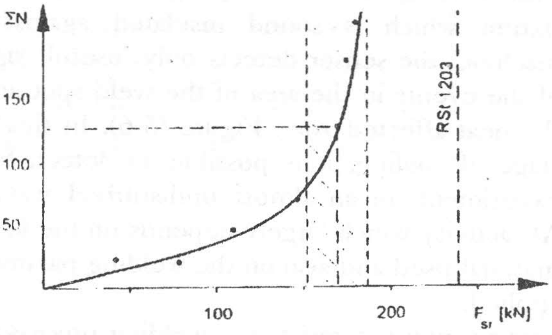

Figure 6. Dependence of tension-shear strength on AE in the case of structural steel St 1203.

An essential contribution to the AE investigation development has been made by Kenneth R. Notvest. He has split he welding process into separate time intervals and detected signals of characteristic amplitudes separately, Figure (7) /10/. He has ascribed AE sources during welding to the following:

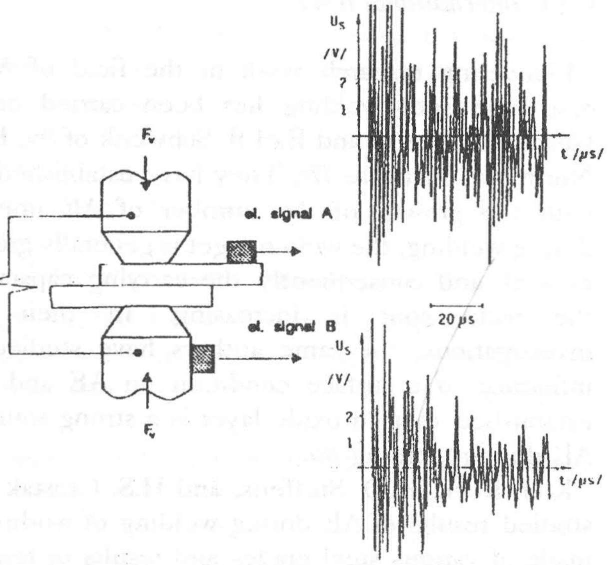

Figure 7. Dissimilarities in oscillograph records of AE signal.

- weld nugget formation,
- expulsion
- crack formation in the period of electrode holding.

A special field of interest present AE studies during application of stress to the welded joint. Judging from a low number of relevant publications, this field is not particularly interesting. J. Einsenblatter and other investigators state that similar mathematical interrelationship is valid for unwelded workpieces as it is for stressed welded joints /11, 12, 13/. One can notice an important influence of the kind of thermal treatment on AE activity of a stressed workpiece.

The results published and those obtainable of AE studies in resistance spot welding show that AE includes information on the process of formation of the weld spot. These statements are mainly qualitative in nature and very generalised. A common and general statement is that the size of the weld nugget and AE activity during welding are in a casual connection, i.e. a greater volume of the weld nugget results in a stronger AE activity /8, 11/. It has also been established that AE activity depends a great deal on the kind of material used and on the surface condition, as well as that spatter during welding contributes a great deal of AE and diminishes the reliability of prediction of size of the weld nugget /9, 11/.

With reference to the afore-mentioned results, it is interesting to state that, in spite of very extensive AE studies in engineering as well as in welding engineering culminating in the mid-seventies, these studies almost came to an end in the eighties.

4.2. *Investigations carried out at the Faculty of Mechanical Engineering*

AE studies in resistance spot welding were started in the second part of the eighties when it was noticed, after a critical survey of results obtained on the international level, that there were still several segments of this field which were little explored or unexplored, e.g. causes of AE during welding, AE dependence and welding parameters, AE detection during cooling of a freely lying workpiece after welding.

Except for a contribution of V.A. Troicki and A.R. Donin, we traced no article on a sensor mounting different from that on the electrode /14/. But the afore-mentioned authors did not describe the differences in AE detection in the case when the sensor was mounted in a different manner.

We selected the sensor mounting offering several advantages in studies since it less distorts the original AE signal and at the same time permits AE detection also after the electrode return. Figure (7) shows two direct presentations of oscillograph records for structural steel C.0147, thickness $\delta = 2x2$ mm, $I_v = 7.15$ kA, $t_v = 0.8$ s.

In order to make the comparison of results of AE during cooling of freely lying workpieces after welding as correct as possible, a special commutator has been developed at the Faculty of Mechanical Engineering, which switches on a ratemeter only after the electrode return Figure (8).

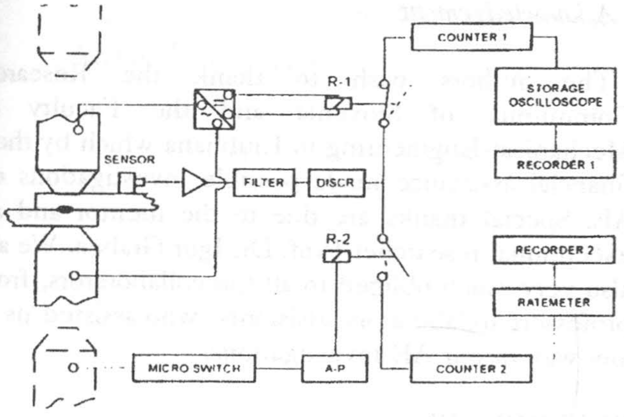

Figure 8. Schematic presentation of connection of instrumentalities for a separate AE detection during welding and after welding.

An analysis and comparison of AE results for workpieces made of various materials and welded with various parameters can be summed up in the following statements:

a) AE detection during welding:

- By mounting the sensor on the workpiece, more reliable results are obtained, including less noise. (Under our conditions, noise contributed 20 - 30% of all impulses.).
- AE activity is influenced by quality of the material used, which can be perceived only after longer welding times (workpieces with broader zone of plastic deformation show stronger AE activity).
- Also in welding of aluminium alloys, similarly as in welding of steels, one can notice the influence of alloying elements on AE (with steels, AE activity is promoted by those elements which increase hardenability; with aluminium alloys, it is promoted by those which increase hardening).
- A surface condition, which has an important influence on the weld nugget quality, influences also AE activity (rusted workpieces with 10 - 30% fewer AE impulses had on the average by 20 - 60 % lower strength of the weld spot).
- A change in welding current intensity results in a change in AE activity (a higher welding current intensity results in a stronger AE activity and vice versa).
- Other parameters remaining unchanged, AE activity in steel almost does not change in time (with aluminium alloys, AE activity is stronger at the beginning and reduces with welding time).
- A comparison of the results of the AE detected with the results of strength tests and metallographic examinations shows that the total number of detected AE impulses during welding N_v is a relatively reliable indicator of formation and size of the weld nugget Figure (9).

b) AE detection after welding:

- A chemical composition and microstructure exert a decisive influence on AE. Steel workpieces with martensite structure show even by 10-times stronger AE activity than workpieces with ferrite-pearlite structure. (In aluminium alloys, a similar increase in AE activity is shown by workpieces made of hardening alloys).
- AE activity approximately exponentially decreases in time (therefore, the hold time of the electrodes should be as short as possible).
- In workpieces made of the same material, a change in welding parameters results in a change in AE (In ferrite-pearlite materials, a higher heat input results in a almost linear increase in AE activity).
- In hardenable steel grades, it was noticed that increase in welding current intensity results on the whole in a decrease in total number of detected impulses per volume unit of the weld spot N_u/V but it starts to increase just above a certain critical (optimum?) value (Such a critical value is different with different kinds of

workpieces and with various thicknesses) Figure (10).

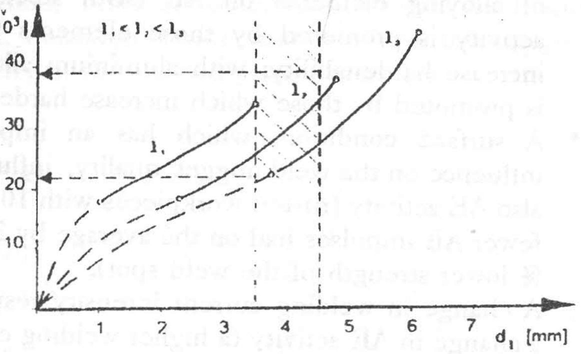

Figure 9. AE during welding as a function of the weld nugget diameter.

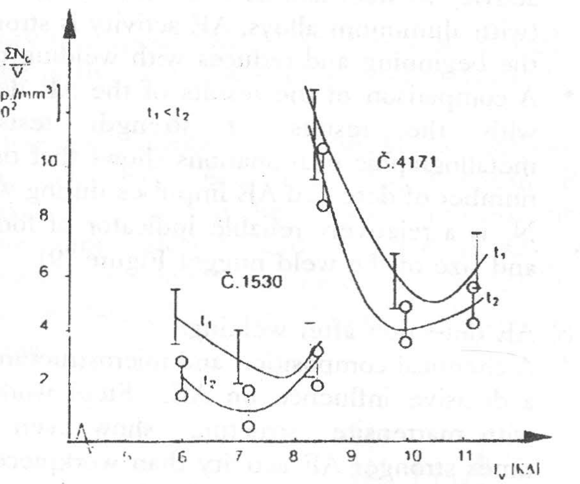

Figure 10. AE after welding as a function of welding current intensity.

5. CONCLUSIONS

In modern industrial manufacture, it is often more difficult to assure the quality required than to introduce a technology itself. This holds specially true with classical, relatively well-known technologies such as welding.

In resistance spot welding, the effective time needed for formation of the weld spot is extremely short. The quality of weld spots is maintained most often by keeping the experimentally established optimum parameters within strictly specified tolerances. Real time monitoring of quality by classical methods of testing is used only exceptionally and is worthwhile in the case of really exacting and expensive products.

The introduction of AE detection as a method of testing and the first published results of investigations in the field of welding provoked too high expectations and (too) optimistic forecasts on the part of welding engineering experts. The method itself has become indispensable (e.g. location of defects in testing of stressed workpieces). In some other spheres, where also monitoring of the resistance spot welding process belongs, this method has proved a useful supplement to classical methods. Results of AE detection make it possible to draw rather reliable conclusions on the weld spot size, while results of AE detection during cooling of a freely lying workpiece can be a support in optimisation of welding parameters.

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