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APPLICATION OF AN ON-LINE WELD MONITORING SYSTEM

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1. Introduction

Welding is a dynamic process and its stability depends on a wide range of factors. Beyond the fact that the welding process has to be stable and consistent to even make a useful weld, all the welds must achieve a minimum level of quality for a structure to survive the service conditions. To achieve this quality, appropriate (optimal) values of the significant factors must be identified, selected, and, increasingly, monitored and/or modified, during the welding process. The major parameters affecting the arc-welding process are the welding voltage, the welding current and the travel speed. Through an optimal combination of these parameters, optimal properties of welded joints are achieved. (Of course, this assumes that appropriate values of less significant factors, like quality and amount of shielding gas and the electrode extension, are also selected.) Acquisition, analysis and real-time manipulation of the welding parameters offer added controls over the weld quality, but, at the same time, add to the complexity of the arc-welding process. Thanks to the continual development of information technology and electronics, it is possible to improve the systems for monitoring of the welding parameters and for management of the welding process. One system of this type was developed in the Mechanical Engineering Faculty in Slavonski Brod during the joint USA-CRO project, JF 137. This system was successfully applied in scientific research as a part of PhD, Masters-degree, and undergraduate student's projects, and in production environments (industrial plants) for the selection of optimal welding parameters and the selection of the optimal flux-cored electrode. Besides the description of some recent results achieved by on-line monitoring, preliminary results of research into weld spatter are also presented in this work.

2. A short description and the application of an on-line monitoring system

An on-line monitoring system is a device for real-time acquisition and analysis of arc welding parameters. Although on-line monitoring systems have the capability to measure many different parameters during the welding process, those found to be most significant for electrical arc processes are the welding voltage and welding current. A more detailed analysis of recorded welding parameters is usually performed after the weld is completed, i.e., off-line. We selected an analog-to-digital (A-D) conversion card and other components so we could capture and store up to 15000 measurements per second per channel. The data (current and voltage) can be expressed as direct functions of time (I=f(t), U=f(t)), and can be processed to indicate the instantaneous power (E_{ef}=f(t)), or can be processed to show ratios between two variables, for example U=f(I). Through off-line analysis of the data with spreadsheets or statistical software, additional characteristics of the welds can be obtained, such as the number of short circuits, the duration of short circuits and of the arcing periods, the droplet transfer frequency, the slope of the current and voltage (di/dt, du/dt), spectral analysis, and auto-correlation analysis. Figure 1 shows the schematic of the on-line

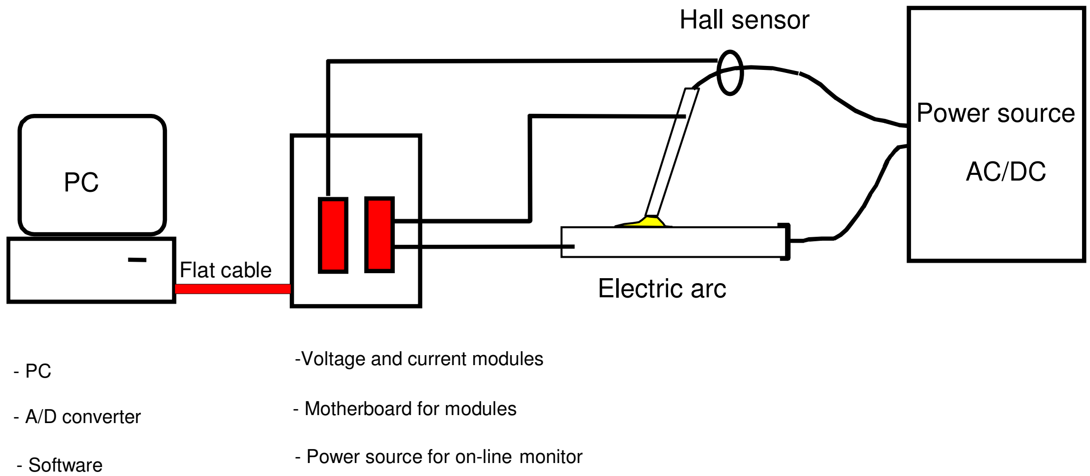

Figure 1. Schematic of the on-line arc-welding monitoring system.

Figure 2. Photo of the on-line arc-welding monitor.

monitoring system, and figure 2 shows the on-line monitoring system while being used in our workshop.

This on-line monitoring system has been successfully applied to the measurement and analysis of welding parameters for SMAW (shielded metal arc welding) with different types of coated electrodes, for semiautomatic MAG/MIG (metal active gas/metal inert gas) welding (with an active shielding gas or gas mixtures and application of solid and flux-cored electrodes), and for automatic TIME (transferred ion metal energy) welding. In the past few years, this system has been applied to a wide variety of tasks, both in the university laboratory and in industry, and has led to a large number of studies, which are summarized in this report. [3-11].

2.1 Examples of the measurement of welding parameters

This section includes examples of the measurement of welding voltage for MAG surfacing on a test plate (with dimensions 600 mm by 200 mm by 12 mm) of composition 15Mo3. The tests included three different filler materials (basic flux-cored electrodes, rutile flux-cored electrodes, and solid electrodes), and three ranges of welding parameters (low, medium, and high). For these three cases, the electrode (wire) was connected to the electrically negative terminal. An additional pass, called Experiment "4" with basic flux-cored wire, was welded with the electrode (wire) connected to the electrically positive terminal. During all these welds, external shielding protection with active CO_2 was used. The design of the experiment and the experimental levels are shown in Table 1.

Table 1. Design of the experiment during surfacing of the test plate with different filler materials and different welding parameters.

Welding parameters	Basic flux-cored wires	Rutile flux-cored wires	Solid wire
Low values	Experiment "1.1"	Experiment "2.1"	Experiment "3.1"
Medium values	Experiment "1.2"	Experiment "2.2"	Experiment "3.2"
High values	Experiment "1.3"	Experiment "2.3"	Experiment "3.3"
High values	Experiment "4"	-	-

Examples of the welding voltage distributions for these tests are included as Figure 3. Further details on the procedures used to generate the welds are contained in references [3] and [11]. However, the following data were not included in references [3] and [11], so they form an extension to the work reported in those studies.

Estimation of the stability of a welding process based on welding parameters implies comparison of the recorded welding parameters (for example welding voltage and/or welding power) to some reference parameters (those previously found to produce satisfactory quality). It should be pointed out that, up to now, standards which clearly define this problem have not been accepted. One of the main problems is the complexity and the dynamics of the welding process.

Evaluation of process stability has significance only if the welding records being compared have the same or almost the same welding parameters, i.e., are all for a single mode of droplet transfer in the electric arc. The main transfer modes are: free-flight (droplet) transfer (typically at higher values for the welding parameters), short-circuit transfer (typically at lower values for the welding parameters), and mixed-mode material transfer (a combination of these two transfer modes and occurring at medium values for the welding parameters). Figure 3 shows that all three modes of material transfer are present in these trials. The welds made with rutile flux-cored electrodes produced free-flight transfer for all welding parameters values. The welds made with basic flux-cored wires produced free-flight transfer only at higher welding parameters values. The other two cases produced mixed-mode transfer. The welds made with solid electrodes produced short-circuiting transfer for the low values of the welding parameters. Increasing the welding parameters increased the proportion of mixed-mode transfer, but pure free-flight transfer could not be achieved.

3. Spatter during welding

On-line monitoring provides information on the stability of the welding process and can detect some disturbances in the arc. This paper presents an introduction to its use in the study of weld spatter. This problem is important not only from the point of view of economics (the cost to remove the undesirable roughness), but also from the point of view of reliability, because spatter metallurgically damages the underlying steel.

3.1 Background on weld spatter

Spatter is the term for the small particles or globules of metal that are often observed adjacent to the weld along its length. Spatter occurs when some of the molten electrode is expelled at an angle to the arc and so does not land in the weld pool, but rather lands a on heat affected zone or on the

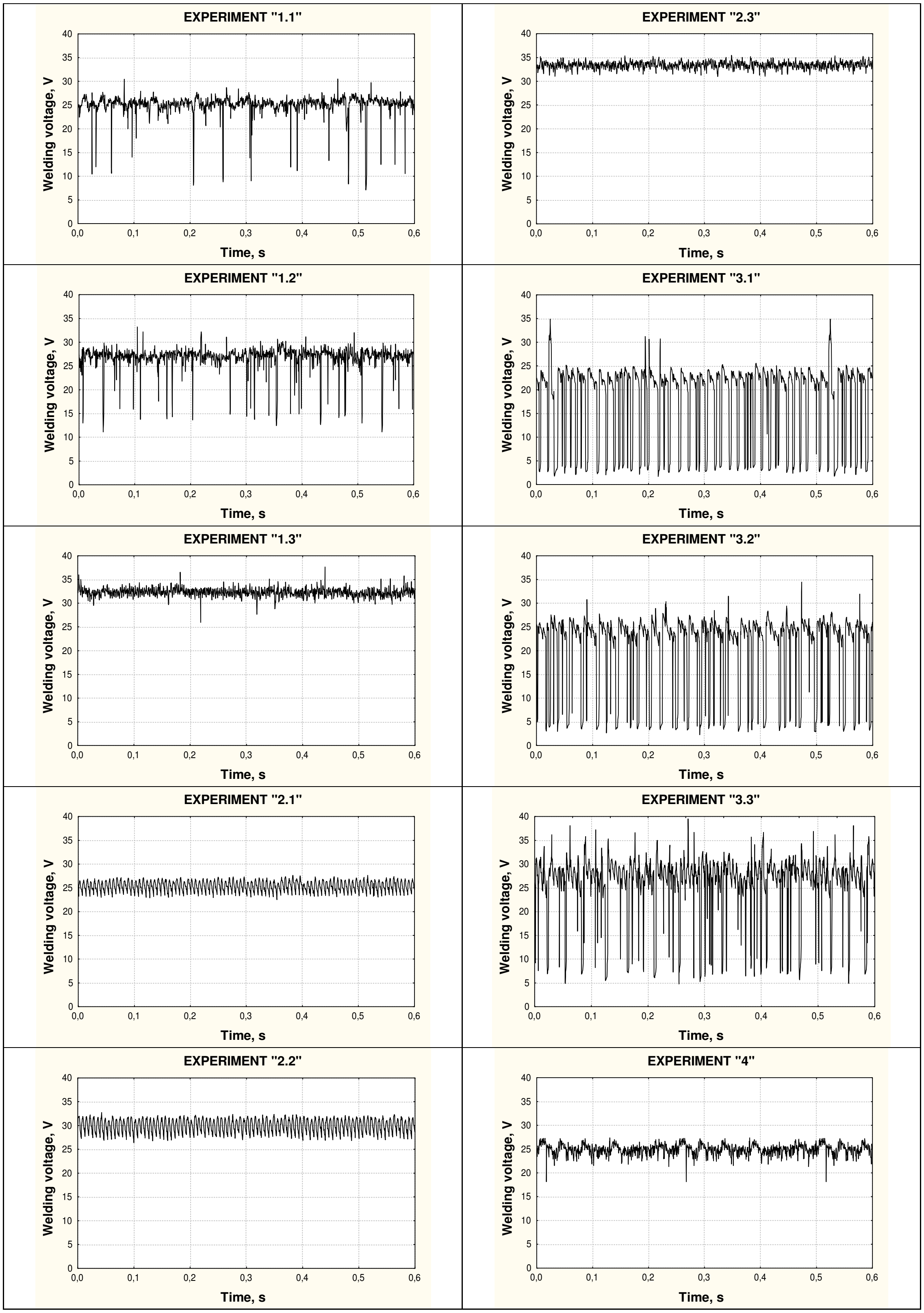

Figure 3. Welding voltage (DC) distribution during 0,6 seconds of welds with flux-cored and solid electrodes for the experimental design in Table 2. Experiment number 4 (with a basic flux-cored electrode connected to the electrically positive terminal) is also shown. Sampling frequency was 1 kHz.

base metal near the welded joint. Smaller droplets solidify before they land (and so can be brushed off), but larger droplets form a metallurgical bond to the base metal. Spatter on low-alloy steels that are not exposed to specific types of corrosion (such as pitting, stress-corrosion cracking, or crevice corrosion) is simply an inconvenience that affects the appearance of the part. However, spatter on heat-sensitive CrNi steels or on steels for aggressive media (for example high-strength steels for storage or transportation of aggressive media) is a different situation. In cases like these, spatter can initiate corrosion and so can have a serious effect on the life of the structure. The spatter can be removed mechanically, sometimes followed by polishing (especially for CrNi steels and aluminium). However, mechanical cleaning of spatter can mechanically damage the surface of the base material or the welded joint, and this must be considered for welded products with a higher risk of failure.

As already mentioned, removal of the spatter takes additional time, which means that the manufacturing costs increase. Also, the loss of filler metal due to spattering is not inconsiderable, especially for more expensive filler metals. The slowing of production is particularly expensive for automatic and robotic welding due to the higher overhead costs.

3.2 Design of experiment

Bead-on-plate welds by the MAG process were produced on three shot-peened test plates. An $Ar+CO_2$ gas mixture and a solid wire (diameter 1,2 mm) were selected to match a production application. The shielding gas flow was 12 L/min. The welder was given 5 minutes to adjust the welding parameters and put the bead on the test plate. The design of the experiment and details of the test plate are shown on figure 4.

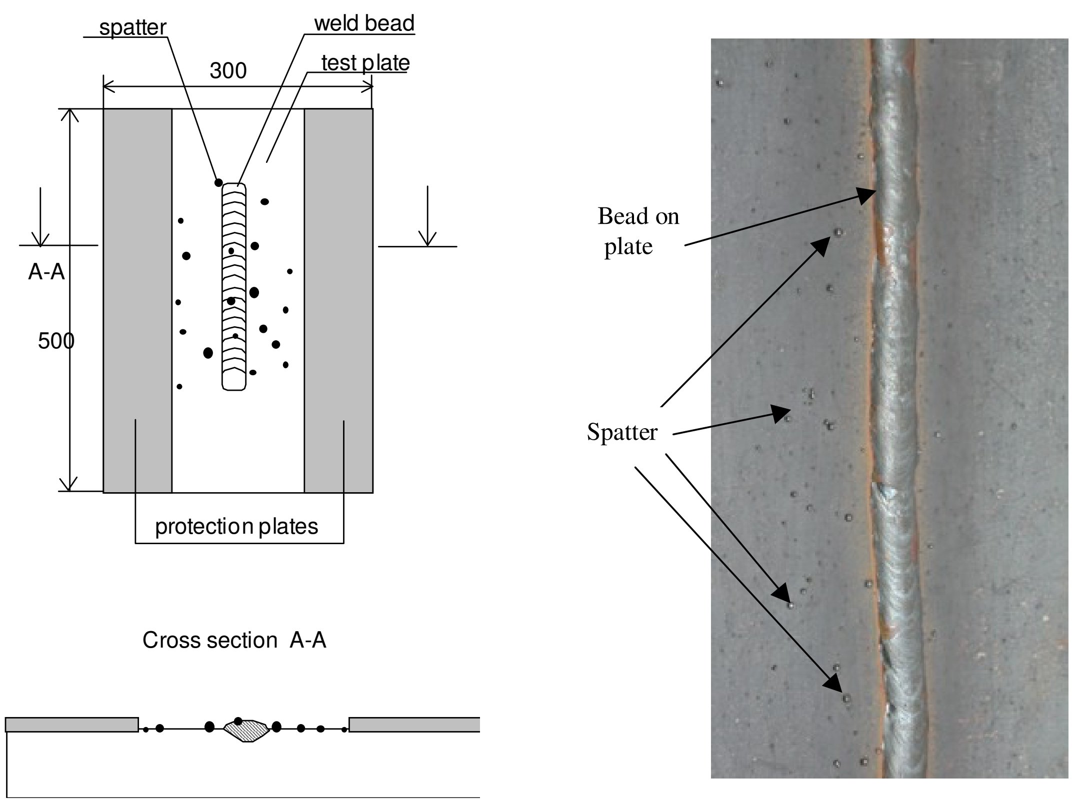

Figure 4. Design of the experiment for surfacing of a test plate (left) and a detail of spatter obtained for a MAG welding with solid wire and $Ar+CO_2$ shielding gas. Dimensions of the surface with the spatter are 65 mm by 110 mm.

4. Summary and future work

This experiment shows that spatter appears in the welded joint area even when a gas mixture that promotes a stable transfer was used. A larger quantity of spatter droplets are expected for welds with CO_2, with a lower flow of shielding gas, or with gas with unsatisfactory quality (impure gas). In future research, MAG and SMAW welds will be produced with a variety of welding parameters (especially current), and shielding quality (type and flow of shielding gas for the MAG welding process, and type and quality of electrode coatings for the SMAW process). During the welding process, the welding parameters will be recorded, and then correlated to the amount and size distribution of the spatter. Additionally, the size of each spatter droplet will be compared to the shear force needed to remove the spatter, and the influence of spatter and the mechanical damage caused by its removal on the corrosion properties will be studied.

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References

[1] Madigan, R.B.; Quinn, T.P.; Siewert, T.A.: Control of Gas-Metal-Arc Welding Using Arc-Light Sensing. NISTIR 5037, 1995.

[2] Davies, A.C.: The science and practice of welding. Vol. 2. Tenth edition. Cambridge University Press, Cambridge, GB, 1996.

[3] Siewert, T; Samardžić, I.; Kolumbić, Z.: Procjena stabilnosti MAG postupka zavarivanja na osnovu monitoringa glavnih parametara zavarivanja. Zbornik radova znanstveno-stručnog savjetovanja „Ekonomski i kvalitativni aspekti visokoučinskih postupaka zavarivanja", Slavonski Brod, "Đuro Đaković", Holding, 2001.

[4] Lukačević, Z.; Samardžić, I.: Possibilities of dynamic monitoring of the main parameters in arc welding processes. Zavarivanje 42(1998)1/2, page 11-18. Croatian Welding Society, Zagreb, 1999.

[5] Lukačević, Z. Samardžić, I., Siewert, T.: Characterization of a Welding Procedure Based on Monitoring of Welding Variables. International Institute of Welding (IIW) Conference Doc. XII-1627-00, Florence (Firenca), 9-14 July 2000.

[6] Samardžić, I.; Grubic, K.: Computer aided welding parameters monitoring. Zavarivanje 39(1996)1/2, page 23-28. Croatian Welding Society, Zagreb, 1996.

[7] Samardžić, I.; Köveš, A.: Weldments quality assurance supported by welding parameters monitoring and processing system. Proceedings of International Conference "Welding in Shipbuilding", Croatian Welding Society, Zagreb, 1998.

[8] Samardžić, I. Dunđer, M. Kolumbić, Z. Control of arc-welding using arc-sensing during welding. Međunarodno savjetovanje CIM 2000, Lumbarda, Korčula (Hrvatska), str. V39-V50, bibl. 5., UDK 621(063)658:52.011.56(063), ISSN 953-97181-0-4

[9] Samardžić, I., Siewert, T. Reliability Improves in Repair Welding of High-strength Steels. IIW Doc. IX-2002-01. 54th Annual Assembly of International Institute of Welding (IIW), Ljubljana, July 2001.

[10] Kolumbic, Z, Samardzic, I,, and Klaric, Š. Dynamics of the gas metal arc welding process research – laboratory system and sound monitoring module-, Proceedings of the 12th International DAAAM symposium "Inteligent manufacturing & automation: Focus on precision engineering", Jena, October 2001.

[11] Samardžić,I., Kolumbić,Z.,Baotić,M.: Doprinos primjeni praškom punjenih žica za zavarivanje MAG postupkom. Tehnički vijesnik 8(2001)(3,4)23-35.

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