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ANALYSIS OF WELDING PARAMETER DISTRIBUTION IN STUD ARC WELDING

Ivan Samardžić
Mechanical Engineering Faculty
Trg Ivane Brlić Mažuranić 2,
HR-35000 Slavonski Brod, Croatia
Ivan.Samardzic@sfsb.hr
Tel : 00385 35 446 188
Fax : 00385 35 446 446

Štefanija Klarić
Mechanical Engineering Faculty
Trg Ivane Brlić Mažuranić 2,
HR-35000 Slavonski Brod, Croatia
Stefanija.Klaric@sfsb.hr
Tel : 00385 35 446 188
Fax : 00385 35 446 446

Tom Siewert
NIST
325 Broadway
Boulder CO 80305, USA
1-303-497-3523
1-303-497-5030

Key Words: arc stability, on-line monitoring, stud arc welding

Abstract:

This paper describes the application of an on-line monitoring system for recording welding current and voltage during stud arc welding with a ceramic ferrule. Recorded values of welding current and voltage are analyzed off-line for the weld process with both stable arcs and purposely induced instabilities, and presented as welding current versus voltage distribution diagrams. Stability is evaluated from the welding voltage and current relationship diagrams. Macroscopic sections of weld joints with good weld quality and those with weld defects are also presented.

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1. INTRODUCTION

Stud arc welding is a well-known welding process in steam boiler production, bridge construction, the automobile industry and other production areas. There are many advantages of the stud welding process, especially in the reduction of production costs (a short time cycle, the possibility of automation, etc), but special attention has to be paid to quality and repeatability of these joints. According to [1], quality concerns traditionally associated with drawn-arc welding processes are related to variables inherent in stud welding (weld current, weld time, arc voltage, plunge, lift, etc.) and more general manufacturing variables (sheet cleanliness, joint geometry, etc.). Some of the factors that contribute to weld stud failures are incorrect base plate material or plate surface condition, inappropriate weld settings, malfunctioning or obsolete equipment, little or no training for stud welding operators, and lack of quality control and inspection procedures [2].

The effects of variations in the process and manufacturing factors that influence the quality of short-duration drawn-arc stud welding are investigated in [1], and the use of welding parameters (welding current and voltage) for monitoring drawn-arc stud welding with ceramic ferrule is discussed in [3,4]. A broader background in weld sensing is included in [5 – 7].

This study was conducted to evaluate the stability of the welding process and its relation to the joint quality based on monitoring of the main welding parameters (current and voltage) and the analysis of macroscopic sections of welded stud joints. In this study, the effects of oil, primer, and rust on the base metal sheet, the influence of a wet ceramic ring, induced arc blow, and a missing stud tip were examined.

2. EXPERIMENTAL PROCEDURE

In the experimental design, the main parameters for stud welding with a ceramic ferrule (plunge P, mm; lift L, mm; time t, s and welding current I, A) were kept constant. During welding, the current and voltage were recorded to evaluate the stability of the process (figure 1). Welding was performed with a commercial semiautomatic unit. An on-line monitoring system was used for acquisition of the main welding parameters: current and voltage (figure 1) [4]. The sampling frequency of the process was 5 kHz (on each channel).

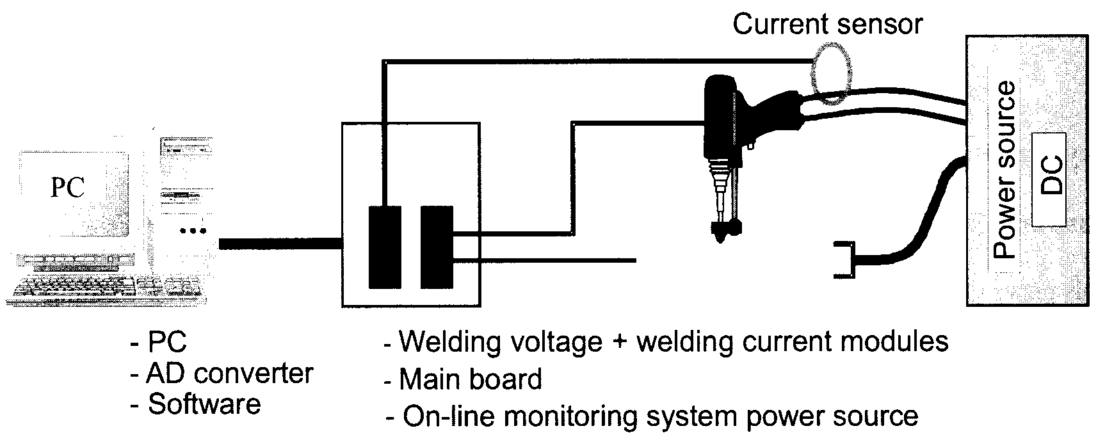

Figure 1. Scheme of experimental setup with on-line monitoring system for acquisition of arc welding process main parameters

The setup of selected welding variables is shown in table 1. Experiments were performed on steel plates, type 16 Mo 3 (EN 10028-2).

Table 1. Stud welding parameters

Trial No.	Welding current *I*, A	Welding time *t*, s	Plunge *P*, mm	Lift *H*, mm	Welding condition
1	600	0,4	2,9	2,5	Clean surface
2	600	0,4	2,9	2,5	Oil on surface
3	600	0,4	2,9	2,5	Surface with rust
4	600	0,4	2,9	2,5	Surface with primer
5	600	0,4	2,9	2,5	Wet ceramic ring
6	600	0,4	2,9	2,5	Arc blow
7	600	0,4	2,9	2,5	Missing stud tip

3. EXPERIMENTAL RESULTS

3.1. Results of welding parameter monitoring

Variations in current and arc voltage for a properly welded stud, and parameter distribution during stud welding under unstable conditions are shown in figure 2.

Validation of process stability was performed by *off-line* analysis of collected data –current and voltage, as well as power and resistance (table 2). The welding process starts and stops were excluded. The moment when the current exceeded a value selected on the welding power source was the criterion for the start of the analysis (figure 3a – welding on a clean base metal surface). The voltage drop at short circuit due to submerging the stud into the base metal (figure 3b) marked the end of the analysis.

In further analysis of the process, the diagrams of arc voltage versus welding current were made for the process (figure 4). Again, process starts and stops were excluded. Figures 2 and 4 confirm that the variations in welding voltage are more intense than variations in welding current, an expected result, since the stud welding process uses a constant current power source. The frequency diagrams of welding voltage for the parameters in table 1 are shown in figure 5.

3.2. Macroscopic sections of weld joints

The stability of the welding process and its relation with joint quality was validated by visual evaluation of a macroscopic section through a joint (figure 5), and by mechanical and other tests of the joint.

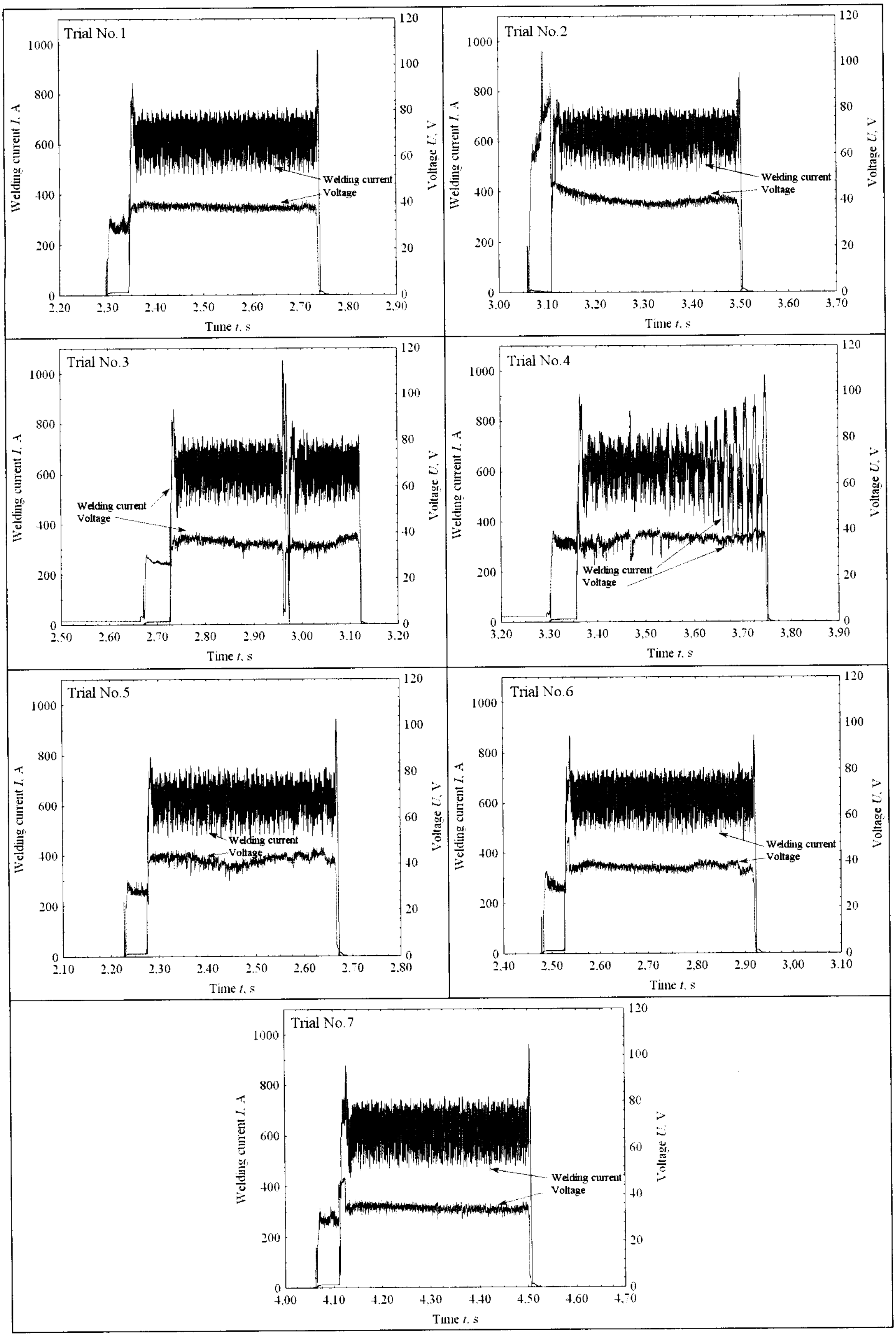

Figure 2. Current and voltage records for the arc stud welding test matrix

Table 3 Results of statistical processing of the recorded welding parameters

Trial No.	Variable	Number of samples	Mean	Minimum	Maximum	St. Dev.
1	Current I, A	1942	631	447	850	72
	Voltage U, V	1942	38,1	18,2	41,5	1,37
	Resistance R, Ω	1942	0,06	0,02	0,08	0,0068
	Power P, kW	1942	24,1	15,4	33,9	3,15
2	Current I, A	1942	631	474	874	70
	Voltage U, V	1942	40,0	15,4	63,4	2,96
	Resistance R, Ω	1942	0,06	0,02	0,13	0,0083
	Power P, kW	1942	25,3	12,1	37,6	3,45
3	Current I, A	1947	632	464	824	74
	Voltage U, V	1947	37,5	20,6	42,5	1,69
	Resistance R, Ω	1947	0,06	0,03	0,083	0,0073
	Power P, kW	1947	23,7	15,4	32,9	3,13
4	Current I, A	1940	632	275	979	111
	Voltage U, V	1940	36,0	24,5	47,1	2,4
	Resistance R, Ω	1940	0,059	0,028	0,13	0,0115
	Power P, kW	1940	22,8	9,0	35,9	4,49
5	Current I, A	1941	631	460	837	71
	Voltage U, V	1941	41,7	23,4	47,0	2,2
	Resistance R, Ω	1941	0,07	0,03	0,10	0,0086
	Power P, kW	1941	26,3	17,3	34,7	3,26
6	Current I, A	1945	631	446	870	73
	Voltage U, V	1945	37,6	14,4	50,7	2,01
	Resistance R, Ω	1945	0,06	0,02	0,08	0,0071
	Power P, kW	1945	23,7	12,0	35,5	3,25
7	Current I, A	1937	631	435	876	78
	Voltage U, V	1937	34,4	17,2	47,7	2,17
	Resistance R, Ω	1937	0,06	0,02	0,08	0,0071
	Power P, kW	1937	21,8	13,26	35,6	3,29

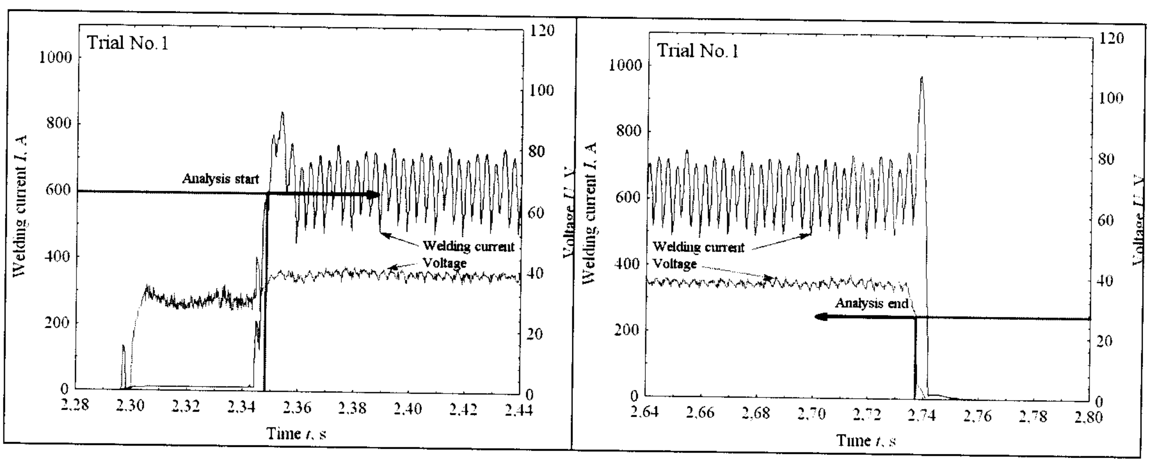

Figure 3. The stud welding process starts and stops, and the criteria for process stability analyses (Trial No. 1 – table 1)

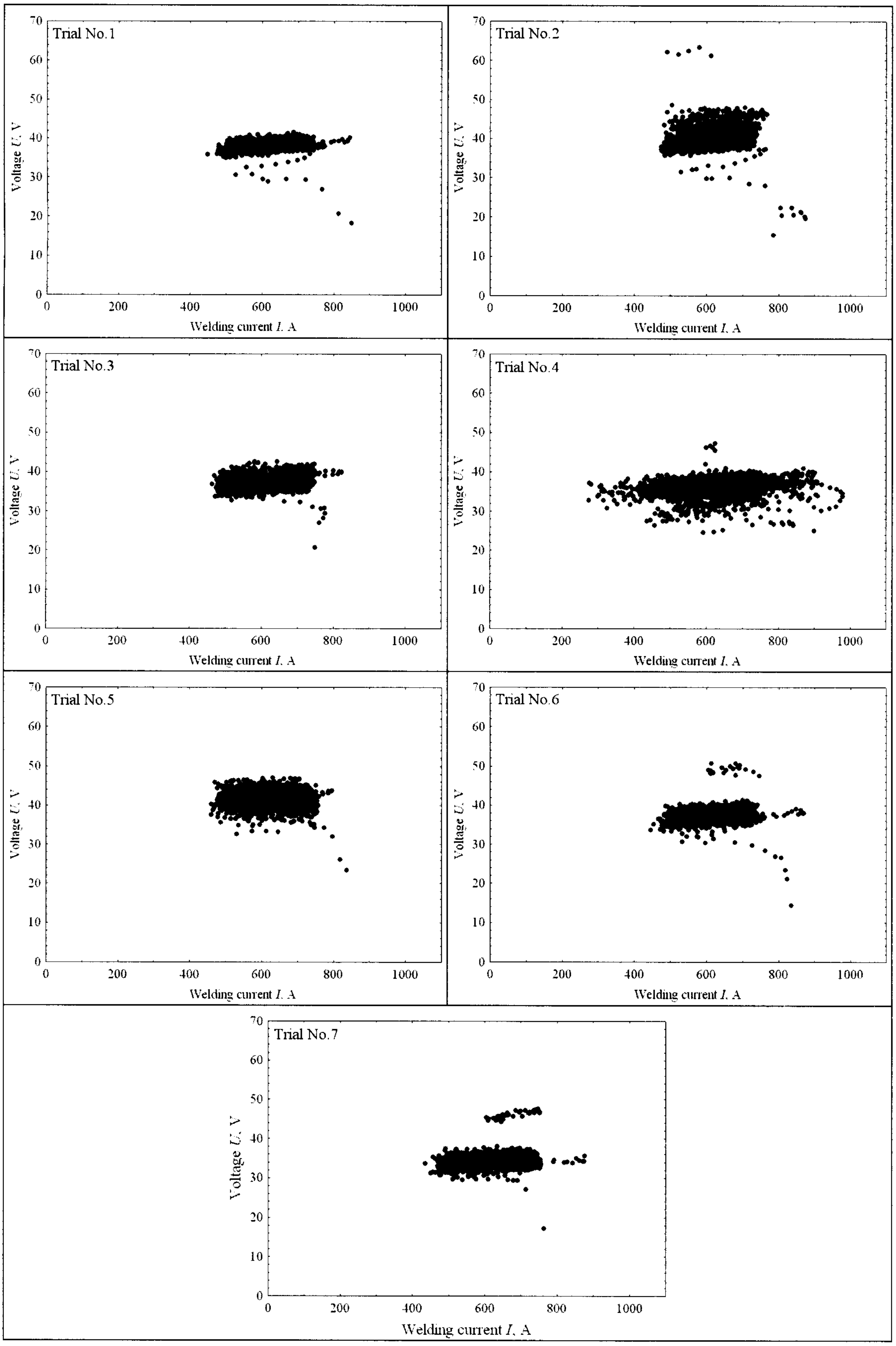

Figure 4. Dependence of the arc voltage on the welding current for the welding parameters shown in table 1

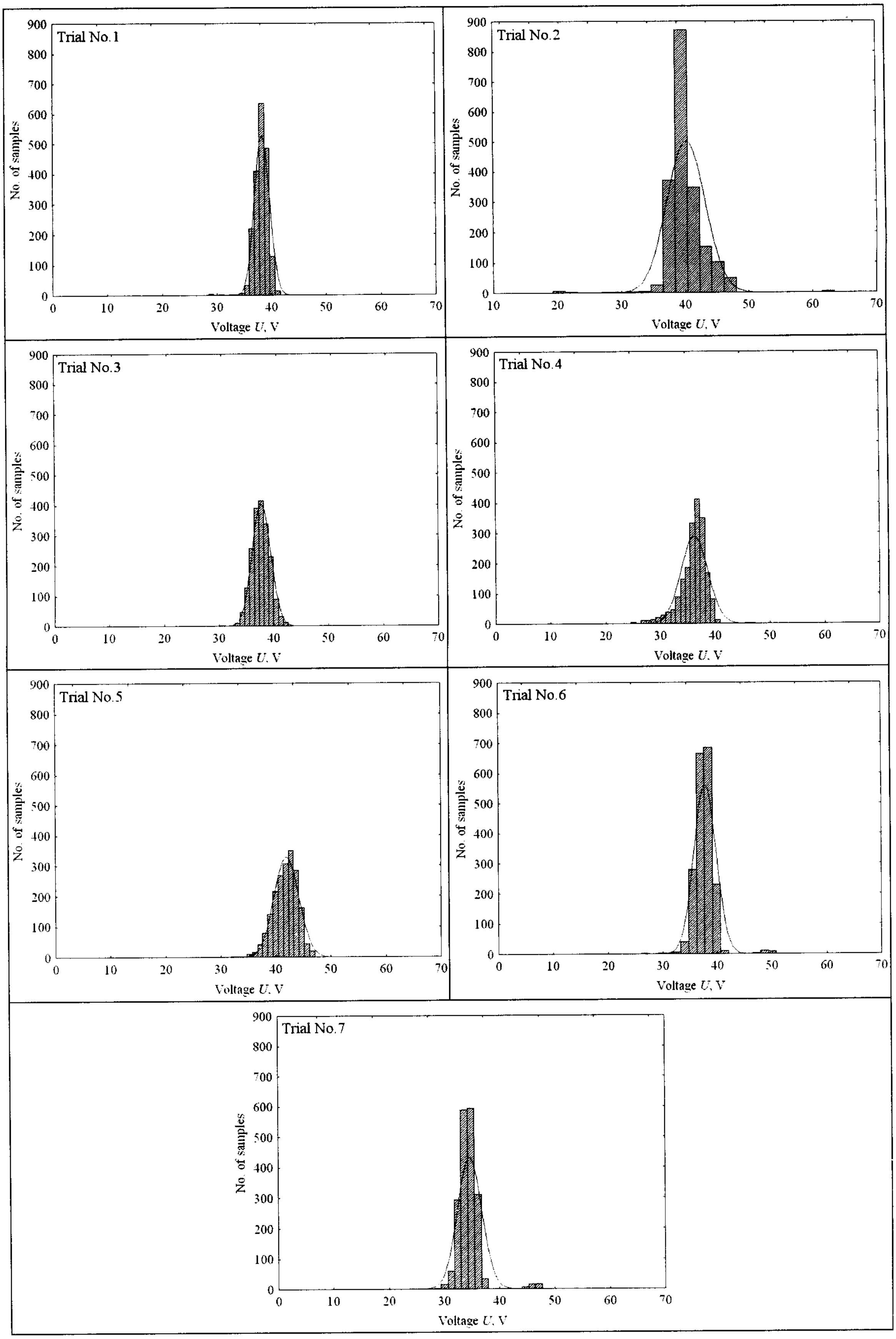

Figure 5. Frequency histograms of welding voltage for the welding parameters shown in table 1

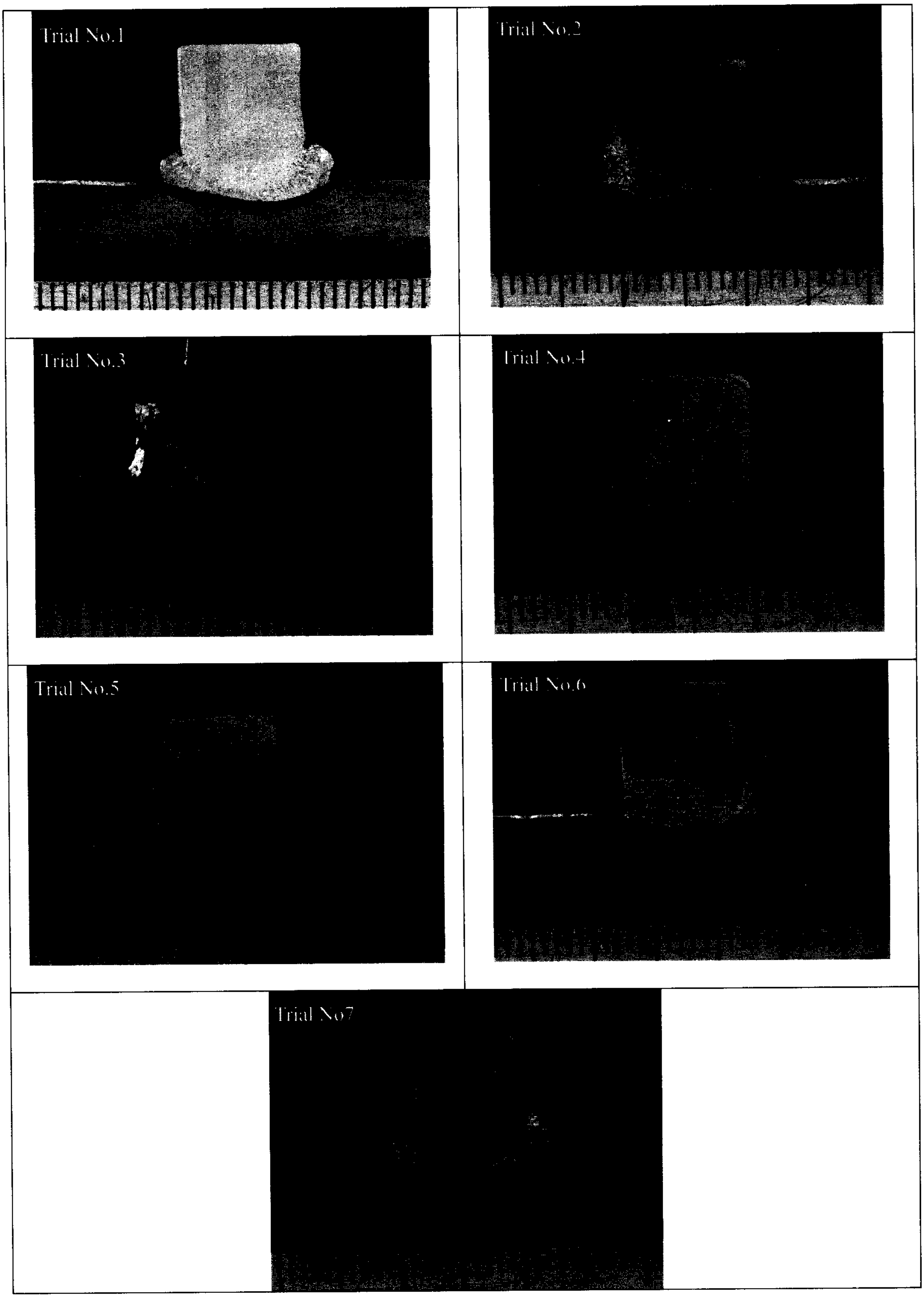

Figure 6. Macro sections of welded joints (welding parameters according to table 1)

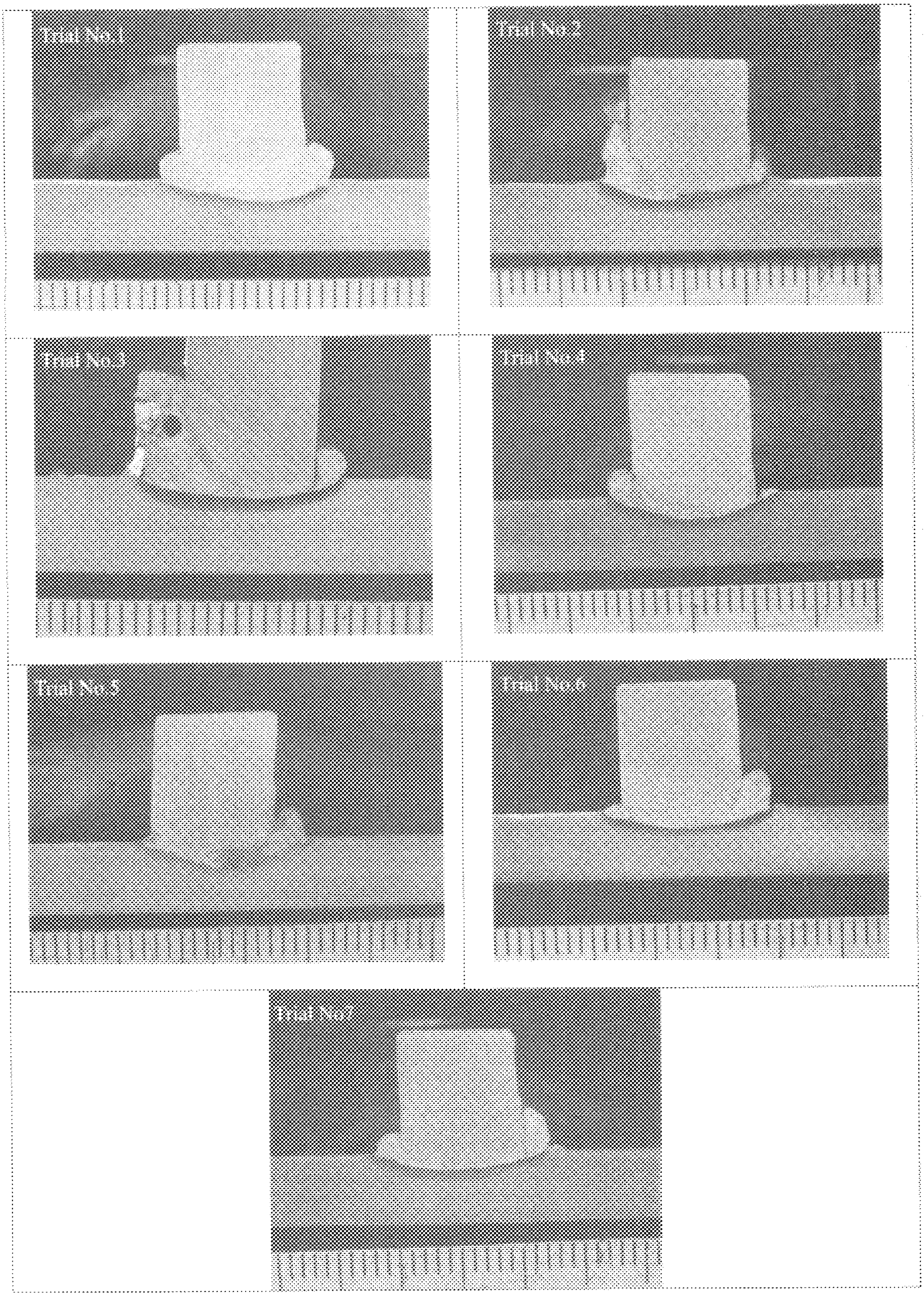

Figure 6. Macro sections of welded joints (welding parameters according to table 1)

3.3. Data analysis

Comparison of the minimal and maximal values of the parameters and their standard deviations confirms that the electric arc is most stable when welding is performed under normal conditions. Thus, the diagram for trial no. 1 (figure 2) presents the characteristic reference diagram for a stable arc stud welding process. During welding with disturbances, especially on base plate with primer (trial no. 4), the instability is evident as wider variations in the diagrams of the welding current and voltage on figure 2, and also from the diagrams in figure 4.

During welding on base metal with oil, rust or discoloration, the instabilities of the welding parameters can be observed in figure 2 and figure 4. Although the frequency histograms of welding voltage for the parameters shown in table 1 shows some of the disturbance, the additional changes in parameter distributions on the weld process start (figure 7) are excluded from this analysis.

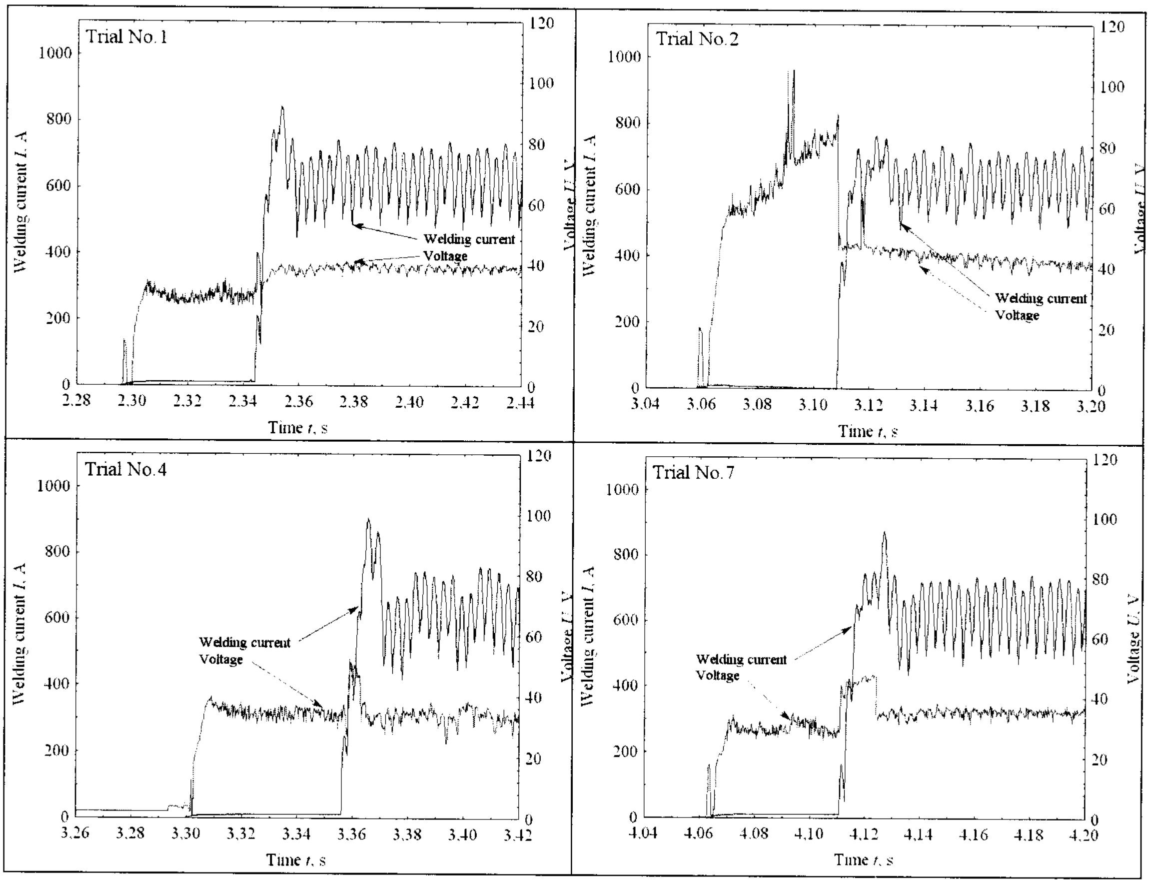

Figure 7. Weld process start (welding parameters shown in table 1)

Macroscopic sections shown in figure 6 confirm the relation of welding quality and stability of arc welding parameters (there is porosity and arc blow for almost all parameters). For the stable welding conditions, the weld joint is free of defects (trial no 1).

4. CONCLUSION

The development of defects in stud arc welding is associated with a disturbance of the electric arc during the process, and the disturbances were consistently observed for common defect conditions. Parametric analysis shows an increased variation of welding voltage, but at still larger disturbances (i.e., welding on base metal with primer), the welding current is also affected (figure 2, trial no. 4). Although the welding process starts and stops were excluded from this analysis, changes in the welding parameters here are also evident. These changes during arc ignition might be taken into consideration (figure 7).

Besides analyzing parameter changes at the beginning of the arc stud welding process, subsequent research will investigate different statistical methods for monitoring arc stability in the stud welding process.

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