ANALYSIS OF WELDING PARAMETERS DISTRIBUTION IN STUD ARC WELDING

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Abstract:

This paper describes the application of 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 processes with purposely induced instabilities, and presented as welding current versus voltage distribution diagrams.

In the second part of the paper, stability is evaluated from the welding voltage and current relationship diagrams, and also the macro sections of weld joints with good weld quality and with weld defects are presented.

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, depth, etc.) and more general manufacturing variables (sheet cleanliness, joint geometry, etc.). Some of the factors that cause 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 effect of variations in the process and manufacturing factors that influence the quality of short-duration drawn-arc stud welding is 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].

This study was conducted to evaluate the stability of the welding process and its relation to the weld joint quality based on monitoring of the main welding parameters (welding current and voltage) and the analysis of macro 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 our experimental design, the main welding parameters for stud welding process with a ceramic ferule (plunge *P*, mm; lift *L*, mm; time *t*, s and welding current *I*, A) were kept constant. During welding, the welding current and voltage were recorded to evaluate the stability of the welding 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; welding current and voltage (figure 1) [4]. The sampling frequency of the welding process was 5 kHz (on each channel).

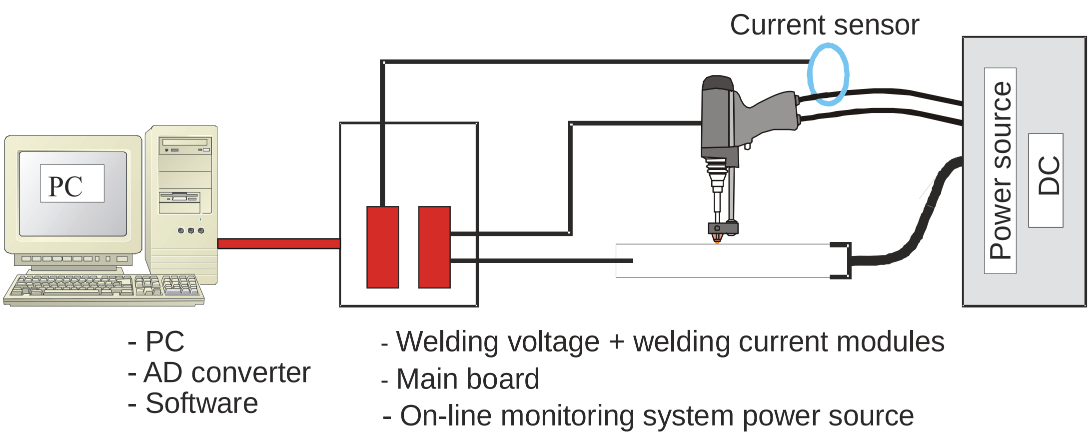

Figure 1. Scheme of experimental setup with on-line monitoring system for acquisition of arc welding process main parameters

The setup of selected welding variables is shown in table 1. Experimental welding was performed on the base plate steel, 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. PRESENTATION AND ANALYSIS OF EXPERIMENTAL RESULTS

3.1. Results of welding parameter monitoring

Variations in welding current and arc voltage for a properly welded stud, and welding parameters distribution during stud welding at unstable welding conditions are shown in figure 1.

Validation of the welding process stability was performed by *off-line* analysis of collected data – welding current and voltage, but also welding power and resistance (table 2). The welding process starts and stops are excluded.

The moment when the welding current value exceeds a value selected on the welding power source is the criterion for the start of the analysis (figure 3a – welding on a clean base metal surface), and the voltage drop at the moment of the short circuit due to submerging the stud into the base metal (figure 3b) marks the end of the analysis.

During further analysis of the welding process, the diagrams of arc voltage versus welding current are made for the process (figure 4). Again, the welding process start and stop are excluded.

Figures 2 and 4 confirm that the welding voltage variations are more intense than variations of welding current, an expected result, since the stud welding process uses a constant current power source. The frequency diagrams of welding voltage for the welding parameters in table 1 are shown in figure 5.

3.2. Macro sections of weld joints

The stability of welding process and its relation with weld joint quality can be validated by visual evaluation of weld joint macro section (figure 5), but also with the mechanical and other tests of weld joint.

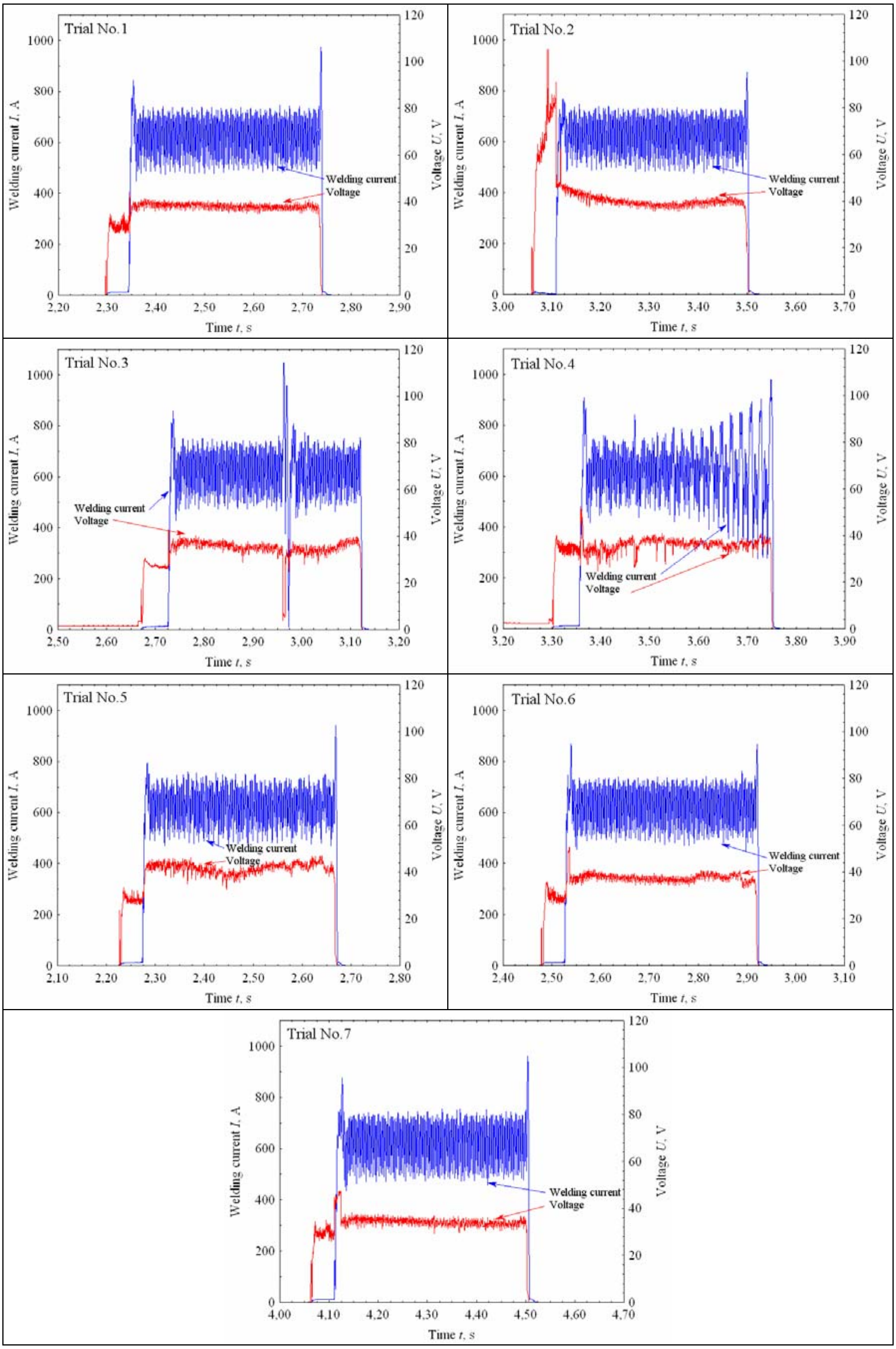

Figure 2. Welding current and voltage records for the arc stud welding test matrix

Table 3 Results of statistical processing of the recorded welding parameters

Trial No.	Variable	Number of samples	Mean	Minimum	Maximum	St. Dev.
1	Welding current *I*, A	1942	631,30	447,10	850,40	72,42
	Welding voltage *U*, V	1942	38,14	18,22	41,56	1,37
	Welding resistance *R*, Ω	1942	0,06	0,02	0,08	0,0068
	Welding power *P*, kW	1942	24,11	15,49	33,96	3,15
2	Welding current *I*, A	1942	631,92	474,90	874,00	69,86
	Welding voltage *U*, V	1942	40,06	15,45	63,39	2,96
	Welding resistance *R*, Ω	1942	0,06	0,02	0,13	0,0083
	Welding power *P*, kW	1942	25,32	12,16	37,59	3,45
3	Welding current *I*, A	1947	631,71	463,70	824,50	73,70
	Welding voltage *U*, V	1947	37,56	20,60	42,55	1,69
	Welding resistance *R*, Ω	1947	0,06	0,03	0,083	0,0073
	Welding power *P*, kW	1947	23,75	15,44	32,96	3,13
4	Welding current *I*, A	1940	631,58	275,10	979,00	110,83
	Welding voltage *U*, V	1940	36,01	24,58	47,16	2,41
	Welding resistance *R*, Ω	1940	0,059	0,028	0,13	0,0115
	Welding power *P*, kW	1940	22,79	9,02	35,94	4,49
5	Welding current *I*, A	1941	631,12	460,20	836,70	70,97
	Welding voltage *U*, V	1941	41,73	23,36	47,03	2,23
	Welding resistance *R*, Ω	1941	0,07	0,03	0,10	0,0086
	Welding power *P*, kW	1941	26,34	17,26	34,74	3,26
6	Welding current *I*, A	1945	631,52	445,70	870,10	73,23
	Welding voltage *U*, V	1945	37,56	14,37	50,72	2,01
	Welding resistance *R*, Ω	1945	0,06	0,02	0,08	0,0071
	Welding power *P*, kW	1945	23,75	12,01	35,49	3,25
7	Welding current *I*, A	1937	631,33	435,50	876,00	78,04
	Welding voltage *U*, V	1937	34,45	17,24	47,67	2,17
	Welding resistance *R*, Ω	1937	0,06	0,02	0,08	0,0071
	Welding power *P*, kW	1937	21,79	13,16	35,60	3,29

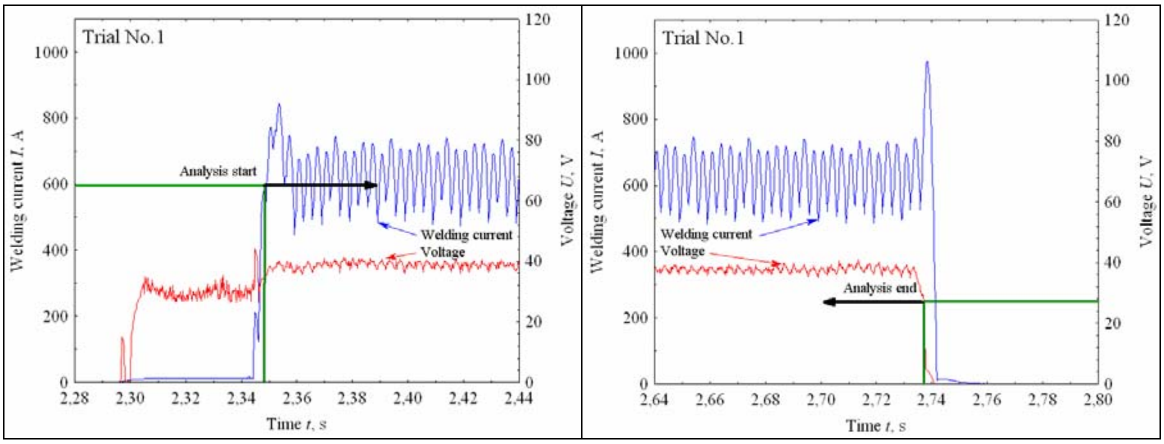

Figure 3. The stud welding process start and end and the criteria for the weld process stability analyse (Trial No. 1 – table 1)

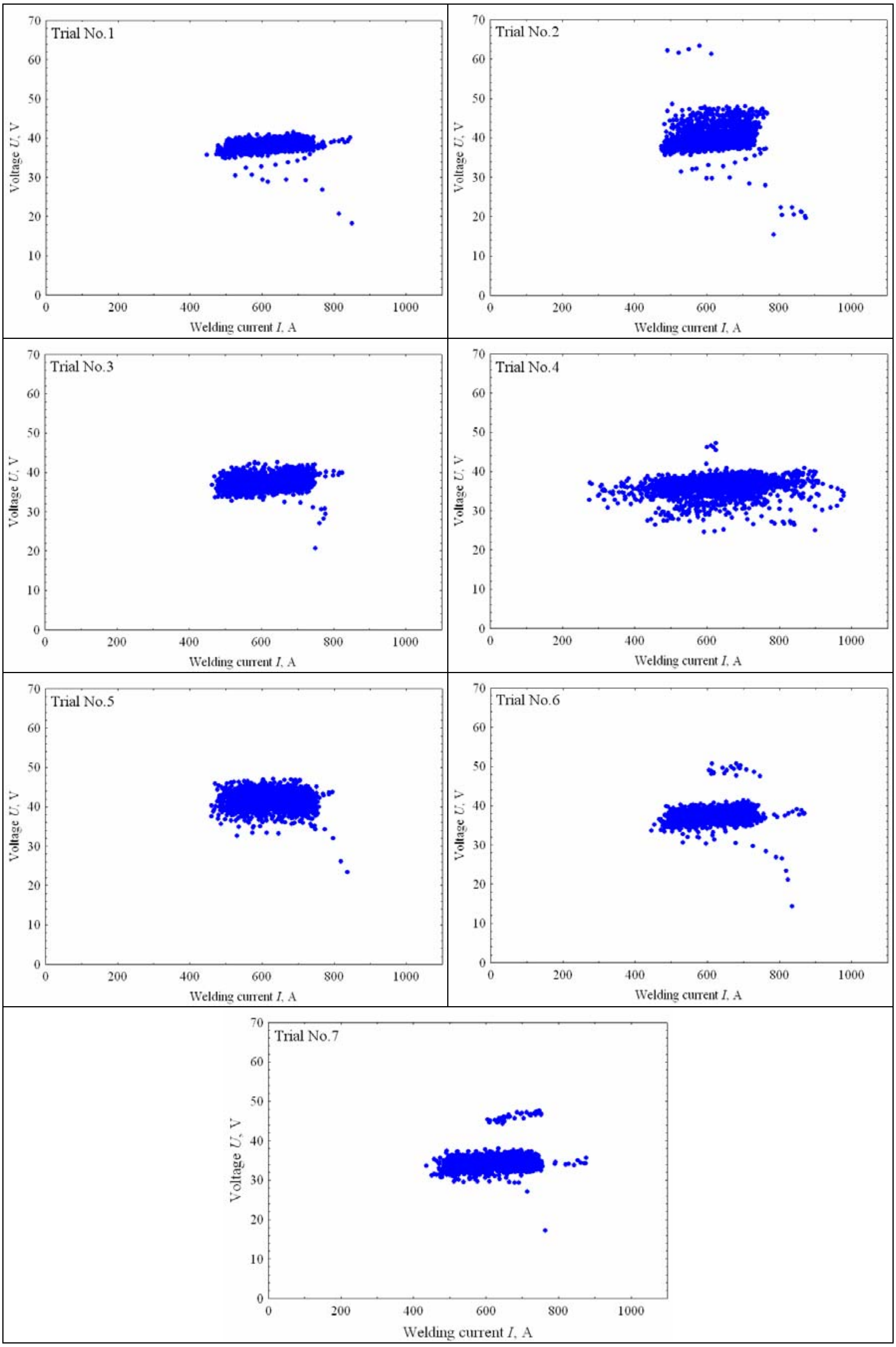

Figure 4. Dependence of the arc voltage on the welding current for the welding parameters shown in table 1

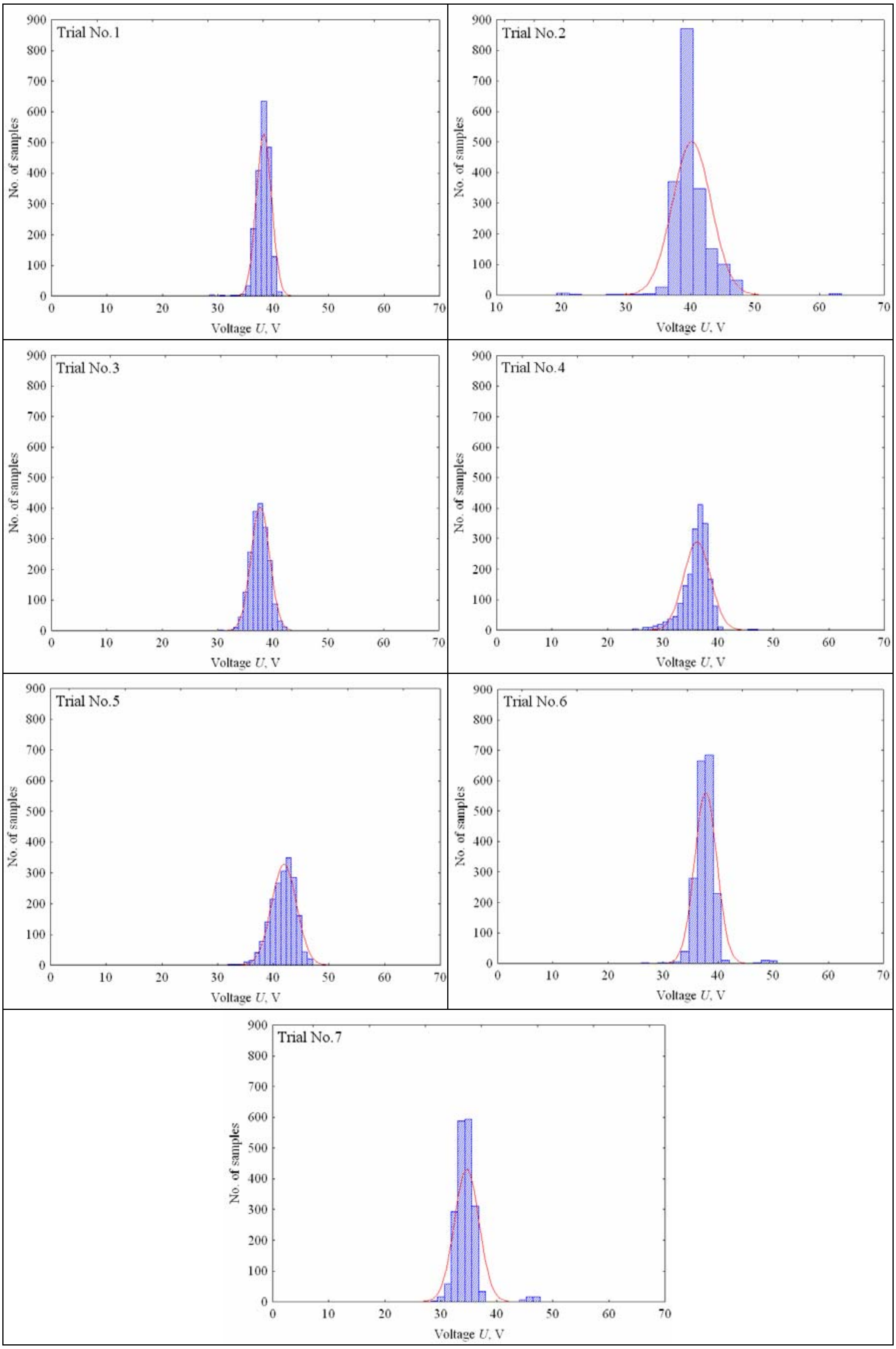

Figure 5. Frequency histograms of welding voltage for the welding parameters shown in table 1

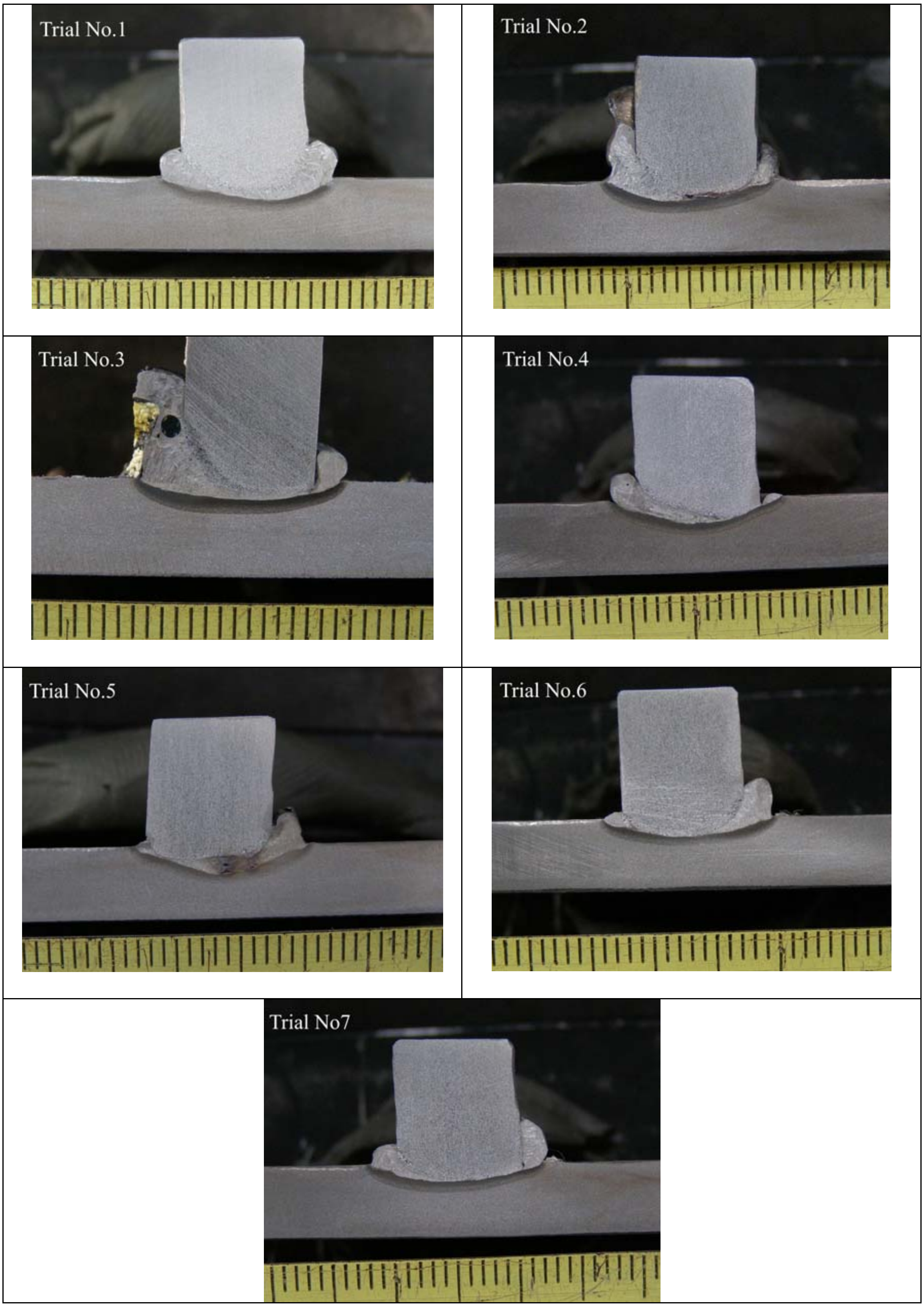

Figure 6. Macro sections of welded joints (welding parameters according to table 1)

3.3. Data analysis

Comparison of the minimal and maximal values of the parameters and their standard deviations confirms that the stability of the electric arc is greatest when welding is performed under normal welding conditions. Thus, the diagram for the 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 the 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 from the figure 2 and figure 4, but although the frequency histograms of welding voltage for the welding parameters shown in table 1 shows some of the disturbance, the additional changes of welding parameters distributions on the weld process start (figure 7) are excluded from this analysis.

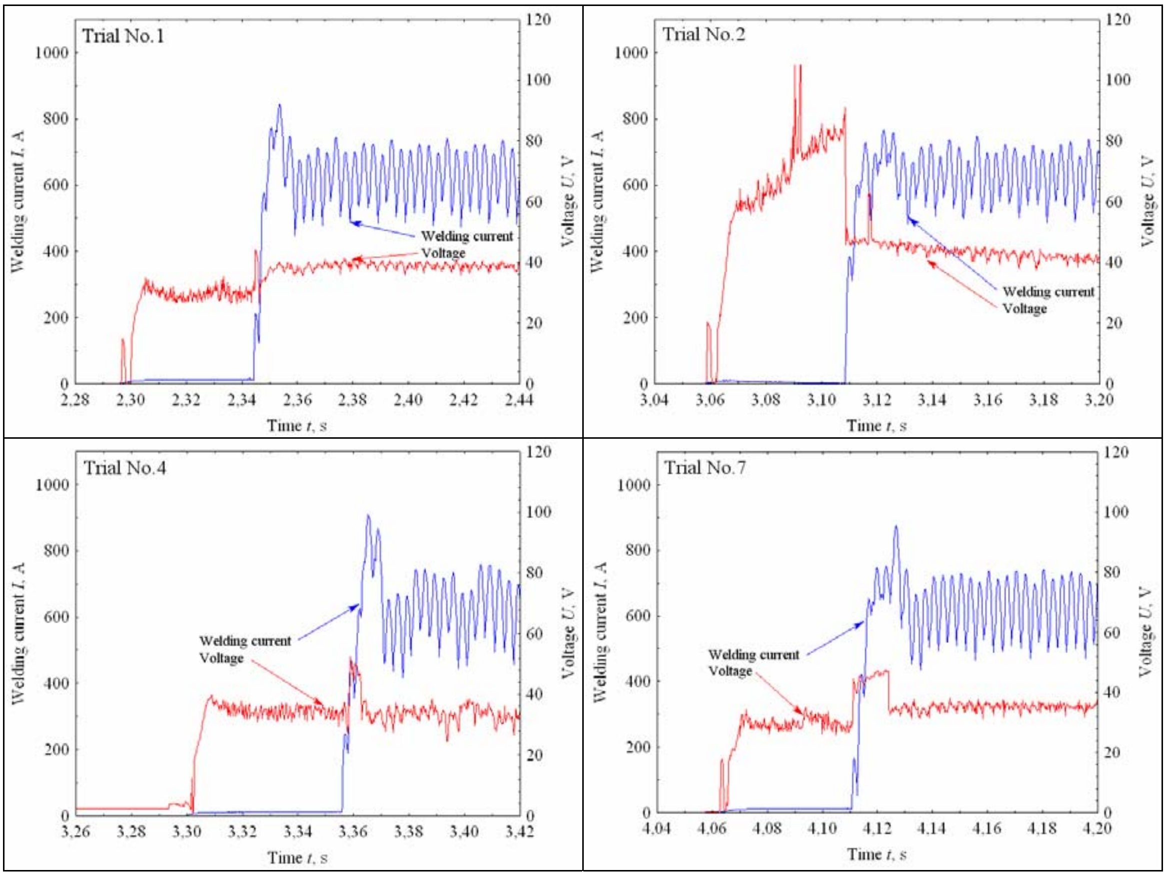

Figure 7. Weld process start (welding parameters shown in table 1)

Macro 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 welding parameters). For the stable welding conditions, the weld joint is free of welding defects (trial no 1).

4. CONCLUSION

The development of weld defects in stud arc welding is associated with a disturbance of the electric arc during the welding process, and the disturbances were consistently observed for common weld 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, Tr.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 the analysis of parameter changes at the beginning of arc stud welding process, the follow-on research will investigate different statistical methods for monitoring the arc stability in the stud welding process.

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