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THE INFLUENCE OF THE STUD ARC WELDING PROCESS PARAMETERS ON THE WELD PENETRATION

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Abstract: *Due to short time of welding cycle, simplicity in equipment use and cost efficiency the application of stud arc welding process is well known in various manufacturing fields. In this paper, the influence of welding parameters (welding current, welding time, stud plunge and lift) during Drawn Arc Welding process with ceramic ferule on the weld penetration depth is experimentally investigated. The experiment was conducted according to the four-factor design of experiment and the influence of individual factors (welding current, welding time, stud plunge and lift) and their interactions on the weld penetration depth during arc stud welding process was determined statistically.*
Key words*: stud arc welding process, welding parameters, penetration depth, design of experiment*

1. INTRODUCTION

Stud arc welding process involves the same electrical, mechanical and metallurgical principles as other arc welding processes [2, 4]. The quality of weld joint at Drawn Arc Welding process with ceramic ferule (DAW) depends on number of factors like type of base metal and stud material, welding position etc., but proper selection of welding parameters have important role.

Considered welding parameters of DAW process are: plunge *P*, mm (the length of stud that protrude beyond the ferrule); lift *L*, mm (the distance achieved when gun pulls the stud away from the base material, the lift creates a air gap that electric current must bridge); time *t*, s (the duration of the welding process) and welding current *I*, A (a measure of current across the gap created by the lift) [2].

Due to mentioned importance of proper parameter selection, in this paper the analysis of weld joint geometry according to set values of welding current, welding time, stud lift and plunge is conducted at arc stud welding process with ceramic ferrule. The main purpose of this investigation is to ascertain the assumption that the specific selection of welding parameters will have the influence on weld penetration depth and that the proper selection of parameters will give the weld joint with proper geometrical characteristics.

2. APPLICATION AREA

Arc stud welding process is applied today in different production areas. The application of Draw Arc Welding with ceramic ferrule has important role in steam boiler production and bridge construction (composite steel/concrete structures). Also this process is successfully used in ship building, automobile industry etc.

In the experimental part of the paper the Draw Arc Welding with ceramic ferrule is foreseen and also measuring of penetration depth for studs applied in steam boiler production. These studs are applied in steam boiler parts production for placing isolation on boiler membrane panels and walls (Figure 1).

a) *b)*

Fig. 1 *Arc stud welding on membrane panels in steam boiler production (a), detail of welded studs from boiler production (b) [7]*

3. RESEARCH COURSE

This study was conducted to evaluate the influence of welding parameter changes on the difference in welding geometry during welding (precisely on the weld penetration depth). According to experimental setup, the DAW stud welding was foreseen and it was performed with semiautomatic equipment Nelson Stud Welding, Inc., Oh, USA (power source: ALPHA 850, stud welding gun NS 40 B). The following variables are selected for examination: welding time *t*, s; welding current *I*, A , the values of the stud plunge *P* and lift *L*. The setup of selected welding variables is applied according to design of experiment (central composite design). Experimental welding was performed on studs "Nelson KS 10,0×50" with ceramic ferrule “Nelson KW 10/5.5”; stud was made from X10CrAl18 (EN 10095), and base metal of plate and pipes was steel type 16 Mo 3 (EN 10028-2).

After experimental welding, the specimens were cut in order to measure the depth of penetration *d*, mm. The cut surfaces were grained and etched. The macro-structure photos were taken from these etched surfaces and the penetration depth was measured by a UTHSCSA ImageTool (IT) program [9]. A schematic illustration of bead penetration measurement is shown in Figure 2.

Having in mind that experiment is often only reliable source of quantitative information, statistical planning of experiment deals with planning methods of experiment that will ensure data acquisition that is appropriate to statistical analysis. Statistical analysis will be the base for reliable conclusion about research subject [1, 5, 6].

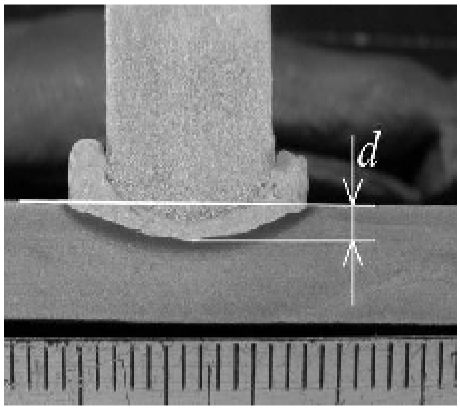

Fig. 2 *Illustration of penetration depth measurement*

After the qualitative analysis, the five-level, four-factor, central composite factorial design consisting of 31 sets of coded conditions is selected. The selected design matrix is comprised of full replication of 2^4 factorial design plus several additional test points (seven center points and eight star points, two on every axes). Thus, the 31 experimental runs allowed the estimation of the linear, quadratic and two-way interactive effects of the welding variables on the weld joint penetration [3]. Table 1 shows the values (limits) of factors (welding current, welding time, stud plunge and lift) for every experiment level.

Table 1. *Factors and Their Limits*

Factor	Designation	Limits				
Welding current *I, A*	A	450	500	550	600	650
Welding time *t, s*	B	0,25	0,35	0,40	0,45	0,55
Plunge P_s, mm	C	1	1,5	2	2,5	3
Lift *L*, mm	D	1,5	2	2,5	3	3,5

4. RESULTS

Table 2 shows values of individual factors (welding current, welding time, stud plunge and lift) for every experiment level. For every experimental level the three welded joint are produced (three macro-sections; as there are three repetition of every experiment level).
So experimental welding was conducted on 93 samples, and on every sample, after the macro-section preparation, the weld joint penetration depth was measured. Besides, for every weld joint, in program UTHSCSA ImageTool [9], three measurements of weld penetration are conducted and mean value of results was selected.

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Values of measured weld penetration as a response are also shown in table 2. To determine which factor, individually or in interaction with other factors has important influence on response, the analysis of variance is conducted.

The information on significance of calculated effects are gained by conducting the analysis of variance, and the results are shown in table 3. From tables of *F* distribution the critical value for 95% confidence for *F*(1,78 df) is 3,96. In this case, if v>3,96 the observed factor is significant.

Table 2. *Results of 31 tests of weld penetration as response*

Run No.	A – Welding current *I*, A	B – Welding time *t*, s	C – Stud plunge *P*, mm	D – Stud lift *L*, mm	Weld penetration, mm		
101	550	0,4	2	2,5	1,14	1,21	1,22
102	500	0,35	1,5	2	0,98	1,08	1,22
103	600	0,35	1,5	2	1,44	1,46	1,21
104	500	0,45	1,5	2	1,15	1,29	1,20
105	600	0,45	1,5	2	1,70	1,78	1,75
106	500	0,35	2,5	2	0,91	0,97	0,97
107	600	0,35	2,5	2	1,40	1,26	1,38
108	500	0,45	2,5	2	1,34	1,26	1,34
109	600	0,45	2,5	2	1,36	1,29	1,42
110	500	0,35	1,5	3	0,96	1,01	1,00
111	600	0,35	1,5	3	1,16	1,13	1,44
112	500	0,45	1,5	3	1,23	1,28	1,05
113	600	0,45	1,5	3	1,76	1,60	1,73
114	500	0,35	2,5	3	1,10	1,14	0,94
115	600	0,35	2,5	3	1,28	1,38	1,34
116	500	0,45	2,5	3	1,35	1,18	1,27
117	600	0,45	2,5	3	1,67	1,96	1,72
118	450	0,4	2	2,5	1,01	1,07	0,98
119	650	0,4	2	2,5	1,83	1,69	1,86
120	550	0,25	2	2,5	0,63	0,90	0,77
121	550	0,55	2	2,5	1,57	1,77	1,67
122	550	0,4	1	2,5	1,28	1,19	1,38
123	550	0,4	3	2,5	1,32	1,39	1,32
124	550	0,4	2	1,5	1,37	1,36	1,29
125	550	0,4	2	3,5	1,71	1,42	1,64
126	550	0,4	2	2,5	1,38	1,35	1,36
127	550	0,4	2	2,5	1,36	1,36	1,35
128	550	0,4	2	2,5	1,36	1,48	1,43
129	550	0,4	2	2,5	1,28	1,36	1,36
130	550	0,4	2	2,5	1,13	1,51	1,34
131	550	0,4	2	2,5	1,48	1,47	1,48

Table 3. *Analysis of variance for selected experiment design (Data from Table 2)*

Source of variation	Sum of squares *SS*	Degr. of freedom *DF*	Mean of square *MS*	Variance ratio *v*	Significance level *p*
(1) Welding current *I*	2,362	1	2,362	175,87	0,000
Welding current I^2	0,001	1	0,001	0,09	0,763
(2) Welding time *t*	2,104	1	2,104	156,69	0,000
Welding time t^2	0,102	1	0,103	7,66	0,007
(3) Stud plunge *P*	0,000	1	0,000	0,00	0,984
Stud plunge P^2	0,032	1	0,032	2,36	0,129
(4) Stud lift *L*	0,057	1	0,057	4,22	0,043
Stud lift L^2	0,028	1	0,028	2,11	0,151

1L i 2L	0,030	1	0,030	2,23	0,139
1L i 3L	0,022	1	0,022	1,61	0,208
1L i 4L	0,018	1	0,018	1,31	0,255
2L i 3L	0,002	1	0,002	0,18	0,673
2L i 4L	0,036	1	0,036	2,70	0,104
3L i 4L	0,114	1	0,114	8,50	0,005
Error	1,047	78	0,0134		

Table 4. *Regression Coefficients of Models*

	Coefficient	Standard error	*t*-value (86)	Significance level *p*
C	-2,0199	0,54182	-3,7281	0,00035
I	0,00362	0,00028	12,8718	0,00000
t	8,1851	1,87449	4,36658	0,000345
t^2	-6,6407	2,32439	-2,857	0,00536
P	-0,4881	0,17461	-2,7951	0,0064
L	-0,3339	0,1407	-2,373	0,01987
P·L	0,195	0,06893	2,82893	0,00581

By comparison of variance ratio in table 3 with critical value as significant factor the welding current, welding time, stud lift and interaction of stud lift and plunge can be taken in consideration. As it is shown in table 3, some of the factors are statistically important in linear, and some in quadratic form, and some in interaction with another factor (significance level $p < 0,05$) [8].

After the analysis of variance, the regression coefficients were calculated and shown in equation 1. The second-degree response surface includes factors shown in table 4. Also, table 4 shows the results of the *t*-test. This test confirms (together with the value of the *p* level) the significance of coefficients. The final reduced mathematical models with the significant coefficients are given (A, B, B^2, C i D) in term (1):

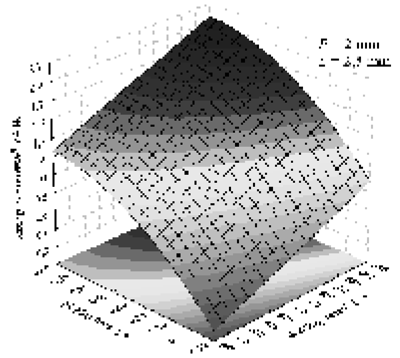
$$d = -2{,}0199 + 0{,}0036 \cdot I + 8{,}1851 \cdot t - 6{,}6407 \cdot t^2 - 0{,}4881 \cdot P - 0{,}334 \cdot L + 0{,}195 \cdot P \cdot L \qquad (1)$$

Figure 3 shows estimated regression parameter surface for weld penetration with effect of individual factors.

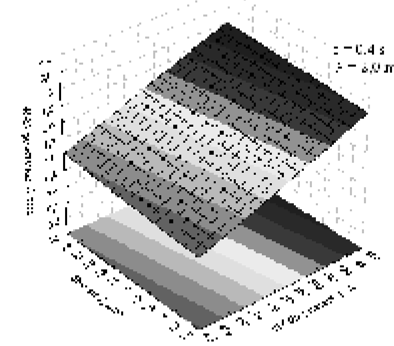
5. CONCLUSION

With conducted laboratory investigations and statistic analysis of results, the influence of welding parameters at arc stud welding process on the penetration depth are researched.

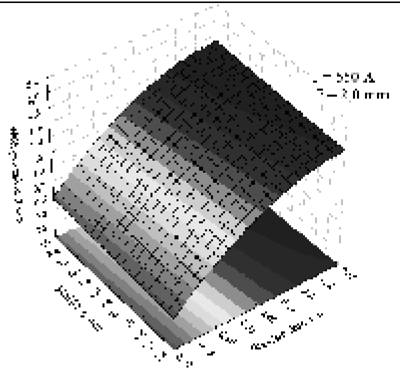
In order to determine the influence of level changes on weld penetration depth, the design of experiment was conducted and four factors are varied (welding current, welding time, stud plunge and lift). The analysis of variance and regression surfaces shown on the figure 3 have shown that welding current has the biggest influence on the weld penetration depth increase. The next important factor is welding time (the maximal weld penetration depth can be achieved form maximal values of welding current and time), while other two factors have less significance.



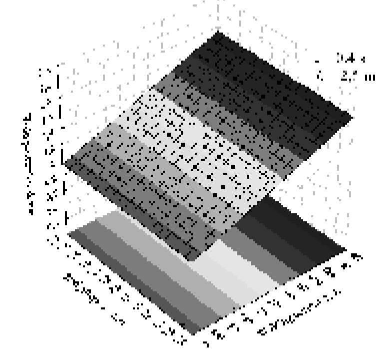
a) P = 2 mm, L = 2,5 mm



b) t = 0,4 s, P = 2 mm



c) I = 550 A, P = 2 mm



d) t = 0,4 s, L = 2,5 mm

Fig. 3 *Regression surface of the weld penetration*

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