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# THE INFLUENCE OF WELDING PARAMETERS ON WELD CHARACTERISTICS IN ELECTRIC ARC STUD WELDING

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In this paper the influence of welding parameters on weld geometry during stud welding (Drawn Arc Welding process with ceramic ferrule) on steel plate and pipe is analyzed as a variation of weld penetration. The changes of weld characteristics are also confirmed through measurements of HV0,2 across the weld joint and analysis of hardened zone.

*Key words:* stud welding parameters, weld geometry, penetration depth, HV0,2

**Utjecaj parametara zavarivanja na karakteristike zavarenog spoja kod elektrolučnog zavarivanja svornjaka.** U ovom je radu analiziran utjecaj parametara zavarivanja na geometriju zavara kod zavarivanja svornjaka (elektrolučnog zavarivanja svornjaka s keramičkim prstenom) na čelični lim i cijev kroz promjene dubine protaljivanja zavara. Također, promjene karakteristika zavara su potvrđene kroz mjerenja tvrdoće HV0,2 preko zavarenog spoja i analize zone otvrdnuća.

*Ključne riječi:* parametri elektrolučnog zavarivanja svornjaka, geometrija zavara, dubina protaljivanja, HV0,2

## INTRODUCTION

The application of the stud welding process is well established in different production areas: steam boiler production, bridge and other types of construction industries, automotive and appliance industry. This is a highly efficient welding process where a stud is welded on the work piece based on heat developed in short lasting electric arc that locally melts the welding spot, and short time pressure that creates physical joining of the weldment. There are different types of stud welding processes like: drawn arc stud welding with ceramic ferrule or shielding gas, short-cycle drawn arc stud welding, capacitor discharge drawn arc stud welding, capacitor discharge stud welding with tip ignition and drawn arc stud welding with fusible collar [1]. According to [2] the manufacturers are able to address many of the cost reduction targets by using drawn arc stud welding, but the quality and reproducibility of such stud welds have been a concern, although over the years, improvements of the power supply and more precise welding heads increase the reliability of this process.

It is a well known fact that optimal selection of welding parameters plays an important role in the quality of arc welding processes, but it is still the subject of researches for different arc welding processes [2-6]. In this experimental research the welding was performed by drawn arc stud welding with ceramic ferrule process (DAW with ceramic ferrule), as this welding process is widely used in steam boiler production for placing the isolation coatings on membrane walls affected by flue gasses. The studs for this application are usually made from temperature resistant steel types that can have conditional weldability. Depending on the shape and dimensions of the studs, it is possible to weld up to 1000 studs in one working shift [7]. The operation sequence for DAW process with ceramic ferrule is shown in Figure 1.

There are following welding parameters during stud welding with ceramic ferrule: plunge $P$/mm (the length of stud that protrudes beyond the ferrule); lift $L$/mm (the distance the gun pulls the stud away from the base material, the lift creates an 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 from the power source that flows across the air gap created by the lift) [9].

This study was conducted to evaluate the influence of welding parameter changes on the difference in welding geometry during welding on a plane surface and on a pipe. The weld characteristic changes, due to welding with different parameters, are also analysed by weld joint hardness measurements (HV0,2).

## EXPERIMENTAL SETUP

According to experimental setup, the DAW stud welding was foreseen and it was performed with semiau-

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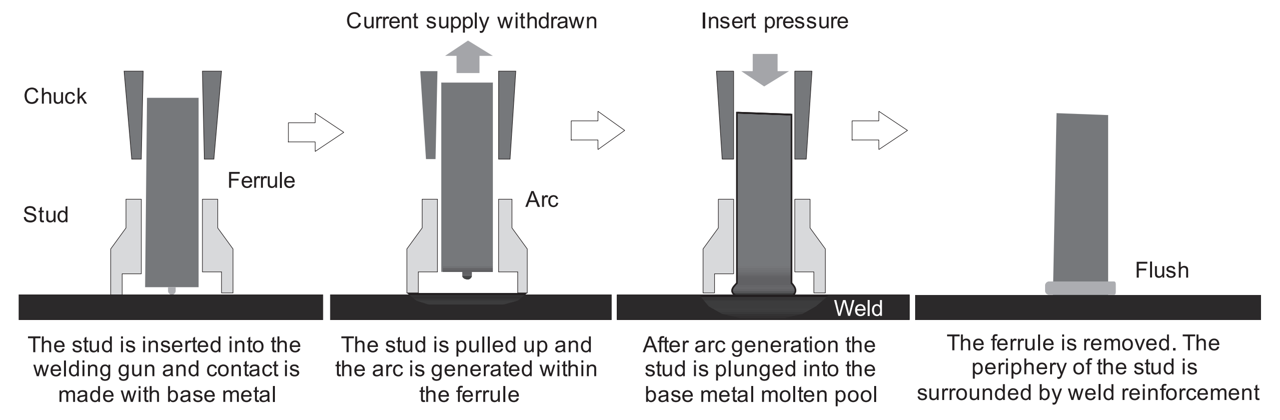


**Figure 1.** Welding operation sequence for stud arc welding with ceramic ferrule [8]

Table 1. **Experimental design (stud welding parameters)**

| Welding time *t* / s | Welding current *I* / A | Base metal geometry | Specimen No. | | | Type of test |
|---|---|---|---|---|---|---|
| 0,35 | 500 | Plate | 1A | 1B | 1C | Analysis of weld macro-structure (penetration depth measurements) Hardness HV0,2 (lengths of hardened zones of welded joint) |
| | 600 | Plate | 2A | 2B | 2C | |
| 0,45 | 500 | Plate | 3A | 3B | 3C | |
| | 600 | Plate | 4A | 4B | 4C | |
| 0,35 | 500 | Pipe | 5A | 5B | 5C | Analysis of weld macro-structure (penetration depth measurements) |
| | 600 | Pipe | 6A | 6B | 6C | |
| 0,45 | 500 | Pipe | 7A | 7B | 7C | |
| | 600 | Pipe | 8A | 8B | 8C | |

tomatic 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 and base material geometry: welding was performed on the steel plate and on the steel pipe (pipe diameter was 63,5 mm). The values of the plunge and lift were held constant ($P$ = 2,9 mm and $L$ = 2,5 mm). The setup of selected welding variables is shown in Table 1.

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).

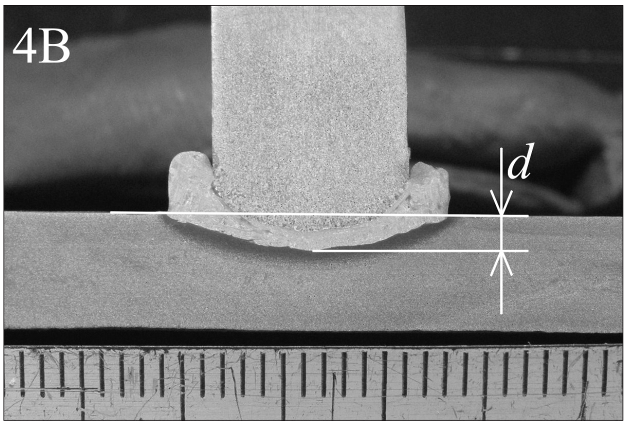


**Figure 2**. Illustration of penetration depth measurement (specimen no 4B)

## Macro section analysis

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 [10]. A schematic illustration of bead penetration measurement is shown in Figure 2.

## Hardness measurement

In order to additionally analyze and confirm weld characteristic changes due to welding with different parameters, hardness measurements HV0,2 were performed on the samples welded on the steel plate (Table 1, samples from 1A to 4C). The macro section of the specimen 4B with marked direction of hardness measurement is shown in Figure 3. In the base metal the hardness measurement steps were 0,5 mm and 0,25 mm in the area of expected heat affected zone and in the weld zone.

## TEST RESULTS AND ANALYSIS

24 specimens altogether with different welding current, weld time and base metal geometry were welded

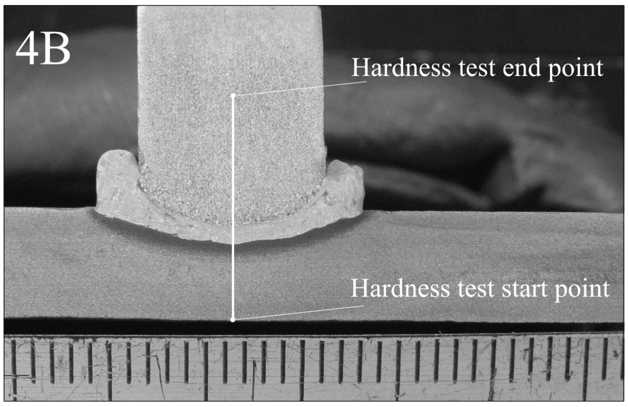


**Figure 3.** Illustration of hardness measurement HV0,2 (specimen no 4B)

and the depth of penetration was measured for all cases. The results are shown in Table 2 (the table is adapted for analysis purposes of full factorial designs in two levels $2^3$). The factors (A – welding current, B – welding time and C – type of base metal geometry Plate/Pipe) and their levels are defined.

Table 2. **The depth of penetration results**

| **Penetration depths *d*, mm** | **$C_1$ Plate** | | **$C_2$ Pipe** | |
|---|---|---|---|---|
| | $B_1$ $t$ =0,35 s | $B_2$ $t$ =0,45 s | $B_1$ $t$ =0,35 s | $B_2$ $t$ =0,45 s |
| $A_1$ $I$=500 A | (1) 0,98 1,08 1,22 | (b) 1,15 1,29 1,2 | (c) 1,18 1,05 1,17 | (bc) 1,31 1,43 1,37 |
| $A_2$ $I$=600 A | (a) 1,44 1,46 1,21 | (ab) 1,7 1,78 1,75 | (ac) 1,59 1,69 1,52 | (abc) 2,22 2,16 2,14 |

## ANALYSIS OF WELD JOINT GEOMETRY

The analysis of the values of the penetration depth is conducted in two steps: Effect analysis and Analysis of variance.

The values for main and interaction effect are listed in Table 3. From the effects analysis it is evident that the increase of the values for all parameters is connected with the increase of penetration depths. Also it is clear that welding current (factor A) is the most important factor and then follows the welding time and the base metal geometry. The interactions of factors are less significant in all combinations, since the effect values are low.

The information on significance of calculated effects are also gained by conducting the analysis of variance, and the results are shown in Table 4. From tables of $F$ distribution the critical value for 95 % confidence for $F$(1,16 df) is 4,49.

From the comparison of the calculated variance ratio $v_o$ with the value $F$ for 95 % confidence it is visible that factors A (welding current), B (welding time) and C (type of base metal geometry Plate/Pipe) are meeting criteria $v_0 > F$. The interaction of these three factors does not meet the criteria $v_0 > F$.

Table 3. **Full design matrix for two level full factorial $2^3$ design with effect calculations**

| Effect mark | (1) | a | b | ab | c | ac | bc | abc | Sum | Div. | Effect |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | - | + | - | + | - | + | - | + | 6,23 | 12 | 0,52 |
| B | - | - | + | + | - | - | + | + | 3,91 | 12 | 0,33 |
| AB | + | - | - | + | + | - | - | + | 1,77 | 12 | 0,15 |
| C | - | - | - | - | + | + | + | + | 2,57 | 12 | 0,21 |
| AC | + | - | + | - | - | + | - | + | 1,39 | 12 | 0,12 |
| BC | + | + | - | - | - | - | + | + | 0,95 | 12 | 0,08 |
| ABC | - | + | + | - | + | - | - | + | 0,25 | 12 | 0,02 |
| M | + | + | + | + | + | + | + | + | 35,09 | 24 | 1,46 |

Table 4. **Analysis of variance**

| **Source of variation** | **Sum of squares *SS*** | **Degr. of freedom *DF*** | **Mean of square *MS*** | **Variance ratio $v_o$** |
|---|---|---|---|---|
| A | 1,617 | 1 | 1,617 | 221,66 |
| B | 0,637 | 1 | 0,637 | 87,31 |
| AB | 0,131 | 1 | 0,131 | 17,89 |
| C | 0,275 | 1 | 0,275 | 37,72 |
| AC | 0,081 | 1 | 0,081 | 11,03 |
| BC | 0,038 | 1 | 0,038 | 5,15 |
| ABC | 0,003 | 1 | 0,003 | 0,36 |
| Error | 0,117 | 16 | 0,00732 | |

## ANALYSIS OF THE LENGTHS OF HARDENED ZONES OF WELDED JOINT

From the analysis of the measured hardness HV0,2 (the examples of the measured values for it are specimens no 1B and 4B as shown in Figure 4) it is evident that with an increase of welding parameters (welding current and voltage) there is a growth of hardened zone in the weld area. Since the object of this investigation was to determine the influence of the mentioned parameters on the hardened zone due to welding process (the zone of structural transformation), it was necessary to make the dimensional analysis of this zone. So, the problem was to define the zone of hardness increase (hardened zone). If it is supposed that the average level of hardness for the base metal was 205 HV0,2 and for the stud 215 HV0,2 then the area with hardness increase of 10 % can be considered as hardened (226 HV0,2 for the base metal and 237 HV0,2 for the stud). In Figure 4 the results of measured hardness that are meeting the given criteria for the hardened zone are shown by the marked area.

The results of determined length of hardened zone defined by described criteria are shown in Table 5 (the table is adapted for analysis purposes of full factorial designs in two levels $2^2$). The factors (A – welding current, B – welding time) and their levels are defined. The analysis of the values of the length of hardened zone is also conducted in two steps: effect analysis and analysis of variance.

Table 5. **The length of hardened zone**

| Lengths of hardened zones $l$/mm | $B_1$ $t$ =0,35 s | $B_2$ $t$ =0,45 s |
|---|---|---|
| A1 $I$=500 A | (1) 1<br>1,25<br>1,75 | (b) 1,5<br>1,75<br>1,75 |
| A2 $I$=600 A | (a) 2<br>2,25<br>2 | (ab) 2,25<br>3<br>3,25 |

The values for main and interaction effect are listed in Table 6. From the effect analysis it is evident that the increase of the values for both parameters is connected with the increase of hardened zone length. It is also clear that welding current (factor A) is far more important. The interaction of factors is the least significant since the effect value is low.

Table 6. **Full design matrix for two level full factorial $2^2$ design with effect calculations**

| Effect mark | (1) | a | b | ab | Sum | Divisor | Effect |
|---|---|---|---|---|---|---|---|
| A | - | + | - | + | 5,75 | 6 | 0,958 |
| B | - | - | + | + | 3,25 | 6 | 0,542 |
| AB | + | - | - | + | 1,25 | 6 | 0,208 |
| M | + | + | + | + | 23,75 | 12 | 1,979 |

The results for analysis of variance are shown in Table 7. From tables of $F$ distribution the critical value for 95 % confidence for $F$(1,8 df) is 5,32. From the comparison of the calculated variance ratio $v_o$ with the value $F$ for 95 % confidence it is visible that both factors (A - welding current, B - welding time) are meeting the criteria $v_0 > F$. The interaction of these factors does not meet this criterion.

Table 7. **Analysis of variance**

| Source of variation | Sum of squares $SS$ | Degr. of freedom $DF$ | Mean of square $MS$ | Variance ratio $v$ |
|---|---|---|---|---|
| A | 2,755 | 1 | 2,755 | 24,05 |
| B | 0,880 | 1 | 0,880 | 7,68 |
| AB | 0,130 | 1 | 0,130 | 1,14 |
| Error | 0,917 | 8 | 0,115 | |

## CONCLUSION

With conducted laboratory investigations of arc stud welding process, the influence of welding parameters on the penetration depth and additionally, on hardened zone length, are researched.

In order to determine the influence of level changes on penetration depth, the design of experiment was conducted and three factors are varied (welding current, welding time and base metal geometry: plate or pipe) on two levels. The effect analysis has shown an important influence of welding current, time and weld geometry on penetration during welding. Interactions of factors show low significance. The analysis of variance has also shown that welding current has the biggest influence on the penetration depth increase. Also, the highest pene-

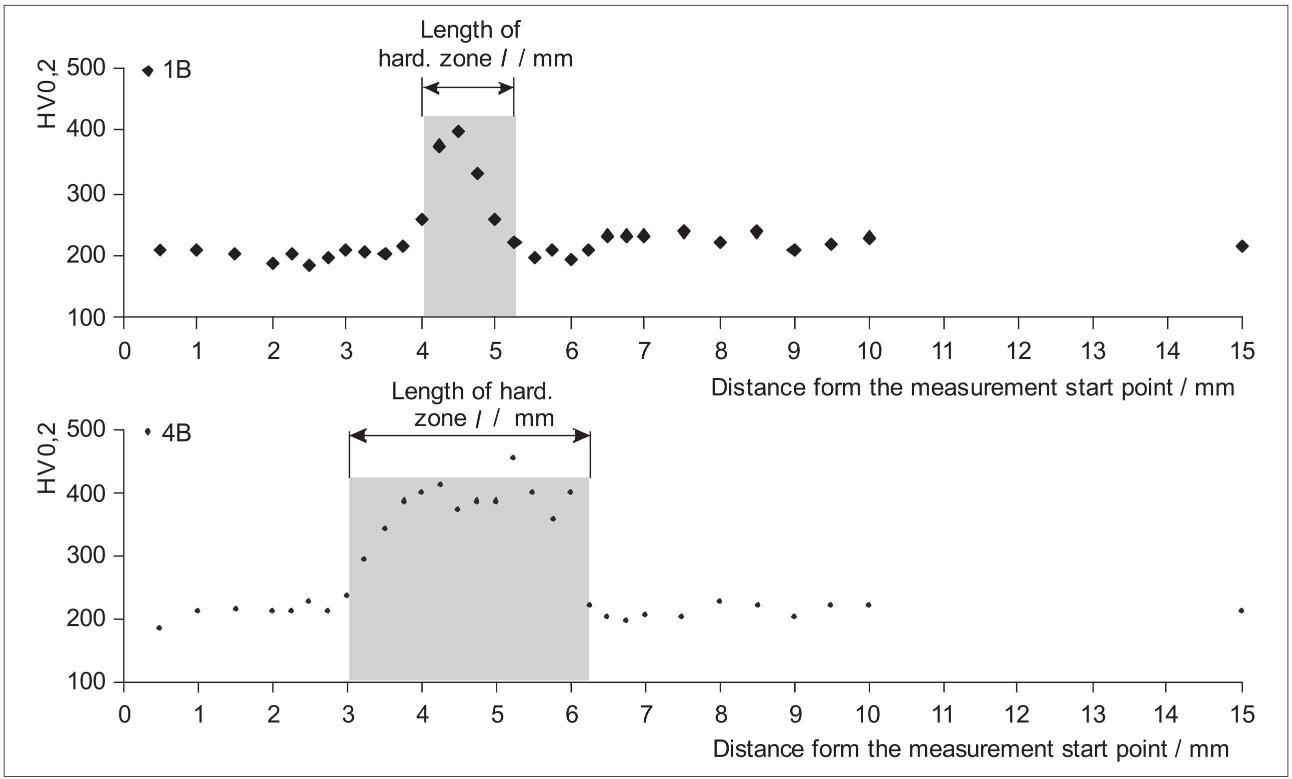


**Figure 4.** Weld hardness HV0,2 (hardened zone) for the specimen no 1B and 4B

tration depth is achieved during welding on pipe with high level of welding current and welding time.

The analysis of the lengths of hardened zones of welded joint was also performed as effect analysis and the analysis of variance through design of experiment as two factors were varied (welding current and welding time) on two levels. Both analyses have shown that welding current has a huge influence on the hardened zone increase.

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