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FACTORS AFFECTING WELD SHAPE IN WELDING WITH A TRIPLE-WIRE ELECTRODE

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The article describes the influences of welding parameters, modes of metal transfer through the arc and the number of wires applied on weld formation and final shape. Diagrams show the influence of current intensity and arc voltage while a figure shows the influence of streaming and rotating metal transfers on the final weld shape. Diagrams and macro specimens, however, show the influence of the number of wires used on the weld shape and weld formation in submerged arc welding with a triple-wire electrode.

Key words: *weld, triple electrode, fusion arc welding, metal transfer*

Faktori koji utječu na oblik zavara kod elektrolučnog zavarivanja trostrukom žičanom elektrodom. U članku je opisan utjecaj parametara zavarivanja, utjecaj načina prolaska materijala kroz električni luk i utjecaj broja žica na nastajanje zavara i njegov konačni oblik. Pomoću dijagrama su prikazani utjecaji jačine struje zavarivanja i napetosti električnog luka, a slika prikazuje utjecaj prelaska materijala tečenjem i utjecaj prelaska materijala okretanjem na završni oblik zavara. Dijagramima i pomoću makrobrušenih uzoraka prikazan je utjecaj broja žica na oblik i nastanak vara kod zavarivanja trostrukom žičanom elektrodom pod zaštitom praha.

Ključne riječi: *zavar, trostruka žičana elektroda, elektrolučno zavarivanje topljenjem, prelazak materijala*

INTRODUCTION

In fusion arc welding the final weld shape is influenced by welding parameters, mode of metal transfer, number of welding wires used and their arrangement in the contact tube, type of material to be welded, type of shielding medium and similar.

In some articles, descriptions of investigations on the influence of the kind of material and the type of shielding medium used on the weld shape and size can be found [1-4]. Articles describing the influences of temperature gradient of surface tension, in which the arc is burning, and of electromagnetic forces on motion of the weld pool and the weld depth and shape can also be found [5-7]. M. Ushio supplies even a mathematical description of motion of the weld pool in TIG welding [8, 9].

Not even a single publication, however, has been found to report on influences of metal transfer and the number of wires in the contact tube on weld formation.

INFLUENCE OF WELDING PARAMETERS ON WELD FORMATION AND FINAL SHAPE

The welding current is the most important parameter. An increase in this parameter produces an increase in the penetration depth and the weld cross section.

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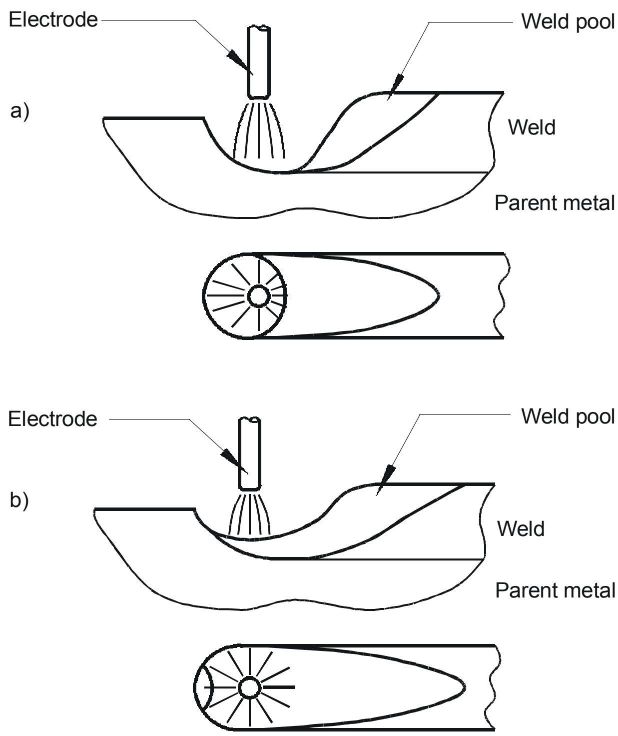


Figure 1. **Two different modes of melting the parent metal: a) directly by arc, b) indirectly by arc via the weld pool**
Slika 1. **Dva različita načina topljenja osnovnog materijala: a) izravno električnim lukom, b) neizravno električnim lukom preko taljevine zavara**

Welding voltage *U* is influenced mostly by the arc length. Increase in the arc length produces increase also in the range of movement of the cathode spot and anode spots on the workpiece, which consequently produces increase in the weld width.

Welding speed *v* is a very important welding parameter too. An increase in welding speed produces a decrease in heat input and the volume of deposited metal per unit of length of the weld. Welding speed has a specific influence on the weld penetration. At a high speed the weld pool, which is formed from the parent metal and the filler material, can not follow the arc and will lag behind. In this case, the arc will burn between the electrode and the unmolten workpiece, which results in a greater penetration depth h_u than in the case of a somewhat lower welding speed *v*, where the arc is burning between the electrode and the weld pool, which prevents the arc to melt the parent metal deeper. Figure 1. shows both modes of arc burning described above.

The influence of welding speed *v* on the penetration depth h_u is shown in Figure 2.. The penetration depth as a function of the welding speed is shown with two different sets of welding conditions. The first curve shows the in-

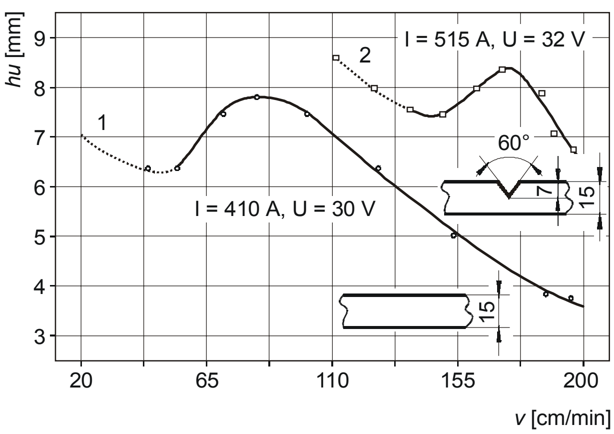


Figure 2. **Influence of welding speed *v* on the penetration depth *hu* in submerged arc welding with triple electrode, wire *d* = 3 mm, *b* = 9 mm, *L* = 25 mm, electrode positive**

Slika 2. **Utjecaj brzine zavarivanja na dubinu uvara kod zavarivanja trostrukom elektrodom pod prahom: žica *d* = 3 mm, *b* = 9 mm, *L* =25 mm, plus pol na elektrodi**

fluence of welding speed *v* on the penetration depth in triple-wire electrode submerged arc welding on a flat plate, without welding edge preparation, with a current intensity *I* of 410 A per wire, and with a welding voltage *U* of 30 V. The diagram shows that the penetration depth h_u decreases with the increase in welding speed *v* up to 45 cm/min, then it begins to increase along with the increase in welding speed *v* from 45 cm/min up to 75 cm/min, and finally it again decreases if welding speed *v* is increased above 75 cm/min. The initial and final parts of the curve are quite logical since with increase in the welding speed, heat energy input decreases, which causes the penetration depth to reduce. The part of the curve indicating the increase in the penetration depth h_u, however, can be explained by a transition from the indirect mode of melting the parent metal to the direct one. This indicates that the increase in the welding speed *v* above 45 cm/min produces decrease in the weld pool depth under the first arc, i.e. the weld pool begins to lag behind with regard to the first arc.

Similar findings could be stated for curve no. 2 in the same diagram, the only difference being that the transition from the indirect melting of the parent metal to the direct one is going on at a much higher welding speed *v* due to a higher current intensity *I* and a differently shaped welding groove [10].

INFLUENCE OF THE MODE OF MATERIAL TRANSFER ON WELD FORMATION AND SHAPE

The mode of material transfer is largely influenced by welding parameters, the shielding medium used, the type of power source, and the pressure in which the arc is burn-

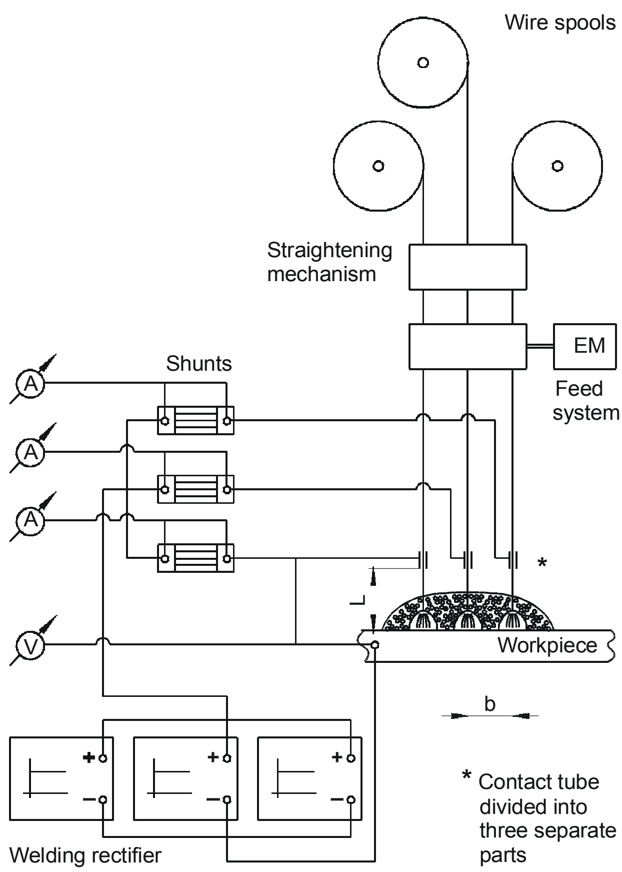


Figure 3. **Schematic representation of equipment for triple-wire welding: *L* - wire extension length, *b* - distance between two wires**

Slika 3. **Shematski prikaz naprave za zavarivanje trostrukom žičanom elektrodom. *L* - slobodna duljina elektrodne žice; *b* - razmak između dvije žice** ing. Modes of material transfer may be classified, according to the International Institute of Welding (IIW), into eight groups [1].

The greatest influence on the weld shape is exerted by the rotating material transfer. Current density in the wire is so high that electromagnetic forces induce rotation of the wire extension, the melted material of the wire extension flows in a stream into the weld and forms a rather wide penetration.

INFLUENCE OF THE NUMBER OF WIRES USED ON WELD FORMATION AND FINAL WELD SHAPE

It has already been stated that almost no data are available in the literature on the influence of the number of wires used on weld formation or on the function of individual wires in weld shaping in multiple-wire welding.

The influence was investigated in submerged arc welding with a triple-wire electrode. Equipment for triple-wire welding is schematically shown in Figure 3.. All three wires are fed through a joint contact tube, they have a common power source, the same feed rate and joint regulation. In our investigations, the wires were arranged in the tandem position, i.e. one after another in the welding direction [11].

In the investigations, a wire for submerged arc welding with a diameter d of 2 mm was used, the distance between wires b being 8 mm and the wire extension length L 25 mm. Welding was carried out at welding speeds v of 0.7 m/min, 1.4 m/min, and 1.8 m/min. With each speed, a differently shaped groove was applied (Figure 4.).

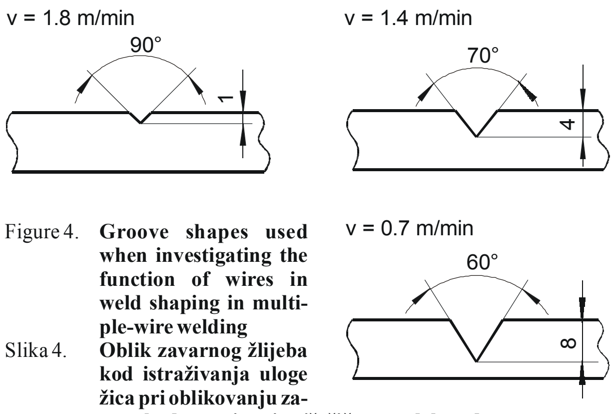


Figure 4. **Groove shapes used when investigating the function of wires in weld shaping in multiple-wire welding**

Slika 4. **Oblik zavarnog žlijeba kod istraživanja uloge žica pri oblikovanju zavara kod zavarivanja višežičanom elektrodom**

Current intensity I was 390 A for the first three welds and 480 A for the other three welds. That is to say that the modes of weld formation and the influence of the wires in weld shaping were investigated in eighteen different welds, i.e., six of them with a single wire, six with a twin-wire electrode, and six with a triple-wire electrode. All the welds were submerged arc welded, the conditions per wire being the same for all. This is further to say that the welding speed v and the arc voltage U were constant.

Each welding performed, the weld concerned was cut, a macrosection was made, its dimensions were measured, and the results obtained were plotted in the diagram shown in Figure 5.. The diagram shows six curves each consisting of three parts. The first (left) part of each curve represents the penetration depth h_u and the penetration width b_u of a weld produced with a single wire, the second (middle) part of each curve the penetration depth and width of a weld produced with a twin-wire electrode, and the third (right) part of each curve the penetration depth and width of a weld produced with a triple-wire electrode. In all three variants of welding shown with a single curve, the welding current per wire, the wire feed speed and the welding speed were the same. All six curves, however, indicate that the first wire, either in a twin-wire electrode or in a triple-wire electrode, primarily affects the penetration depth h_u and the penetration width b_u least.

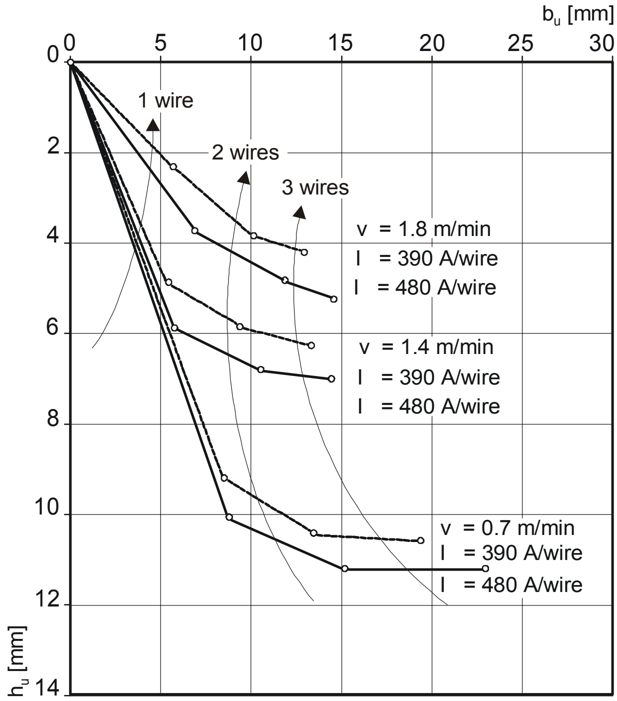
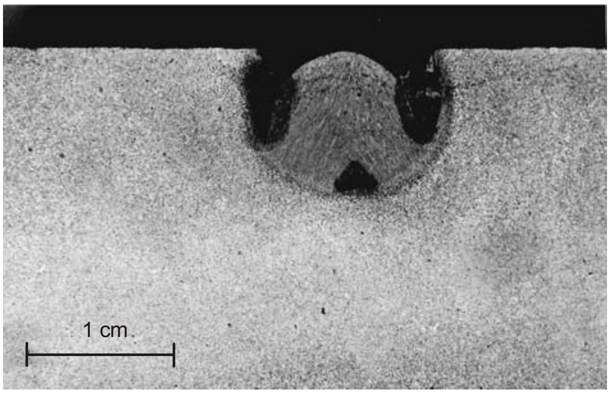


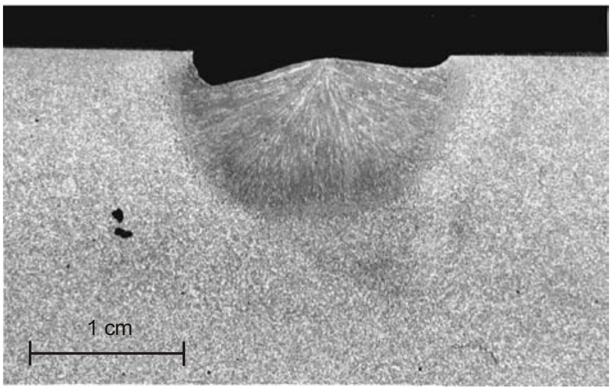
Figure 5. **Influence of the number of wires used on formation of penetration depth hu and width bu in submerged arc welding**

Slika 5. **Utjecaj broja upotrebljenih žica kod nastajanja dubine hu i širine uvara bu pri zavarivanju pod prahom**

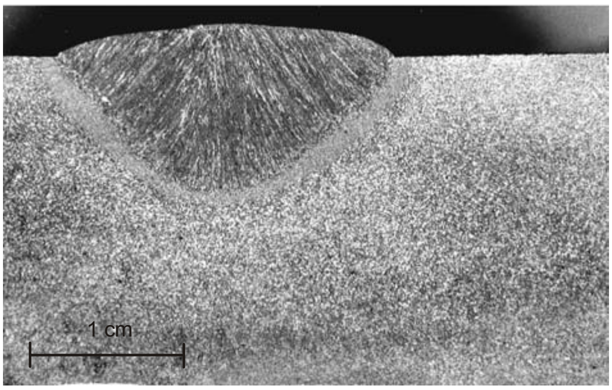
The welding parameters stated permitted, in all the cases of welding, direct melting of the parent metal. The welding speeds v were namely selected in such a way that the weld pool lagged behind with regard to the first arc. This holds true for welding with the single electrode as well as with the twin and triple electrodes. Macrographs in Figure 6. indicate that direct melting of the parent metal, in order to obtain a quality weld, may be achieved only in welding with several wires or with a multiple-wire electrode.



1st weld - single wire



2nd weld - twin wire



3th weld - triple wire

Figure 6. **Macro sections of welds; submerged arc welding with single-wire, twin-wire and triple-wire electrodes with constant welding speed and with the same welding parameters per wire: *I* = 480 A /wire, *U* = 35 V, *v* = 0.7 m/min, wire *d* = 2 mm, *L* = 25 mm**

Slika 6. **Makrobrušeni uzorci zavara, zavarenih jednostrukom, dvostrukom i trostrukom žičanom elektrodom pod prahom s konstantnom brzinom i jednakim parametrima zavarivanja na jednu žicu: *I* = 480 A/žici, *U* = 35 V, *v* = 0,7 m/min, žica *d* = 2 mm, *L* = 25 mm**

The second wire, either in a twin-wire electrode or in a triple-wire electrode, affects the penetration depth h_u far less than the first one. The weld pool being formed under the second wire, the arc is burning between the second wire and the weld pool, while arc energy only partly produces melting of the parent metal. The third wire contributes to a greater penetration depth h_u only with higher welding speeds *v*, while with lower welding speeds *v* it has no effect on the penetration depth h_u (Figure 6.).

CONCLUSIONS

The paper treats influences of welding parameters, modes of metal transfer through the arc and the function of wires in multiple-wire welding in weld formation and the final weld shape.

Theoretical and practical investigations have confirmed some known facts and permitted to draw some new conclusions as follows:

- direct melting of the parent metal can be obtained practically only in multiple-wire welding or multiple-electrode welding;
- the first wire in triple-wire welding primarily affects the penetration depth;
- the second wire partly affects the penetration depth and partly the penetration width;
- in welding with the triple-wire electrode, the third wire in the welding direction practicallydoes not affect the weld depth but it affects the penetration width and finally shapes the weld face.

Physical quantities / Popis fizikalnih veličina

b - distance between two wires, mm
b_u - penetration width, mm
d - wire diameter, mm
h_u - penetration depth, mm
I - welding current, A
L - electrode extension length, mm
U - arc voltage, V
v - welding speed, m/min

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