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Varjenje z večžično elektrodo Multiple-Wire Electrode Welding

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V članku je podan pregled raziskav in dobljenih rezultatov pri varjenju z večžično elektrodo v različnih zaščitah. Raziskave so bile opravljene na Fakulteti za strojništvo v Ljubljani v zadnjih sedmih letih. V uvodnem delu je podan kratek pregled literature s tega področja in najpomembnejše dosedanje objave obeh avtorjev. Nadalje je opisan razvoj varilne naprave za zvarjanje in navarjanje z dvojno, trojno in četverno žično elektrodo. Prikazane so poglavitne tehnološke in ekonomske značilnosti postopka in podani podatki o trdnostnih lastnostih zvarov, narejenih pod prškom z večžično elektrodo. Na koncu so prikazane glavne prednosti varjenja z večžično elektrodo v primerjavi z varjenjem z eno samo žico v kontaktni šobi.

The paper reviews investigations carried out at the Faculty of Mechanical Engineering in Ljubljana in the last seven years and the results obtained in welding with a multiple-wire electrode in various shielding atmospheres. The first part gives a short authors of the present literature survey in this field and states the most important publications issued by the present paper to date. The development of a welding apparatus for welding and surfacing with double-wire, triple-wire and quadruple-wire electrodes is then described. Basic technological and economic characteristics of the process and data on strength properties of the welds made by submerged arc welding with multiple-wire electrode are given. In conclusion, basic advantages of welding with multiple-wire electrode over welding with single wire in a contact nozzle are shown.

0. UVOD

V varilni tehniki je splošno znano zvarjanje in navarjanje s taljivo in z metaljivo elektrodo v različnih zaščitah. O varjenju s taljivo elektrodo govorimo, kadar se dodajni material tali in skupaj z osnovnim materialom sestavlja zvarni spoj. Pri varjenju z metaljivo elektrodo, običajno je to volframova z dodatnimi legirnimi elementi, je ta namenjena samo za vzdrževanje oblaka. Lahko se vari brez dodajnega materiala ali z njim, in sicer v obliki žice, traku ali kovinskega prahu. Že dolgo pa je iz literature znano in v praksi uveljavljeno zvarjenje in navarjanje z dvojno taljivo žično in tračno elektrodo v zaščitnem plinu in pod prškom [1] do [4].

Razlikujemo varjenje z večžično elektrodo pod zaščito prška, varjenje v zaščiti plinskih mešanic in varjenje s strženskimi žicami brez zaščite, v zaščiti plinov ali prškov.

0. INTRODUCTION

In welding engineering, welding and surfacing with both consumable and non-consumable electrodes in various shielding atmospheres are commonly used. Welding with a consumable electrode is a process in which the filler material melts and, jointly with the parent metal, forms a welded joint. Welding with a non-consumable electrode is a process in which the electrode, usually tungsten with additional alloying elements, serves only to maintain the arc. Welding can be performed with or without filler material, which can be in the form of wire, strip or metal powder. However, gas-shielded and submerged arc welding and surfacing processes with double wire electrode and strip electrode have been described in the literature, [1] to [4], and established in practice for a long time.

Within submerged arc welding, we distinguish multiple-wire electrode, gas mixture shielded arc welding and welding with flux-cored wires without shielding or gas-shielded arc welding with flux-cored wires.

O raziskavah in dobljenih rezultatih smo tudi že poročali na številnih domačih [5]–[7] in tujih [8]–[14] posvetovanjih ter domačih [15]–[18] in tujih revijah [19]–[21]. Na tem področju je bilo opravljenih več diplomskih del [22]–[26], eno magistrsko delo [27] in ena doktorska disertacija [28]. Zelo ugodni rezultati raziskav varjenja z večžično elektrodo so bili tudi temelj za razvoj prve industrijske naprave za varjenje s trojno žično elektrodo v tovarni Iskra – Avtomatika v Ljubljani.

Razpored žic pri varjenju z večžično elektrodo v trikotni, četverokotni in drugih oblikah v skupni kontaktni šobi je tudi zaščiten s patentom.

Najnovejši rezultati raziskav varjenja z večžično elektrodo pod praškom potrjujejo tudi boljši prehod legirnih elementov iz varilnega praška v var v primerjavi z varjenjem z enojno žično elektrodo [29].

1. NAPRAVA Z VEČŽIČNO ELEKTRODO

Varilna naprava za varjenje z večžično elektrodo se bistveno ne razlikuje od naprave za varjenje z enojno žično ali enojno tračno elektrodo v različnih zaščitah. V tem primeru ima naprava enotno kontaktno šobo, skozi katero se pomikata dve do pet ali več žic hkrati. Vse žice imajo skupen pogon in ravnalni mehanizem, en sam vir varilnega toka in skupno enotno regulacijo.

Na sliki 1 je shematsko prikazana varilna naprava s trojno žično elektrodo s pogonskim in ravnalnim mehanizmom ter s skupno kontaktno šobo.

Razporeditev žic v kontaktni šobi je lahko zelo raznolika in je odvisna od konkretnne praktične potrebe.

We have reported on the investigations carried out and on the results obtained in numerous domestic, [5]–[7] and foreign, [8]–[14] conferences and in domestic, [15]–[18] and foreign, [19]–[21] journals. In this field, several graduation papers, [22]–[26], one Master's thesis [27] and one doctoral thesis [28] have been written. The very favourable results of the investigation of welding with a multiple-wire electrode were the basis for the development of the first industrial welding unit for welding with a triple-wire electrode in the company Iskra – Avtomatika of Ljubljana.

The arrangement of wires in welding with a multiple-wire electrode in triangular, rectangular and other forms in a joint contact nozzle is also patented.

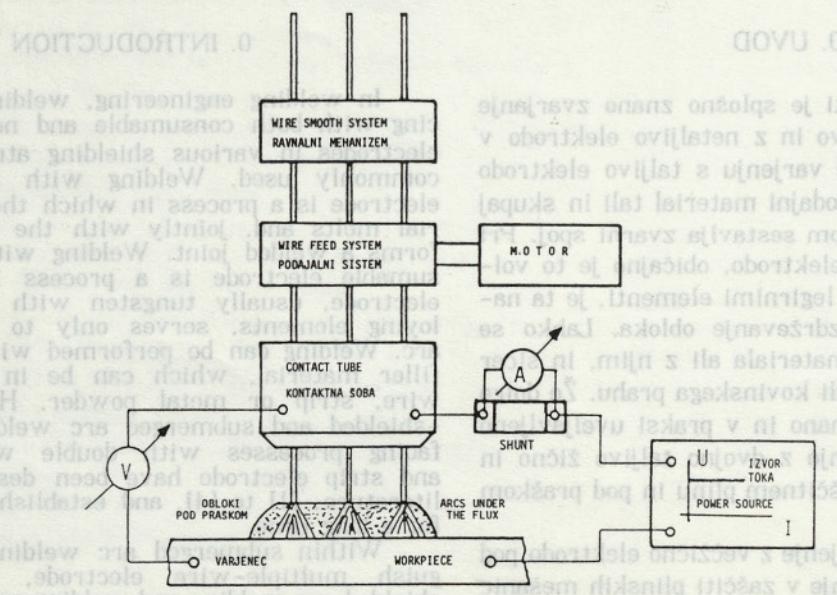
The latest results obtained in the study of submerged arc welding with a multiple-wire electrode also provide evidence of a more favourable transfer of alloying elements from the welding powder into the weld metal in comparison with welding with a single-wire electrode [29].

1. UNIT WITH A MULTIPLE-WIRE ELECTRODE

A welding unit for welding with a multiple-wire electrode does not differ essentially from a welding unit for welding with a single-wire electrode or with a single-strip electrode in various shielding atmospheres. In this case, the unit has a joint contact nozzle through which two to five or more wires at a time are fed. All the wires have a common feed and straightening mechanism, a single power source and a common uniform control.

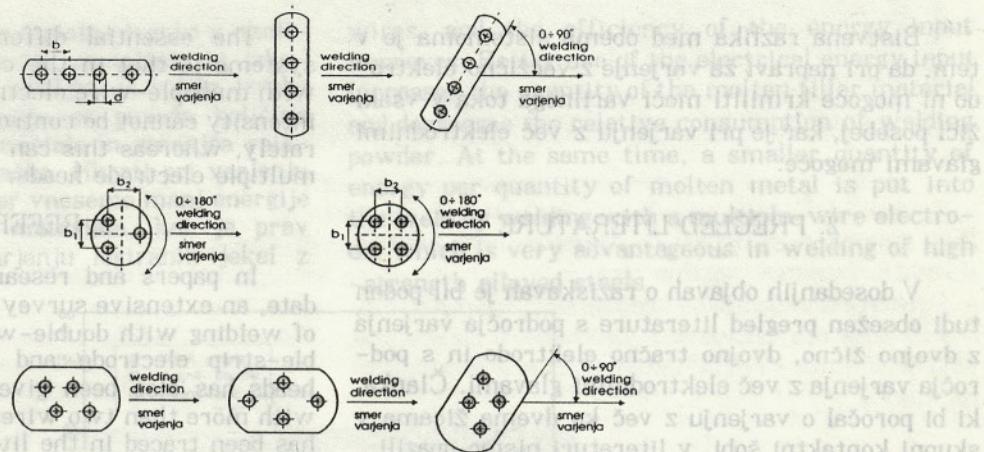
Fig. 1 is a schematic presentation of a welding unit with a triple-wire electrode with a drive and straightening mechanism and a joint contact nozzle.

The wire arrangement in the contact nozzle can be very varied and depends on the particular practical requirements.



Sl. 1. Shematski prikaz naprave za varjenje s trojno žično elektrodo.

Fig. 1. Schematic presentation of a welding unit with triple-wire electrode.



Sl. 2. Mogoče razporeditve žic v skupni kontaktni šobi pri varjenju z večžično elektrodo.

Fig. 2. Possible wire arrangements in the joint contact nozzle in welding with multiple-wire electrode.

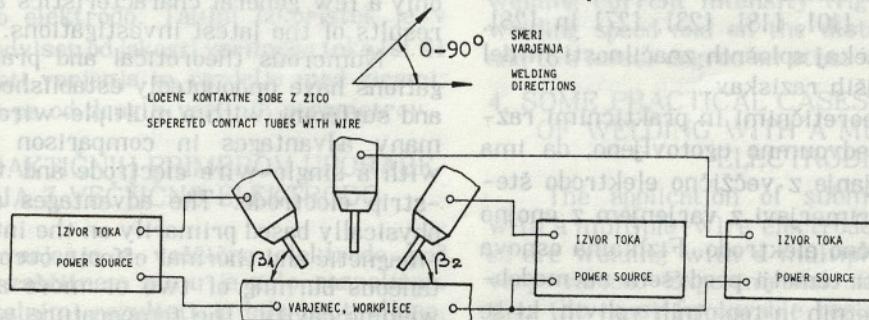
Na sliki 2 je prikazanih samo nekaj primerov razporeda žic v kontaktni šobi pri varjenju s trojno in četverno žično elektrodo.

Z razporedom žic je mogoče vplivati na geometrijsko obliko varja, na količino vnesene energije v varjence, na talilni učinek in drugo. Z nesimetričnim razporedom žic pa je mogoče v zvarni spoj tudi nesimetrično vnesti energijo in raztaljeni dodajni material. Te prednosti, ki jih ima naprava za varjenje z večžično elektrodo, se zelo ugodno izkorisčajo za zvarjanje nesimetričnih varjencev, različnih oblik, dimenziij in mas.

Napravo je mogoče uporabiti za zvarjanje dveh ali več varjencev in za navarjanje obrabljenih ter drugih površin.

Varilna naprava z večžično elektrodo se bistveno razlikuje od naprave za varjenje z več elektrodnimi glavami. Na sliki 3 je takšna naprava shematsko prikazana.

S primerjavo naprav na sl. 1 in 3 lahko ugotovimo, da so razlike očitne in da gre za dve zelo različni varjenji oziroma dva postopka, ki sta uporabna na različnih področjih. Pri napravi za varjenje z več elektrodami pomeni vsaka elektroda oziroma varilna glava svoj celovit sistem za varjenje. Vsaka žica ima svoj pogonski in krmilni sistem, svojo kontaktno šobo in lasten vir varilnega toka.



Sl. 3. Shematski prikaz naprave za varjenje s tremi elektrodami.

Fig. 3. Schematic presentation of a welding unit with three electrodes.

Fig. 2 shows various cases of wire arrangement in the contact nozzle in welding with triple-wire and quadruple-wire electrodes.

On the basis of the wire arrangement, it is possible to affect the weld geometry, the quantity of energy put into a workpiece, melting rate, etc. By means of an asymmetric wire arrangement, it is also possible to put energy into the melted filler material asymmetrically. The advantages offered by the unit for welding with multiple-wire electrode can be turned to profitable use in welding of asymmetric workpieces, workpieces having different forms, dimensions and masses.

The welding unit can be used for welding of two or more workpieces and for surfacing of worn and other surfaces.

The welding unit with multiple-wire electrode, however, does essentially differ from the welding unit with multiple electrode heads. Fig. 3 schematically presents such a welding unit.

Comparison of the units in figs. 1 and 3 shows clearly that these are two very different welding processes applicable in different fields. In the welding unit with multiple electrodes, each electrode and electrode head is itself a complete welding system. Each wire has its own drive and control mechanisms, its own contact nozzle and its own power source.

Bistvena razlika med obema sistemoma je v tem, da pri napravi za varjenje z večžično elektrodo ni mogoče krmiliti moči varilnega toka v vsaki žici posebej, kar je pri varjenju z več elektrodnimi glavami mogoče.

2. PREGLED LITERATURE

V dosedanjih objavah o raziskavah je bil podan tudi obsežen pregled literature s področja varjenja z dvojno žično, dvojno tračno elektrodo in s področja varjenja z več elektrodnimi glavami. Članka, ki bi poročal o varjenju z več ko dvema žicama v skupni kontaktni šobi, v literaturi nismo opazili.

V tem članku bo zaradi tega navedenih le nekaj najnovejših objav, ki obravnavajo varjenje z dvojno žično elektrodo pod praškom in v zaščitnem plinu.

V poročilu švicarskega podjetja Oerlikon so prikazane tehnične, tehnološke in gospodarske prednosti varjenja z dvojno žično elektrodo pod praškom [30]. Prav tako nadaljujejo raziskave varjenja z dvojno žično elektrodo na Patonovem institutu v Kijevu [31].

Varjenje z dvojno žično elektrodo je mogoče uporabiti tudi v kombinaciji z več elektrodnimi glavami [32].

V zadnjem času smo zasledili še nekaj objav, ki poročajo o varjenju z dvojno žično elektrodo pod praškom [33], [34], [35] in v zaščitnem plinu v ozki reži [36].

Vse te objave dokazujejo, da varjenje z dvojno žično elektrodo še vedno ni dovolj raziskano in ima postopek številne praktične prednosti v primerjavi z varjenjem z enojno žično elektrodo.

3. EKONOMSKO-TEHNOLOŠKE ZNAČILNOSTI VARJENJA Z VEČŽIČNO ELEKTRODO

Pod ekonomsko-tehnološke značilnosti varilnega postopka štejemo talilni učinek, porabo praška in porabo energije, geometrijsko obliko zvara in navara ter nekatere druge značilnosti. Glede na to, da so bile omenjene karakteristike varjenja z večžično elektrodo že opisane v dosedanjih objavah [7], [10], [18], [23], [27] in [28], bomo tu podali le nekaj splošnih značilnosti in del rezultatov najnovejših raziskav.

S številnimi teoretičnimi in praktičnimi raziskavami je bilo nedvoumno ugotovljeno, da ima zvarjanje in navarjanje z večžično elektrodo številne prednosti v primerjavi z varjenjem z enojno žično in enojno tračno elektrodo. Fizikalna osnova omenjenih prednosti temelji predvsem na medobločnih elektromagnetskih in topotnih vplivih, ki se pojavijo ob hkratnem goreњu dveh ali več oblokov v skupni varilni kopeli. Temperatura v področju

The essential difference between the two systems is that in the case of the welding unit with multiple-wire electrode, the welding current intensity cannot be controlled for each wire separately, whereas this can be done in welding with multiple electrode heads.

2. REFERENCES

In papers and research reports published to date, an extensive survey of literature in the field of welding with double-wire electrode, with double-strip electrode and with several electrode heads has also been given. No paper on welding with more than two wires in a join contact nozzle has been traced in the literature.

The present paper will, therefore, mention only a few of the latest publications on submerged arc welding with a double-wire electrode and gas-shielded arc welding with a double-wire electrode.

A report by the Swiss firm, Oerlikon, states the technical, technological and economic advantages of submerged arc welding with a double-wire electrode [30]. Investigations on welding with a double-wire electrode arc have also taken place at the Paton Welding Institute in Kiew [31].

Welding with a double-wire electrode can also be applied in combination with several electrode heads [32].

There have recently been a number of reports on submerged arc welding with a double-wire electrode, [33], [34], [35], and on narrow-gap gas-shielded arc welding with a double-wire electrode [36].

All these papers demonstrate that welding with a double-wire electrode has not yet been sufficiently investigated, and that it has numerous practical advantages in comparison with welding with a single-wire electrode.

3. ECONOMIC AND TECHNOLOGICAL CHARACTERISTICS OF WELDING WITH A MULTIPLE-WIRE ELECTRODE

The economic and technological characteristics of the welding process comprise the melting rate, powder consumption, energy consumption, weld geometry, surfacing geometry and certain other characteristics. Since the characteristics mentioned above of welding with a multiple-wire electrode have already been described [7], [10], [18], [23], [27] and [28], we will discuss here only a few general characteristics and part of the results of the latest investigations.

Numerous theoretical and practical investigations have undoubtedly established that welding and surfacing with a multiple-wire electrode has many advantages in comparison with welding with a single-wire electrode and with a single-strip electrode. The advantages mentioned are physically based primarily on the inter-arc electro-magnetic and thermal effects occurring in simultaneous burning of two or more arcs in a joint welding cavity. The temperature within the arcs rises, relative thermal losses into the environment decrease with the increase in the number of

oblokov se zviša, relativne toplotne izgube v okolico se z večanjem števila žic zmanjšajo in izkoristek dovedene energije izboljša. Z boljšo izrabo dovedene električne energije se poveča količina raztaljenega dodajnega materiala in zmanjša relativna poraba varilnega praška. Hkrati pri varjenju z večjično elektrodo v zvar vnesemo manj energije na količino raztaljenega materiala, kar je prav tako zelo ugodno pri varjenju legiranih jekel z veliko trdnostjo.

Na sliki 7 je prikazana koeficienta talilnega izkoristka zvisla po smeri varjenja in vpliv teh dodatnih materialov in toplotne izgube.

Poleg z razporedom žic v zaporedni postavitev žic, žica $\varnothing = 2 \text{ mm}$.

Sl. 4. Vpliv jakosti varilnega toka na talilni izkoristek pri varjenju pod praškom z enojno, dvojno in s trojno žično elektrodo: $U = 29 \text{ V}$, $v_v = 1.5 \text{ m/min}$, zaporedna postavitev žic, žica $\varnothing = 2 \text{ mm}$.

Fig. 4. Influence of welding current intensity on melting rate in submerged arc welding with single-wire, double-wire and triple-wire electrodes: $U = 29 \text{ V}$, $v_v = 1.5 \text{ m/min}$, series arrangement of wires $\varnothing = 2 \text{ mm}$.

Na sliki 4 je v diagramu prikazan vpliv jakosti varilnega toka na talilni izkoristek pri varjenju z enojno, dvojno in trojno žično elektrodo pod praškom. Talilni izkoristek je definiran z enačbo:

$$\eta = \frac{1340 \text{ M}}{U I}$$

kjer pomenijo: $M (\text{g/s})$ – talilni učinek, $U (\text{V})$ – obločno napetost, $I (\text{A})$ – moč varilnega toka.

Enačbo (1) sta zapisala avtorja tega članka in popisuje izkoristek pretaljevanja pri obločnem talilnem varjenju. Vrednost 1340 J/g je vzeta iz literature [37] in pomeni teoretično potrebno energijo za raztalitev 1g malo- in srednjeglegiranega jekla brez izgub.

Talilni izkoristek sicer ne poda absolutne vrednosti odstotka izrabe v proces dovedene električne energije, toda zelo dobro pokaže boljšo izrabo energije pri varjenju z večjično elektrodo v primerjavi z enojno žično elektrodo. Talilni izkoristek je v največji meri odvisen od jakosti varilnega toka (sl. 4) delno od hitrosti varjenja in razdalje med žicami, v manjši meri pa od drugih varilnih parametrov.

4. NEKAJ PRAKTIČNIH PRIMEROV UPORABE VARJENJA Z VEČJIČNO ELEKTRODO

Uporaba varjenja z večjično elektrodo pod praškom in v zaščitnem plinu je zelo raznolika. Z eksperimentalnimi rezultati je bilo ugotovljeno, da se pri zvarjanju dosežejo najugodnejši rezultati z uporabo treh žic v zaporedni postavitev v smeri

wires, and the efficiency of the energy input improves. Better use of the electrical energy input increases the quantity of the molten filler material and decreases the relative consumption of welding powder. At the same time, a smaller quantity of energy per quantity of molten metal is put into the weld by welding with a multiple-wire electrode, which is very advantageous in welding of high-strength alloyed steels.

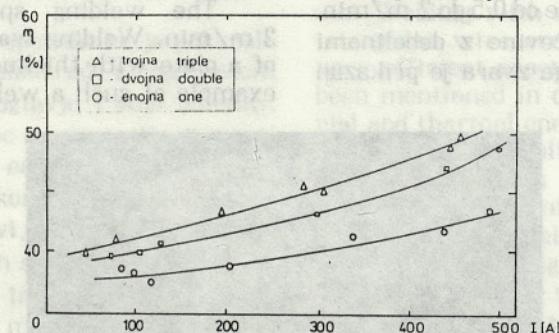


Fig. 4 shows the influence of welding current intensity on the melting rate in submerged arc welding with single-wire, double-wire and triple-wire electrodes. The melting rate is defined by the equation:

$$100 (\%) \quad (1)$$

where: $M (\text{g/s})$ – melting rate, $U (\text{V})$ – arc voltage, $I (\text{A})$ – welding current intensity.

Equation (1) was written by the authors of this paper and describes the remelting rate in arc fusion welding. The value 1340 J/g is taken from literature [37] and represents the theoretically required energy for melting 1g of low-alloy or middle-alloyed steels without losses.

The melting rate does not give an absolute value of consumption, in percentage, of electrical energy put into the process, but it testifies to the better use of energy in welding with multiple-wire electrode in comparison with single-wire electrodes. The melting rate depends most of all on the welding current intensity (fig. 4), partly on the welding speed and on the distance among wires, and to a lesser degree on other welding parameters.

4. SOME PRACTICAL CASES OF APPLICATION OF WELDING WITH A MULTIPLE-WIRE ELECTRODE

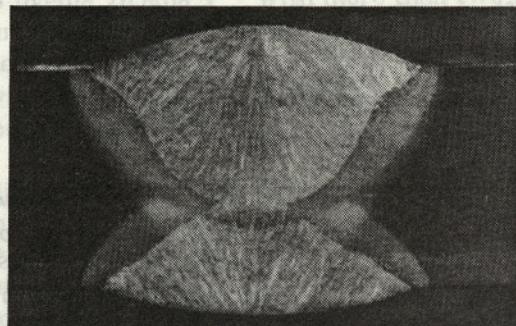
The application of submerged arc welding with a multiple-wire electrode and of gas-shielded arc welding with a multiple-wire electrode is very varied. Experimental results have proved that the most favourable results are obtained in submerged arc welding with three wires in a series arrangement in the welding direction.

varjenja pod zaščito praška. Varili smo z žicami s premerom od 1,6 do 3,2 mm s polno in s stržensko žico. Razdaljo med žicami smo določali po enačbi:

$$b = 1,2(d + 4) \pm 1 \quad (2)$$

kjer pomenita: b (mm) — razdaljo med žicami, d (mm) — premer varilne žice.

Hitrosti varjenja so znašale od 0,5 do 2 m/min. Varili smo obojestransko, pločevine z debelinami od 5 do 15 mm. Primer takšnega zvara je prikazan na sliki 5.



Sl. 5. Makro obrus zvarnega spoja, varjenega s trojno žično elektrodo pod praškom: $I = 3 \times 190$ A, $U = 27$ V, $v_v = 1,9$ m/min, žica $\varnothing 2$ mm, zaporedna postavitev žic, pozitivni pol na elektrodi.

Fig. 5. Macrosection of the welded joint made with submerged arc welding with a triple-wire electrode: $I = 3 \times 190$ A, $U = 27$ V, $v_v = 1.9$ m/min, wire $\varnothing 2$ mm, series wire arrangement, positive electrode.

Za navarjanje priporočamo uporabo večjega števila tanjših žic v prečni postavitvi na smer varjenja. Zelo ugodne rezultate smo dosegli z navarjanjem pod praškom, s četverno žično elektrodo s premerom 1,2 mm. Razdalja med žicami za navarjanje mora biti večja kakor za zvarjanje in je ni mogoče izračunati po enačbi (2). Funkcionalna povezava med premerom žice in razdaljo med žicami za navarjanje ni linear, kar sicer velja za zvarjanje in jo je zato tudi matematično težje popisati.

Za žice s premerom 1,2 mm je razdalja med žicami znašala 9 mm. Najugodnejše rezultate je mogoče doseči pri navarjanju z relativno majhno jakostjo varilnega toka in visoko obločno napetostjo. Hitrosti navarjanja so bile od 0,2 do 0,4 m/min, to je do 100 odstotkov hitreje kakor pri navarjanju s tračno elektrodo. Navare smo prekrivali 50-odstotno, da smo dosegli ugodnejšo stopnjo razmešanja ter ravnejšo obliko temena navara in globino uvara.

Primer navara s četverno žično elektrodo, je prikazan na sliki 6.

Proces navarjanja z večžično elektrodo in dobljene navare smo primerjali s procesom navarjanja s tračno elektrodo in z dobljenimi navari. Ugotovili smo, da sta postopka popolnoma enakovredna in ima navarjanje z večžično elektrodo z ekonomsko-tehnološkega vidika celo nekaj prednosti v primerjavi z navarjanjem s tračno oblikovanou elektrodo.

Welding was carried out with solid and flux-cored wires having diameters from 1.6 to 3.2 mm. The distance between the wires is determined by the equation:

$$b = 1,2(d + 4) \pm 1 \quad (2)$$

where: b (mm) — distance between wires d (mm) — welding wire diameter

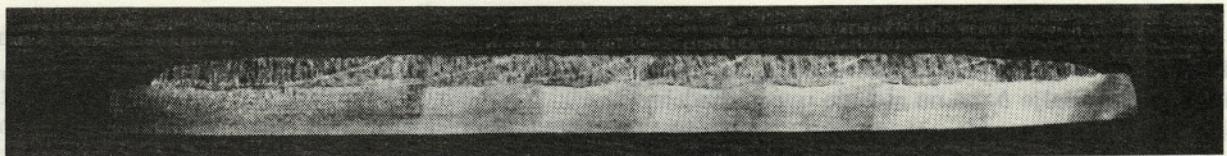
The welding speed ranged from 0.5 to 2 m/min. Welding was carried out on both sides of a plate with thicknesses from 5 to 15 mm. An example of such a weld is shown in fig. 5.

For surfacing, application of several thinner wires arranged transversely to the welding direction is recommended. Very favourable results were obtained in submerged arc surfacing with a quadruple-wire electrode with diameter of 1.2 mm. The distances between the wires should be greater for surfacing than in welding and cannot be calculated by equation (2). The functional dependence of the wire diameter and distances between the surfacing wires is not linear as is the case in welding; it is therefore more difficult to describe mathematically.

With wires having a diameter of 1.2 mm, the distance between the wires was 9 mm. The most favourable results are obtained in surfacing with a relatively low welding current intensity and high arc voltage. Surfacing speed ranged from 0.2 to 0.4 m/min, which is up to doubly higher than in surfacing with a strip electrode. The surfacings were overlapped by half in order to achieve a better distribution and more regular straight surface and penetration depth.

An example of a surfacing made with a quadruple-wire electrode is shown in fig. 6.

The surfacing process with a multiple-wire electrode and the surfacings obtained were compared to surfacing with strip electrode and the surfacings obtained. It was established that the processes are equivalent and that welding with multiple-wire electrode has even some advantages from the economic and technological point-of-view if compared with welding with a strip electrode.



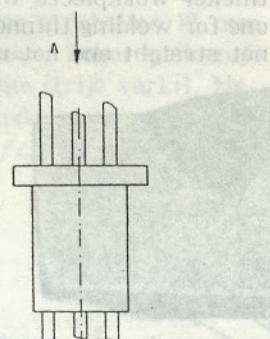
Sl. 6. Makro obrus navara, varjenega s četverno žično elektrodo pod praškom: $I = 4 \times 187 A$, $U = 41 V$, $v_v = 0,38 m/min$, negativni pol na elektrodi. $L = 30 mm$, $b = 9 mm$, žica $\varnothing 1,2 mm$.

Fig. 6. Macrosection of submerged arc surfacing made with quadruple-wire electrode: $I = 4 \times 187 A$, $U = 41 V$, $v_v = 0.38 m/min$, negative electrode, $L = 30 mm$, $b = 9 mm$, wire $\varnothing 1.2 mm$.

Za zelo dobro praktično uporabo se je pokazalo tudi varjenje s trojno žično elektrodo s razporedom žic v trikotni obliki. Že v poglavju 1 smo omenili, da je tako mogoče v varjenec nesimetrično vnesti dodajni material in topotno energijo.

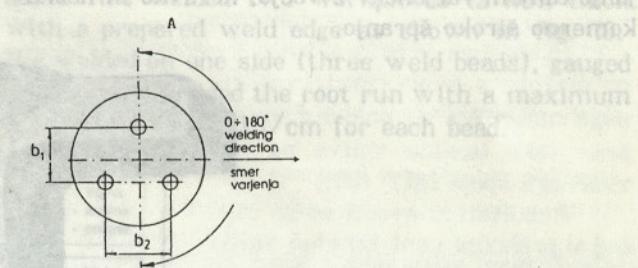
Na sliki 7 je prikazana kontaktna šoba s tremi žicami v trikotni razporeditvi, na sliki 8 pa mogoče smeri varjenja in vpliv teh smeri na obliko varja.

Poleg z razporedom žic in smerjo varjenja je na geometrijsko obliko varja mogoče vplivati tudi s spremenjanjem razdalje med žicami.

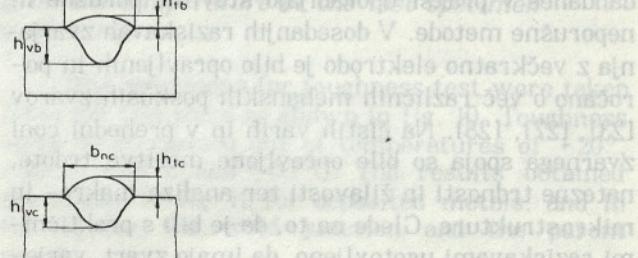
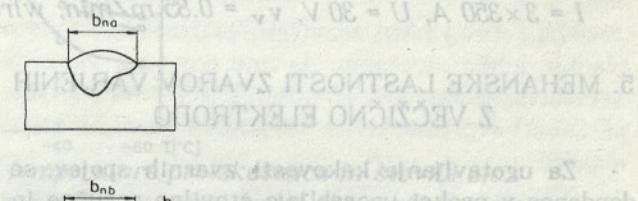


Sl. 7. Kontaktna šoba z razporedom treh žic v trikotni obliki.

Fig. 7. Contact nozzle with wire arrangement in triangular form.



Sl. 8. Vpliv smeri varjenja na obliko navara pri varjenju s trojno žično elektrodo z razporedom žic v trikotni obliki v skupni kontaktni šobi.



$$\begin{aligned} h_{tb} &< h_{tc} \\ h_{vb} &> h_{vc} \\ b_{nb}, b_{nc} &= f(b_1) \\ b_{na} &= f(b_1) \end{aligned}$$

Sl. 8. Vpliv smeri varjenja na obliko navara pri varjenju s trojno žično elektrodo z razporedom žic v trikotni obliki v skupni kontaktni šobi.

Fig. 8. Influence of welding direction on the surfacing form in welding with a triple-wire electrode with a triangular wire arrangement in a joint contact nozzle.

Welding with a triple-wire electrode with a triangular wire arrangement also proved to be a very efficient practical application. It has already been mentioned in chapter 1 that the filler material and thermal energy can be put into the workpiece asymmetrically in such a way.

Fig. 7 shows a contact nozzle with three wires in a triangular arrangement, while fig. 8 shows possible welding directions and the influence of the welding direction on the weld form.

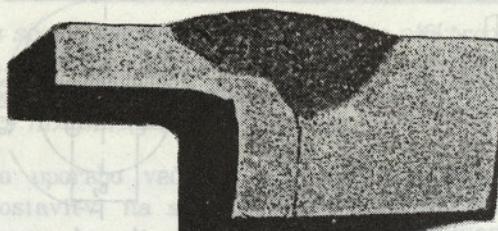
In addition to the wire arrangement and the welding direction, the weld geometrical shape can also be influenced by changing the distance between the wires.

S spremenjanjem razdalje b_1 (sl. 8, zgornji primer) vplivamo na širino temena b_{na} , s spremenjanjem razdalje b_2 pa na globino uvara. Podobno velja za druga dva primera na sliki 8. Razdalja med vzporednima žicama v smeri varjenja b_2 ima vpliv predvsem na širino temena b_{nb} in b_{nc} , razdalja b_1 pa na globino uvara. Pri varjenju, kakršnega prikazuje srednji primer na sliki 8, potuje prva žica v smeri varjenja po »hladnem« varjencu in zaradi tega po njej teče nekoliko večji varilni tok, s tem doseže nekoliko globlji uvar kakor v spodnjem primeru. Višina temena vara je nekoliko višja v spodnjem primeru, v primerjavi s srednjim, ker zadnja žica potuje po sredini in oblikuje temo vara.

Praktična uporaba zgornjega primera s slike 8 je predvsem primerna za zvarjanje nesimetričnih varjencev in varjencev različnih oblik in mas, kakor je prikazano na sliki 9. Uporaba srednjega primera (sl. 8) je primerna za zvarjanje dveh debelejših varjencev brez špranje in primer c za zvarjanje tanjih varjencev z večjo, neravno in neenakomerno široko špranjem.

By changing the distance b_1 (see fig. 8, upper case) we influence the width of the weld face b_{na} , and by changing the distance b_2 we influence the penetration depth. The same applies in the other two examples in fig. 8. The distance between the two parallel wires in welding direction b_2 influences first of all the width of weld faces b_{nb} and b_{nc} , and distance b_1 influences the penetration depth. In the welding shown in fig. 8 in the middle example, the first wire travels in the welding direction along a »cold« workpiece, so a somewhat higher welding current is flowing and a somewhat greater penetration depth is achieved than in the bottom example. The reinforcement is somewhat higher than in the bottom example than in the middle one, because the last wire travels along the central line and forms the weld face.

The upper example in fig. 8 can be practically applied to welding of asymmetric workpieces and workpieces having various forms and masses as shown in fig. 9. The application of the middle example (fig. 8) is suitable for welding of two thicker workpieces without a gap, and the bottom one for welding thinner workpieces with a larger, not straight and not uniformly wide gap.



Sl. 9. Makro obrus zvara varjenega pod praškom z razporedom žic v trikotni obliki: $I = 3 \times 350$ A, $U = 30$ V, $v_v = 0,85$ m/min, žica $\varnothing 2$ mm, $b_1 = 10$ mm, $b_2 = 8$ mm (glej sl. 8).
Fig. 9. Macrosection of a submerged arc weld made with wire arrangement in triangular form: $I = 3 \times 350$ A, $U = 30$ V, $v_v = 0,85$ m/min, wire $\varnothing 2$ mm, $b_1 = 10$ mm, $b_2 = 8$ mm (see fig. 8).

5. MEHANSKE LASTNOSTI ZVAROV VARJENIH Z VEČŽIČNO ELEKTRODO

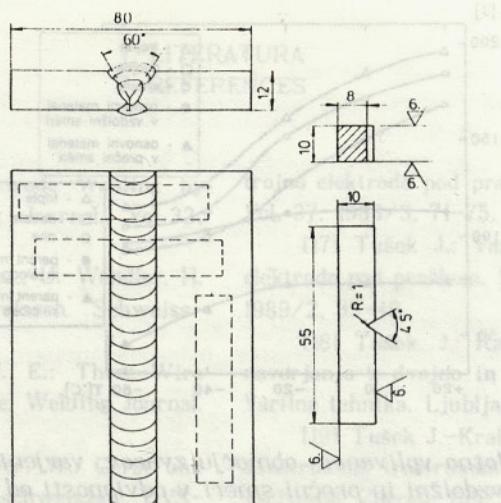
Za ugotavljanje kakovosti zvarnih spojev se dandanes v praksi uporabljo številne porušne in neporušne metode. V dosedanjih raziskavah zvarjanja z večkratno elektrodo je bilo opravljenih in poročano o več različnih mehanskih poskusih zvarov [23], [27], [28]. Na čistih varih in v prehodni coni zvarnega spoja so bile opravljene meritve trdote, natezne trdnosti in žilavosti ter analiza makro- in mikrostrukture. Glede na to, da je bili s praktičnimi raziskavami ugotovljeno, da imajo zvari, varjeni z večkratno elektrodo, v primerjavi z zvari, varjenimi z enojno elektrodo, enakovredne ali celo boljše mehanske lastnosti in je bilo o tem v omenjeni literaturi že poročano, bomo tu prikazali le rezultate testa žilavosti s preizkušanci ISO-V.

Varili smo drobnozrnato mikrolegirano jeklo z visoko mejo tečenja. Za dodajni material smo uporabili varilno žico, kakršno priporoča izdelovalec

5. MECHANICAL PROPERTIES OF WELDS MADE WITH A MULTIPLE-WIRE ELECTRODE

Numerous destructive and nondestructive testing methods are used for the assessment of welded joint quality in practice. In investigations of welding with a multiple-wire electrode, carried out to date, various mechanical tests of welds have been carried out and reported in [23], [27] and [28]. Hardness, tensile strength and toughness measurements, macro- and microstructure analyses have been carried out in the deposited metal and in the weld junction of welded joints. Only the results of the toughness test with ISO-V test specimens will be shown here since it has been established in practical investigations that welds made with a multiple-wire electrode have equal or even better mechanical properties than those made with a single electrode. This has already been reported in the literature mentioned.

We welded a fine-grained microalloyed steel with a high yield point. As a filler material, we used the welding wire recommended by the

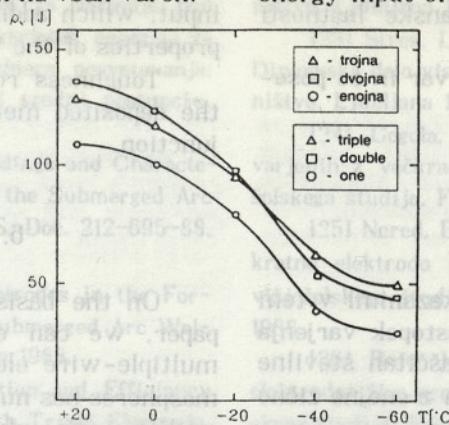


Sl. 10. Dimenzijs in oblika varjenca in preizkušanca ter mesta jemanja vzorcev.

Fig. 10. Dimensions and form of the workpiece and of test specimens and the location of taking test pieces.

omenjenega osnovnega materiala. Pri praktičnem varjenju smo zvarjali varjene z debelino 12 mm s pripravljenim zvarnim robom, kakor prikazuje slika 10. Varili smo enostransko (trije varek), žlebili koren in varili tudi korenki varek, z največjim vnašanjem energije 15 kJ/cm na vsak varek.

manufacturer of the parent metal mentioned above. We welded two workpieces 12 mm thick with a prepared weld edge as shown in fig. 10. We welded on one side (three weld beads), gauged the root and welded the root run with a maximum energy input of 15 kJ/cm for each bead.



Sl. 11. Žilavost čistih varov v odvisnosti od temperature preizkušanca in števila žic.

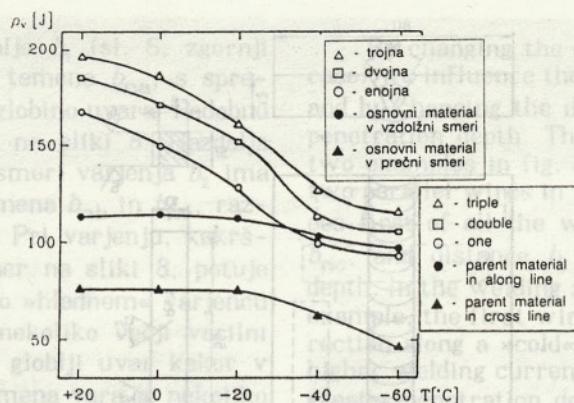
Fig. 11. Toughness of deposited metal depending on the temperature of the test specimen and the number of wires.

Vzorci za preizkus žilavosti so bili vzeti iz preizkušanca, kakor prikazuje slika 10. Preizkuse žilavosti smo opravili pri temperaturah +20 °C, -20 °C, -40 °C in -60 °C. Dobljeni rezultati so za čiste vare prikazani na sliki 11, za prehodno cono in osnovni material pa na sliki 12.

Krivulje, ki prikazujejo žilavost čistih varov, potekajo precej skupaj in ne kažejo bistvene razlike. Nekoliko večjo žilavost zvarov, varjenih z dvojno in s trojno žično elektrodo, si razlagamo z »drugačnim« vnašanjem energije v zvar [28]. Zelo pomembno pri tem je, da so žice med seboj oddaljene z optimalno razdaljo (2), tako da vse žice se stavljajo enotno varilno kopel.

Test specimens for toughness test were taken from the test piece as shown in fig. 10. Toughness tests were carried out at temperatures of +20 °C, -20 °C, -40 °C and -60 °C. The results obtained are shown in fig. 11 for deposited metals, and in fig. 12 for the weld junction and the parent metal.

The curves showing the toughness of the deposited metal run nearly together and show no essential difference. The somewhat higher toughness of welds made with double-wire and triple-wire electrodes can be explained by a »different« energy input in the weld [28]. It is very important that the distance between the wires is optimum (2) so that each wire makes a uniform welding cavity.



Sl. 12. Žilavost v topotno vplivanem območju zvarov, varjenih z večžično elektrodo in osnovnega materiala v vzdolžni in prečni smeri v odvisnosti od temperaturo preizkušanca.

Fig. 12. Toughness of the heat affected zone of welds made with a multiple-wire electrode and of the parent metal in the longitudinal and the transverse direction, depending on the temperature of the test specimen.

Tudi v literaturi [38] najdemo podobno ugotovitev pri varjenju z več elektrodami.

Poleg tega je pri varjenju z večžično elektrodo mogoče v zvar vnesti več raztaljenega dodajnega materiala ob enakem vnašanju energije, kar prav tako ugodno vpliva na mehanske lastnosti zvarnega spoja [27], [39].

Rezultati žilavosti so za čisti var in še posebej v prehodni coni izredno veliki.

6. SKLEPI

Z ugotovljenimi rezultati, prikazanimi v tem članku, lahko zapišemo, da ima postopek varjenja z večžično elektrodo v različnih zaščitah številne prednosti v primerjavi z varjenjem z enojno žično elektrodo.

Celotne sklepe lahko strnemo v nekaj točkah:

- Standardno varilno napravo za varjenje z enojno žično elektrodo je mogoče prilagoditi za varjenje z večžično elektrodo.
- Z razporedom žic v skupni kontaktni šobi je mogoče vplivati na geometrijsko obliko zvara, na talilni učinek in na celotni proces varjenja.
- Z večanjem števila žic se poveča produktivnost varjenja in izboljša izkoristek uporabljene energije in varilnega praška.
- Varjenje z večžično elektrodo je mogoče uporabiti za zvarjanje (zaporedna postavitev žic) in navarjanje (vzporedna postavitev žic).

A similar statement regarding welding with multiple electrodes can be found in [38].

Moreover, in welding with a multiple-wire electrode, it is possible to put in a greater quantity of the molten filler material with an equal energy input, which additionally favours the mechanical properties of the welded joint [27], [39].

Toughness results are remarkably high for the deposited metal and especially for the weld junction.

6. CONCLUSIONS

On the basis of the results stated in this paper, we can establish that welding with a multiple-wire electrode in various shielding atmospheres has numerous advantages over welding with a single-wire electrode.

The following conclusions can be drawn:

- A classical welding item for welding with a single-wire electrode can be adapted to welding with a multiple-wire electrode.
- Weld geometry, melting rate and the entire welding process can be influenced by the wire arrangement in the joint contact nozzle.
- The productivity of welding increases and the efficiency of the energy applied and of the welding efficiency improves with the increase in the number of wires.
- Welding with a multiple-wire electrode can be applied to welding (series arrangement of wires) or to surfacing (parallel arrangement of wires).

UDK 535–374

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