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SUBMERGED ARC SURFACING WITH A MULTIPLE-WIRE ELECTRODE

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Submerged arc surfacing with a multiple-wire electrode is a new process variant which has been rarely used, in spite of its numerous advantages in comparison to other processes, in practical applications. The unit for surfacing with the multiple - electrode differs little from a classic unit for submerged arc welding with a single-wire electrode. The difference between them consists in that in our unit several wires travel through a joint contact tube simultaneously. All of the wires are fed with the same rate and have a joint regulation and power source. In welding with the multiple-wire electrode it is possible to weld with two, three, four or even more wires simultaneously. In the joint contact tube wires of different diameters and different chemical composition and solid or flux-cored wires may be used. Mechanical properties of surfacing welds depend on the type the parent metal and the filler material, welding parameters and the type of welding flux used.

Key words: *submerged arc surfacing, multiple-wire electrode, melting rate, dilution, macro specimen, strip electrode, flux*

Navarivanje pod prahom s višežičanom elektrodom. Navarivanje s višežičanom elektrodom pod prahom novi je postupak koji se, usprkos brojnim prednostima pred ostalim postupcima, još uvijek ne upotrebljava u praksi. Naprava za zavarivanje s višežičanom elektrodom suštinski se ne razlikuje od klasične naprave za zavarivanje sa samo jednom žicom. Razlika je samo da pri novoj napravi kroz kontaktnu mlaznicu istovremeno putuje više žica. Sve žice imaju istu brzinu, zajedničko podešavanje i samo jedan izvor električne struje. Pri zavarivanja sa višežičanom elektrodom moguće je upotrijebiti dvije, tri, četiri ili čak i više žica istodobnno. Kroz kontaktnu mlaznicu mogu prolaziti žice različitih promjera, kemijskog sastava, moguće je upotrijebiti masivne ili punjene žice. Mehanička svojstva navarenog sloja ovise od vrste osnovnog i dodatnog materiala, parametara zavarivanja i vrste zaštitnog praha.

Ključne riječi: *navarivanje pod prahom, višežičana elektroda, učinak topljenja, miješanje, makro brušeni uzorak, trakasta elektroda, zaštitni prah*

INTRODUCTION

Surfacing is a technological procedure of applying a layer of filler material to a surface of another material, i.e. a product. By surfacing, it is possible to improve chemical, mechanical, and physical properties of the parent metal, and, consequently, those of the product surfaced. Surfacing may be applied to worn surfaces as well as to new products. A surfacing weld may have the same, similar or completely different chemical, physical, and mechanical properties as the parent metal.

In everyday practice several different processes can be used for application of the filler material to the parent metal, i.e., a product. They are welding, spraying, and brazing.

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In general the processes for the application of the filler material to a surface can be classified according to two criteria, i.e., either according to the kind of energy used or according to the state of the filler material deposited. The energy used may be thermal or mechanical. Thermal energy will generate in the electric arc or in a flame due to the combustion of a fuel gas in oxygen.

Mechanical energy can be produced explosion (explosion surfacing) or rolling (cladding). The filler material can be applied in solid state by mechanical energy, in the liquid by the arc, plasma or flame, even in the gaseous and ionised state by a plasma arc.

Surfacing with the multiple-wire electrode is a new variant of the arc surfacing process, which has almost not been used in practice yet. Well-known variants are surfacing with single or double-wire electrode and surfacing with strip electrode. Surfacing with the multiple-wire electrode treated in the present paper offers a number of application opportunities, including renewal of worn surfaces and surfacing of other surfaces.

LITERATURE REVIEW

It has already been mentioned that surfacing with the multiple-wire electrode is a new variant, on which no reports have been found in the welding literature yet. It has been reported on our investigations and results obtained several times, but only on the local level at conferences. Surfacing with the multiple-wire electrode was partly treated in several articles on welding with the multiple-wire electrode [1-5].

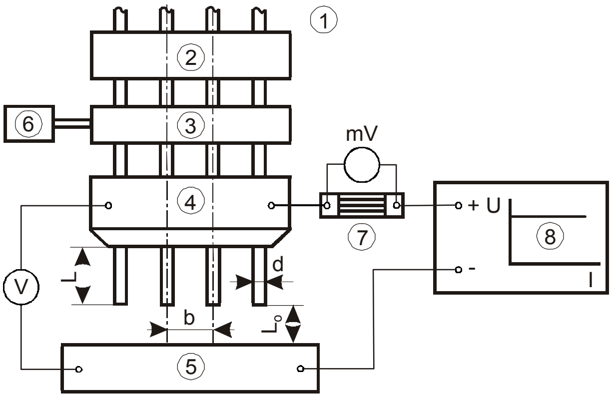

Figure 1. **Schematic representation of the unit for submerged arc surfacing with a multiple wire electrode: *b* - distance between wires; *L* - electrode extension length; *d* - wire diameter; L_0 - arc length; 1 - surfacing (welding) wires; 2 straightening mechanism; 3 - feed system; 4 - contact tube; 5 - workpiece; 6 - electromotor; 7 - shunt; 8 - power source**

Slika 1. **Shematski prikaz naprave za navarivanje s višežičanom elektrodom pod prahom: *b* - udaljenost između žica; *L* - dužina slobodnog kraja elektrode; *d* - promjer žice; L_0 - dužina električnog luka; 1 - žice za navarivanje; 2 - mehanizam za ravnanje; 3 - sistem za dovođenje žice; 4 - kontaktna mlaznica; 5 - radni komad; 6 - elektromotor; 7 shunt; 8 - izvor električne struje**

More literature data on surfacing with a strip electrode will be given together with an analysis of surfacing with the multiple-wire electrode and its comparison with some other surfacing processes.

DESCRIPTION OF A UNIT FOR SURFACING WITH THE MULTIPLE-WIRE ELECTRODE

A unit for surfacing with the multiple-wire electrode differs little from both a classic unit for single-wire electrode welding and a unit for surfacing with a strip electrode. The unit concerned has a single contact tube through which two, three, four or even more wires travel simultaneously. All of the wires are fed with the same rate of speed, have a joint regulation system and power source. The arrangement of the wires in the contact tube and their distance from one another may differ. The unit is schematically shown in Figure 1..

Surfacing may be performed with solid and flux cored wires of various materials, diameters and types. The power source used may have either a drooping characteristic or a horizontal static characteristic. Welding may be carried out either with direct current or alternating current. The experiments made show that it is most favourable to use a welding rectifier with the horizontal static characteristic and the DC electrode negative.

Arrangement of the wires in the contact tube and the distance among them

In surfacing with the multiple-wire electrode the wires are usually arranged in a line in the direction transverse to the welding direction (Figure 2.). The angle α can be 0° or larger. If thicker layers are to be surfaced, the may be arranged in two lines as shown in Figure 2.. The distances among the wires b_1, b_2 and b_3 depend on the wire diameters, the welding parameters, the kind of material, and the wire types used.

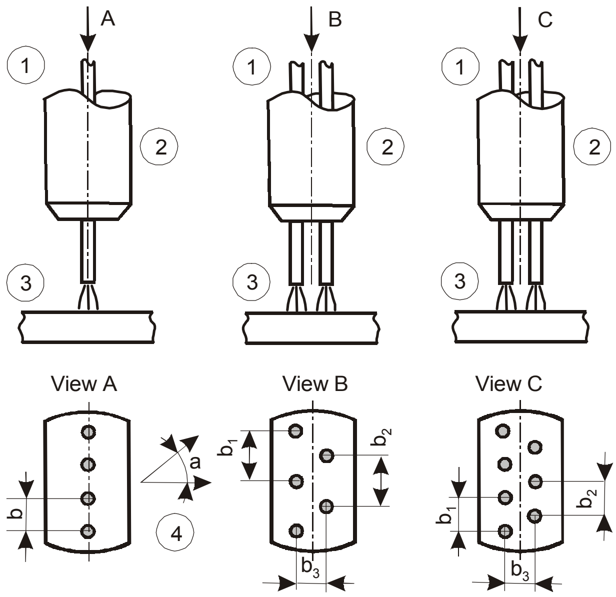

Figure 2. **Some of possible arrangements of wires in the contact tube for surfacing: - possible surfacing directions; *b* - distance between wires; 1 - wires; 2 - contact tube; 3 - arcs**

Slika 2. **Neki od mogućih razmještaja žica u kontaktnoj mlaznici: - mogući smjerovi navarivanja; *b* - udaljenost između žica; 1 - žice; 2 - kontaktna mlaznica; 3 - električni lukovi**

If surfacing is performed with the wires arranged in a single line, it is recommended that the distance between the wires is calculated using the following equation:

$$b = 5(d_w + 3) \pm 1 \text{ [mm]} \qquad (1)$$

where d_w is the wire diameter.

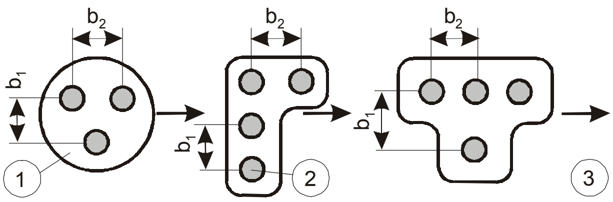

Figure 3. **Asymmetric arrangement of wires in the contact tube: 1 - contact tube; 2 - wire; 3 - surfacing direction; *b* - distance between wires**

Slika 3. **Nesimetrični razmještaj žica u kontaktnoj mlaznici: 1 - kontaktna mlaznica; 2 - žica; 3 - smjer navarivanja; *b* udaljenost između žica**

The wires may be arranged in the welding direction not only symmetrically but also asymmetrically (Figure 3.). In this case an asymmetric surfacing weld is obtained. In practice this may be applied to surfacing of irregular surfaces, e.g. simultaneous welding of a groove and surfacing of a small area around the weld.

Wire diameters

For surfacing, thin wires with a diameter ranging from 0.9 to 2 mm are recommended. In special cases thicker wires and wires of various diameters can be used simultaneously (Figure 4.). The use of different wire diameters affects the welding process, the melting rate of the wires

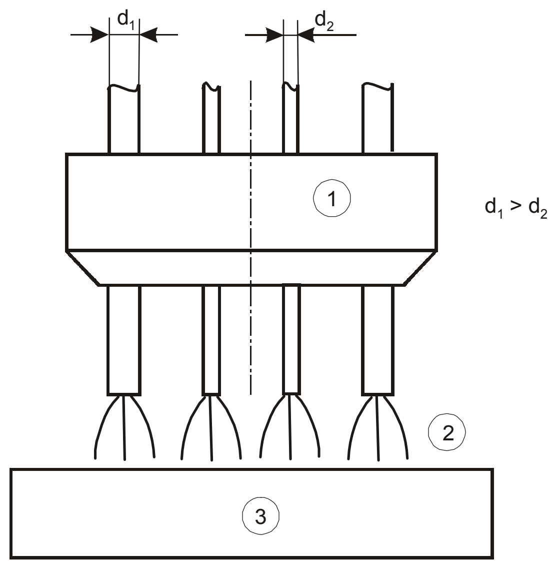

Figure 4. **Contact tube for surfacing with wires of different diameters; *d* - wire diameter; 1 - contact tube; 2 - arcs; 3 workpiece**

Slika 4. **Kontaktna mlaznica za navarivanje žicama različitih promjera; *d* - promjer žice; 1 - kontaktna mlaznica; 2 električni lukovi; 3 - radni komad**

and the parent metal as well as the shape of the surfacing weld. Because of different wire diameters, the currents carried by the wires are of different intensity.

Because of arc self-adjustment as a function of current, the length of all the arcs concerned is the same. The wire feed speed is the same with all the wires and does not depend on the wire diameter. This means that in thicker wires the current intensity is higher, and consequently, the portion of the thicker wires in the surfacing weld is higher than that of the thinner wires.

If wires of the same diameter are used in surfacing, a somewhat convex surfacing weld is obtained (Figure 5. - left). This is due to electrodynamic forces of surface tension and the blowing effect of the welding arcs. The blowing effect of the arcs occurs because of electromagnetic forces in the welding arcs. The arcs attract each other because direct welding current is conducted through them.

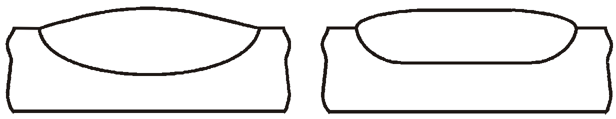

Figure 5. **Shape of the surfacing weld as a function of the arrangement of wires of different diameters**

Slika 5. **Oblik navara zavisno od rasporeda žica različitih promjera**

By an arrangement of wires having different diameters (Figure 4.) a surfacing weld having a more uniform reinforcement is obtained (Figure 5. - right).

Wire types

In submerged-arc surfacing with the multiple-wire electrode, it is possible to apply several wires of different quality and produced by different production techniques. Surfacing may be performed jointly with wires of low-alloy

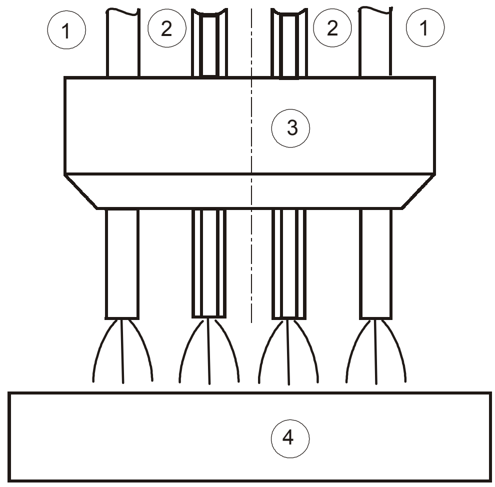

Figure 6. **Joint contact tube for surfacing with solid and flux cored wires: 1 - solid wire; 2 -flux cored wire; 3 contact tube; 4 - workpiece**

Slika 6. **Zajednička kontaktna mlazanica za navarivanje s masivnim i punjenim žicama: 1 - masivna žica; 2 - punjena žica; 3 - kontaktna mlaznica; 4 - radni komad** steel and a wire of high-alloy steel to improve mechanical properties of the surfacing weld.

It is possible to use solid and cored wires jointly in the same contact tube too (Figure 6.). By their core melting, cored wires make ionisation in the arc easier, which permits a more stable arc burning. By means of the core it is possible to alloy the surfacing weld and thus improve mechanical properties or to simply increase the melting rate.

An asymmetric surfacing weld can be obtained by arranging wires of different quality in the joint contact tube. It is often required that machine elements have edges or individual parts particularly hard whereas the complete machine part has to endure dynamic loads. This can be achieved by using wires alloyed with different alloying elements (Figure 7.).

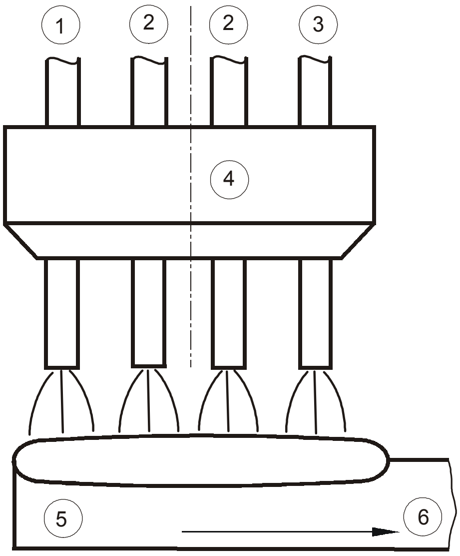

Figure 7. **It is possible to obtain an asymmetrically alloyed surfacing weld by using different alloyed wires: 1   high alloy wire - high hardness of the surfacing weld; 2   high alloy wire - high toughness of the surfacing weld; 3 - wire having a composition similar to that of the base metal; 4 contact tube; 5 - workpiece; 6 - direction in which hardness of surfacing weld decreases but its toughness increases**

Slika 7. **Upotrebom različito legiranih žica moguće je dobiti nesimetrično legirani navar: 1 - visoko legirana žica velika tvrdoća navara; 2 - visokolegirana žica - velika žilavost navara; 3 - žica, čiji je sastav sličan sastavu osnovnog materiala; 4 - kontaktna mlaznica; 5 - radni komad; 6 - smjer u kojoj tvrdoća navara pada, a žilavost raste**

Figure 7. shows a contact tube with four wires of different quality the surfacing weld obtained having different mechanical properties. The edge of the surfacing weld is very hard. Hardness decreases from the left to the right while toughness increases in the same direction.

EXPERIMENTAL WORK

In the experimental work, a unit was used which permitted surfacing with single-wire, twin-wire, triple-wire, and quadruple-wire electrodes (Figure 1.). Welding was performed with wires of 1.0, 1.2 and 1.6 mm in diameter and made of low carbon steel and high-alloy austenitic stainless steel respectively. The unit permitted wire feed speeds from 0.5 do 9 m/min, and welding speeds from 0.1 to 1 m/min.

The optimum welding parameters, the distance between the wires, the wire diameters, and the electrode extension length for the optimum shape of the surfacing weld were investigated. The melting rate, the flux consumption, the energy efficiency, the degree of dilution and the surface effect were studied too. A comparison of surfacing with the strip electrode and surfacing with the multiple-wire electrode was made.

Study of the optimum welding parameters

Numerous cases of trial welding showed that submerged-arc surfacing with the multiple-wire electrode requires a comparatively high arc voltage. The higher arc voltage produces a longer arc and higher flux consumption, which is one of basic conditions for obtaining a nice, uniformly deposited surfacing weld with low penetration. Another advantage of surfacing with a longer arc is that alloying elements are transferred from the flux to the surfacing weld with more ease. This is of particular importance in alloying of the surfacing weld from the flux. It was found out that the flux efficiency, i. e., alloying of the surfacing weld from the flux, is more favourable in welding with the multiple-wire electrode than in surfacing with a single wire, the welding parameters being the same [6].

Because of a better degree of dilution and a flatter surfaced layer, the surfacing welds were made to overlap in their width by 25 % and 50 % respectively (Figure 8.).

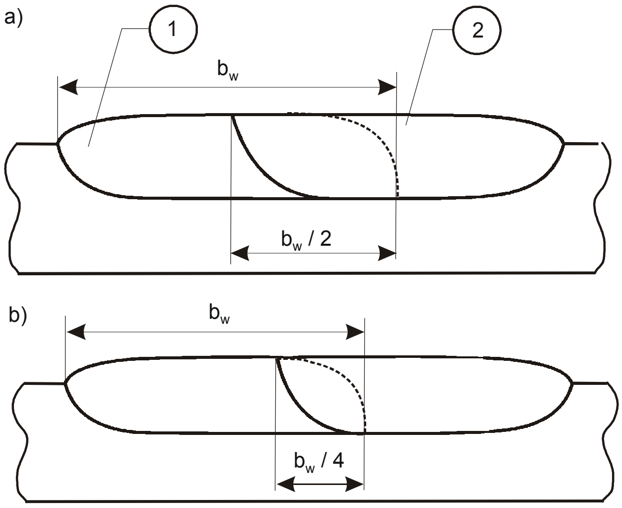

Figure 8. **Overlapping of surfacing welds: b_w - weld width; 1 - first surfacing weld; 2 - second surfacing weld; a) 50 % overlapping of surfacing welds; b) 25 % overlapping of surfacing welds**

Slika 8. **Prekrivanje navara: b_w - širina vara; 1 - prvi navar; 2 - drugi navar; a) 50% prekrivanje navara; b) 25% prekrivanje navara**

The degree of dilution was calculated using equation (2). In the literature other definitions and equations for calculation of the degree of dilution may be found too [7-13].

$$\gamma = \frac{A_u}{A_u + A_n} \cdot 100 \quad [\%] \qquad (2)$$

where A_u (mm^2) is the penetration area and A_n (mm^2) is the surfacing-weld area.

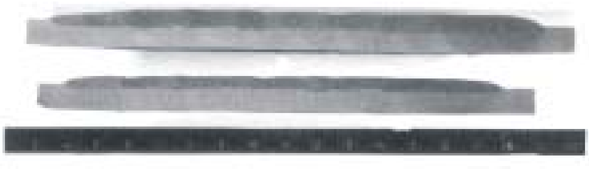

Figure 9. **Macro specimens of the welds surfaced with a triple-wire electrode: d_w = 1.2 mm; I = 190 A/wire; U = 41 V, v_w = 0.3 m/min; b = 8 mm; L = 20 mm; electrode negative; above: 25 % overlapping; below: 50 % overlapping**

Slika 9. **Makrobrušeni navari s trostrukom žičanom elektrodom; d_w = 1.2 mm; I = 190 A/žici; U = 41 V; v_w =0.3 m/min; b = 8 mm; L = 20 mm; minus pol na elektrodi; gore: 25% prekrivanje; ispod: 50% prekrivanje**

Figure 9. shows two surfacing welds. They were both submerged arc surfaced with the triple-wire electrode with a wire diameter of 1.2 mm and the electrode negative. The figure above shows a surfaced layer with the 25 % overlapping, and the figure below the 50 % overlapping of the surfacing welds. The degree of dilution obtained in the upper case was around % and in the lower case around 28 %. These values are similar to those stated by various authors for surfacing with a strip electrode [14, 15].

In the investigations conducted the selected welding parameters, the selected distance between the wires, the appropriate number of wires in the contact tube, and overlapping of the surfacing welds permitted to obtain almost an optional degree of dilution. The lowest degree of dilution, which was obtained in surfacing with four wires in the contact tube, was 7 %. This is, however, not recommendable in practical applications because the surfacing weld may peel off due to a too low penetration. The degree of dilution of the surfacing weld and the parent metal recommended for practical application should range from 12 to 20 %.

TECHNOLOGICAL AND ECONOMIC ASPECTS OF SUBMERGED-ARC SURFACING WITH THE MULTIPLE-WIRE ELECTRODE

During experimental submerged-arc surfacing with the multiple wire electrode, the welding parameters, the wire feed speed, the welding speed, the surfacing-weld weight, the surfacing weld size, and the flux consumption were measured. On the basis of the data obtained, the melting rate, the degree of dilution, the relative flux consumption, and the surface effect were calculated. Figure 10. shows the melting rates in submerged arc welding with single-wire, double-wire, triple wire, and quadruple-wire electrodes respectively.

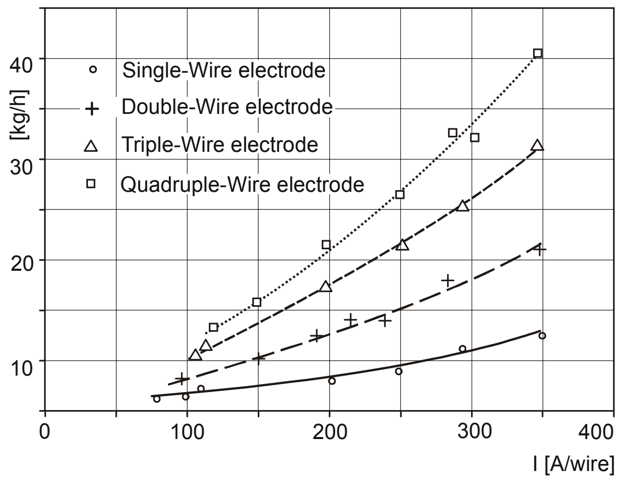

Figure 10. **Melting rate as a function of current intensity in surfacing with single-wire, twin-wire, triple-wire and quadruple-wire electrodes respectively; d_w = 1.2 mm; L = 20 mm; b = 8 mm; v_w = 0.2 m/min; U = 38 - 42 V**

Slika 10. **Brzina otaljivanja ovisno o jačine struje kod navarivanja s jednostrukom dvostrukom, trostrukom i četverostrukom žičanom elektrodom; d_w = 1,2 mm; L = 20 mm; b = 8 mm; v_w = 0,3 m/min; U = 38-42 V**

Figure 10. clearly shows that the melting rate increases exponentially with the increase of the number of wires, and not linearly. This can be explained by two physical laws. The first is related to heat transfer. The welding arc melts the filler material and the parent metal and additionally warms the neighbouring wires, which produces an increase in the electric resistance in the wire and contributes to a higher melting rate.

The second is related to the electromagnetic influence of the electric current on the neighbouring wires and arcs. Because of the electromagnetic field generated around a welding wire, which changes as welding current in the wire changes, the electric resistance in the neighbouring wire increases. The electric resistance in the wire increases exponentially with the increase in current due to superposition of both influences.

This is to say that with a constant feed speed of all the wires the highest current is carried by the welding circuit if there is only one wire in the contact tube. If instead of one wire two three or more wires are used and the wire feed speed remains unchanged, the current in the wires is nott hree times higher but lower. That is why in multiple-wire welding the wire feed speed has to be increased if we wish to have a constant welding current per single wire.

The comparison of the melting rate obtained in welding with the multiple-wire electrode and the melting rates obtained in welding with various strip electrodes is shown in Figure 11.. The comparison was made for current intensities of 600 A and 1000 A respectively. Both comparisons show that the melting rate in welding with the multiple-wire electrode is almost equal to the melting rate obtained in welding with the strip electrode.

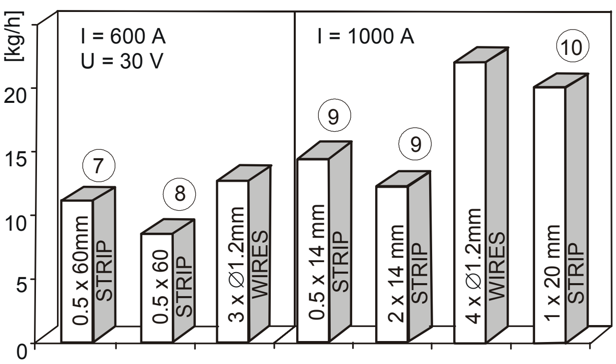

Figure 11. **Comparison of melting rates obtained with various strip electrodes with the melting rate obtained in welding with a multiple-wire electrode**

Slika 11. **Usporedba brzine otaljivanja više različitih trakastih elektroda s brzinom otaljivanja kod zavarivanja s višežičanom elektrodom**

A very important indicator of the surfacing efficiency is the surface effect. It is defined by the surfacing rate and the surfacing-weld width, i. e.

$$P = v_w \cdot b_w \ [\mathrm{cm^2/min}] \qquad (3)$$

where v_w is the surfacing speed and b_w is the surfacing-weld width.

The surface effect is thus a function of the surfacing rate and the surfacing-weld width. It is also directly dependent on the number of wires used and the distance among them in the transverse arrangement and the strip width respectively, and indirectly on the welding current, the filler materialsize, the wire extension length and the arc voltage.

CONCLUSIONS

Based on the experimental and theoretical studies on submerged-arc surfacing with the multiple-wire electrode presented in the paper, the conclusions may drawn:

- the unit for surfacing with the multiple-wire electrode permits feeding of several wires through a single contact tube,
- the arrangement of wires in the contact tube is optional,
- it is possible to surface with wires of different diameters, quality and produced by different production techniques,
- it is possible to produce a surfacing weld with an asymmetric shape, asymmetric chemical composition, and different mechanical properties,
- it is possible to obtain a very low degree of dilution, i.e. the one almost equal to that obtained in surfacing with a strip electrode,
- with the same welding parameters, it is possible to achieve, in surfacing with the multiple-wire electrode, the same or even a higher melting rate than that in surfacing with a strip electrode,
- with the same energy input, the surface effect obtained is stronger in surfacing with the multiple-wire electrode than in surfacing with the strip electrode,
- with the same welding parameters, the welding flux efficiency, i.e. transfer of alloying elements from the flux to the surfacing weld, is easier and higher in quantity in surfacing with the multiple-wire electrode than in surfacing with the single-wire electrode.

The most important advantage of surfacing with the multiple wire electrode is that the surfacing unit is simple The classical unit for submerged arc welding with the single-wire can easily be adapted to surfacing with single-wire, twin-wire or multiple-wire electrodes. Only one power source is required. It is also possible to connect several equal power sources in a parallel way so that with the same arc voltage the welding current intensity can be higher.

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