WELD CLADDING WITH COATED ELECTRODE OF RECTANGULAR CROSS-SECTION

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Ključne riječi: *navarivanje, pravokutna obložena elektroda, REL, tvrdoća*

Sažetak

Navarivanje se često upotrebljava za reparaturno zavarivanje oštećenih površina i proizvodnjo različitih površinskih slojeva. Konvencionalne obložene elektrode okruglog su presjeka i posljedično širina navara je mala. Namješanje osnovnog materijala u metalu zavara je prilično veliko i ZUT je relativno dubok. Sa promjenom geometrija jezgra elektrode može se uvećati produktivnost i uz to smanjiti namješanje i dubinu metala zavara.

Sprovedeno je bilo eksperimentalno navarivanje. Upotrjebljene su bile dvije rutilno obložene elektrode različitog pravokutnog presjeka 12,56×1 mm i 6,28×2 mm, i konvencionalna rutilna cilindrična elektroda promjera ϕ 4 mm RUTILEN 2000 S. S235JR čelik bio je upotrjebljen kao osnovni materijal. Cilj istraživanja je bio odrediti optimalne parametre navarivanja za pravokutne elektrode i usporediti geometriju i mehaničke karakteristike navara. Izmjerene su bile Tvrdoća dimenzije metala navara i ZUT-a. Najmanje namješanje bilo je kod pravokutne elektrode 12,56×1 mm, dok su rezultati namješanja za pravokutno elektrodu 6,28×2 mm i konvencionalno elektrodu ϕ 4 mm bili slični.

Keywords: *weld cladding, rectangular coated electrode, SMAW, hardness*

Abstract

Weld cladding or weld overlay is a frequently used method for repair welding of damaged surfaces and for production of different surface coatings. The conventional coated electrodes have a circular cross-section and, consequently, the weld width is small. In addition, the dilution of base material in weld metal is high and the heat-affected zone (HAZ) is quite deep. By changing the geometry of the electrode core, the productivity can be increased, while the dilution, depth of the fusion zone and HAZ can be reduced.

Experimental weld cladding was carried out. Two rutile coated electrodes of rectangular cross-sections of 12.56×1 mm and 6.28×2 mm were used, and for reference, also a conventional ϕ 4 mm electrode Rutilen 2000 S. Both rectangular electrodes were made of the same core material and coating as the conventional one. The base material was the structural steel S235JR. The goal of investigation was to determine the welding parameters for the rectangular electrodes and to compare geometries and mechanical properties of the welds. Hardness and the dimensions of weld metal and HAZ were measured. The smallest dilution was observed with the flat 12.56×1 mm electrode, while the results for the 6.28×2 mm and the conventional ϕ 4 mm electrode were similar.

1. Introduction

The conventional coated electrodes for manual weld cladding exhibit a circular cross-section [1]. They are frequently used for cladding to repair damaged surfaces and for production of different surface coatings. Due to geometry of the electrode's cross-section, the cladding process with this type of electrodes is time-consuming. Consequently, they are mostly used when MIG, MAG and SAW processes are not suitable.

While a lot of research was dedicated to development of optimum coatings [2, 3], much less was done with respect to the shape of the electrodes cross-section. The most successful was the tubular filled electrode. However, also with this type, the ratio between the weld cap width on one side and the depth of the fusion zone and HAZ on the other side remained unfavourable.

To achieve further improvement of the overall performance of coated electrodes for manual weld cladding, a change of cross-section's shape from circular to rectangular was considered. Currently, a coated electrode of rectangular cross-section is under development in order to increase the width of the weld cap and to diminish the dilution.

2. Experimental procedure

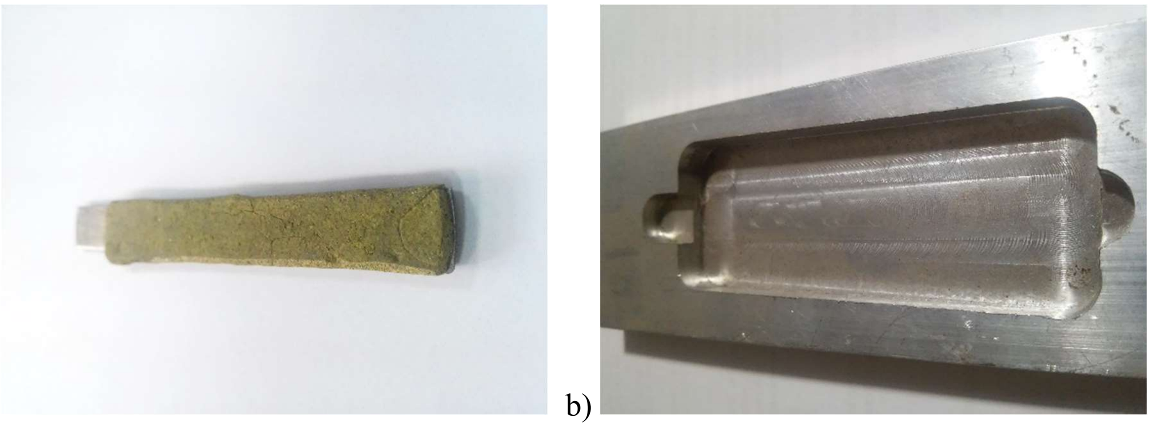
2.1 Preparation of the rectangular coated electrodes

Solid metallic cores for rectangular electrodes were punched from 1.0 mm and 2.0 mm thick DC01 cold rolled steel strip, with chemical composition very similar to the core wire of the standard cylindrical electrode Rutilen 2000 S, produced by Elektrode Jesenice d.o.o.

The width of the flat cores was selected so that the cross-section area was equal to the cross-section of a 4 mm cylindrical electrode, i.e. 12.56 mm^2, regardless to the electrodes width and thickness. The total length of rectangular electrodes was 205 mm while the coated length was about 190 mm, Fig. 1a. The dimensions of both rectangular electrodes are summarised in the Table 1.

Table 1 Dimensions of metallic cores for rectangular electrodes

Core thickness / mm	1.0	2.0
Core width / mm	12.56	6.3
Cross-section area / mm^2	12.56	12.56
Total core length / mm	205	205
Coated length / mm	190	190



a) b)

Fig. 1 Coated electrode of rectangular cross-section (a); Aluminium model for casting of rectangular coatings (b) [4]

As the main purpose was to test the influence of the core-cross-section shape, an already existing coating was applied. Selected was the rutile coating of the standard electrode Rutilen 2000 S. The coatings were cast in the laboratory of Electrode Jesenice d.o.o.

Due to combination of good satisfactory mechanical properties and easy machining, an aluminium alloy was chosen for preparation the of the moulds. A separate mould was milled for each geometry of the rectangular electrode. All moulds had a wider and deeper 190 mm long central area and a narrower and shallower area on each end, to support the metallic core during casting of the coating, Fig. 1b.

2.2 Experimental welding and welding properties

As base material steel plates 80×10×250 mm were used, machined from steel S235JR N+N according to standard EN 10025:2004. For experimental welding, the welding source Varstroj Varus 600 was used. Welding current was DC 80-180 A with the electrode holder connected to the negative-pole, Table 2. The electrode tilt angle was from 60 to 80° to the base plate.

Table 2 Welding parameters

Electrode	Current / A	Sample	Polarity
12.56×1 mm	80	A1	DCEN
	100	A2	DCEN
	120	A3	DCEN
	140	A4	DCEN
6.28×2 mm	100	T2	DCEN
	120	T3	DCEN
	140	T4	DCEN
	160	T5	DCEN
ϕ 4 mm	120	N3	DCEN
	140	N4	DCEN
	160	N5	DCEN
	180	N6	DCEN

2.3 Examination of test welds

Visual testing was done after welding and cross-sections were machined. Classic metallographic preparation was applied, consisting of grinding, polishing and etching. Macro- and microstructures were examined with optical microscope Leica Wild M10 and Nikon Epiphot 300, respectively. Geometry of the welds was determined: height and area of the weld caps, fusion zone and HAZ. Hardness HV10 across the welds was measured by using a Zwick 3202 apparatus.

3. Results and discussion

3.1 Visual examination and weld properties

No excessive spattering was observed, and the spatters could be easily removed. The slag spalled by itself and on the weld caps no significant surface defects were found, Fig 2 a. In general, a flatter weld cap favours easy slag removing.

Rectangular electrodes burned evenly, Fig 2b. The arc was narrower than the core and was steadily commuting between the edges.

a)  b) 

Fig. 2 The slag was easy to remove (a); the electrode after welding (b)

3.2 Macro- and microstructure

On the cross-sections, the most obvious differences were observed between the samples A and N. Representative macrostructures are depicted in Fig. 3.

a)  b) 

Fig. 3 Electrode 12.56×1 mm^2, sample A4, welding current 140 A (a); standard cylindrical electrode ϕ 4 mm, sample N6, welding current 180 A (b)

Much higher ratio weld cap width / depth of diffusion zone can be achieved with the rectangular electrode 12.56×1 mm. On one hand, wider welds increase the productivity, on the other hand shallower diffusion zone enables less dilution of the filler material. Less dilution is also favourable for cladding because it means less influence of the base material on the chemical composition of the surface layer and because it is possible to reach the microstructure of pure filler metal with less layers.

The microstructures in characteristic areas were typical for weldable unalloyed low-carbon construction steels, Fig. 4. Fig 4a shows the outer area of the HAZ. In the bottom right corner of the micrograph, large ferritic grains can be observed, in size and shape very similar to those in the normalised base material. In this area, the temperature only slightly exceeded A_{C1}, while in the upper left corner it already exceeded A_{C3}, but only for a short time period, which resulted in very fine-grained normalised structure.

Fig. 4b shows the coarse-grained area of HAZ. Here, the temperature was higher and material remained austenitic for longer time-period. Quite rapid cooling followed, which lead to growth of large acicular (needle-like) ferritic crystals. Some bainite can also be observed, but bainite-fraction is low. Microstructure is predominantly ferritic pearlitic.

Transition area from the HAZ to the fusion zone can be observed in the Fig. 4c. In the lower part of the micrograph, the microstructure consists of equiaxed grains, while in the upper area, longish ferritic grains can be observed, which indicates the transition to columnar solidification. Here, as well as in the rest of the weld, the microstructure is predominantly ferritic pearlitic with some small bainitic areas.

Fig. 4d shows columnar structure, characteristic for welds, which forms upon directional solidification. Columnar grains grew upwards. Columnar form was during further cooling adopted by austenite, and below A_{R3} growth of ferrite started on grain boundaries. Therefore, also the first ferritic grains are pointed upwards. The needle-like side-branches indicate quite high cooling rates. Upon further cooling, the areas in-between transformed into finer structure, whereat the growth of ferrite was still acicular.

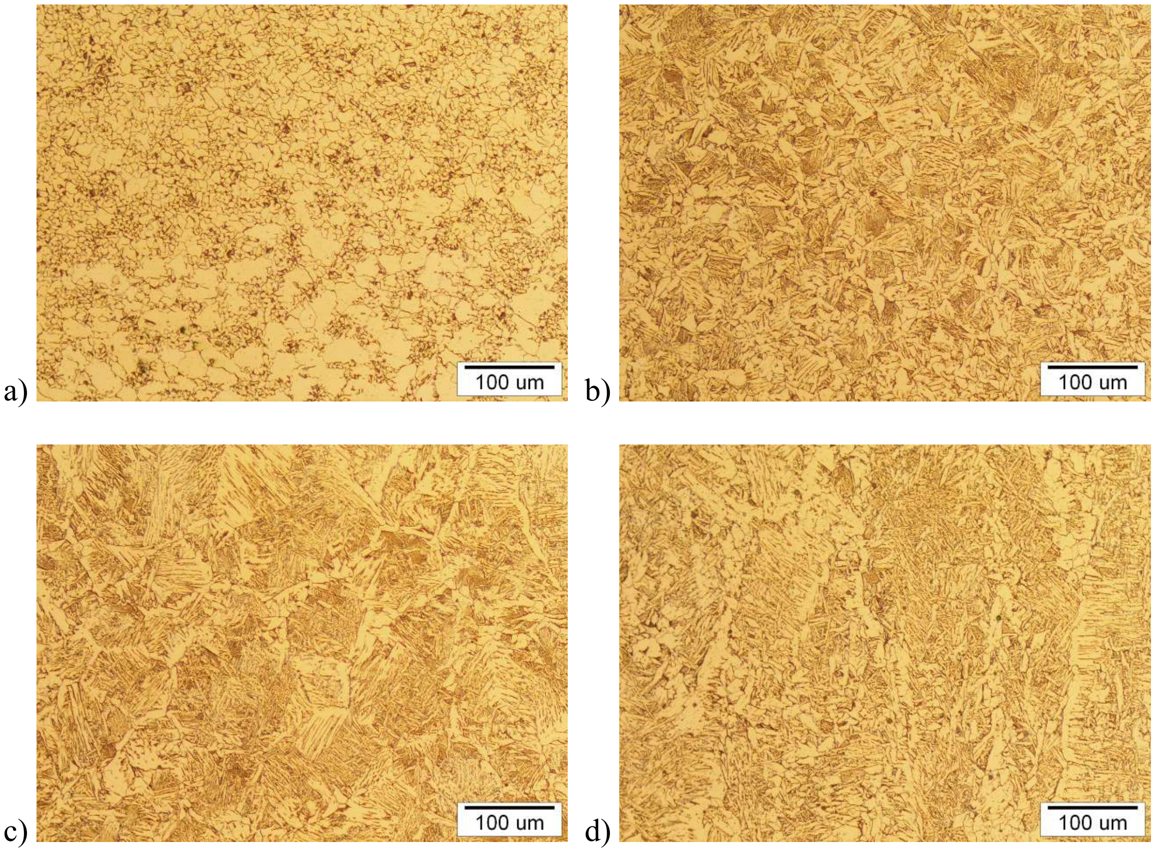


Fig. 4 Characteristic microstructure of the welds and HAZs; HAZ, transition zone to unaffected base material (a), HAZ, coarse-grained area (b), transition from HAZ to fusion zone (c), fusion zone – area of columnar growth (d)

3.3 Dimensions of welds and dilution

Dimensions of the welds and HAZs were measured and dilution X was calculated according to equation:

$$X = \frac{A\,(fusion\ zone\ (BM))}{A\,(weld)} \cdot 100\ \% \qquad (1)$$

The geometry is defined as shown in the Fig. 5. Again, the results for series A and N were significantly different, while the results for series T were quite similar to results for series N. Therefore, further discussion will be limited to series A and N.

Welding tests showed that rectangular electrodes, especially the thin and wide 12.56×1 mm electrode, require significantly lower welding currents than the standard cylindrical electrodes of equal cross-section area, due to moving of the arc along the electrode width. While the current at cylindrical electrode had to be at least in vicinity of the range, recommended by the manufacturer, i.e. 130-170 A to obtain a good quality deposition layer, the current could be as low as 80 A with the rectangular electrode 12.56×1 mm.

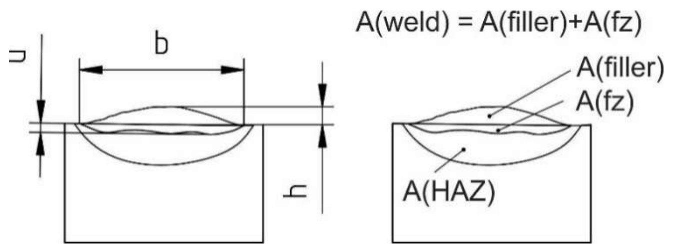


Fig. 5 Characteristic dimensions of the cladded weld; b - weld cap width, u - depth of fusion zone, h - height of the weld cap, A(filler) - area of the weld cap cross-section, A(fz) - area of the fusion zone cross-section, A(HAZ) - area of the HAZ cross-section

The dimensions of the welds are presented in the Fig. 6. Cross-section areas of weld cups, fusion zones and HAZs and dilutions vs. welding current are shown in the Fig. 7.

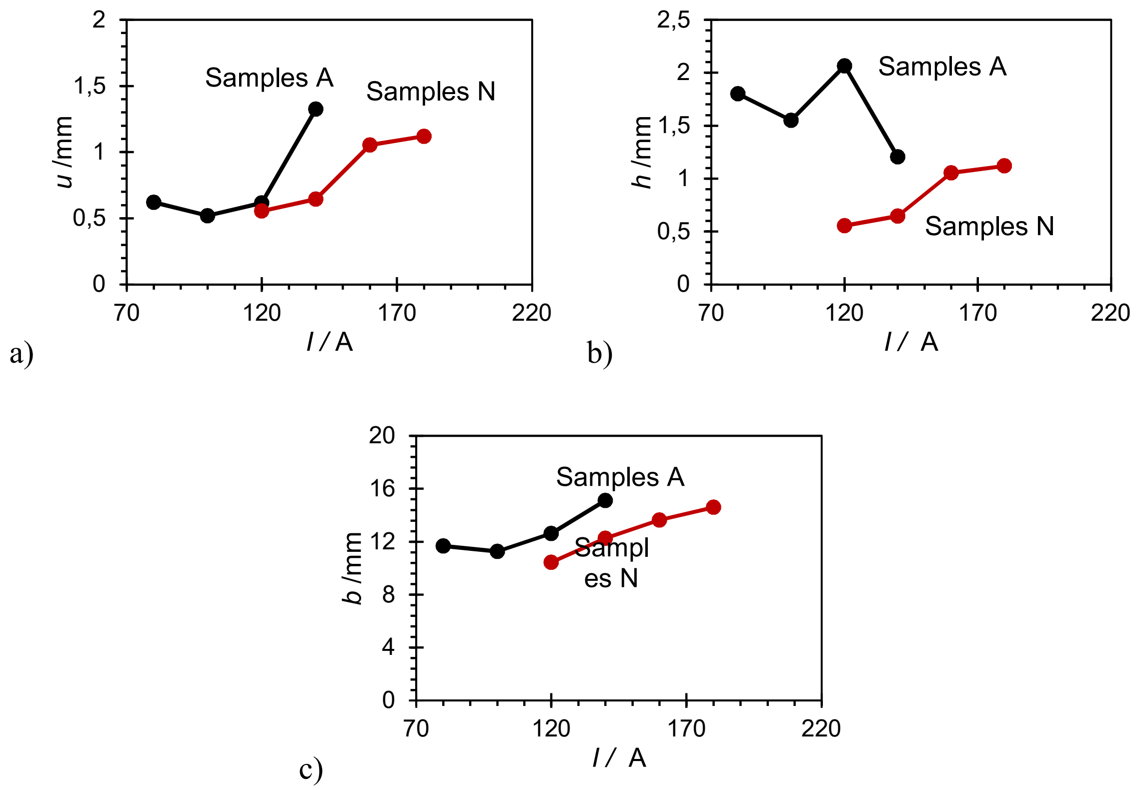


Fig. 6 Dimensions of the welds: Depth of fusion zones vs. welding current (a), height of the weld cap vs. welding current (b), weld cap width vs. welding current (c)

The diagrams in fig. 6 show, that for the rectangular electrode, a current about 80-100 A was optimum with respect to weld width and fusion zone depth. Similar results with cylindrical electrode could be achieved with significant higher currents, about 120-140 A. However, with the cylindrical electrode, at comparable weld widths the dilution was always higher than with the rectangular electrode, Fig.6 and Fig. 7. The fusion zone area and the dilution were larger.

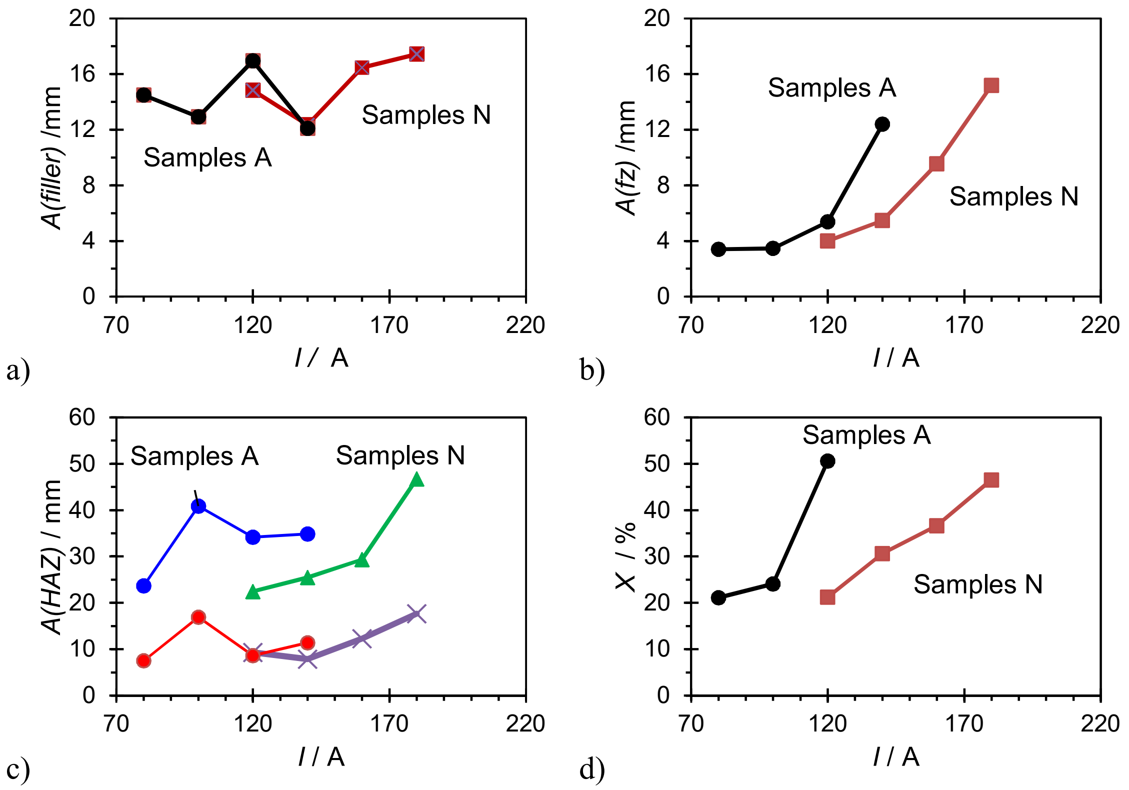


Fig. 7 Cross-section area of weld cap (a), cross-section area of fusion zone (b), total cross-section area of HAZ (upper curves) and cross-section area of phase-transformed HAZ (lower curves) (c), dilution X (d)

3.4 Hardness

Vickers hardness HV10 was measured horizontal and vertical across the weld area. Positions and directions of measuring are shown in the Fig. 8. Results for welding with the rectangular electrode 12.56×1 mm (samples A) are presented in the Fig. 9 and results for the standard cylindrical electrode in the Fig. 10.

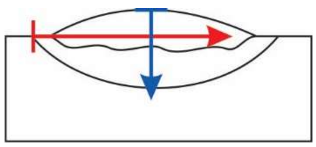


Fig. 8 Positions and directions of hardness measurements

The diagrams in the Figs. 9 and 10 indicate, that at both electrode-geometries lower currents resulted in higher average hardness.

First, it should be noted that in most diagrams in the Figs. 9 and 10 the first value is significantly lower than the following ones. The first value was always measured only 0.5 mm from the sample's edge, which was too close to the edge for measurement with a 10 kg load. Consequently, the strongly deviant first values are not are not reliable, are most likely much too low, and should not be taken into account.

Average hardness in horizontal direction slightly above 200 HV10. In vertical direction, Fig. 9b, a peak hardness over 220 HV10 was measured in the weld cap, while in the fusion zone the hardness was only slightly lower.

Welding with 120 A, sample A3, resulted in lower hardness. In horizontal direction, Fig. 9c, only in three points the hardness was above 200 HV10. In vertical direction, Fig. 9d, also in this sample the highest hardness was measured in the weld cap and in the fusion zone, however, the values were all slightly below 200 HV10.

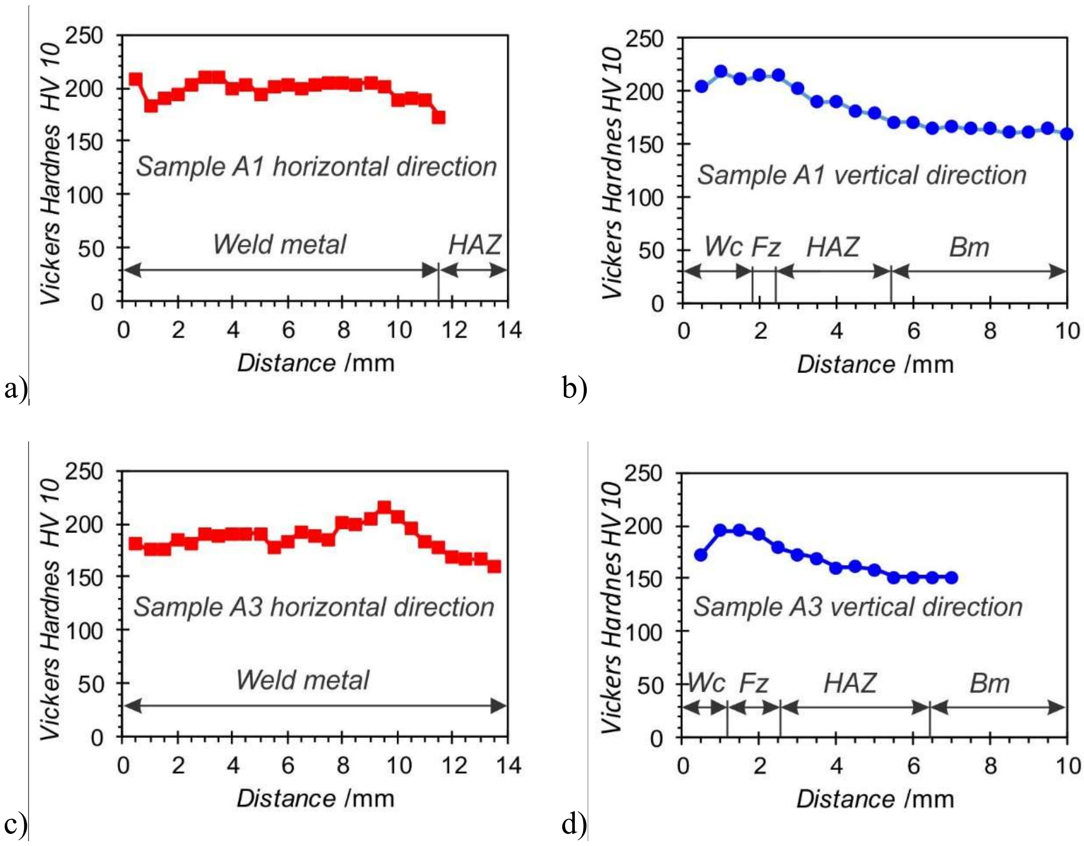


Fig. 9 Hardness of samples A – rectangular electrode 12.56×1 mm; sample A1, 80 A, horizontal direction (a), sample A1, vertical direction (b), sample A3, 120 A, horizontal direction (d), sample A3, vertical direction (d). Abbreviations represent Wc – Weld cap, Fz – Fusion zone, HAZ – Heat affected zone, Bm – Base material

Welding with a standard cylindrical electrode with a current of 120 A resulted in average hardness above 240 HV10 with very little scattering in horizontal direction, Fig. 10a. Also in vertical direction, Fig. 10b, in the weld cup and in the fusion zone the hardness was over 230 HV10, while across the HAZ it gradually decreased to the hardness of the base metal.

Most evenly was the hardness of the sample N6, welded with a cylindrical electrode and a high current of 180 A. All values are slightly below 200 HV10, without noteworthy deviations in any direction, Fig. 10c and Fig. 10d. However, in the sample N6, fusion zone and HAZ were deep and the dilution high, Figs. 6 and 7.

At a comparable weld geometry and dilution, hardness was lower with the rectangular electrode. This indicates that with rectangular electrodes perhaps a little higher impact toughness and ductility of deposition layers may be expected. However, this assumption was not yet verified.

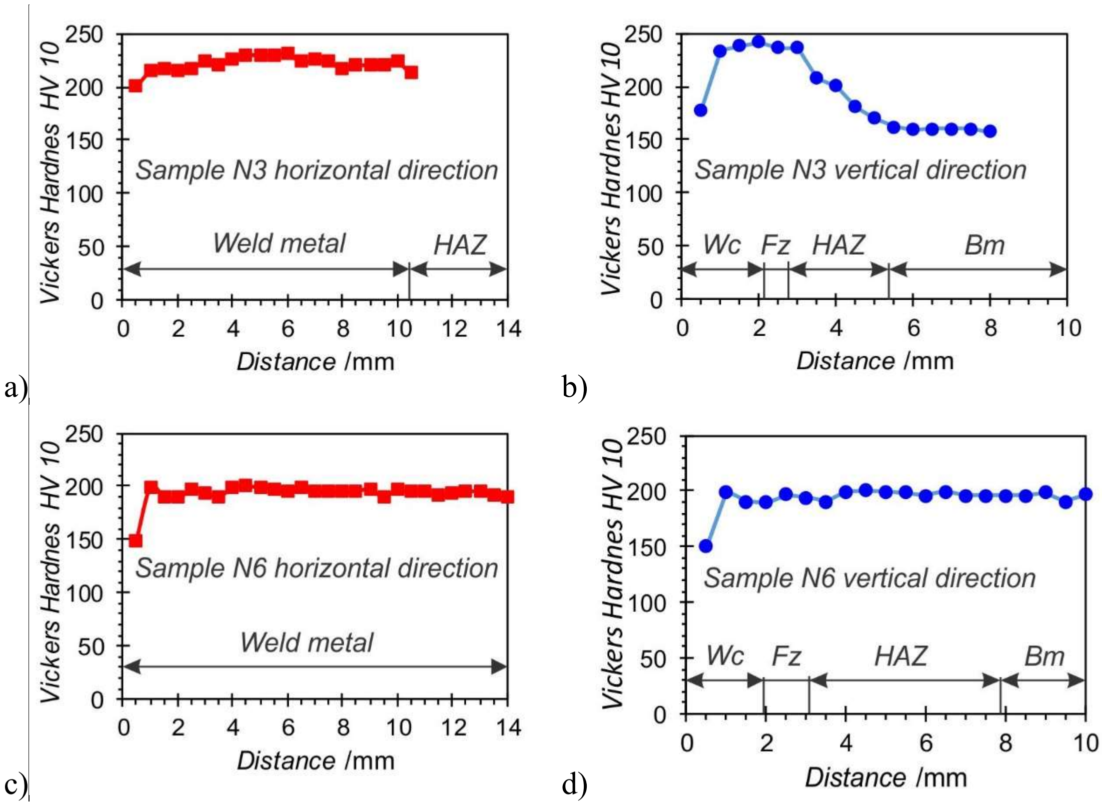


Fig. 10 Hardness of samples N – standard cylindrical electrode ϕ 4 mm; sample N3, 120 A, horisontal direction (a), b) sample N3, vertical direction, c) sample N6, 180 A, horizontal direction, d) sample N6, vertical direction. Abbreviations represent Wc – Weld cap, Fz – Fusion zone, HAZ – Heat affected zone, Bm – Base material

4 Conclusions

Coated electrodes of rectangular cross-sections of 6.28×2 mm and 12.56×1 mm were manufactured. The chemical compositions of the metallic core and the coating corresponded to the standard cylindrical electrode Rutilen 2000 S.

Weld-cladding were carried out with rectangular electrodes as well as with standard electrodes Rutilen 2000 S of the equal cross-section area.

Lower welding current was required to obtain a good quality of the deposition layer welded with significantly wider rectangular electrode compared to the standard electrode. No excessive spattering was observed, and the spatters could be easily removed. The slag spalled by itself immediately after welding.

With respect to weld width and fusion zone depth, a current of about 80-100 A was optimum for the 12.56×1 mm rectangular electrode. With cylindrical electrode, similar results could be achieved with significantly higher currents, about 120-140 A. However, with the cylindrical electrode, at comparable weld widths the fusion zone area, the dilution and hardness were always higher than with the rectangular electrode.

5 References

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