

TECHNOLOGICAL ASPECTS OF THE SELF-SHIELDING TUBULAR WIRE WELDING OF OVERLAP JOINING ON REINFORCING STEEL

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Abstract—Welding of reinforcing steel is usually made on site. One could envisage the making of big subassemblies in specialized workshops, their joining being made on site. Therefore it is very easy to adopt the electric manual arc welding process. This paper proposes a method which would provide a more productive welding, which can be used on the site i.e. the process of MAG(METAL ACTIV GAS) Self-shielding tubular wire welding.

Keywords—MAG welding, self-shielding tubular wire, metal active gas (MAG) welding, lap welded joints, welding technology.

I. INTRODUCTION

WELDING of reinforcing steel is a relatively difficult operation requiring high workload. Welding is often made on site in circumstances which confine the range of the welding procedures to be used. The most common welding method is the manual arc welding with coated electrode, which provides both the necessary shielding for the arc and metal bath and meets the quality requirements for the welds made. The major disadvantage of this process is the low welding productivity.

An alternative to manual arc welding with coated electrode used for steel reinforcing welding on site is the MAG Self-shielding tubular wire welding - ST 1. The electrode wire (core) fulfils by melting the same functions as the electrode coating i.e. mainly the shielding function by means of the volume of gas from the combustion of the ingredient substances. Moreover, the process enables the productivity twofold up to four times higher than the manual arc welding with coated electrode.

For steel reinforcing welding one uses currently two norms, as follows:

- 1) Norm INCERC C28/83
- 2) European standard SR EN 481-1/2012

The paper presents the technological aspects of the Self-shielding tubular wire welding of overlap joining on reinforcing steel as an alternative to manual arc welding

with coated electrode. The paper presents experimental research on setting-up a feasible welding technology in order to qualify the welding method. The Timisoara branch of INCERC is interested to be the first company who implement this technology in Romania in the case of steel reinforcing welding.

II. PRESENTATION OF WELDING CONDITIONS

Research conducted in the study hereinafter was performed according to norm SREN481/1-2012 [2] on Ø 25(mm) reinforcing steel bars. Welding of the reinforcing steel according to the norm aforementioned can be carried out in the case of the following types of welded joints and welding methods:

- 1) Projection welding;
- 2) Flash butt welding;
- 3) Friction welding;
- 4) Arc welding, lap seam welding and bridge spot welding;
- 5) Arc flash butt welding butt with or without the root support.

Arc welding of fittings can be made by means of the following methods, see SR EN 4063:

- 1) Manual welding with coated electrode - 111;
- 2) Self-shielding tubular wire welding - 114;
- 3) MAG welding - 135;
- 4) Tubular wire welding with additional gas shielding - 136.

According to this norm, steel reinforcing joining can be ensured through butt joints or lap welded joints. At their turn, lap welded joints can be with or without bridge spot welding on one side or both sides.

Preparation of reinforcing steel bars for the arc welding of welded lap joints parts is outlined in Fig. 1 below.

In the case of welding on both sides, the minimum length of the weld should be 2.5 d (compared to welding on one side of at least 4d, see Fig. 1 above). An estimate of the thickness of the weld can be approximated by the

ratio $a \approx 0.5w$.

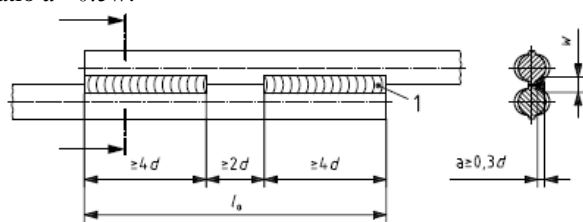


Fig. 1. Preparation of reinforcing bars – lap joint

1. welding; a - weld thickness: $a \geq 0.3 d$; d - nominal diameter of the bars; l_0 - total length of bars overlapping; w - width of the weld

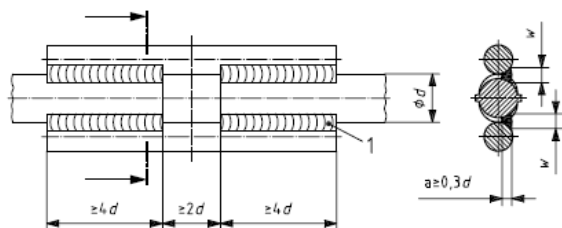


Fig. 2. Preparation of reinforcing bars – butt joint

1. welding; a - weld thickness: $a \geq 0.3 d$; d - nominal diameter of the thinnest bar; l_0 - total length of bars overlapping; w - width of the weld

If the butt straps and the reinforcing steel bars have the same mechanical properties, the cross-sections of the two butt straps have to be equal to or greater than the two cross-cutting sections of the reinforcing steel bars to be welded. If the butt straps and the reinforcing steel bars do not have the same mechanical properties, the cross-sectional area of the butt straps shall be adjusted by the nominal ratio of the Re yield strength of the two

materials.

Welding is possible on both sides, with a minimum length of weld of 2.5 d. An efficient estimate for the height of the weld can be approximated by the ratio $a \approx 0.4w$.

Reinforcing steel welding can be done only by qualified welders for such work i.e. by means of certified welding procedures. According to the norm for welders certification, in the case of overlapping welds one should perform three (3) samples to be put to tension stress and for the certification of the welding procedures one should perform three (3) tensile tests. Breaking the sample during the tensile test should take place in the base metal. Defects admitted in the case of welded joint should be within the level of acceptability C - average, according to SRENISO 5817.

III. PRESENTATION OF THE PARENT (MATRIX) METAL

Brands and technical quality terms on hot rolled reinforcing steel used to reinforce concrete are presented in the norm SR 431-1/2012 [1].

TABLE I
CLASSIFICATION OF THE REINFORCING STEEL

Class	Steel brand	Steel group	Profile type
I	OB 37	Carbon steel	Flat
II	PC 52	Low-alloy steel	High bond
III	PC 60		

The chemical composition of the steel concrete brands is shown in Table I and the corresponding mechanical characteristics are shown in Table III below

TABLE II
CHEMICAL COMPOSITION OF THE LIQUID STEEL

brand	Steel								Equivalent carbon content
	C max.	Si max.	Mn max.	S max.	P max.	V max.	Ti or Nb Max.	C _e max.	
	OB 37	0.23	0.40	0.75	0.045	0.045	-	-	-
	PC 52	0.22	0.55	1.6	0.045	0.045	-	0.06	0.50
	PC60	0.27	0.55	1.6	0.045	0.045	0.10	-	0.50

TABLE III
MECHANICAL CHARACTERISTICS

Steel brand	Nominal diameter mm	Yield stress R_{eH} or $R_{p0.2}$ N/mm ² min.	Tensile breaking strength R_m N/mm ² min.	Elongation at break A_5 % min.	Cold bend test	
					Angle of bend	Arbor diameter
OB37	6...12	255	360	25	180°	0,5 _d
	14...40	235				
PC52	6...14	355	510	20	180°	3 _d
	16...28	345				
	32...40	335				
	> 40	By mutual agreement between parties				
PC60	6...12	420	590	16	180°	3 _d
	14...28	405				
	32...40	395				

Delivery of the steel can be in the form of coils or bars form dependent on nominal bars diameter ranging between 6 ... 40mm. Depending on the brand of

reinforcing steel it can be smooth, i.e. brand OB 37 or high bond i.e. brands PC52, and PC60. High bond reinforcing steel is provided with opposite longitudinal

ribs and helical ribs equally spaced and inclined at an angle of 55 ... 65° from the longitudinal ribs. In order to distinguish between the two steel brands and to avoid confusion, winding fins are arranged in the same direction on both halves of the profile in the case of steel PC52, and they are arranged in opposite directions on the two halves of the profile for the brand PC60, respectively.

IV. EXPERIMENTAL RESEARCH

Experiments research aimed at establishing a feasible self-shielding tubular wire welding technology in the case of overlapping welded joints for steel bars applicable to site conditions as an alternative to manual welding with coated electrode with the purposes of increasing welding productivity in the same working conditions and at a quality level equivalent reached when welding with coated electrode. Tests were run on Ø 25 (mm). PC52 steel brand reinforcing bars. Helpful Hints

A. Choosing welding equipment

Large Welding equipment used in half-powered self-shielding tubular wire welding are no different much as compared to standard welding equipment used in MIG/MAG welding.

When choosing welding equipment in this case, however, one should take into account the following:

1) Welding (power) source should have first feasible welding programs for self-shielding tubular wire welding; not all MIG / MAG (METAL INERT GAS/METAL ACTIV GAS) welding sources are provisioned with this feature;

2) If the welding (power) source does not meet the condition aforementioned, we must allow the possibility of changing the polarity of the electrical current, since the self-shielding tubular wire welding generally requires the use of direct polarity DC^- and MIG/MAG welding sources are ready for being use with reverse polarity DC^+ as required by solid wire (core) welding;

3) A self-shielding tubular wire welding torch (gun) is different from the standard solid wire (core) welding torch (gun), as the former has a particular welding head and it misses both the gas nozzle and diffuser, and it does not a gas tube since the welding is not a shielding gas based; basically it is about a simplified welding torch (gun);

4) In order to drive the cored wire it is recommended to use the drive rollers provided with teeth in the slot guide to reduce the down force and prevent distorting the wire with all the negative consequences that may occur, given both the manufacturing method and that most of these wires are manufactured and delivered with open outline (they are not welded on generators as the remaining tubular wires); therefore self-shielding tubular wires are not coppery on their surface;

5) Based on the above recommendation, it is necessary that the self-shielding tubular wire Bowden be made on steel and not rayon as recommended in additional gas

shielding tubular wire welding with closed outline; the impressions left on the wire surface by the teeth lead to premature wear of the rayon tube and block the welding process, the wire acting in this case as a cell.

In order to run experimental research one used a modern welding source equipped with a Phoenix 300 inverter manufactured by the company EWM, and which we do have within our department equipment. Unfortunately this source lacks technology programs for self-shielding cored wire welding and therefore it is conceived and delivered to DC^+ reverse polarity welding. Therefore the power (welding) source had to be adapted to the welding conditions required by wire; in doing so one set a existing welding program as closely as possible to the requirements of wire used to ensure welding process stability and to alter the welding circuit by using the polarity reversal by means of an additional welding cable which would allow an easy and appropriate altering of the polarity without affecting the welding machine's performance.

Fig. 3 below shows the welding power source ready to self protecting tubular wire welding as recommended above.

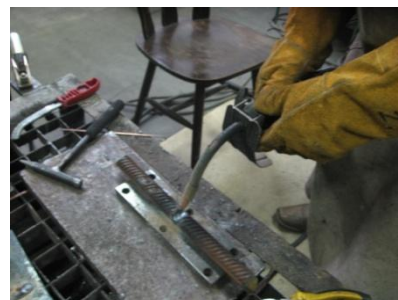


Fig. 3. Preparing welding equipment

The welding program set on the front panel of the source was conceived taking into consideration the following conditions: basic cored wire, 100 % CO_2 shielding gas, G3/4Si1 wire material, Ø 1.6 (mm) wire, and a Lincoln welding torch specialized for self-shielding tubular wire welding.

B. Choosing self-shielding tubular wire

In order to make tubular wire welding, one used FCW 71T - Selfshield brand wire classified as E71T -11 according to AWS norms, and classified S50GB according to JIS YFW delivered by company EWM and designed for welding plain carbon steel, e.g. S185 ... S355, P235 ... P355, etc. In this category one could include the PC 52 brand reinforcing steel. Wire is supplied in diameters ranging from 0.9 to 1.2 - 1.6 mm. For the Ø 1.6 mm diameter wire used for testing, the manufacturer recommends a 180 - 280(A) welding current.

Chemical composition and mechanical properties of weld deposit are shown in Table 4 below, [4].

TABLE IV
CHARACTERISTICS OF THE WELD DEPOSIT

C	Si	Mn	P	S	Al
0.19	0.35	0.6	0.011	0.006	1.2

Remember One may note that for welding it is recommended to use the direct polarity DC--. One of the characteristics of the self tubular wires is the high level of Al (ranging between 0.9 ... 1.6%) to prevent oxidation and nitration of the weld deposit metal ($2Al + 3O = Al_2O_3$, $Al + N = AlN$, respectively). The amount of Al which remains in weld deposit can control and change

TABLE V
WELDING PARAMETERS DEPENDING ON THE DIAMETER OF THE WIRE, [6]

Diameter (mm)	Electrical Stick-out (mm)	Wire Feed Speed inch/min	Wire Feed Speed cm/min	Current (approx. A)	Arc Voltage (V)	Deposition Rate (kg/h)	kg Wire kg Weldmetal
0,9	10	50	125	30	14	0,3	1,22
		90	230	90	16	0,6	1,22
		110	280	120	16,5	0,8	1,22
1,1	14	70	180	120	15	0,5	1,22
		110	280	160	17	1	1,22
		130	330	170	18	1,2	1,22
1,7	19	40	100	120	15	0,8	1,22
		75	190	190	18	1,5	1,22
		175	440	320	23	3,5	1,22
2,0	19	50	130	180	16	1,4	1,09
		75	190	250	18	2,2	1,09
		150	380	350	22	4,3	1,09
2,4	19	50	130	235	16	2,0	1,10
		55	140	250	18	2,3	1,10
		100	250	370	20	4,2	1,10

Type Based on the above recommendations, the welding technology will be adapted within the experimental research to EWM - FCW 71T - Selfshield brand wire to obtain an arc stability as good as possible, a minimum level of splashing, and an optimal geometry of weld required by legislation in force.

C.2. Preparing welding of components

Define For welding purposes, 300 (mm) length samples were taken from DIAMETER 25 (mm) steel bars. By overlapping the two concrete steel bars one gets the natural joint shape, see.



Fig. 4. Positioning components - provisional welding-foto-

Therefore in the case of overlapping welding of steel reinforcing the shape and size of the joint results implicitly from the relative position of the bars and/ or butt straps yielding an atypical, non-standard joint shape.

Fig. 5 below shows the joint as a result of positioning rods or butt straps, Section A1 (the one in red).

the microstructure and evolution of weld-deposited metal, [5].

C. Experimental tests

C.1. Technological advi

In order to perform the first experimental tests one started from the recommendations of the manufacturers of tubular wire for this class and category of wires i.e. the Lincoln company' recommendations for self-shielding tubular wire Innershield NR 211MP Ibrand shown in the product catalogue, see Table V below.

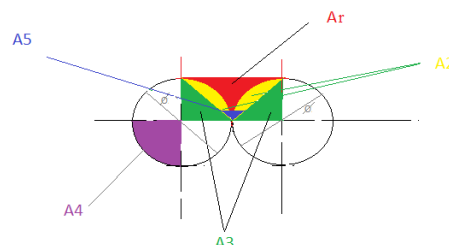


Fig. 5. Positioning components - provisional welding-drawing-

From the geometric calculation it results the formula of the joint area formed by overlapping the two bars, depending on their diameter:

$$A_r = \frac{d_b^2}{2} - \frac{\pi d_b^2}{8} = \frac{d_b^2}{2} \left(1 - \frac{\pi}{4} \right) = \frac{0,2d_b^2}{2} = 0,1d_b^2 \quad (1)$$

Where: d_b - diameter steel bar concrete

Theoretical calculation of the joint area is a rough but easy calculation because it does not take into account the area of the section corresponding to the lack of penetration of the weld root, which is inherent in such cases (i.e. the blue area), and it does not take into account of the presence of ribs on the surface of the bars, but the error is insignificant from the practical standpoint.

C.3. Establishing welding technology

Experimental tests performed to establish a reliable steel bars overlapping welding technology with FCW 71T wire starting from the manufacturer's recommendations aimed at establishing the optimum welding parameters from the arc stability standpoint, the minimal splashes, the quality and appearance of welds, lacking acceptable defects in the welded joint, and the disposition of pass and operating mode.

Experimental tests have finally led to the following welding technology parameters considered as optimal:

- 1) Wire feed speed $v_{as} = 4.5 \pm 0.1$ (m/min);
- 2) Welding current $I_s = 280 \pm 15$ (A);
- 3) Arc voltage $U_a = 21.5 - 22$ (V);
- 4) Welding speed:
 - a) $v_s = 25$ (cm/min) – at the root, without swinging,
 - b) $v_s = 20$ (cm/min) – at joint filling, with swinging;
- 5) Electrode wire diameter $d_s = 1.6$ (mm);
- 6) Length of the free end of the wire electrode $L_{CL} = 17 - 19$ (mm);
- 7) Welding torch (gun) positioning $\alpha = 80^\circ \pm 5$;
- 8) Welding direction: back-hand welding or drawing (always for wire welding generating slag/hards).

The fluctuations of technological parameters of the welding are shown in Fig. 6 below.



Fig. 6. Fluctuations of welding current and arc voltage parameters

The exterior of the first layer is shown in Fig. 7 below



Fig. 7. Exterior appearance of layer 1

Welding was made starting from the bars' ends inward to prevent the leakage and suffusion of metal bath at the ends. One may notice partial coverage of welding with slag (hards) i.e. the left side, and a uniform appearance of deposit with flat surface.

Fig. 8 below presents the exterior of welds on both sides for layer 1 and layer 2.



a. On side 1: layer 1 – left; layer 2 – right



b. Detail



c. On side 2

Fig. 8. Exterior appearance of weld

Welding was done in two layers. Welding of the layer was done without swinging the welding torch with focusing of the electric arc at the root of the joint for achieving a maximum possible penetration to prevent leakage in metal bath in front of arc resulting in the lack of root penetration. For the fusion of joint sides one requires swinging welding of the layer 2 leading to an aesthetic, smooth slightly canted surface. Welding direction of the two layers can alternate to ensure a better control of the crater. One may notice a good and uniform melting of joint flanks without the leakage trend of the molten metal at the ends of the bars. One should avoid overheating bars which would make the control of metal bath difficult and the closure of the crater relatively large. By making additional deposit in the crater after the cooling and solidification of the metal bath one could achieve the crater closure with an improving in appearance the aesthetics. The main current and arc voltage welding parameters were kept unchanged for the two layers to avoid repeated adjustments of wire feed speed with consequences on welding productivity. Due to the last layer oscillation, welding speed decreases slightly. For the macroscopic metallographic analysis of the weld, two metallographic samples were collected by means of mechanical sawing from two welds in order to highlight the reproducibility of welding (see Fig. 8). Macro-structural appearance of the weld is shown in Fig. 9 below.



a. sample 1



b. sample 2

Fig. 9. Macroscopic appearance of the weld (under 10% NITAL test)

There were noticed no macroscopic internal defects reported on welded joints i.e. cracks, slag inclusions, pores, etc.

Lack of penetration or lack of fusion at the root is not a major flaw as it might seem at first, because it is inherent in this case due to the geometry of the joint resulted from the steel bars positioning (see Fig. 1 and Fig. 2). It is possible that a trend consisting in the lack of sides' fusion of joint in the root area might occur; see top-right side of Fig. 8 to root on the right side, accompanied by the danger of leakage of molten metal in the gap between the reinforcing steel bars. This can be seen on the root of the weld on the sample 2, on the upper right side, where the lack of melting of the base metal might occur. The cause for such flaws can be due to the improper positioning and direction of the welding torch in use, poor control of the metal bath with the flow of the molten in front of the arc, the too low arc current, too high arc voltage, too large volume of metal bath, cold part at the start of welding, the presence of ribs on the surface of the bars, etc. The first layer has a slightly concave outer shape which is favourable to depositing layer 2. There is a good overlapping of the two passes through. There appear no external defects in welding i.e. marginal notches, metal leakage, crater cracks, etc. The outer surface of the weld is uniform, smooth, slightly convex which is specific to tubular wire welding.

The quality of the weld is suitable for the C level acceptance of flaws which should fall within reinforcing steel welds, according to the norm EN 481/1. Norm states that the estimate of the weld thickness (defined in Fig. 1 and Fig. 2), $a \geq 0.3 d_b$ for welds on one hand, and to $\approx 0.5 d_b$ in the case of welds on both sides. While applying the conditions in this case i.e. the bar $\varnothing d_b = 25\text{mm}$, it results the thickness of the resulting weld $\approx 12.5\text{ mm}$. It is noted that in this case the thickness can not be obtained by a single passes because it would require a too low welding speed reported to a high volume of the metal bath, which would lead to the danger of leakage of the bath metal to the electric arc with all related consequences. The thickness of the first weld pass is approx. 6 ... 8mm which is insufficient, requiring a second pass. To compensate for the inherent lack of penetration in root one requires that when making the second layer, the outer surface of the weld has at least the same diameter as the outer diameter of the bar.

The research made above on 25mm diameter bars welding one confirms the appropriateness of applying self-shielding tubular wire welding on making on site of steel reinforcing in concrete as an alternative to manual welding with coated electrode and at a level of quality compared to the former but with an increased productivity.

The results obtained allow further research towards the certification of WPS welding procedures, and the certification of authorized welders for reinforcing steel welding by means of half-powered tubular wire welding.

V. CONCLUSION

Steel reinforcing in concrete welding is a relatively difficult operation and a involved a great deal of work, being often made on the site under conditions that limit the choice of the welding method used typically in manual welding with coated electrodes.

This paper proposes an alternative to manual welding with coated electrode of steel reinforcing in concrete site by half powered self-shielding tubular wire welding; the research results to obtaining appropriate quality welds similar to manual welding with coated electrode but with an increased welding productivity.

The norm EN 481/1 allows the application of self-shielding tubular wire welding method - 114 at the welding of reinforcing steel both for butt joints and overlapping welds with or without butt straps, a recommendation which is not provided in the normative INCERC C28 / 87 for obvious reasons.

From the knowledge of authors the tests performed are run for the first time in Romania i.e. half-powered tubular wire welding of joints by steel reinforcing overlapping and it is an issue of interest for INCERC Timisoara Branch for further research in order to certify such welding procedures.

Research will continue in the direction of butt welding of steel reinforcing.

This paper proposes the dissemination of results among companies and specialists in the field of welding, especially builders concerned with the implementation of new and more productive welding processes of reinforcing steel.

REFERENCES

- [1] *** SR EN 481-1/2012 – *Welding – reinforcing steel welding*.
- [2] M. Burcă, R.C., Moisa, R. ș.a. - *Cercetari privind sudarea cap la cap cu sarmă tubulară cu autoprotecție a armăturilor de oțel beton*, Annual Conference of ASR, Sibiu, România, 2014.
- [3] M. Burcă, St. Negoitescu – *Sudarea MIG/MAG*, SUDURA Printing house, Timișoara, Romania, 2004.
- [4]
- [5] *** SR 438-1/2012 – *Produse de oțel pentru armarea betonului. Partea 1 Oțel beton laminat la cald. Mărci și condiții tehnice de calitate*.
- [6] *** EWM - *Catalog de consumabile pentru sudare*.
- [7] S.S. Babu, s.a. – *Modeling Microstructura Development in Self Shielded Flux Cored Arc Welds*, Welding Journal, WJ nr. 4, April 2001, Welding Research.
- [8] *** LINCOLN – *Consumabile pentru sudare*.