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SELECTION OF THE WELDING TECHNOLOGY OF RELIABLE ASEMBLIES USING GMAW PROCESS

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Abstract: *In this paper it will be given a procedure of determination of optimized shielded gas welding technology of the high reliable assemble built-up of the massive pipes on plate. Determination of welding regime, besides of welding method choosing, welding joint and welding groove, filler metal and welding equipment, calculating of energy-technological parameters, implies preliminary estimate of the base metal weldability. That estimate can be resumed as evaluation of resistance to cracks in the base metal during welding procedure, as well as determining prior and the follow-up thermal treatment of base metal if needed.*

Key words: *weldability, welding technology, preheating, GMA welding, cracks.*

1. INTRODUCTION

In this paper is exposed only a part of results of determination of welding technology for reliable assembly to be used in Cern research installment in Switzerland. According to Figure 1a, the central pipe (position 1) should be welded for the plate (position 2), with previously prepared groove according to detail "A" (Figure 1b). After that, it is also necessary to weld the two cut pipes (position 3) with the circular joint to the pipe detail "B" (Figure 1c), as well as longitudinally to the pipe along the two generator lines according the detail "C" (Figure 1d). Here we consider technology of welding of central pipe for plate wall only.

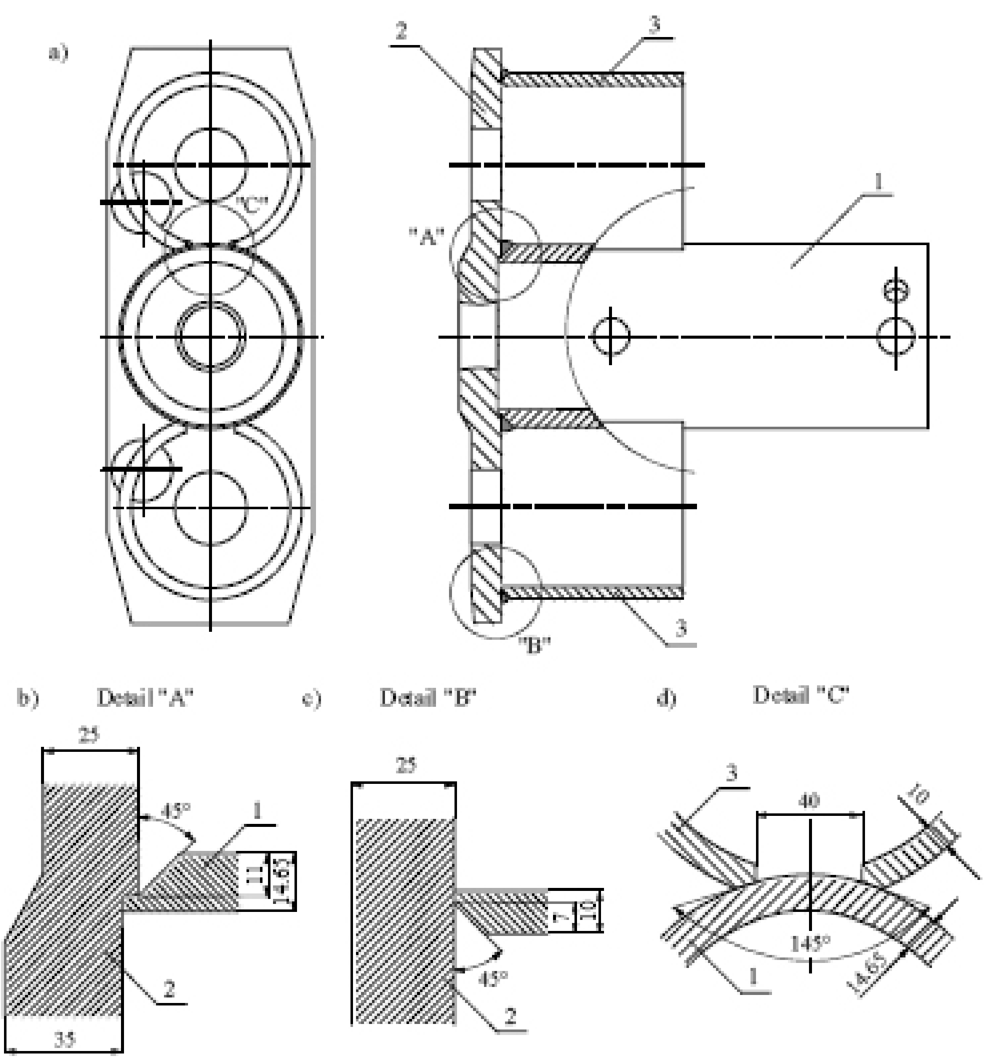

Figure 1. Welding of the central and peripheral pipes to the plate (a) and appearance of the individual grooves (b, c, d)

2. EVALUATION OF THE BASE METALS WELDABILITY

Chemical composition and mechanical properties of the base metal (positions 1 and 2) - St 52.0 and C 15, taken from catalogues and obtained by chemical analysis, are given in Tables 1 and 2, respectively.

Table 1. Chemical composition and mechanical properties of the welded steel - St 52.0 (DIN 2448/81, DIN 1629/84)

Content of individual elements, %									
	C	Si	Mn	P	S	Cr	Ni	Cu	Al
Catalogue	0.14-0.20	0.40-0.55	1.20-1.50	≤0.04	≤0.04	≤0.30	≤030	≤0.03	-
Analyzed	0.17	0.45	1.33	0.008	0.009	-	-	-	0.028

Mechanical properties			
	R_{eH}, MPa	R_m, MPa	A_5, %
Catalogue	min 355	500-650	min 21
Analyzed	377	577	30.8

Based on the chemical and metallographic analyses of the welded steel, one can say that here we deal with the small grain C-Mn steel of the increased strength (R_m= 577 MPa, R_{eH}= 377 MPa, A_5= 30.8%) of the lamellar ferrite-perlite structure.

Table 2. Chemical composition and mechanical properties of the welded steel - C 15 (DIN 17 2109

Content of individual elements, %									
	C	Si	Mn	P	S	Cr	Ni	Cu	Al
Catalogue	0.12-0.18	≤ 0.40	0.30-0.60	≤0.045	≤0.045	-	-	-	-
Analyzed	0.14	0.02	0.38	0.010	0.008	0.02	0.04	0.05	0.033

Mechanical properties				
	R_{eH}, MPa	R_m, MPa	A_5, %	HB
Analyzed	274	369	37	118

Based on the chemical and metallographic analyses of the welded steel, one can say that here we deal with the steel of the lamellar ferrite-perlite structure.

According to calculations criteria (given in detail in literature [1, 2, 3, 4, 5, 6, 7]), here we deal with steels of good weldability. Thus, with adequately selected technology, these positions can be successfully welded with different welding procedures (SMAW, GMAW).

The base metals are resistant to both cold cracks, and, especially, to hot cracks, due to negligible content of impurities [3, 5, 8, 9].

3. WELDABILITY OF THE BASE METALS

We selected the metal arc gas welding with gas mixture, at the semi-automatic numerical machine for circular welding. In order to fix the pipe cover for the plate three joints at three points at 120° angles were made. Prior to joining, the perpendicularity of the pipes and the plate was checked, for each assembly. Joining was done with 82% Ar + 18% CO_2 shield, manually (with the wire of diameter 1.6 *mm* and current of intensity I ≈ 280 *A*), and the joints' length was about 20 *mm*. After cooling down to the room temperature, the beginnings and ends of joints on all three joints were fix.

3.1 Calculation of the welding parameters

Technological parameters of metal arc gas welding were calculated according to the following method [5]:

- Groove area: $A_g = 2 \cdot P_\Delta = 11 \cdot 11/2 = 60.5\ mm^2$;
- Joint area: $A_j \approx 1.1 \cdot A_z = 1.1 \cdot 60.5 = 66.55\ mm^2$;
- Single joint layer area: $A_z \approx 33\ mm^2$;
- The single layer mass per unit length: $M = \rho \cdot A_z \cdot L = 7.85 \cdot 0.33 \cdot 1 = 2.59\ g$;
- Quantity of the deposited material per time unit: $m_{1.6} = 0.64 + 0.55 \cdot M - 0.055 \cdot M^2 = 1.70\ g/s$;
- Welding speed: $v_z = \frac{m \cdot 6000}{A_z \cdot \rho} = 0.656\ cm/s$;
- Wire speed: $v_t = \frac{0.012132 \cdot A_z \cdot v_z}{d^2} = 6.46\ m/\min$;
- Welding current: $I_{1.6} = 378 \cdot \log v_t + 26 = 332\ A$;
- Operating voltage: $U = 14 + 0.05 \cdot I = 31\ V$;
- Heat input energy: $q_l = \frac{U \cdot I}{v_z} \cdot \eta = 13336\ J/cm$;
- Welding depth: $\delta = 0.3 \cdot r = 0.3 \cdot 0.00537\sqrt{q_l} = 0.186\ cm$;

- Shielding gas type: mixture (82% Ar + 18% CO_2);
- Shielding gas flow: q ≈ 20 *l/min*.

The calculated welding parameters serve as the initial ones for selecting the welding regime in the metal arc gas welding. The same are then compared to ones proposed from experience and, eventually, the correction of calculations is done prior to the welding itself. After testing of the realized joints, those welding parameters are adopted that produce the best results [8].

3.2 Selection of the filler metal

As the filler metal is used the steel (copper platted) wire - VAC 60, ∅1.6 *mm* (DIN 8559/94 - SG-2-CY 4233), aimed for welding in the gas shielded atmosphere. Mechanical properties of the clean welding layer and chemical composition of the wire are given in Tables 3 and 4, respectively [5, 10].

Table 3. Mechanical properties of the clean welded layer

Yield strength R_{eH}, *MPa*	Tensile strength R_m, *MPa*	Elongation A_5, %	Toughness (-40°C) ISO-V, *J*
410-490	510-590	22-30	> 47

Table 4. Wire chemical composition (Welding current: DC-E.+)

C	Si	Mn	P	S
0.08	0.90	1.50	<0.025	<0.025

3.3 Selection of the welding technology and control of the realized joints

Prior to commencing the continuous welding, for both the test and for real ones, the circular radial deviation of each working piece was checked. This deviation was within the range of 0.1 to 0.2 *mm*, what was considered as acceptable. In addition, prior to welding, the joint pieces were degreased by washing with the adequate cleanser, and then they were dried.

In order to select the optimum technology, the numerous test welds were performed with the calculated parameters, under the conditions without preheating, in two passes. After these tests, we decided to weld pipes for the plate in two passes and without preheating. Passes were done immediately one after the other. The capping pass 2 relaxes the root pass 1 what gives better microstructure, the possible brittle zones are avoided, and the level of the residual stresses is decreased. With this way of welding the necessary excess weld metal is formed, which is removed by machining due to final ultrasonic control. From the test joints, the metallographic ground test samples were prepared, at which the micro hardness was measured (HV1) and the microstructure was read off individual zones of the welded layer (Table 5). The welding regime in these tests was the following: U= 31 *V*, I= 333*A*, v_z= 0.6 *cm/s*, q_l= 14624 *J/cm*.

Table 5. Measured hardness and read off microstructure of individual joint zones (2-layers, $T_p \approx 20°C$)

Tested zone	Read off microstructure	Maximum and minimum hardness, HV1
B.M.1	Lamellar perlite-ferrite	185-193
HAZ_1	Interphase + tempered martensite	210-310
WELDING METAL	Small grain Vidmansteten + granular (globular) perlite + bainite	239-245
HAZ_2	Needle martensite + bainite + tempered martensite + perlite	289-400
B.M.2	Lamellar perlite-ferrite	175-189

Based on read off microstructure and measured micro-hardness (Table 5), one can notice that in HAZ_2 the hardness is somewhat bigger than the prescribed limit value (HV≈ 350). Though it is allowed that in HAZ hardness can be bigger than this value, under the condition that the wire is dry and clean, we did, for the sake of better filing of the groove, nicer appearance of the weld and somewhat lesser value of the HAZ_2 hardness, correct the welding parameters, and then continued with the test welds. In these additional tests, the welding regime was: U= 32 *V*, I= 345 *A*, v_z= 0.42 *cm/s*, q_l= 21300 *J/cm*. The measured hardness and microstructure of individual zones of the weld, done by this regime, are shown in Figure 2.

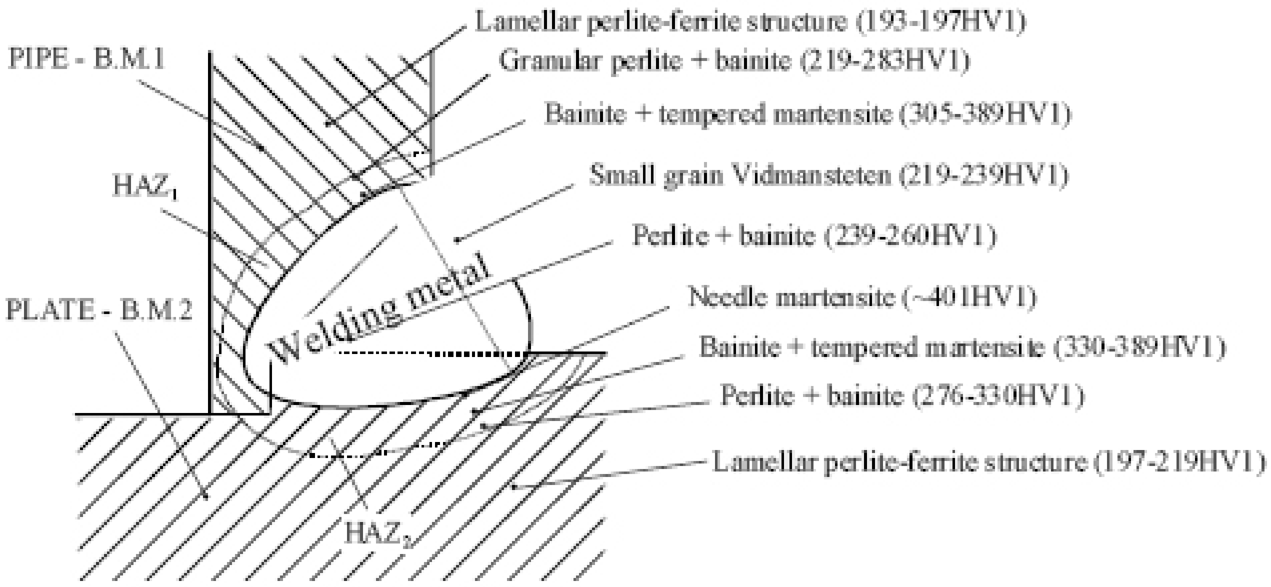

Figure 2. Measured hardness and read off microstructure of individual zones of the weld (2 layers, $T_p \approx 20°C$)

By comparative analysis of the obtained results on samples with the original and corrected welding regimes, the negligible changes can be noticed, both of hardness and microstructure of individual zones of the weld (especially in the HAZ_2, along the joining line of the weld and the plate). The reason for the increased hardness should be looked for in increased cooling speed due to significantly bigger plate thickness (35 *mm*) than the pipe of thickness (14.65 *mm*). Regardless of the fact that the increased harness could be tolerated due to low level of the diffused hydrogen, we decided to perform the two-pass welding with preheating. Parts were heated in the furnace up to T_p= 200°C, heated through for 2 hours at that temperature and welded. Reason for this is to prevent appearance of the needle martensite in the HAZ_2. Welded assemblies, where the preheating temperature dropped below 150°C, were additionally heated by the gas burner immediately prior to welding. The temperature was there controlled by thermo-chalks.

During performing the two-pass welding the energetic parameters were constantly monitored (I, U and v_z), related to driving power which, in welding of real parts, ranged within limits q_l= 14624-21300 *J/cm*. This energy, with application of preheating provides for necessary welding in, convenient hardness and microstructure, as well as the adequate output mechanical properties.

4. CONCLUSION

Considering the extensive theoretical and experimental analyses, which are related to weldability of the base metal, the adopted procedure, chosen filler metal, applied technology and metallographic-laboratory control of the welded joints, the following conclusions can be drawn:

- The base metal is from the high steels class and its weldability is good,
- This steel is not prone to forming of cracks and brittle zones during welding by melting,
- Welding can successfully be performed by metal arc gas welding procedure with the proposed technology,
- The two-pass welding is necessary due to construction of the given type of groove,
- Experimental investigations with preheating showed negligible increase of hardness form the prescribed limit value,
- By preheating the danger of forming the brittle phases and appearance of undesirable microstructure were prevented.

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