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Analysis of welding of the rear bridge semi-housing assembly of a firefighter truck by the semi-automatic procedure in gas protection

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Abstract

The problem considered in this paper is the welding technology of the steel assembly of a firefighter truck rear bridge semi-housing. Since in this procedure the welding is done of the two dissimilar steels, it is necessary to analyze effects of welding on mechanical properties and microstructure of individual joint's zones. The weldability of the base metal was considered first (semi-housing tube and flange), then the welding method and the filler metal were selected and, finally, the technological parameters of welding were calculated. The computational and experimental methods were used for the base metal weldability estimate, based on the hardness measurements in the joint's critical zones and analysis of their structures. Experimental investigations performed were aimed for verification and/or eventual correction of the proposed welding technology.

Keywords: firefighter truck, rear bridge semi-housing, welding, weldability.

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1. Introduction

Semi-housing of a truck represents a responsible machine part/assembly, which is "carrying" the truck's rear bridge and axle that is at the ends connected to wheels (Fig. 1). Depending on the type of a vehicle and terrain configuration, the semi-housing is in exploitation subjected to remarkably high bending load, especially at points of the cross-section change and the welded joints. In addition, after the welding it is necessary to geometrically adjust all the parts of the assembly. All these point to the fact that this is clearly a responsible machine part, to welding of which one must approach very carefully considering all the possible influential factors.

The semi-housing assembly is being manufactured by welding at the semi-automatic device, where the necessary dimensions are being measured from the front of the semi-housing tube, Fig. 1 [1]. The order of the working operations is the following: the flange (3) is being manufactured as the first (by the fillet weld 5×5), then the ring (2) by the weld of the same dimensions; that is followed by flange welding on the opposite side (by the fillet weld 7×7 facing the ring). The said welding operations are being executed by the special tools, which enable proper positioning and prevent the assembly's deformation.

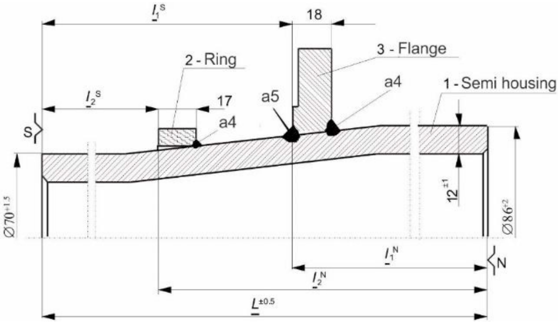

Fig 1. The semi-housing assembly with ring and flange

Numerous problems were noticed during the welding of the semi-housing tube with the ring and the flange (Fig. 2) in the existing production conditions (like the incorrectly chosen support base, impossibility of simultaneous welding of both parts, longer welding time, higher consumption of the cutting tool in the consecutive operations of mechanical machining). Therefore, the completely new apparatus for welding with two guns for the simultaneous welding was constructed, what significantly reduced appearance of the mentioned problems. The apparatus consists of large number of different components (mechanical, electrical, pneumatic, logic and combined). Its schematics is shown in Fig. 3.

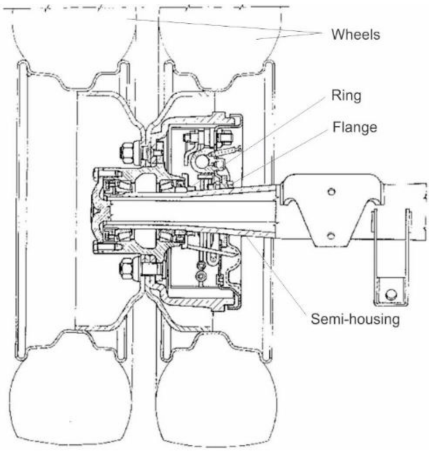

Fig. 2. The semi-housing assembly with the ring and flange

The welding apparatus consists of the servomotor with tacho-generator and incremental sensor, clutch and reductor, as the driving group, then the apparatus skeleton, protective doors with two micro-switches, longitudinal and vertical burner's supports, burner, mechanism for the fine adjustment of a burner, the fixture device, pedal foe activating the pneumatic fixing cylinder, base plate and protective cables. The programmable controller LPA 512 consists of combined switching and linear unit LNAP 19 predicted for supplying the power to the microcomputer unit from two modules, the basic functions of which are related to communication of the apparatus with the peripheral devices. Transformers controlled by the thyristor LPA 500 (made by ESAB, with the flat current - voltage characteristics) are chosen in such a way that they make possible to select the previously set welding parameters. Devices for addition of the wire MED 44, are intended for moving the wire with the speed of 2 to 18 m/min. Coolers (of the OCC1 type) are used for water cooling of the burner, while the device for gasses mixing MIMA serves for selecting the protective gasses mixture. The hard controls stand contains 14 buttons, potentiometers and selectors, while the manual control stand consists of 20 code switches, buttons, 6 indicating instruments for welding parameters readout and 7 signaling lamps. The welding apparatus also contains the system of pneumatic components and corresponding executing and control organs, ventilation system for removing the gasses, etc.

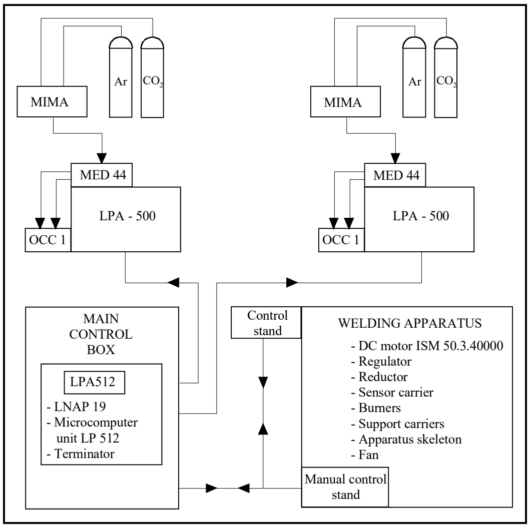

Fig. 3. The welding apparatus schematics

The mentioned welding device is equipped by the control module, which provides for introducing the basic welding parameters, as well as executing the continuous or intermittent circular weld [1-4]. Welding of the semi-housing must be performed very carefully, otherwise an initial crack can appear on some part of the assembly, propagation of which can lead to a fracture [5-7].

Thickness of joints was defined based on requirements of the manufacturer (FIAT). Though it seems that the joint thicknesses are small for the parts of that thickness, manufacturer has performed tests prior to the batch production of the assembly. In addition, it should be pointed out that in the case of the flange, Fig. 1, the double joint was executed (i.e. on both sides of the flange), which makes possible for the joint(s) to be of the smaller dimensions as compared to standard dimensioning of the part.

2. Base and filler metals properties

When selecting the complete welding technology (the welding procedure, filler metal, welding parameters, type of the protective gas) one starts from the chemical composition and thickness of the base metal (BM) and of its mechanical and thermo-physical properties. One primarily must take into account requirements defined by the construction drawing, which are related to the required geometry and the especially emphasized safety measures, the so-called "S" characteristics. The standard chemical composition of the base metal, as well as the laboratory tested one, are given in Table 1, while Table 2 contains its mechanical properties, thickness and microstructure [1, 8-9]. The 25CrMo4 steel belongs into a group of the low-alloy tempered steels, which possess exceptional mechanical properties and which are used for responsible constructions [10-12]. However, this group of steels has the so-called conditional weldability, thus the welding technology has to be carefully selected and defined, so that the steels' properties, obtained by the primary mechanical and heat treatment would not be cancelled [13-15].

The filler metal used for welding of the considered assembly was the solid wire (VAC 60 Ø 1.6 mm), however application of the core wire (FLUXOFIL 42 – Ø 1.2 mm) was considered, as well, in conditions without and with the preheating. Table 3 presents the chemical composition of these wires, the protective gas composition and mechanical properties of the pure weld metal [1].

The protective gas was the mixture of argon and carbon-dioxide, where the different ratios of the gas were tested, thus it was established that the best results are obtained with the ratio Ar/CO_2 = 80/20, what is in accordance with recommendations from the literature [1, 9].

Table 1. Base metals chemical compositions

				Chemical elements, %									
Part	Mark	Standard	Requirement	C	Mn	Si	P	S	Cr	Cu	Mo	Al	N
1	25CrMo4	UNI 6403 IVECO-52541	Prescribed	0.20 to 0.28	1.20 to 1.70	0.15 to 0.35	max 0.035	0.020 to 0.040	0.30 to 0.60	max 0.30	-	0.020 to 0.050	-
			Analyzed	0.26	1.28	0.15	0.012	0.020	0.40	-	-	-	-
2	25CrMo4	UNI 6403 IVECO-52541	Prescribed	0.22 to 0.29	0.50 to 0.80	0.15 to 0.40	max 0.035	max 0.035	0.90 to 1.20	-	0.15 to 0.30	-	-
	≈ 25CrMo4	EN 10025	Analyzed	0.27	0.71	0.26	0.033	0.027	1.13	-	0.21	-	-
3	FE 510	IVECO-52891	Prescribed	max 0.22	max 1.70	max 0.60	max 0.050	max 0.050	-	-	-	min 0.020	0.009
	≈ S355JR	EN 10025	Analyzed	0.15	1.17	0.18	0.013	0.020	-	-	-	0.022	-

Table 2. Mechanical properties of base metals, thickness and microstructure

Part	Mark	R_m *MPa*	R_P *MPa*	A_5 %	HV	S *mm*	Microstructure
1	25CrMo4	875	640	14	172	10	Interphase tempering structure (dominantly sorbite)
2	25CrMo4	980	700	11	252	13	Interphase tempering structure (dominantly sorbite)
3	(FE510) ≈ S355JR	565	185	27	170	12	Lamellar ferrite-pearlite microstructure

Table 3. Filler metals' chemical compositions, protective gas type and he pure weld metals' mechanical properties

Wire type	Chemical composition, %						Gas mixture Ar/CO_2, %	Mechanical properties of the pure weld metal			
	C	Si	Mn	Cr	Ni	Mo		R_m, *MPa*	R_{eH}, *MPa*	A_5, %	KV, *J*
VAC 60 solid	0.1	0.9	1.5	-	-	-	80/20	510 - 590	410 - 490	22 - 30	80 - 125
FLUXOFIL 42 core	0.05	0.35	1.3	0.4	2.4	0.4	80/20	730 - 830	670 - 720	16 - 20	80 - 120

3. Welding parameters

According to the corresponding calculation methods and recommendations for selection of the welding parameters in the protective CO_2 gas, it is possible to calculate the initial parameters for all the three welds. The computational method for the fillet welds (5×5) and (7×7) was executed by the method tested in previous research works by these authors [1-4] and according to examples from practice.

Besides the computational parameters some recommendations based on experience should be taken into account, like those related to the length of the drawn (free) part of the electrode – wire, position of the wire electrode with respect to the joint plane, distance of the gas nozzle from the work-piece surface, polarity of the wire electrode, the welding position, variable inductivity, etc.

It is not sufficient to relay only on the calculated welding parameters in the protective gas atmosphere, one has to compare them to recommendations from the literature or the welding equipment manufacturers' catalogues, as well. Based on those, the calculated parameters can be corrected and adjusted prior to commencing the real welds executions.

That enabled executing the test welds with varying the basic parameters within the recommended limits. Besides the visual evaluation of the welded joints, the post-welding control was conducted by destructive tests of the realized joints. In this way, the optimal welding regime was defined, primarily based on realized geometry – thickness of the weld and depth of the weld penetration, what is, besides the hardness, the basic criterion for the process control to approve these weldings as the manufacturing operations. The fillet welds (5×5) and (7×7) were executed separately, though the technological possibility exists for the simultaneous execution of those welds.

The basic welding parameters, driving energy and the realized welds characteristic dimensions are given in Table 4, for the weld realized according to Fig. 4, [1]. The characteristic dimensions were measured by the specially cut samples aimed for metallographic investigations and prepared by the grinding, polishing and etching procedures.

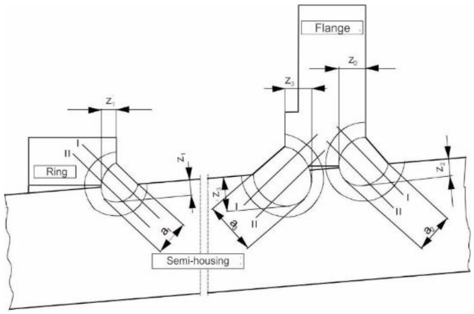

Fig. 4. Sketch of the welds positions and points of the hardness measurements

Table 4. Basic welding parameters and welds' dimensions (VAC 60 ∅ 1.6 mm)

Welds' dimensions	Basic welding parameters by the CO_2 procedure					q_l	a	z_1, (z_1', z_1'')	z_2, (z_2', z_2'')
weld	*I, A*	*U, V*	v_z, *cm/s*	v_t, *m/min*	Q, l/min	*J/cm*	*mm*	*mm*	*mm*
5×5 Tube-ring	260-300	28-30	0.722-0.778	4.2-5.3	16-18	8500-10000	6.2	2.2	3.2
5×5 Tube-flange	260-300	28-30	0.805-0.861	4.2-5.3	16-18	8500-10000	6.8	6.8	3.2
7×7 Tube-flange	300-350	30-32	0.55-0.61	5.3-7.2	18-20	14000-18000	8.0	3.8	2.8

4. Estimate of the base metal weldability

Steels, that the tubes and ring of the semi-housing are made of (positions 1 and 2 in Figure 1) have approximately the same chemical composition, though the IVECO standard recommends to use the completely same materials. According to the chemically equivalent carbon and parametric equations for weldability estimate, these low carbon steels should be preheated, or the adequate welding technology must be selected. However, regardless of application of these precautionary measures, it is possible to obtain hardness values higher than the permissible limit of 350 HV (or 450 HV depending on the diffused hydrogen) at some points of the welded joint. That is why, in order to prevent appearance of the cold cracks, one must use dry and clean wires, when the matter of welding in the protective gas atmosphere is in question.

The flange (position 3 in Figure 1) is made of the C-Mn steel of higher strength, weldability of which is estimated based on the equivalent carbon formula (CE) and base metal thickness (s). Since in this case the value of CE is smaller than 0.45 and thickness is less than 45 mm, it is considered that this steel is well weldable and not prone to appearance of the cold cracks, i.e. the transformation brittleness. To the fact also testifies the fact that hardness values, measured in the heat affected zone (HAZ) are lower than 350 HV. By selecting the adequate welding regime, it is possible to realize the optimal toughness of all the welded joint zones.

5. Hardness measurements and microstructure investigation results

Hardness was measured on a specially prepared device ZWICK 3812 with the indentation force of 3 N, only for the samples welded with the solid wire. Since no major differences were noticed in values of the maximal hardness in cross-sections of the three welded joints, here are presented results only for the joints tube-ring (5×5), tube-flange (5×5) and tube-flange (7×7), executed by the solid wire [1]. The microstructure results in the characteristic zones of the welded joints are presented, as well. Before conducting an analysis of the joints' microstructures, it is important to show the macrographic appearance of one of the characteristic welded joints (7×7) (Fig. 5), [1]. Variation of micro-hardness in basic zones of the fillet weld (5×5), which connects the ring for the semi-housing, is presented in Figure 6, while in Figure 7 are presented the microstructures of those zones. In Figures 8 and 9 is presented variation of hardness in characteristic zones of the welded joint semi-housing tube – flange (5×5) and (7×7), respectively, while in Figure 10 is presented appearance of microstructure in those zones.

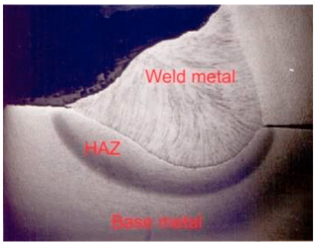

Fig. 5. Macrostructure of executed welded joint [1]

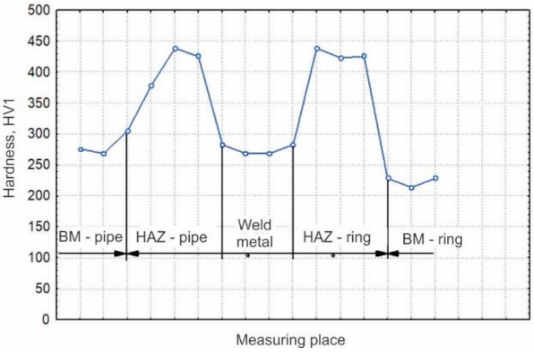

Fig. 6. Variation of hardness in characteristic zones of the welded joint semi-housing-ring (5×5)

BM – semi-housing tube
Interphase tempering structure – dominantly sorbite

HAZ – on the ring side
Interphase structure with share of the tempered martensite

Weld metal
Widmanstaetten structure

BM - ring
Interphase tempering structure – dominantly sorbite

Fig. 7. Microstructure of individual zones of the welded joint semi-housing – ring (5×5) (200×)

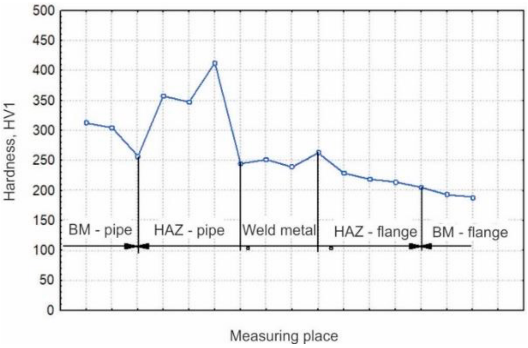

Fig. 8. Variation of hardness in characteristic zones of the welded joint semi-housing tube - flange (5×5)

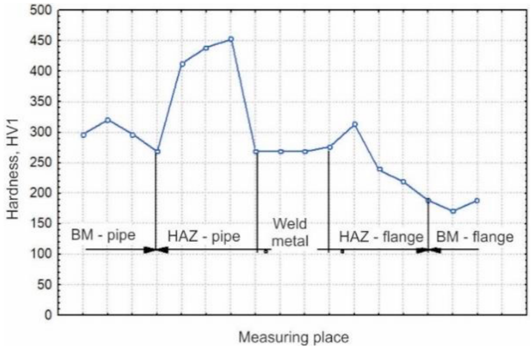

Fig. 9. Variation of hardness in characteristic zones of the welded joint semi-housing tube - flange (7×7)

BM – semi-housing tube
Interphase tempering structure – dominantly sorbite

HAZ – on the tube side
Interphase structure with traces of the tempered martensite

Weld metal
Widmanstaetten structure

BM - flange
Lamellar ferrite – pearlite structure

Fig. 10. Microstructure of the welded joint individual zones (200×) – tube flange (7×7) (200×)

Material's weldability was estimated according to measured hardness and analysis of microstructure of all the zones of the welded joints. Despite the fact that hardness within the HAZ of joints is somewhat higher than the usual values (350 HV), in this case it fulfills requirements of the manufacturer, since the base metal is a high strength steel (HSS) and a bit higher hardness is tolerated. In addition, the manufacturing process itself is such that all the welding conditions, related to humidity and base metal cleaning, are precisely controlled. Authors do not exclude the possibility of application of preheating prior to welding, what would cause reduction of hardness, however, that operation would cause increase of costs, as well as time needed for manufacturing of the assembly.

6. Influence of preheating on hardness within the Heat Affected Zone

Since the obtained hardness was somewhat higher, though that can be tolerated for this type of steels, authors decided to perform additional test to investigate influence of preheating on the output hardness of the weld. The preheating temperature was calculated according to the Seferian formula [15] and the obtained value was approximately 100 °C. That welding was executed with the same parameters and the filler metals. Obtained results are presented in Fig. 11.

As can be seen from Fig. 11, influence of preheating on hardness in different zones of the welded joint is rather strong, especially for the Heat Affected Zone, where the hardness drop was from 4000 HV to values below 300 HV. This, of course, points to the conclusion that application of preheating would be desirable. However, since hardness did not significantly exceed the prescribed limits, manufacturer of the assembly did not want to include the preheating operation on the welding procedure for the sake of reducing the costs and time of manufacturing.

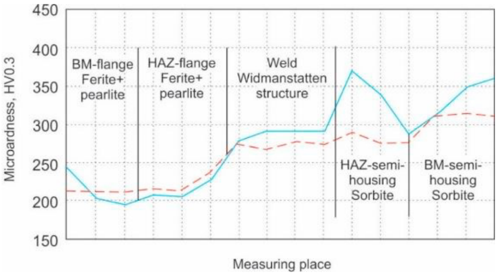

Fig. 11. Hardness of the model weld without preheating (solid line) and with preheating (broken line)

7. Conclusions

The rear bridge of the firefighter truck is a particularly important assembly for its safe and reliable operation. Therefore, it is necessary not only to prescribe the welding technology of the rear bridge semi-housing individual parts, but to experimentally verify that procedure by checking the mechanical properties and microstructure of welded joints in each and every of their characteristic zones. In addition, to improve the quality of welds executed on the assembly, the new welding apparatus was constructed for simultaneous welding of the flange on both sides. Though some traces of martensite were spotted during the metallographic investigations of experimental samples, meaning that certain zones of increased hardness do exist, that can be allowed under the condition that here prescribed welding technology is strictly followed and applied when the real semi-housing is manufactured. It is concluded that the increased hardness can be tolerated if the content of the diffused hydrogen in the weld metal and heat affected zone is reduced to a minimum. That is achieved by the strict control of a content and flow of the protective gases, welding in the room free of draft, maintaining the technological parameters within the prescribed limits, controlling the position of the gun during the welding, using the clean and dry filler metals (wires), as well as by preparation of the dry and clean groove and its surrounding. Though that additional tests have shown that preheating can cause lowering of the hardness values in the critical zones of the welded joint, it was decided to perform the welding procedure without the preheating operation, since it was estimated that slightly increased hardness would not negatively influence the quality of the welded joints or the integrity of the whole construction.

Acknowledgement

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