Research on the Effect of Applying the *Sacrifice Layer* Technique on the Chemical Composition of the Welded Deposits

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All vessel-type products operating under extreme conditions of temperature, pressure and corrosive environments, such as those in the power, chemical and petrochemical industries, are subjected to intense chemical / structural degradation processes that may lead to cracks. These may propagate in time, causing the product to fail, generating significant economic and material consequences, leading in some cases even to the loss of human lives. The paper presents some effects of the sacrifice layer repairing technique used to restore the geometrical shape by welding of the area from where the flaw material was removed, on the chemical composition.

Keywords: sacrifice layer, chemical composition, welding renewal

In order to realize and maintain the pressure vessels used in energetic/chemical/petrochemical industry, important financial resources are consumed and longer production times are needed. From this reason, any period of time in which the product is not in use leads to the extension of the recovering time of the investment made in acquisition.

To keep under observation the vessel-type products in such a way that no major problems arise, they are subjected to non-destructive testing programmed at specific periods of time with the purpose of highlighting the crack type nonconformities.

Because of the specific shape – the radius on the top bigger than the length, if detecting any cracks, regardless of their position, in the base material or in the welded seam, the areas must be removed and repaired. The most common process applied to restore the geometrical shape is welding, such as manual metal arc welding (MMA) and gas metal arc welding (GMAW). These processes may lead to significant changes of the chemical composition in the areas where the repairing is made because of the technological parameters, the filling material and the welding techniques.

Besides the welding process used, the repairing technique is also important.

Generally, the techniques used are Half-bead technique, Temper bead, cold repair, Consistent Layer Technique, Sacrifice layer deposit, Controlled Deposition Technique and Alternate Temper Bead Technique [1- 4].

Each technique, because of the different heat quantities introduced in the repairing area, even in the case of the same repairing technique, may lead to important changes in the chemical composition.

During the welding reconditioning process, the filler material which, generally containing C, Si, Mn and Mo, melts along with a part of the base material which, in the case of common steels used energetic and petrochemical industry, contain C, Mn, Si, S, P, N, Cr, Ni, Ti and other element, forming the welding bath. During the melting process of the two materials, several reactions take place in the welding bath, resulting the increase or decrease of the concentration of certain chemical elements [5].

The main phenomena and chemical reactions that must be taken into consideration when forming the welding bath are related to the metal oxides reduction, which is realized with the help of chemical composition and temperature adequate indicators to which the process is taking place, fallowing the reaction:

$$MeO + R = Me + RO \quad (1)$$

where: *Me* is the metal from the composition of the base or filler; *R* – the reductant.

Amza et all, in [6] indicates a series of reactions that may take place in different temperatures: under 570^0, between 570^0 C and 910^0 and over 1250^{0}C and Semenescu et all, in [7,8] indicates the main gases resulting from the repairing process.

The most important reactions that take place at the surface of the welding bath are:

-Direct and indirect reduction reactions

$$MeO + CO = Me + CO_2 \uparrow \quad (2)$$

-Reactions that take place at temperatures lower than 570^0 C

$$2MnO + 2C = 2Mn + CO \uparrow \quad (3)$$

$$2SiO + 2C = 2Si + 2CO \uparrow \quad (4)$$

$$SiO_2 + 2C = Si + 2CO \uparrow \quad (5)$$

$$2CrO + 2C = 2Cr + 2CO \uparrow \quad (6)$$

-Metalothermic reduction reactions

$$MnO_2 + \frac{4}{3}Al = Mn + \frac{2}{3}Al_2O_3 \quad (7)$$

$$2MnO + Si = 2Mn + SiO_2 \quad (8)$$

-Reactions that take place at temperatures higher than 910^0 C and have as a result the interaction between the sulfide and the oxide or sulfate of the same metal. (9)

$$MeS + 2MeO = 3Me + SO_2 \uparrow \quad (10)$$

$$MeS + MeSO_4 = 2Me + 2SO_2 \uparrow$$

-Complex reactions that take place at temperatures higher than 1250^{0}C: (11)

$$5(CuO \cdot Fe_2O_3) + 2FeS = 5Cu + 2Fe_3O_4 + 2SO_2 \uparrow$$

The used welding technique *was sacrifice layer deposit*. The technique involves the deposit of additional layers on the middle of the closing seam or in the connection area between the closing seam and the base material, for tempering the HAZ [7] (fig. 1).

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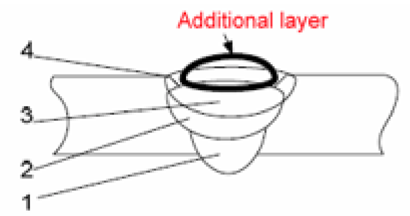

Fig. 1. Weld toe tempering technique

In figure 1, with 1, 2, 3 and 4 are symbolized: *Layer of root, Filling layer, Closure layer* and *Layer* of *heat treatment*

Experimental part

For the experimental part, 13CrMo4-5 steel type was used, a material used for the manufacturing of the pressure vessels for energetic and petrochemical industry. The samples subjected to welding reconditioning were taken, after a periodical revision, from a vessel that functioned for a certain period of time.

According to the SR EN ISO 10028-2/2009 [9], in the standard chemical composition of the 13CrMo4-5 steel the fallowing chemical elements are found: C= (0.08…0.18%), Si = max. 0.35%, Mn = (0.4…1.00%), S= max. 0.01%, P = max. 0.025%, Cr=(0.7…1.15%), Mo= (0.4…0.6%) si N= max. 0.012%.

Due to its high productivity, the chosen welding process was metal active gas welding (MAG), robotized version.

The filler material, chosen based on the principle of chemical compatibility with the base material, was GCrMo1Si wire which contains, according to the manufacturer, the following elements: C=0.09%, Mn=0.929%, Si=0.641%, Mo=0.459%, Cr=1.190%, Ni=0.019% and Cu=0.112%.

The deposit regime parameters, as well as the sample codification, are indicated in table 1. In order to analyze the efficiency of the obtained results by using the new reconditioning technique, a series of samples were made using classical reconditioning technologies. The samples are codified in table 1 with I-a, I-b, VI and VII.

Results and discussions

A series of images with the obtained samples are presented in figure 2.

After obtaining the samples, they were processed by removing the reinforcement of the welded seams, so that that from the base material were removed 1.5 mm.

An intermediate stage of removing the reinforcement of the welded seam is presented in figure 3.

The samples obtained after removing the reinforcement and polishing the surfaces of interest, were undergone a chemical attack in order to highlight the characteristic areas of the welded seams.

For each area, BM, HAZ and WB, 3 tests for chemical composition determination were performed using the

Table 1
SAMPLES CODIFICATION AND DEPOSIT REGIME PARAMETERS

Sample codification	Layer type	Is [A]	Ua [V]	vs [cm/min]	El * [kJ/cm]
I-a**	Deposit	292	29.2	25	18.417
	Sacrifice layer	-	-	-	-
I-b***	Deposit	292	29.2	25	18.417
	Sacrifice layer	-	-	-	-
II	Deposit	292	29.2	25	18.417
	Sacrifice layer	292	29.2	55	8.371
III	Deposit	292	29.2	25	18.417
	Sacrifice layer	292	29.2	45	10.232
IV	Deposit	292	29.2	25	18.417
	Sacrifice layer	292	29.2	35	13.155
V	Deposit	292	29.2	25	18.417
	Sacrifice layer	292	29.2	25	18.417
VI****	Deposit	292	29.2	25	18.417
	Sacrifice layer	200	14.5	40	3.915
VII****	Deposit	292	29.2	25	18.417
	Sacrifice layer	200	14.5	20	7.830

** The heat input was calculated with relation 12:*

$$E_i = 60 \cdot \eta \cdot \frac{U_a \cdot I_s}{v_s \cdot 1000} \qquad (12)$$

where: η- Process yield (0.9 for MAG); U_a *– Arc voltage [V];* I_s *– Welding current [A];* v_s *– Welding speed [cm/min].*

**** After deposit a post reconditioning heat treatment was made, having the following parameters [9, 10]: - Heat treatment temperature,* $T_{treatment}$ *= 620 ^{0}C; - Heating speed –* v_i *- 80^{0}C/h; - Heat treatment temperature maintaining time* t_m *= 3 h; - Cooling speed –* v_i *- 50^{0}C/h;*

***** - for samples VI and VII a superficial melting was made by WIG process, with the parameters indicated in table 3, maintaining a constant 16 mm nozzle-sample distance.*

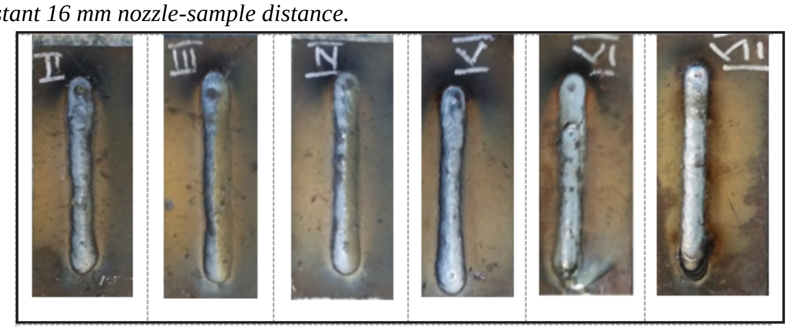

Fig. 2. The samples resulted from the experiments

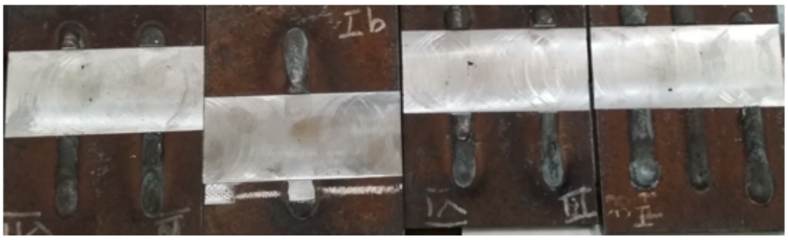

Fig. 3. Samples aspect - intermediate stage of removing the reinforcement in order to highlight the chemical composition

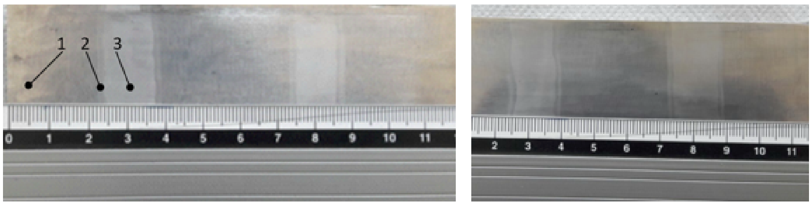

Fig.4. Samples obtained after preparing in order to highlight the chemical composition
1- Base Material (BM); 2 – Heat Affected Zone (HAZ); 3 – Welding Bead (WB)

X-ray fluorescence method with Olympus Delta X Professional equipment.

The mean values of the results obtained from the determination of the chemical composition are presented in tables 2 and 3.

Table 2
MEAN VALUES OF THE CHEMICAL ELEMENTS - HAZ AREA

No.	Sample	HAZ							
		Cr	Mn	Mo	Si	Ni	Cu	V	P
		[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
1	Ia	1.02	0.675	0.414	0.19	0.052	0.035	0	0.014
2	Ib	1.04	0.73	0.415	0.71	0.0545	0.034	0	0.013
3	II	1.03	0.7	0.42	0.28	0.05	0.035	0	0.011
4	III	1.045	0.67	0.406	0.24	0.037	0.029	0	0.011
5	IV	1.02	0.705	0.418	0.3	0.053	0.03	0	0.0135
6	V	1.02	0.71	0.421	0.28	0.052	0.033	0	0.0065
7	VI	1.02	0.725	0.411	0.24	0.0585	0.027	0	0.013
8	VII	1.045	0.7	0.421	0.27	0.0475	0.019	0	0.0055

Table 3
MEAN VALUES OF THE CHEMICAL ELEMENTS - WB AREA

No.	Sample	WB							
		Cr	Mn	Mo	Si	Ni	Cu	V	P
		[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
1	Ia	1.035	0.555	0.435	0.22	0.0415	0.038	0	0.008
2	Ib	1.065	0.67	0.4195	0.77	0.0305	0.0355	0	0
3	II	1.05	0.61	0.4275	0.33	0.03	0.0445	0	0.005
4	III	1.055	0.605	0.415	0.31	0.0265	0.039	0	0.016
5	IV	1.055	0.63	0.4295	0.36	0.0325	0.044	0	0.007
6	V	1.07	0.585	0.429	0.36	0.032	0.038	0	0.012
7	VI	1.035	0.575	0.412	0.3	0.0275	0.0335	0	0.005
8	VII	1.04	0.645	0.4265	0.33	0.0575	0.0345	0	0.007

For Cr-Mo type steels, the representative chemical elements are Cr, Mn, Mo and Si.

From the analysis of the data presented in tables 2 and 3, it can be noticed that the variation of the parameters of the welding reconditioning regime influences differently the chemical composition:

-The maximum value of the Cr in HAZ was 1.045% and was highlighted in the case of sample III, and for WB the 1.07% value was obtained for sample Ib;

-The maximum value of the Mo in HAZ was 0.421% and was highlighted for sample V, and for WB the 0.435% value was obtained for sample Ia;

-The maximum value of Mn in HAZ was 0.73% and was highlighted for sample Ib, and for WB the value of 0.67% was also obtained in sample Ib;

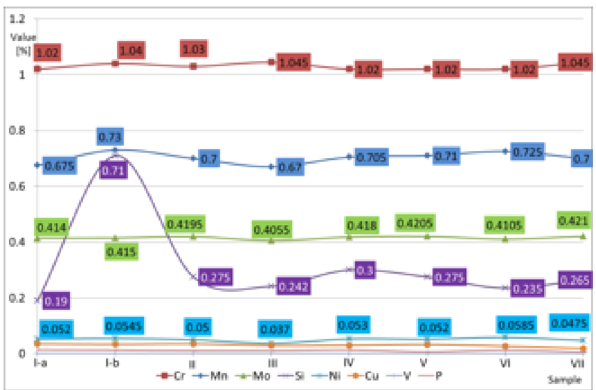

Fig. 5. Percentage values variation of the chemical elements- HAZ area

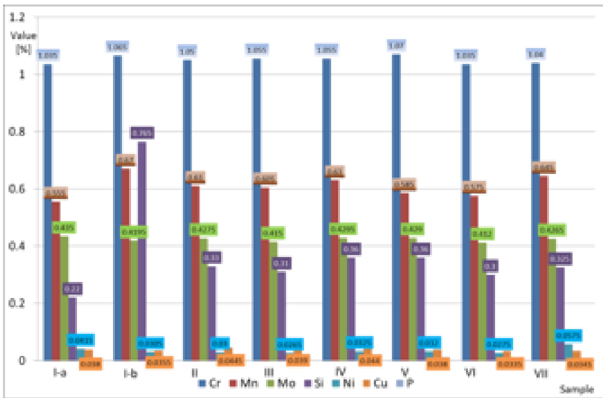

Fig. 6. Percentage values variation of the chemical elements - WB area

-The maximum value of Si in HAZ was 0.71% and was highlighted in the case of sample III, and for WB the value of 0.77% was also obtained in sample III;

Based on the values indicated in tables 2 and 3, the graphics in figures 5 and 6 were drawn, in order to represent the variation of the chemical elements in the areas of interest, HAZ and WB.

Conclusions

From the experiments and obtained results the following conclusions can be drawn:

-The parameters used in the experiments have led to important results from the point of view of the effect on the chemical composition;

-By modifying the welding reconditioning parameters, even within the same technique, it leads to the modification of the chemical composition in the seam and HAZ area;

-The greatest difference between the maximum and the minimum percentage values of the chemical elements was obtained for the chemical element Si, 0.52% in the HAZ and 0.55% in the WB.

-The researches carried out may be the starting point for setting the welding reconditioning parameters, in the cases when it is intended to obtain, in the repaired area, a particular value of a certain chemical element.

-To determine the optimum welding reconditioning regime, the structures obtained in the HAZ and WB areas should be analyzed, as well as the determination of the hardness values obtained in the above mentioned areas.

Acknowledgement: This work has been funded by University Politehnica of Bucharest, through the Excellence Research Grants Program, UPB – GEX. Identifier: UPB–EXCELENTA–2016 "Alternative solutions for welding reconditioning of the „recipient" type products used in energetic and chemical industry, without post repairing heat treatment" , Contract number 31/26.09.2016.

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Manuscript received: 15.05.2017