The Influence of the Deposit Parameters on the Medium Chemical Composition of the Welded Joint

DUMITRU TITI CICIC[1], CORNELIU RONTESCU[1]*, ANA MARIA BOGATU[1], CATALIN GHEORGHE AMZA[1], OANA ROXANA CHIVU[1]
[1]University Politehnica Bucharest, Faculty of Engineering and Management of Technological Systems, 313 Splaiul Independentei, 060042, Bucharest, Romania

Recipient type products from energetic and chemical industry undergo a wide combined process of corrosion and ware, due to working environment. In order to put this products back in use, in a shorter period of time, welding reconditioning procedures are applied which mainly aim to restore the geometrical configuration but also the characteristics growth. Any welding technology applied, involves melting a filler material but also a part of the base material, mixing them, thereby obtaining the welded joint. The paper present the experimental results obtained in determining the optimal parameters for Metal Active Gas welding deposit that are going to be used for the restoration of some components from energetic and chemical industry and that are highlighting the dependence between the deposit parameters and the chemical composition of the juncture.

Keywords: cladding, renewal, building-up welding, average chemical composition

Components operating at high temperature or harsh working conditions are subjected to different failure regimes which require special consideration [1,2].

Repair welds, are frequently used in material structure either to remedy initial fabrication defects or to rectify in service degradation of component. Some previous investigations indicate that repair welding by techniques [3].

The welding parameters influence the geometrical elements of the seam, thus the chemical composition, giving the possibility of choosing a rational regime in order to obtain a certain shape of the seam [1].

One of the technological operations often used for superficial layers with enhancement, is the welding operation. Depositing by welding can be performed by several welding processes such as manual metal arc welding (MMA), metal inert gas (MIG) or metal active gas (MAG), tungsten inert gas (TIG), submerged arc welding (SAW) [4-7].

To determine the chemical composition of the layers obtained by welding deposit can be used:

-Qualitative methods that involve taking parts of seam, proper processing, polishing, followed by a chemical attack that takes into account the type of material and analysis;

-Quantitative methods which are based on mathematical relationships.

The general calculation formula underlying the average chemical composition predetermination is [8]:

$$Ec = KmaEd + KmbEb \quad (1)$$

where:

Ec, Ed, Eb – the concentration of the general chemical element E in the seam (c), deposited material (d) and the base material (b);

Kma , Kmb – participation coefficient of the filler material and base material to form the seam.

Kma and Kmb participation coefficients are defined as to be the quantities of base/filler material which contributes to form the seam.

Both groups of methods for determining the chemical composition present some disadvantages such as:

-Qualitative methods: long time, welded joint destruction for samples, using acids etc.

-Quantitative methods: trials to simulate the real situation of deposit, practical determination of the participation coefficients (Kma , Kmb) which involves fallowing some stages similar to qualitative determination of chemical composition, it takes no account of the possible reactions that may take place in the liquid metal bath , etc.

The main reactions that can influence the average chemical composition of the welded joint, when using MAG process, are:

-Oxidation, which can be direct (relation 2) or indirect (relation 3)

$$Me + \frac{1}{2}O_2 \leftrightarrows MeO + Q \quad (2)$$

The necessary oxygen for the reaction coming from the atmosphere, carbon dioxide dissociation (CO_2), water vapors, carbonates (violent reaction)

$$Me + Me'O \leftrightarrows MeO + Me' \quad (3)$$

The way of the reaction being given by the concentration of the elements which react and the affinity towards the oxygen (O_2) of different chemical elements.

-Deoxidation, based on chemical elements (relation 4) or through diffusion:

The general deoxidation reaction for steels, when deoxidants are used, is:

$$x[FeO] + y[Me] \leftrightarrows (MeyOx) + x[Fe] \quad (4),$$

by metal, Me, denoting the introduced deoxidant, the [ ] meaning product contained by the metal and ( ) meaning product passing into slag.

The main deoxidants that occur in welding are: Si, Mn, Ti, Al, C and H_2.

Experimental part

The base material, in form of sheet metal with dimensions of 200 x 100 x 6, used in the experiments, is S235JR steel and as a filler material it has been used a full cooper coated wire GCrMo1Si having a 1.2mm diameter. The chemical composition of the base material is presented in table1.

The welding deposit process used in the experiments is metal active gas (MAG).

The parameters used in the experiment are presented in table 2, furthermore using:

* email: corneliu.rontescu@upb.ro

No.	Material \ Chemical element	C [%]	Mn [%]	Si [%]	S [%]	P [%]	Mo [%]	Cr [%]	Ni [%]	Cu [%]	N [%]
1	Base material*: S235JR	0.171	1.390	0	0.035	0.035	0	0	0	0.540	0.011
2	Filler material** G Cr Mo 1 Si	0.09	0.929	0.641	0.011	0.004	0.459	1.190	0.019	0.112	0.000

Tabel 1
CHEMICAL COMPOSITION OF THE S235JR STEEL AND OF THE GCrMo1Si WIRE [9]

** values taken from the quality certificate of the base material*

*** values taken from the quality certificate of the filler material*

Table 2
EXPERIMENTAL PARAMETERS

No.	Sample code	Modified parameter	v_a [m/min]	I_s [A]	U_a [V]	v_s [cm/min]	E_l* [kJ/cm]
1	1	Reference experiment	6	180	22	55	3.89
2	2	Welding speed variation; h=f(v_s)	6	180	22	25	8.55
3	3		6	180	22	45	4.75
4	1		6	180	22	55	3.89
5	4		6	180	22	65	3.29
6	5		6	180	22	75	2.85
7	6	Welding current variation; p=f(I_s)	4	135	22	55	2.92
8	7		5	165	22	55	3.56
9	1		6	180	22	55	3.89
10	8		7	220	22	55	4.75
11	9		8	280	22	55	6.05
12	10	Arc voltage variation B=f(U_a)	6	180	16	55	2.83
13	11		6	180	19	55	3.36
14	1		6	180	22	55	3.89
15	12		6	180	25	55	4.42
16	13		6	180	28	55	4.95

**The heat input was calculated with relation 5; v_a – wire feeder speed*

-Flow rate Dg = 16 L/min; Gas: Ar + 18%CO_2 [10]

$$E_l = \frac{60x\ \eta\ x\ U_a x\ I_s}{v_s\ x\ 1000}\ [kJ/cm] \quad (5)$$

where: η- process yield (0.9 for MAG)
U_a – arc voltage [V];
I_s – welding current [A];
v_s – welding speed [cm/min];

Results and discussions

For the experiments, the equipments and devices used in welding deposit were first calibrated. The fallowing things were determined: the free length of the wire, the welding gun's position towards the sample, the parallelism between the sample and the welder.

A series of seams were verified as it can be seen in figure 1.a.

After eliminating possible errors, the testing seams were deposited.

Images taken during and after the experiments are presented in the figures below.

After the samples were cooled to the ambient temperature, these were cut in order to determine the participation coefficients of the base and filler material (fig. 2).

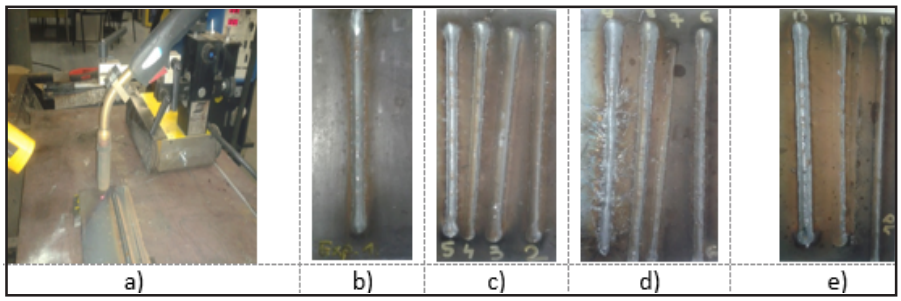


Fig. 1. Samples obtained after welding deposit. a) The welding process of the samples; b) Sample 1 – reference sample; c) Samples 2,3,4 and 5; d) Samples 6, 7, 8 and 9; e) Samples 10, 11, 12, 13

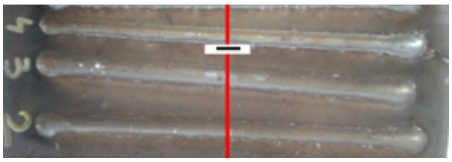
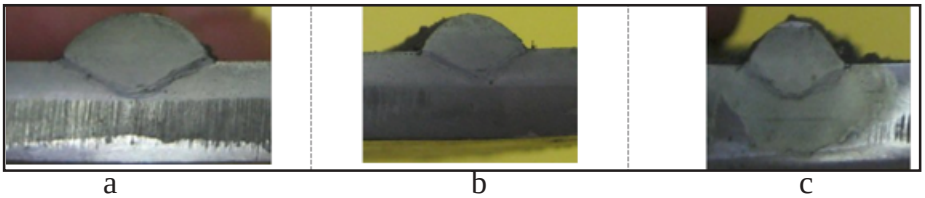


Fig. 2. l cutting direction for metallographic processing



a b c

Fig. 3. Macroscopic images highlighting the seam: a - Sample 4, b - Sample 5 c - Sample 8

After the cut, the samples were polished with metallographic paper with 600 and 800 granulation and attacked with NITAL 2%. Images taken during the metallographic process, for different samples, are presented in figure 3.

After fallowing the necessary steps in order to obtain the macroscopic images it was possible to establish the precise outline of the seam.

The macroscopic images were inserted in a soft that was able to measure the A and B.M. squares (fig. 4).

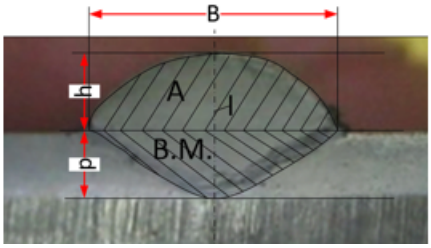


Fig. 4. Representative areas for K_{ma} , K_{mb}
h- Reinforcement; p – penetration; B- Bead width; A – area due filler material; B.M. – area due base material; I – direction for chemical composition determination

The following steps were taken in order to measure the areas for the filler material:

-scaling the macroscopic images, taking as reference the thickness of the base material

-creating outlines to define the deposit areas between A and B.M;

-measuring the geometrical parameters (the penetration and the reinforcement)

-determining the areas for A and M.B.

With the help of areas A and M.B., K_{ma} and K_{mb} were calculated with the following relations:

$$k_{ma} = \frac{A}{A+B.M.} \quad (6)$$

$$k_{mb} = \frac{B.M.}{A+B.M.} \quad (7)$$

The chemical composition was determined as follows:

- Quantitative, with relations 1,6 and 7 and,

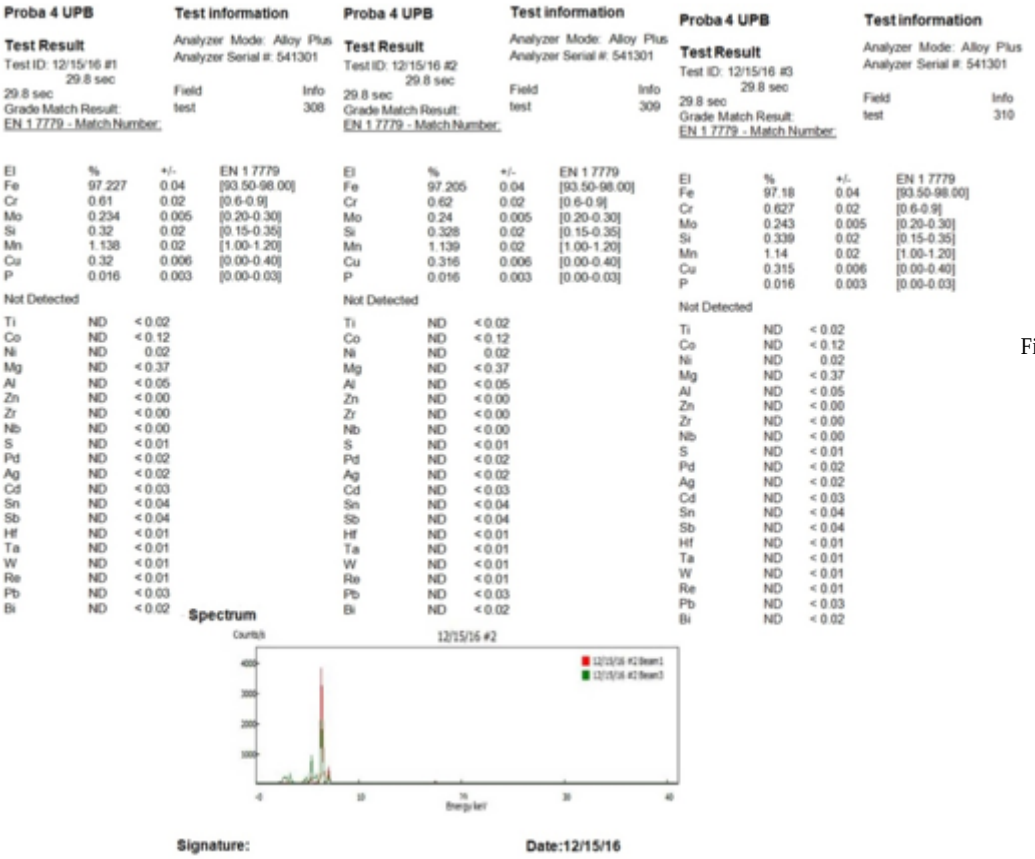
- Qualitative, by X-ray fluorescence method with Olympus Delta X Professional equipment, taking measurements in 3 points.

On l direction, presented in figure 4, measurements of the chemical composition were taken in 3 points. It was aimed to measure the chemical composition, with the equipment mentioned above, in the centre, lower and upper part of the seam.

A complete report, containing the results of the 3 measurements for sample 4, is presented in figure 5.

Because of the limitations coming from the equipment used to determine the chemical composition, certain chemical elements, such as S, Ni, couldn't be highlighted.

The situation concerning the S chemical element is remarkable because, according to the values indicated by the equipment used to determine the chemical composition, it would be present in the seam with a percent of maximum 0.01%, although it existed in the base material with 0.035 % percentage and in the filler material with 0.011% percentage.



Proba 4 UPB — **Test information**

Test Result

Test ID: 12/15/16 #1 — Analyzer Mode: Alloy Plus — Analyzer Serial #: 541301

29.8 sec — 29.8 sec

Grade Match Result: — Field: test — Info: 308

EN 1.7779 - Match Number:

El	%	+/-	EN 1.7779
Fe	97.227	0.04	[93.50-98.00]
Cr	0.61	0.02	[0.6-0.9]
Mo	0.234	0.005	[0.20-0.30]
Si	0.32	0.02	[0.15-0.35]
Mn	1.138	0.02	[1.00-1.20]
Cu	0.32	0.006	[0.00-0.40]
P	0.016	0.003	[0.00-0.03]

Not Detected

Ti	ND	< 0.02
Co	ND	< 0.12
Ni	ND	0.02
Mg	ND	< 0.37
Al	ND	< 0.05
Zn	ND	< 0.00
Zr	ND	< 0.00
Nb	ND	< 0.00
S	ND	< 0.01
Pd	ND	< 0.02
Ag	ND	< 0.02
Cd	ND	< 0.03
Sn	ND	< 0.04
Sb	ND	< 0.04
Hf	ND	< 0.01
Ta	ND	< 0.01
W	ND	< 0.01
Re	ND	< 0.01
Pb	ND	< 0.03
Bi	ND	< 0.02

Proba 4 UPB — **Test information**

Test Result

Test ID: 12/15/16 #2 — Analyzer Mode: Alloy Plus — Analyzer Serial #: 541301

29.8 sec — 29.8 sec

Grade Match Result: — Field: test — Info: 309

EN 1.7779 - Match Number:

El	%	+/-	EN 1.7779
Fe	97.205	0.04	[93.50-98.00]
Cr	0.62	0.02	[0.6-0.9]
Mo	0.24	0.005	[0.20-0.30]
Si	0.328	0.02	[0.15-0.35]
Mn	1.139	0.02	[1.00-1.20]
Cu	0.316	0.006	[0.00-0.40]
P	0.016	0.003	[0.00-0.03]

Not Detected

Ti	ND	< 0.02
Co	ND	< 0.12
Ni	ND	0.02
Mg	ND	< 0.37
Al	ND	< 0.05
Zn	ND	< 0.00
Zr	ND	< 0.00
Nb	ND	< 0.00
S	ND	< 0.01
Pd	ND	< 0.02
Ag	ND	< 0.02
Cd	ND	< 0.03
Sn	ND	< 0.04
Sb	ND	< 0.04
Hf	ND	< 0.01
Ta	ND	< 0.01
W	ND	< 0.01
Re	ND	< 0.01
Pb	ND	< 0.03
Bi	ND	< 0.02

Proba 4 UPB — **Test information**

Test Result

Test ID: 12/15/16 #3 — Analyzer Mode: Alloy Plus — Analyzer Serial #: 541301

29.8 sec — 29.8 sec

Grade Match Result: — Field: test — Info: 310

EN 1.7779 - Match Number:

El	%	+/-	EN 1.7779
Fe	97.18	0.04	[93.50-98.00]
Cr	0.627	0.02	[0.6-0.9]
Mo	0.243	0.005	[0.20-0.30]
Si	0.339	0.02	[0.15-0.35]
Mn	1.14	0.02	[1.00-1.20]
Cu	0.315	0.006	[0.00-0.40]
P	0.016	0.003	[0.00-0.03]

Not Detected

Ti	ND	< 0.02
Co	ND	< 0.12
Ni	ND	0.02
Mg	ND	< 0.37
Al	ND	< 0.05
Zn	ND	< 0.00
Zr	ND	< 0.00
Nb	ND	< 0.00
S	ND	< 0.01
Pd	ND	< 0.02
Ag	ND	< 0.02
Cd	ND	< 0.03
Sn	ND	< 0.04
Sb	ND	< 0.04
Hf	ND	< 0.01
Ta	ND	< 0.01
W	ND	< 0.01
Re	ND	< 0.01
Pb	ND	< 0.03
Bi	ND	< 0.02

Spectrum

12/15/16 #2

Signature: Date:12/15/16

Fig. 5. Chemical composition results - sample 4

Table 3
THE OBTAINED RESULTS (EXCERPT)

Sample code	K_{mb} [-]	K_{ma} [-]	p [mm]	h [mm]	p+h [mm]	Chemical element / Area	Mn [%]	Si [%]	Mo [%]	Cr [%]	Cu [%]
-	-	-	-	-	-	MB	1.3900	0.0000	0.0000	0.0000	0.5400
-	-	-	-	-	-	MA	0.9290	0.6410	0.4590	1.1900	0.1120
4	0.478	0.522	2.22	2.42	4.64	Cus. cant.*	1.1494	0.3346	0.2396	0.6212	0.3166
						Cus. calit.**	1.139	0.329	0.239	0.619	0.317
						Dif.***	-0.0104	-0.0056	-0.0006	-0.0022	0.0004
6	0.445	0.555	1.24	1.54	2.78	Cus. cant.*	1.1341	0.3558	0.2547	0.6605	0.3025
						Cus. calit.**	1.129	0.355	0.252	0.650	0.299
						Dif.***	-0.0051	-0.0008	-0.0027	-0.0104	-0.0035
8	0.512	0.488	2.98	1.89	4.87	Cus. cant.*	1.1650	0.3128	0.2240	0.5807	0.3311
						Cus. calit.**	1.160	0.290	0.223	0.580	0.330
						Dif.***	-0.0050	-0.0228	-0.0010	-0.0007	-0.0011
9	0.543	0.457	3.83	2.31	6.14	Cus. cant.*	1.1793	0.2929	0.2098	0.5438	0.3444
						Cus. calit.**	1.163	0.281	0.191	0.530	0.310
						Dif.***	-0.0163	-0.0119	-0.0188	-0.0138	-0.0344

Where : p – penetration; h – reinforcement; MB – in base material; MA – in filler material; Cus. cant. - chemical composition of the seam determined by quantitative method, * determined with relation 1; Cus. calit.**- chemical composition of the seam determined by qualitative method, as the average of 3 points situated on l line (fig. 4) ; Dif.*** - the difference determined with relation 8*

The results are presented in the table below with the mention that only the values for the representative chemical elements are indicated (Si, Mn, Mo, Cr and Cu).

$$Dif.^{***} = Cus.calit.^{***} - Cus.cant.^{***} \quad [8]$$

Conclusions

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

-Changing the welding deposit regime parameters leads to modifications of the geometrical parameters of the seam (penetration, reinforcement);

-The increase of the heat input does not lead automatically to the increase of the geometrical parameters values of the seam (penetration, reinforcement);

-The real chemical composition of the seam depends on the welding deposit regime values and on the place of the determination – values close to the filler material near the deposit area and values situated between the base material and filler material values at the bottom of the deposit;

-Due to oxidation and deoxidation reactions in the liquid metal bath, the decrease of the Si and Mn chemical elements percentage can be observed, fact leading to the decrease of the mechanical properties of the deposit.

-For the deposit operations that don't require strict conditions concerning the chemical composition of the deposit the predetermination method can be used. This implies deposing in real conditions, cutting, metallographic processing, A and B.M. squares measuring, determining K_{ma}, K_{mb} coefficients with relations 6 and 7, followed by relation 1.

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