THE EFFECT OF DIFFUSIBLE HYDROGEN IN WELD SEAMS ON THE MECHANICAL BEHAVIOUR OF 13CrMo4.5 STEEL PARTS

Catalina Sorina PARFENE[1], Gheorghe SOLOMON[2], Claudiu BABIS[3]

It is noteworthy the negative impact of diffusible hydrogen on the cracking of steels subject to cold working. A key observation for welded joints is the guarantee of strength or breaking energy at a certain temperature, including low temperatures. Thus, the choice of additional materials becomes possible for the welding process. The present paper deals with the effect of diffusible hydrogen on the mechanical characteristics and tenacity of welded joints.

Key words: diffusible hydrogen, hydrogen charge, resilience, breaking energy

1. Introduction

Diffusible hydrogen is responsible for the cold cracks in the welded joints. The hydrogen content, during the welding process, depends on the type of metallic matrix and the welding parameter values, including the thermal history to which the welded joint is subjected (thermal treatments before and after welding)[1, 5]. Low equilibrium thermodynamic microstructures are among the most likely prone to hydrogen embrittlement. In the particular case of steels, in view of an optimum behaviour to embrittlement, it is recommended a clear separation of the pearlite or cementite in the microstructure, as globe like shaped structures [2, 4]. As far as welding is concerned, hydrogen may derive from a variety of sources (humidity in the protective coating or atmosphere, impurities on the metallic surface etc) and the high temperature of the metallic bath may favour dissolution conditions. If solidified, the hydrogen solubility in the metal drops rapidly, producing an over-saturated matrix and, thus, diffusion grades increase either toward the base material or outside the weld seams (diffusible hydrogen). The biggest amount of hydrogen is, thus, directed toward the areas of austenite

[1] PhD. Student., Faculty of Engineering and Management of Technological Systems, Chair of Materials Technology and Welding, University POLITEHNICA of Bucharest, Romania, e-mail: catalina.parfene@yahoo.com
[2] Univ. Prof. PhD, Faculty of Engineering and Management of Technological Systems, Chair of Materials Technology and Welding, University POLITEHNICA of Bucharest, Romania, e-mail: ghe.solomon@gmail.com
[3]As. PhD, Faculty of Engineering and Management of Technological Systems, Chair of Materials Technology and Welding, University POLITEHNICA of Bucharest, Romania, e-mail: claudiubbs@gmail.com

which, nevertheless, undergoes transformation into ferrite under cold working [3,6, 7, 8].

2. Description of the testing workbench and samples

The present paper analyzes the amount of diffusible hydrogen and the way it influences the mechanical properties and plasticity of some samples made by heat resistant steel, type 13CrMo4.5 - 1.7335 according to EN 10216-2. Hence, the present research aims at analyzing the impact of diffusible hydrogen on the mechanical characteristics, tenacity and plasticity for both the hydrogen undergoing welding and the hydrogen charge of samples by means of electrolysis.

In the testing workbench used for hydrogen charge (fig. 1), the electrodes (2) are linked to a 5V direct current source and 0.378A current and sample (3) is clipped to a source. To carry out the electrolysis process and hydrogen ions positively charged (H+), sample 3 acts as a cathode (-) and anode (+) represents the graphite electrodes.

The sample is submerged into a solution consisting of chlorhydric acid (0.06l); hydrazine (0.02l); distilled water (0.6l). The current density during the cathode charging was 378 mA, and a 5V tension at work. The microscopic research was performed by means of an immersion lens microscope, Euromex with digital Euromex vc.3032 type of camera.

The dimensions of V-shaped and U-shaped samples, to determine the tenacity and plasticity characteristics, are 10x10x55 mm, their shape is illustrated in Fig .2a and 2 b, [9].

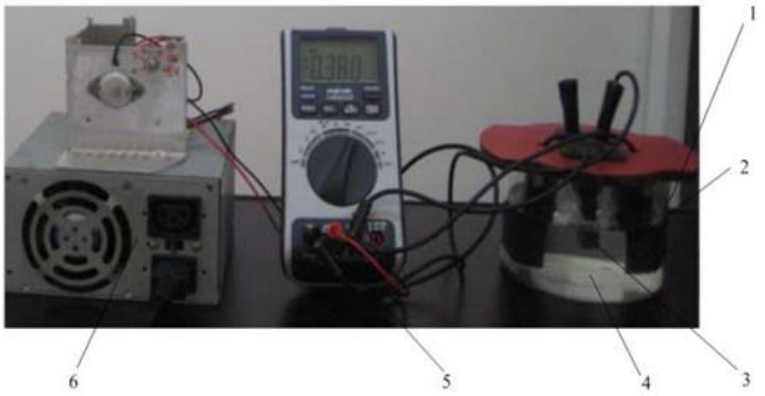

Fig. 1. Testing workbench for electrolytic charge with hydrogen: 1. Glass container; 2. Graphite electrodes; 3. Sample; 4 - Electrolytic solution; 5. Milliammeter; 6. Direct current source for the electrolytic bath.

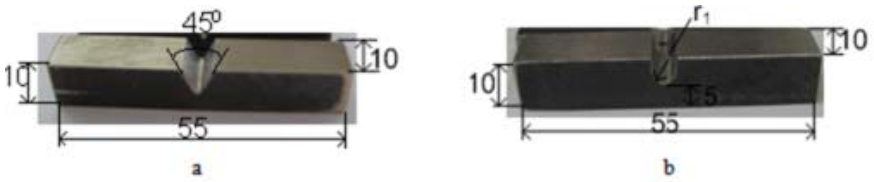

Fig. 2. Types of samples used to determine the plasticity/tenacity characteristics
a- V-shape; b- U-shape

The dimensions of samples required for the determination of mechanical characteristics in the case of static tension and fracture point are 10x31x250 mm, their shape is illustrated in Fig. 3, [10].

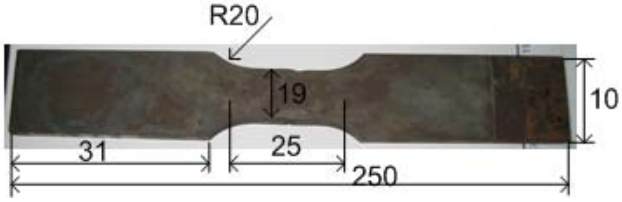

Fig. 3. Type of sample used to determine the mechanical characteristics

Table 1 shows the chemical composition of 13CrMo4.5 – 1.7335 type of steel and Table 2 reveals the mechanical characteristics.

Table 1

Chemical composition of 13CrMo4.5 – 1.7335 type of steel

Material	Chemical composition								
	C [%]	Si [%]	Mn [%]	P [%]	S[%]	Cr [%]	Mo [%]	N [%]	Cu [%]
13CrMo4.5	0.08 0.18	max 0.35	0.4 1	max 0.025	max 0.01	0.7 1.15	0.4 0.6	max 0.012	max 0.3

Table 2

Mechanical characteristics of 13CrMo4.5 type of steel

Material	Mechanical characteristics				
	$R_{p\,0.2}$ [N/mm^2]	R_m [N/mm^2]	A_5[%]	HB	KV [J]
13CrMo4.5	290-300	450-600	19-22	104-154	27

Two sets of samples were used to analyze the effect of diffusible hydrogen on the plasticity and tenacity properties, similar to those illustrated in Figure 2, consisting of 8 pieces each. One set includes V-shaped samples and KV [J] as breaking energy and the other set is made of U-shaped samples and the following: resilience values KCU[J/cm^2] at environmental temperature of 25˚ C, Cr [%] crystallinity, Fb [%] fiber texture and cross compressions T [%]. The samples were marked as P1V…P8V for the V-shaped set and P1U…P8U for the U-shaped set, respectively, in conformity with the specifications shown in Table 3.

Table 3

Types of samples used to determine the tenacity and plasticity features								
Type of sample	P1V	P2V	P3V	P4V	P5V	P6V	P7V	P8V
	P1U	P2U	P3U	P4U	P5U	P6U	P7U	P8U
Sample characteristics	Base Material MB	Base material electrolytically charged with diffusible MBD			Welded base material MBS	Welded base material and electrolytically charged with diffusible hydrogen MBSD		

A key observation is that, in the case of electrolytic hydrogen charging, the charging took 10 hours for samples P2 and P6, 20 hours for samples P3 and P7 and 30 hours for samples P4 and P8. The effect of diffusible hydrogen was evident in the case of both the samples made of unwelded base material (P1V/U; P2V/U; P3V/U; P4V/U) as well as of the welded base material ones (P5V/U; P6V/U; P7V/U; P8V/U), on the tenacity characteristics – V-shaped samples and plasticity – U-shaped samples. It is noteworthy that, an increase in the charging period led to a greater amount of diffusible hydrogen. Hence, the results obtained for tenacity and plasticity were compared for all types of samples designed according to the specifications illustrated in Table 3. In order to determine the effect of the diffusible hydrogen content on the mechanical characteristics, more precisely, on the cracking resilience under static tension, eight samples were used as shown in Figure 3. One of them was marked T1 and made of base material, other three marked as T2; T3 and T4 made of hydrogen base material and one T5, made of welded base material and the last marked as T6; T7 and T8 were made of welded and then electrolytically charged base material.

Welding parameters

Welding process used to perform experimental plan was MMA, using a welding source type 4004 ESAB i. The welding parameters are indicated in Table 4.

Table 4 Welding parameters

Samples	**Welding parameters**				
	I_s [A]	**U_a [V]**	**t_s [s]**	**v_s [cm/min]**	**E_l [kJ/cm]**
P5, P6, P7, P8	85	30	10	0.33	0.58

Weld deposit was achieved by means of a coated electrode type Cromobaz - E CrMo1B42H5 having a coating with basic character in conformity with EN ISO 3580-A. This particular type of electrode was needed in order to introduce smaller quantities of hydrogen during welding. The chemical composition of the deposited metal is shown in Table 5 and the mechanical properties are revealed in table 6.

Table 5

The chemical composition of the deposited metal by means of the electrode E CrMo1B42H5-EN ISO 3580-A

Electrode code	Chemical elements						
AWS A5.5	C [%]	Mn [%]	Si [%]	S [%]	P [%]	Cr [%]	Mo [%]
E8018 B2	<0,12	0,70-0,90	<0,80	<0,020	<0,015	1,0-1,50	0,45-0,65

Table 6

Mechanical characteristics of electrode E CrMo1B42H5-EN ISO 3580-A

Electrode code	Mechanical characteristics		
AWS A5.5 E8018 B2	Yield limit [MPa]	Tension resistence[MPa]	Elongation [%]
	550-680	>460	>20

3. Research results

3.1 Results regarding breaking energy and resilience

In the aftermath of various tests and experiments on fractures by means of a 15 kg mass Charpy impact testing machine, the following KV breaking energy values were achieved for V-shaped samples as shown in Table 7.

Table 7

Values of breaking energy KV for V-shaped samples

Sampling	MB	MBD			MBS	MBSD		
Sample	P1V	P2V	P3V	P4V	P5V	P6V	P7V	P8V
H2 Charge duration [h]	0	10	20	30	0	10	20	30
KV [J]	27	26	25	23	26	24	23	22

The graphical variation of the breaking energy according to the hydrogen charge duration is illustrated in Fig. 4.

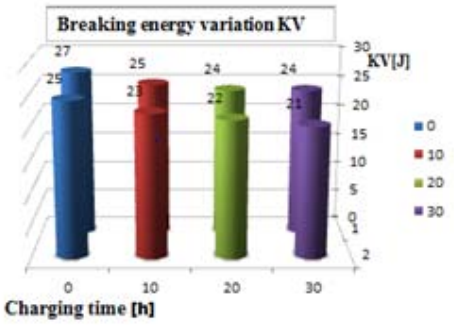

Fig.4 Effect of hydrogen charging time of breaking energy variation KV

Table 8 indicates the values of the breaking energy obtained,W_0 under shock bending by means of the 15 kg mass Charpy impact testing machine, at 25˚C, as well as resilience values KCU, calculated based on relation 1:

Table 8

Resilience values KCU obtained for U-shaped samples

Sampling	MB	MBD			MBS	MBSD		
Sample	P1U	P2U	P3U	P4U	P5U	P6U	P7U	P8U
H2 Charge duration [h]	0	10	20	30	0	10	20	30
S_0[mm^2]	50	50	50	50	50	50	50	50
W_0[J]	90	86	81	74	51	45	40	33
KCU[j/cm^2]	180	172	162	148	102	90	80	66

$$KCU = \frac{W_0}{S_0} \quad (1)$$

where KCU- is the resilience; W_0 - represents the breaking energy and S_0 - is the initial transversal section with notch of the sample.

Graphical variations of the breaking energies Wo and the resilience KCU, for the uncharged samples and for samples charged with hydrogen, as function of hydrogen charge duration are illustrated in Figure 5. These variations are not due only to hydrogen charging but especially imperfections generated by the welding process.

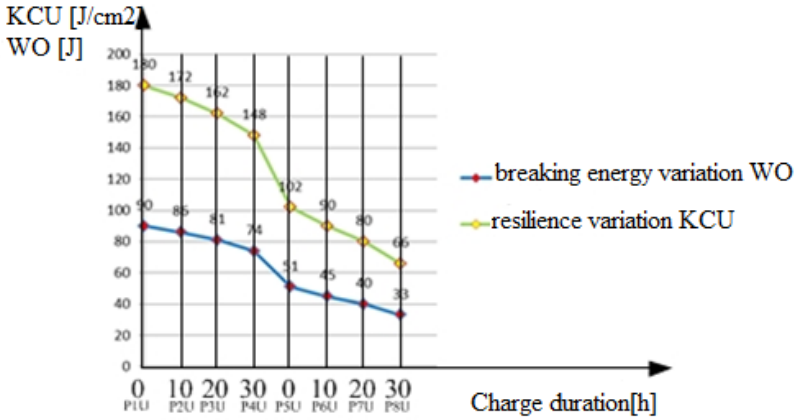

Fig. 5. Variation of the breaking energy W0 and resilience KCU based on the hydrogen charge duration and sampling area for U-shaped samples

The values of the geometrical elements of the brittle breaking sections a_f and b_f, determined for each U-shaped sample, after breaking, by means of a 1/10 beam compass, are shown in Table 9. The same Table indicates the values of section brittle baking areas S_f, ductile S_d respectively, according to relations 2 and .

$$S_f = a_f x b_f \quad (2)$$

$$S_d = S_0 - S_f \quad (3)$$

Table 9

Values of the geometrical elements for breaking sections of the U-shaped samples

Sampling	MB	MBD			MBS	MBSD		
Sample	P1U	P2U	P3U	P4U	P5U	P6U	P7U	P8U
H2 Charge duration [h]	0	10	20	30	0	10	20	30
a_f[mm]	6,3	6,5	6,6	6,8	6,9	6,9	7,2	7,4
b_f[mm]	1,9	1,9	2	2,2	2,2	2,6	2,7	2,9
S_f[mm^2]	11,97	12,35	13,2	14,96	15,18	17,94	19,44	21,46
S_d[mm^2]	38,03	37,65	36,8	35,04	34,82	32,06	30,56	28,54

Once the section areas for brittle and ductile breaking determined, crystallinity C_r, fiber texture F_b and cross compression T were calculated, based on relations 3, 4 and 5, for U-shaped samples. The corresponding values are indicated in table 9. For the T cross compression, b and b1 values were used, determined by means of a 1/10 beam compass (Table 10).

$$C_r = \frac{S_f}{S_0} x100 \quad (4)$$

$$F_b = \frac{S_d}{S_0} x100 \quad (5)$$

$$T = \frac{b - b_1}{b} x100 \quad (6)$$

The graphical variation of the geometrical elements a_f; b_f; b and b_1 are illustrated in Fig. 6 and Fig. 7 shows the graphical variations of the brittle and ductile breaking areas S_f , S_d respectively.

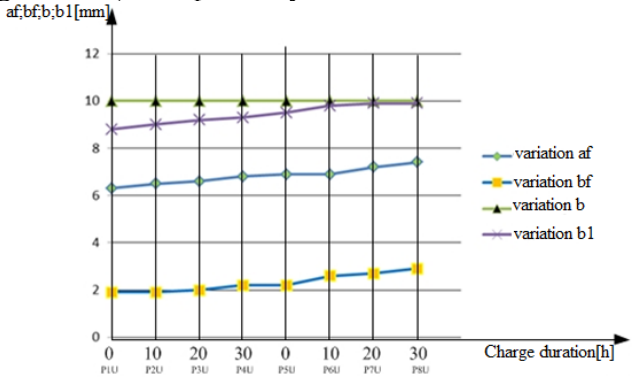

Fig. 6. Variation of the geometrical elements a_f; b_f; b and b_1, according to charge duration and sampling area for U-shaped samples

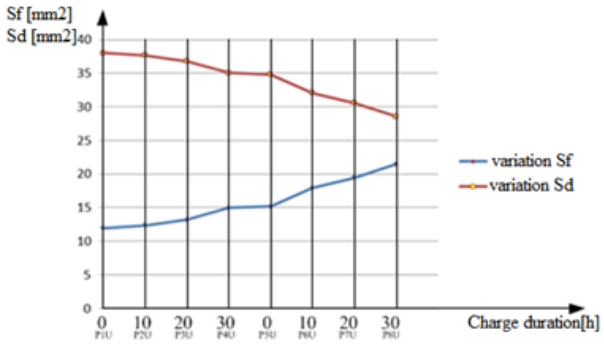

Fig. 7. Variation of brittle S_f and ductile breaking areas S_d, based on the charge duration and sampling area for U-shaped samples

Table 10

Crystallinity values C_r, fiber texture F_b and cross compression T for U-shaped samples

Sampling	MB	MBD			MBS	MBSD		
Sample	P1U	P2U	P3U	P4U	P5U	P6U	P7U	P8U
H2 Charge duration [h]	0	10	20	30	0	10	20	30
b[mm]	10	10	10	10	10	10	10	10
b_1[mm]	8,8	9	9,2	9,3	9,5	9,8	9,9	9,9
C_r[%]	23,9	24,7	26,4	29,9	30,3	35,8	38,8	42,9
F_b[%]	76,1	75,3	73,6	70,1	69,7	64,2	61,2	57,1
T[%]	12	10	8	7	5	2	1	1

Graphical representation of crystallinity Cr, fiber texture Fb and cross compression T based on a10, 20 and 30 hour charge duration and on the type of samples used is illustrated in Figure 8.

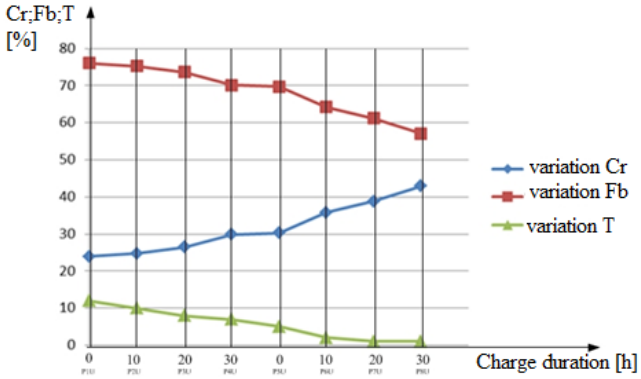

Fig. 8. Variation of crystallinity C_r, fiber texture F_b and cross compression T, based on charge duration and sampling area for U-shaped samples

3.2 Researches on tensile test

The results of the research on ultimate strength are illustrated in table 11.

Table 11

Values of ultimate strength Rm

Sampling	MB	MBD			MBS	MBSD		
Sample	T1	T2	T3	T4	T5	T6	T7	T8U
H2 Charge duration [h]	0	10	20	30	0	10	20	30
Rm[N/mm^2]	550	530	520	490	520	510	480	450

The graphical variation of the ultimate strength Rm based on the hydrogen charge duration and the type of sample subjected to breaking by ultimate strength is indicated in Figure 9.

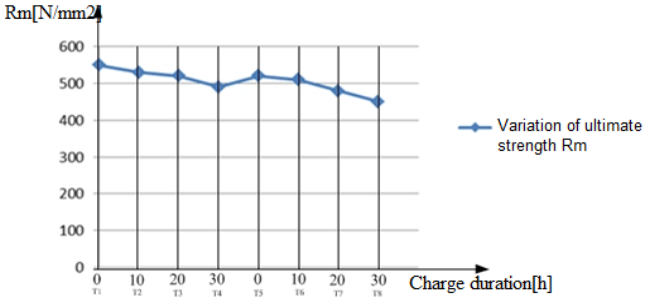

Fig. 9. Variation of ultimate strength Rm, based on charge duration and sampling area for U-shaped samples

4. Conclusions

With regard to the data indicated in all the tables and figures above, the following conclusions can be drawn:

- a decrease in the KV plasticity values and KCU, when a simple MB base material is changed for an MBD electrolytically hydrogen charged material, for an MBS welded base material and then for welded and electrolytically hydrogen charged MBSD material, provided the charging duration prolongs from 10 to 30 hours. The lowest values are achieved for welded base materials as compared to the values of the MB base material

- these values do not differ significantly for the same hydrogen charge duration. Hence, resilience tests do not prove the hydrogen embrittlement of a sample;

- a decrease in fiber texture Fb and an increase in crystallinity with the change of MB to MBD; MBS to MBSD, with the prolonging of charge duration from 10 to 20 and even 30 hours; a key observation is the drop in cross compression provided the prolonging of hydrogen charge duration;

- a drop in tenacity and plasticity characteristics with the prolonging of hydrogen charge duration is due to a big amount of hydrogen (positive ions) introduced into the base material or the welded structure. The internal pressure grows and embrittlement of the area occurs. As the research reveals, this can be proved in the case of dynamic stress under shock bending;

- the lowest values of the KV breaking energy, KCU resilience and T cross compression are obtained for welded and hydrogen charged materials, since, by welding, a high amount of hydrogen is introduced from the coated electrode (manual electric arc welding), to which electrolytic hydrogen charge is added. Likewise, internal weld tensions must be considered, since, combined with diffusible hydrogen, can render disastrous consequences;

- regarding the tests on tensile test, the results have revealed that breaking tension does not vary significantly with the prolonging of diffusible hydrogen charge duration.

Acknowledgment

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