METHOD OF ESTABLISHING THE OPTIMUM TECHNIQUE FOR RECONDITIONING BY WELDING, TAKING INTO ACCOUNT THE CONSUMPTION OF FILLER METALS AND ELECTRICAL POWER

Dumitru - Titi CICIC[1], Gheorghe SOLOMON[2], Gabriel IACOBESCU[3], Corneliu RONTESCU[4]

Lucrarea de față își propune stabilirea unei tehnici optime de reparație prin sudare din punctul de vedere al consumului de materialde adaos şi energie electrică.

Sunt prezentate o serie de relații originale care pot sta la baza elaborării unor tehnologii de sudare sau reparație prin sudare, având ca scop nu doar asigurarea unor caracteristici de material mai bune, ci şi minimizarea costurilor prin reducerea consumurilor de material şi energie electrică.

The aim of this paper is to establish the optimum technique for reconditioning by welding, considering the allowable consumption of materials and electrical power

A series of original relations which may constitute the basis of elaborating welding techniques or reconditioning welding techniques are exposed, having as goal not only to ensure better material characteristics, but also to minimize the costs by reducing materials and power consumption.

Keywords: optimization, costs, reconditioning techniques

1. Introduction

Most of the companies, which create welded structures, generate their production depending on the market demand and this constitutes a reason for the importance of assessing the production costs.

In these companies, the production costs can be the result of applying many methods, individually or combined, as it follows [1]:

- *Analytical method***,** which enables costs evaluation having as basis the time necessary for the product to be manufactured. The product is

[1] Lecturer, Faculty of Engineering and Management of Technological Systems, Chair of Materials Technology and Welding, University POLITEHNICA of Bucharest, Romania, e-mail: dumitru.cicic@gmail.com

[2] Prof., Faculty of Engineering and Management of Technological Systems, Chair of Materials Technology and Welding, University POLITEHNICA of Bucharest, Romania

[3] Prof., Faculty of Engineering and Management of Technological Systems, Chair of Materials Technology and Welding, University POLITEHNICA of Bucharest, Romania

[4] Assist. Eng. Faculty of Engineering and Management of Technological Systems, Chair of Materials Technology and Welding, University POLITEHNICA of Bucharest, Romania

decomposed in elementary components and the periods needed in order to achieve them are determined. According to this method, costs are calculated by relation 1.

$$C_T = T_p \cdot M_h \quad (1)$$

where: C_T , total production cost [Lei]; (Lei is currency of Romania); T_p , total time necessary for making the product, defined as the sum of the periods of time necessary to achieve all the components [h]; M_h , Expenses for the manual labour [Lei/h]

- *Parameters method,* in which the production costs are determined by using the mathematical formulas based on the information given by the company. Thus one can establish if there are correlations between different periods of time and production operations.

- *Analogical method,* which is based on products classification and indexation in accordance with the morphological-functional criteria, as well as with those of quality applied by the respective company.

2. Assessment of costs and necessary timing in order to make a welded structure

The assessment of costs and necessary periods of time for achieving a welded product starts from defining a model which integrates the information needed in order to define the respective product and the processes of its achievement. Such a model is shown in Fig. 1

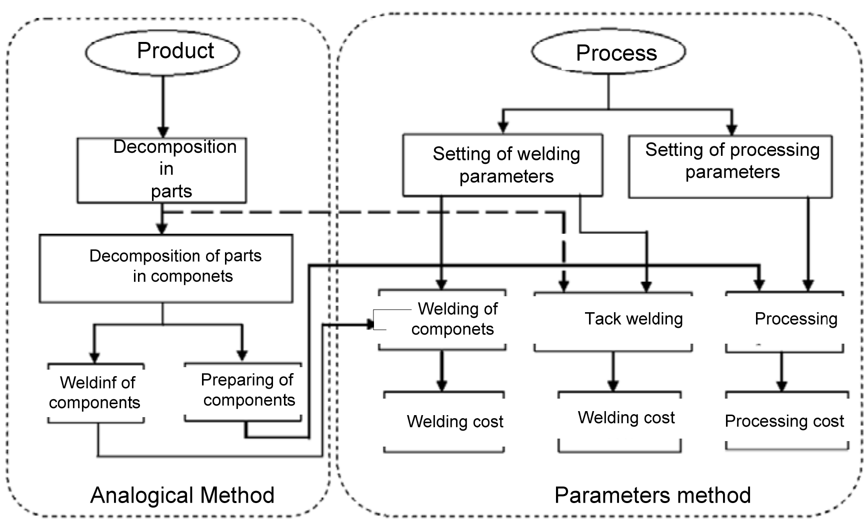

Fig. 1. Model for costs assessment in the welding process [4]

From the structural point of view, such a model should contain at least two types of components:

- *Geometrical and technological description* of the welded assembly and the operations for preparing the components;
- *Actions and operations* which must be achieved in order to make the components of the product.

The model in Fig. 1 is based on defining the volume of material necessary for welding, guided by the geometrical description of the components and by the types of used joints. The data regarding the characteristics of the allowable material and welding operations sequence enables one to establish as well the welding necessary periods of time for each component of the analyzed product.

3. Techniques of reconditioning by welding

3.1. Half Bead Technique [5]

This technique uses manual welding with covered electrodes as welding procedure and consists in increasing the electrode diameter, starting from 2.5 mm, then 3.25 mm, and ending with a 4 mm electrode.

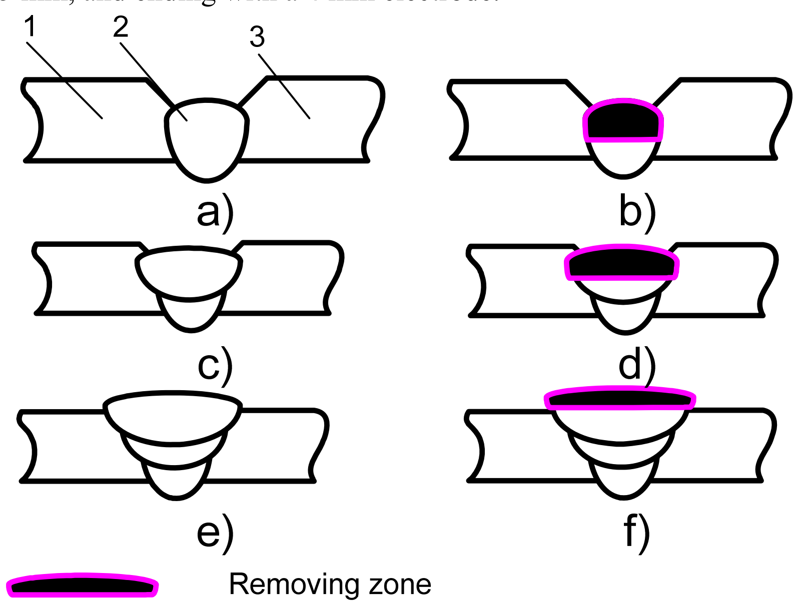

Fig. 2. Reconditioning by welding application scheme using Half Bead Technique
a) depositing stratum I with a 2.5 mm electrode; b) removing half of stratum I; c) depositing stratum II with a 3.25 mm electrode; d) removing half of stratum II; e) depositing stratum III-n with a 4 mm electrode; f) removing half of stratum III-n;

The technique presupposes the following steps, (fig. 2):

- Depositing a stratum with a 2.5 mm diameter electrode on the component edges, which ensures a reduced thermally influenced zone;

- Removing half of the previously deposited stratum by grinding;
- Depositing the next layer with a 3.25 mm diameter electrode. This operation transforms again the incomplete melted zone of the first stratum HAZ (Heat Affected Zone);
- Removing half of the second stratum by grinding. The next strata will be deposited with 4 mm electrodes and half of them will be removed after making each stratum. Each subsequently deposited stratum will have an effect of re-emergence over the previously deposited strata.

3.2. Controlled Deposition Technique

This technique has been employed by the special cases where intercrystalline corrosion and preheating cracking may manifest during the process of reconditioning.

The procedure of manual welding with covered electrodes is used and consists in increasing the linear energy with a certain percent from a stratum to another [5].

The technique consists in:

- depositing the first stratum with a certain value of the linear energy, El;
- the linear energy of the second stratum will be 1.2-1.8 bigger than the one from the first stratum and enables the reconditioning of the material from the Thermally-mechanically Influenced Zone, TIZ;
- the next strata will satisfy the above-mentioned requirement.

3.3. The Post Welding Thermal Treatment

It consists of a technique for reconditioning executed in normal conditions, according to the initial welding conditions, followed by a post-welding thermal treatment adequate to the basic material.

4. Initial data, achieved experiments and obtained results

4.1. Directions of research and codification

If a defect is found at an equipment under pressure from the energetic industry, one can take the following decisions [6, 7, 8]:

- Ignore it or do not take any measure;
- Check again and repair;
- Replace it with another component, identical or of a better quality than the deteriorated one.

The experiments achieved can be classified in two directions:

- The first part in which the analysis and examinations lead to the conclusion that the deteriorated zone must be totally removed;

- The second part in which the analysis and examinations lead to the conclusion that the deteriorated zone must be partially removed.

The techniques of reconditioning used in the experiments are indicated and codified in Table 1, being chosen from the ones presented above.

In the case of partially removing the deteriorated zone, a groove resulted after removing material from the piece, with its dimensions indicated in table 2.

Table 1

General codification of the experiments

Group	Reconditioning by welding in the case of total removal of the zone with defects			Reconditioning by welding in the case of partial removal of the zone with defects		
Name of the welding technique	Controlled Deposition Technique	Half-Bead Technique	Post Welding Thermal Treatment	Controlled Deposition Technique	Half-Bead Technique	Post Welding Thermal Treatment
Codification	CDT	HBT	PWTT	CDTD	HBTD	PWTTD

Table 2

Depth of the groove resulted in the material at the partial removal

The technique of reconditioning by welding	Breadth [mm]	Length [mm]	A_{d1} [mm]	A_{d2} [mm]	A_{d3} [mm]	A_{med} [mm]
CDTD	20	86	7,5	7,6	7,3	7,46
HBTD	20	86.7	7,4	7,4	7,5	7,43
PWTTD	20	87.4	7,7	7,7	7,4	7,6

The removal of the material has been made by mechanical processing, taking into account the following aspects:

- avoiding to introduce supplementary stresses and thermal shocks in the material which would cause changing its structure;
- eliminating the phenomenon of carbon increase in the zone adjacent to processing, phenomenon which appears especially in the case of thermal conditioning.

All the other conditions established during the experiments are available in both the research directions.

4.2. Technological parameters used in the experiments

In order to make the experiments SA 387 Gr.12 has been used as base material, and ECrMo1B42H5 electrodes, (Cromobaz) as filler material.

The technological parameters which have been used in the experiments are indicated in Table 3 and have been established according to the recommendations of the producers of basic and filler material.

Table 3

Technological parameters used in the experiments

Technique	$Ø_e$ [mm]	Tcal [^{0}C]	Ment. Time min. [min]	T_{pr} [^{0}C]	Parameters of welding regime		Post welding treatment			
					Is [A]	Ua [V]	$v_î$ [^{0}C/h]	v_r [^{0}C/h]	T_d [^{0}C]	t_d [h]
HBT	2.5				80	22	-	-	-	-
	3.25				120	23	-	-	-	-
	4				180	24	-	-	-	-
CDT	2.5				80	22	-	-	-	-
	3.25				120	23	-	-	-	-
	4				180	24	-	-	-	-
PWTT	2.5				80	22				
	3.25				120	23	100	50	525	5
	4				180	24				
HBTD	2.5				80	22	-	-	-	-
	3.25				120	23	-	-	-	-
	4				180	24	-	-	-	-
CDTD	2.5				80	22	-	-	-	-
	3.25	255	100	110	120	23	-	-	-	-
	4				180	24	-	-	-	-
PWTTD	2.5				80	22				
	3.25				120	23	100	50	525	5
	4				180	24				

The values of the welding parameters are indicated in Table 4.

5 deposits have been made at each technique for each research direction.

4.3. Calculus relations

In order to establish the optimum technology and technique of reconditioning by welding of the energetic equipments like steam drums and collectors, a comparison has been made from the consumption point of view, concretized by the consumption of filler materials and time.

Taking into account that the analyzed welding procedure is manual welding with covered electrode, the filler material consumption represents only the electrodes consumption.

The following periods of time have been taken into account when determining the necessary time for making a sample:

- time of welding, t_w timed during the experiment;
- auxiliary time, t_a, representing the sum of the necessary periods of time in the case of removing half the stratum, removing the slag stratum and changing electrodes. The auxiliary time has been established with the software of the

infrared thermo graphic camera;

- the time spent with preheating the basic material, t_{Tpr};
- the time spent for applying the thermal treatment, t_{TT};
- the necessary time for electrodes calcination, t_c ;

Table 4

Technological parameters resulted during the experiments (extract)

Crt No.	Experiment	Stratum No.	T_p [^oC]	I_s [A]	U_a [V]	t [min]	v_s [cm/min]	E_l [KJ/cm]
1.	CDT	Stratum 1	110	80	22	1,00	9,40	8,99
		Stratum 2	110	120	23	0,98	9,56	13,86
		Stratum 3	110	180	22	0,90	10,44	18,20
2.	CDTD	Stratum 1	110	80	23	1,18	7,27	12,15
		Stratum1’	110	80	23	1,20	7,17	12,32
		Stratum 2	110	120	23,5	1,13	7,59	17,84
		Stratum 3	110	180	23	1,10	7,82	25,42
3.	HBT	Stratum 1	110	80	23	1,00	9,38	9,42
		Stratum1'	110	80	23	1,05	8,93	9,89
		Stratum 2	110	120	23	1,18	7,93	16,71
		Stratum2'	110	120	23	1,08	8,66	15,30
		Stratum 3	110	180	23	1,07	8,79	22,60
		Stratum3'	110	180	23	1,03	9,08	21,89
4.	HBTD	Stratum 1	110	80	23	1,18	7,33	12,05
		Stratum1'	110	80	23	1,13	7,65	11,55
		Stratum 2	110	120	23	1,00	8,67	15,28
		Stratum2'	110	120	23	1,07	8,13	16,30
		Stratum 3	110	180	23	1,00	8,67	22,92
		Stratum3'	110	180	23	0,98	8,82	22,54
5.	PWTTT	Stratum 1	110	80	23	0,90	10,42	8,47
		Stratum 2	110	120	23	1,02	9,23	14,36
		Stratum 3	110	180	23	0,90	10,42	19,07
6.	PWTTTD	Stratum 1	110	80	23	1,25	7,10	12,45
		Stratum1’	110	80	23	0,97	9,18	9,63
		Stratum 2	110	120	23	1,15	7,71	17,18
		Stratum 3	110	180	23	0,98	9,02	22,03

The electric power consumption in the case of electric arc welding is determined by the following formula [9]

$$SS = \frac{U \times I \times t}{\eta \times 1000} \text{ [kWh]} \quad (2)$$

in which :

U - Voltage, [V];

I – power intensity, [A];

t – duration of using the arc, [h]
η – supplying source output, η=0.8.

The calculus of the electrical power consumed in the no-load period has been established by the formula:

$$S_o = U_0 \times I_0 \times t_a \text{ [kWh]} \quad (3)$$

in which:
U_0= no-load voltage, U_0= 79 V;
I_0 = no-load intensity, I_0 = 15 A;
t_a = no-load functioning time, [min].

The quantity of filler material consumed for achieving the samples in each technique of reconditioning analyzed, CE, has been established in the following way:

- 3 electrodes have been weighed, one for each used diameter, of 2.5mm, 3.25 mm and 4 mm, obtaining the total weight, CT, of 137.8 g;
- the unconsumed electrode ends have been weighed for each diameter, CN, in each experiment;
- the electrode consumption necessary for making the sample, CE, has been calculated with the formula :

$$CE=CT-CN \quad (4)$$

When determining the electrodes consumption, the material losses made by drops have been considered null.

The total time for each sample has been determined by the relation:

$$t_{TOTAL\ sample\ i} = t_{w\ sample\ i} + t_{a\ sample\ i} + t_{TT\ sample\ i} + t_{pr\ sample\ i} + t_{c\ sample\ i} \quad (5)$$

where *i* represents the sample .

The total time, t_{wTOTAL}, spent for achieving the set of samples for each technique of reconditioning by welding analyzed has been calculated by the relation:

$$t_{wTOTALsamples} = t_{w\ sample1} + t_{w\ sample2} + t_{w\ sample3} + t_{w\ sample4} + t_{w\ sample5} \quad (6)$$

The total auxiliary time, t_{aTOTAL}, which represents the time necessary for changing the electrodes, removing the slag and/or removing half of the stratum, spent for achieving the set of samples for each technique of reconditioning by welding analyzed has been determined by the formula:

$$t_{aTOTALsamples} = t_{a\ sample1} + t_{a\ sample2} + t_{a\ sample3} + t_{a\ sample4} + t_{a\ sample5} \quad (7)$$

The time values spent for applying the post welding thermal treatment, until reaching the preheating temperature or during calcination, are indicated in Table 7.

The total time necessary for making the set of samples of one reconditioning technique, $t_{TOTALsamples}$, has been determined by the relation:

$$t_{TOTALsamples}= t_{wTOTAL}+ t_{aTOTAL}+ t_{TT}+t_{pr}+t_c \quad (8)$$

All the plates of basic material have been introduced in the oven in the same time, so the time necessary to reach the preheating temperature are equal to the time necessary to preheat a single sample, t_{pr} = 2 h, as in the case of electrodes calcination, t_c =1.66h. This observation was taken into account as well when calculating the total electrical power consumption

The electrical power consumed at the thermal treatment, E_{TT}, has been determined by relation 9.

$$E_{TT}= E_{T\ oven} \times t_{TT} \quad (9)$$

Where $E_{T\ oven}$ = the power of the oven resistances, 1kW

t_{TT} = time necessary for the thermal treatment, 5h

The consumption of electrical power necessary for preheating the basic material, E_{Tpr}, has been calculated as:

$$E_{Tpr}= E_{T\ oven} \times t_{Tpr} \quad (10)$$

where $E_{T\ oven}$ = the power of the oven resistances, 1kW

t_{pr} = time necessary for preheating, 2h

The consumption of electrical power necessary for electrodes calcination, E_C, has been determined in the following way:

$$E_C= E_{T\ oven} \times t_c \quad (11)$$

where $E_{T\ oven}$ = the power of the oven resistances, 1kW

t_c = time necessary for the thermal treatment, 1.66h

The total consumption of electrical power necessary for making one sample, $E_{TOTAL\ sample}$, one reconditioning technique has been determined by:

$$E_{TOTAL\ sample} = S_0+SS+E_{TT}+ E_{Tpr}+ E_C \quad (12)$$

The total consumption of electrical power necessary for making the set of samples of one reconditioning technique, $E_{TOTAL\ samples}$, has been obtained using the relation:.

$$E_{TOTAL\ samples}= S_{0TOTAL}+SS_{TOTAL}+E_{TTTOTAL}+ E_{TprTOTAL}+ E_{CTOTAL} \quad (13)$$

where:

- S_{0TOTAL} represents the total electrical power consumption of the source during the no-load cycle, calculated by relation (14);

- SS_{TOTAL} represents the total electrical power consumption of the source during functioning when making the samples of each reconditioning technique used, calculated by relation (15);
- $E_{TTTOTAL}$, electrical power consumed at the thermal treatment, 5kWh;
- $E_{TprTOTAL}$, electrical power consumed at preheating, 2kWh;
- E_{CTOTAL}, electrical power consumed at calcination, 1.66 kWh

$$S_{0TOTALi} = S_{0sample1} + S_{0sample\ 2} + S_{0sample\ 3} + S_{0sample\ 4} + S_{0sample\ 5} \quad (14)$$

$$SS_{TOTAL} = SS_{sample\ 1} + SS_{sample\ 2} + SS_{sample\ 3} + SS_{sample\ 4} + SS_{sample\ 5} \quad (15)$$

The values obtained after determinations and calculus indicated in Table 5, 6, 7 and 8.

A series of codifications have been used in the tables explained below:

- t_w – welding time, [min];
- t_a – auxiliary time, time spent for electrode consumption, slag removal, half of stratum removal, [min];
- t_{TT}- time necessary for applying the thermal treatment, 5h;
- t_{pr} - time necessary for preheating, 2h;
- t_c - time necessary for calcination, 1.66h;
- CE – electrode consumption, calculated as function of the weight of the electrodes ends left unconsumed at each sample;
- S_0- electrical power consumption of the source during the no-load cycle, relation 3;
- SS- electrical power consumption of the source during functioning, relation 2;
- E_{TT} – electrical power consumed at the thermal treatment;
- E_{Tpr} - electrical power consumed at preheating;
- E_C- electrical power consumed at calcination.

4.4. Results

The values obtained by applying the above mentioned relations are listed in the following tables.

Comparing the obtained values of the electrodes consumption in Table 5 for making the samples in the case of the “Controlled Deposition Technique”, one can observe that the variation of the consumptions among the samples in this experiment is not significant. The value of the electrodes consumption was higher in the case of the CDTR sample, 74.17 g compared to a average value of 46.30 g for the other samples, taking into account that the length of the bead was with approximately 56.4 mm bigger than in the other cases.

As far as the electrical power consumption necessary for making the samples concerns, one can assert that the variation among the samples is not significant, noticing a higher value in the case of CDTR sample, because of the above mentioned reason.

Table 5

Consumption of time and power when making the set of samples with the "Deposition Controlled Tehnique"

Sample Code	Time for welding the sample					CE [g]	Electrical power consumption				
	t_w [min]	t_a [min]	t_{pr} [min]	t_c [min]	t_{TOTAL} sample [min]		S_0 [kWh]	SS [kWh]	E_{Tpr} [kWh]	E_C [kWh]	E_{TOTAL} sample [kWh]
CDT1	2.77	10.37	120	100	233.13	46,57	0,19	0,48	2,00	1,66	4,33
CDT2	2.80	8.62			231.42	46,60	0,16	0,49			4,31
CDT3	2.60	8.15			230.75	46,20	0,15	0,45			4,26
CDTR	3.30	8.23			231.53	74,17	0,15	0,57			4,39
CDTM	2.88	4.63			227.52	46,62	0,09	0,50			4,25
$t_{TOTALprobe}$/ $S_{TOTALprobe}$	14.35	40	120	100	274.35	260,16	0,75	2,49	2,00	1,66	6,90

The consumptions values measured or resulted from making the samples when applying the Half-Bead Technique are indicated in Table 6.

Table 6

Consumption of time and power when making the set of samples with the "Half-Bead Tehnique"

Sample Code	Time for welding the sample					CE [g]	Electrical power consumption				
	t_s [min]	t_a [min]	t_{pr} [min]	t_c [min]	t_{TOTAL} sample [min]		S_0 [kWh]	SS [kWh]	E_{Tpr} [kWh]	E_C [kWh]	E_{TOTAL} sample [kWh]
HBT1	6.42	11.27	120	100	237.68	93,10	0,21	1,80	2,00	1,66	5,67
HBT2	5.20	15.47			240.67	92,90	0,29	1,80			5,75
HBT3	6.00	11.35			237.35	93,00	0,21	2,08			5,95
HBR	5.20	9.50			234.70	152,42	0,18	2,22			6,06
HBM	5.02	12.13			237.15	93,40	0,23	1,74			5,63
$t_{TOTALprobe}$/ $S_{TOTALprob}$	27.83	59.72	120	100	307.55	524,82	1,12	9,64	2,00	1,66	14,42

One can assert on the basis of the values in Table 6 that the variation of the filler material consumption when making the 5 samples with the Half-Bead Technique is not significant, since high values have been observed when making the HBR sample, given the length of the bead bigger with approximately 57 mm than that of the other samples in the experiment.

The values obtained for the consumption of electrodes and electrical power in the case of reconditioning by welding of the partially removed affected zone, are presented in Table 7, in which one can notice an increase of the electrodes consumption in the case of the HBTD sample with approximately 88.74 g compared to the CDTD sample, and with 89.12 compared to the PWTTD sample, respectively. An increase of the electrical power consumption in the case of PWTTD sample compared to the other two samples is also visible, due to the post-welding thermal treatment.

Table 7

Consumption of time and power when making the CDTD, HBTD, PWTTD samples

Sample Code	Time for welding the sample						CE [g]
	t_s [min]	t_a [min]	t_{TT} [min]	t_{pr} [min]	t_c [min]	t_{TOTAL} sample [min]	
CDTD	4.62	4.8	0	120	100	229.42	98,90
PWTTD	4,43	8,9	300	120	100	533,33	98,52
HBTD	6.37	12.5	0	120	100	238.87	187,64

Table 7 (continuation)

Consumption of time and power when making the CDTD, HBTD, PWTTD samples

Sample Code	CE [g]	Electrical power consumption					
		S_0 [kWh]	SS [kWh]	E_{TT} [kWh]	E_{Tpr} [kWh]	E_C [kWh]	E_{TOTAL} sample [kWh]
CDTD	98,90	0,09	0,80	0,00	2,00	1,66	4,55
PWTTD	98,52	0,17	0,77	5,00	2,00	1,66	9,60
HBTD	187,64	0,23	2,21	0,00	2,00	1,66	6,10

The values obtained for the consumption of electrodes and electrical power in the case of the samples obtained at reconditioning by welding followed by post-welding thermal treatment are indicated in Table 8.

5. Conclusions

5.1. The proposed relations may constitute the basis of exact calculus which shows if a technique or technology is optimum from the point of view of consumption of allowance materials and electrical power.

5.2. Comparing the techniques of welding reconditioning from the point of view of electrodes consumption when making the samples, the following hierarchy of reconditioning techniques can be established: 1 – CDT, 2 – PWTT, 3 – HBT;

5.3. Comparing the techniques of welding reconditioning from the point of view of the electrical power consumption when making the samples, the following hierarchy of reconditioning techniques can be established: 1 – CDT, 2 – PWTT, 3 – HBT;

Table 8

Power and time consumption when making the set of samples by PWTT technique

Sample Code	Time for welding the sample						CE [g]	Electrical power consumption					
	t_w [min]	t_a [min]	t_{TT} [min]	t_{pr} [min]	t_c [min]	t_{TOTAL} sample [min]		S_0 [kWh]	SS [kWh]	E_{TT} [kWh]	E_{Tpr} [kWh]	E_C [kWh]	E_{TOTAL} sample [kWh]
PWTT1	2.82	5.05	300	120	100	527.87	46,52	0,09	0,49	5,00	2,00	1,66	9,24
PWTT 2	2.95	7.95	300	120	100	530.90	46,50	0,15	0,51	5,00	2,00	1,66	9,32
PWTT3	2.47	6.65	300	120	100	529.12	46,60	0,12	0,43	5,00	2,00	1,66	9,21
PWTTR	2.68	8.23	300	120	100	530.92	75,14	0,15	0,56	5,00	2,00	1,66	9,37
PWTTM	3.25	6.45	300	120	100	529.70	46,45	0,12	0,47	5,00	2,00	1,66	9,25
$t_{TOTAL\ samples}$/ $S_{TOTAL\ samples}$	14.17	34.33	300	120	100	568.5	261,21	0,64	2,46	5,00	2,00	1,66	11,76

5.4. From Table 7 in which the values obtained for electrodes and electrical power consumption, are listed when applying the technique of welding reconditioning of partially removed affected zone, in the case of HBTD sample one can observe an increase of electrodes consumption with approximately 88.74 g compared to CDTD sample, and with 89.12 compared to PWTTD sample, respectively.

Moreover, an increase of the electrical power consumption can be observed in the case of PWTTD sample compared to the other 2 samples, due to the post-welding thermal treatment.

The general conclusion is that, on the basis of the values obtained during the experiments in the above mentioned conditions, the optimum technique in what concerns the consumption of filler materials, as well as of electrical power, is that of "Controlled Deposition Technique" for both lines of research.

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