RESEARCHES REGARDING QUALITY OF THE WELDED JOINTS OBTAINED BY APPLYING THE TECHNIQUES OF WELDING RENEWAL TO COMPONENTS FROM THE ENERGY INDUSTRY MADE FROM SA 387 GR 12

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În cadrul lucrării se prezintă principalele tehnici de recondiționare prin sudare aplicabile componentelor echipamentelor energetice precum şi limitările acestora, programul experimental, rezultatele obținute şi principalele efecte pe care le au tehnicile analizate în comparație cu varianta clasică de recondiționare prin sudare urmată de tratament termic post sudare.

The main techniques of renewal by welding applicable to energy equipments components are presented in this paper, as well as their limitations, the experimental program, the obtained results and the main effects they have compared to the classical variant of renewal by welding followed by post weld heat treatment.

Keywords: renewal, welding, techniques, heat treatment.

1. General considerations

Energy equipments represent the bridge between the supplier and the user of heat or electricity.

At present, the designed operating period for most of the collectors and boiler drums used as energy equipment expires, or they require lot of repair interventions because of multiple defects that appear during the operation under conditions of high temperatures and pressures.

That is why the need to develop technologies of renewal by welding for the failed equipments becomes increasingly topical.

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The welding processes applied by welding in order to repair the energy equipments are part of the process of welding by melting.

The defects which may occur in the energy equipments can be classified depending on the operating time of the material, as shown in table 1.

Detecting a defect will certainly lead to the one of the following:

- to ignore or not to take any measure;
- to verify again and to repair;
- to replace with an identical component or with one of a better quality.

Table 1

Failure of the energy equipment [2]

Type of defect	**Operating time of the equipment [h]**
Manufacturing defects	Delivery
Undiscovered defects in material to the product delivery	20-30.000
Defects due to operation	over 50.000

When the renewal of the equipments or machinery which were achieved by welding with post welding heat treatment is required, there must be proceeded in the same way as in the case of their initial achievement [3],[4], in accordance with the rules of ASME, EN or SR.

When the repair by welding of a defect is required, the first operation to be performed is the removal of this defect.

The main ways of removing the material which contains defects are shown in Fig. 1.

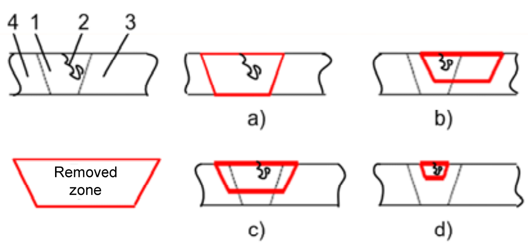

Fig. 1. Ways of removing of the area with defect: a) total removal of the damaged area; b) partial removal of the area with defect from base material MB2; c) partial removal of the area with defect, on the surface from MB 1, C, MB2; d) partial removal of the area with defect, from C.
1 – welding joint, C; 2 – defect; 3 – base material, MB2; 4 – base material, MB1.

2. Techniques used for renewal

Five techniques are used at the renewal by welding of the energy equipments, all these techniques having the same goal: to achieve tempering of the heat affected zone (HAZ).

2.1. Half Bead Technique

At first, this technique has been developed in the nuclear industry, but it became one of the most applied repairing techniques in all the industrial fields that presuppose welding procedure [5], [6].

The technique consists in:
- depositing layer I, using an electrode of 2.5 mm diameter;
- removing half of layer I;
- depositing layer II, using an electrode of 3.25 mm diameter;
- removing half of layer II;
- depositing layers III-n, using an electrode of 4 mm diameter (n- total number of the layers);
- removing half of layer III-n;

The main disadvantages of this technique derive from the impossibility of removing half of the layer with a high accuracy, lasting too long to remove the material, and, in case of removal too much material from the deposited layer, there will no longer be obtained the desired effect of tempering.

2.2. Consistent Layer Technique

In applying this technique there can be used either the method of shielded metal arc welding, or the TIG procedure, with wolfram inert gas. This technique consists in depositing small enough layers, so that the next deposited layer has only the tempering effect on the heat affected zone HAZ which arises from depositing the previous layer.

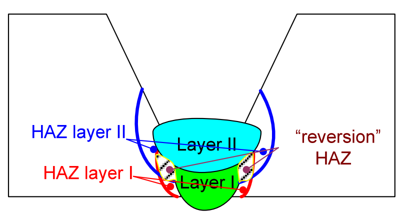

Fig. 2. Application scheme of the consistent Layer Technique

The temperature in the respective area must not exceed Ac_1, so that the ferrite transformation in austenite should not take place.

2.3. Alternate Temper Bead Technique

This technique was developed especially for the classes of steel C-Mn, C-Mo, used in nuclear reactors for the components of products under pressure, [9].

TIG mechanized is used as welding procedure because it is applied especially in areas with high level of radiations. This technique was developed to eliminate or reduce the disadvantages of the half bead technique.

2.4. Controlled Deposition Technique

This technique resulted from special cases where the inter-crystalline corrosion and the reheat cracking may manifest during the repair. The procedure shielded metal arc welding is used and it consists in increasing the linear energy with a certain percentage from one layer to another [7], [9], [10].

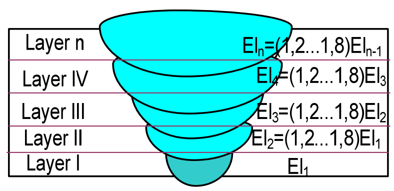

Fig. 3. Application scheme of controlled deposition technique

Technique (fig. 3) consists in:

- depositing the first layer with a given value of linear energy (El_1):
- depositing the second layer, with linear energy $El_2=(1.2…1.8)El_1$, in order to temper the material from the HAZ of the previously layer deposited;
- depositing the following layers which have to meet the requirement above.

2.5. Weld Toe Tempering Technique

This technique involves depositing a layer or a passage of heat treatment on the surface of the welding joint to ensure the tempering of the HAZ created by depositing the previous layer (fig. 4).

The mode of deposition is very important in order to achieve this requirement [5], [10], [11].

After depositing the additional layer and after cooling, it will be removed so that the welded joint has the increased height required by the welding technology.

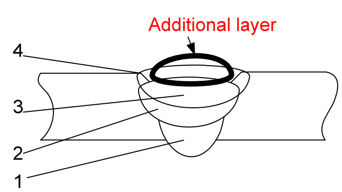

Fig. 4. Application scheme of "Weld Toe Tempering Technique"
1 – layer of root; 2 –filling layer; 3 –closure layer; 4 – layer of heat treatment.

3. Experiments and results

The experimental programme has been developed for the situation in which:

- after analyses and examinations it becomes necessary to totally remove the zone with defects and to renew it by welding using the techniques shown;
- after analyses and examinations it becomes necessary to partially remove the zone with defects and to renew it by welding using the techniques shown.

The presentation in detail and the codification of the experiments achieved is shown in table 2.

In this paper there are presented only the results obtained after applying the experimental programme in the first case.

3.1. The base material

In order to achieve the experiments SA387Gr12 has been chosen as basic material – a type of steel used especially in the energetically sector.

The samples have been taken from a plate and had the following dimensions:

- thickness : 12 mm;
- breadth : 46 mm
- length : 150 mm

It is well known the fact that the additional elements from the steel chemical composition influence its behaviour. That is why its chemical composition has been determined by the spectrometric method and are indicated in table 3.

Table 2.

Experiments codification

Group➔	Renewal by welding in the case of totally removing the area with defects			Renewal by welding in the case of partially removing the area with defects		
The technique of renewal ➔	Controlled Deposition Technique	Half Bead Technique	Post Welding Heat Treatment	Controlled Deposition Technique	Half Bead Technique	Post Welding heat Treatment
Codification ➔	CDT	HBT	PWTT	CDTD	HBTD	PWTTD

3.2. Filler material

The filler material chosen for making the experiments consisted in electrodes of ECrMo1B42H5 type. The chemical composition of the material deposited using this electrod is indicated below:. C: max. 0,12; Si: max. 0,80; Cr:

1,00-1,50; Mo: 0,45-0,65; S: max. 0,020; P: max. 0,015; Mn: 0,70-0,90.

Table 3.

The chemical composition of the base metal determined by spectrometric analize

Crt No.	Chemical Element	UM	Value imposed in ASTM	Obtained value
1	Carbon	%	Max. 0.17	0.15
2	Silicon	%	0.14-0.40	0.25
3	Sulphur	%	0.040	0.0058
4	Phosphorus	%	0.035	0.0079
5	Manganese	%	0.4-0.65	0.58
6	Nickel	%	-	0.03
7	Chrom	%	0.8-1.15	1.015
8	Molybdenum	%	0.45-0.60	0.59
9	Copper	%	-	0.02
10	Colombium	%	-	0.0058

3.3. The technological parameters used

The welding technological parameters used in the experiments are indicated in table 4.

Table 4.

The technological parameters which has been used in the experiments

<table>
<tr><th rowspan="2">Technique</th><th rowspan="2">$Ø_e$ [mm]</th><th rowspan="2">Tcal [^{0}C]</th><th rowspan="2">Min. maintained time [min]</th><th rowspan="2">T_{pr}* [^{0}C]</th><th colspan="2">Parameters of the welding regime</th><th colspan="4">Post welding treatment</th></tr>
<tr><th>Is [A]</th><th>Ua [V]</th><th>$v_î$ [^{0}C/h]</th><th>v_r [^{0}C/h]</th><th>T_d [^{0}C]</th><th>t_d [h]</th></tr>
<tr><td rowspan="3">HBT</td><td>2.5</td><td rowspan="10">255</td><td rowspan="10">100</td><td rowspan="10">110</td><td>80</td><td>22</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>3.25</td><td>120</td><td>23</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>4</td><td>180</td><td>24</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="3">CDT</td><td>2.5</td><td>80</td><td>22</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
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<tr><td rowspan="4">PWTT</td><td>2.5</td><td>80</td><td>22</td><td rowspan="4">100</td><td rowspan="4">50</td><td rowspan="4">525</td><td rowspan="4">5</td></tr>
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<tr><td>4</td><td>180</td><td>24</td></tr>
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* established as function of the method shown in [17]

$Ø_e$ – electrod diameter; T cal – heating temperature; Is – welding amperage; Ua – welding voltage; $v_î$ - heating speed; v_r - cooling speed; T_d - strees relieving temperature ; t_d - maintain time.

Examination methods applied was:

- optical examination , 100%;
- penetrant testing, 100%;
- radiation testing, 100%;

- ultrasonic testing, 100%;

After applying the examination methods mentioned above, for all the samples obtained in the experiments, it wasn't discovered any non-conformity, which could cause the elimination of the sample from the experimental programme.

3.4. Assessment of the samples obtained at the renewal by welding applying the analysed techniques by the tensile test

In order to assess the effect of the mentioned renewal techniques on the mechanical characteristics, test specimens have been taken from the samples obtained, according to EN 895 [18].

The tensile test has been made in an accredited laboratory for destructive control with authorized personnel.

The samples dimensions and the obtained results after the tensile test are indicated in table 5. The samples aspects before and after the tensile tests are indicated in fig. 5.

Table 5.

Dimensions samples and results obtained after the tensile test

Technique of renewal	Half Bead Technique			Controlled Deposition Technique			Post Welding Heat Treatment		
Characteristic	HBT1	HBT 2	HBT 3	CDT1	CDT 2	CDT 3	PWTT1	PWTT 2	PWTT 3
L_c [mm]	100	100	100	100	100	100	100	100	100
L_0 [mm]	80	80	80	80	80	80	80	85	75
a [mm]	8	8,05	8,6	8,6	8,6	8,4	8,5	8,7	8,5
b [mm]	24,5	24,4	24,35	24,6	24,4	24,5	24,4	25,6	20,5
L_t [mm]	298	298	297	298	298	298	298	298	298
S_0 [mm^2]	196	196,42	209,41	211,56	209,84	205,8	207,4	222,72	174,25
F_c [N]	90000	78000	80000	79000	79000	78000	77000	84000	66000
F_m [N]	112000	101000	101500	105500	105000	103000	104500	110500	85500
L_{0f} [mm]	95	96	96,5	97	95	95	96	101	89
a_f [mm]	4,3	4,1	4	4,1	4,2	5	5,05	5,1	5,1
R_p[N/mm^2]	459,18	397,11	382,03	373,42	376,48	379,01	371,26	377,16	378,77
R_m[N/mm^2]	571,43	514,20	484,70	498,68	500,38	500,49	503,86	496,14	490,67
A [%]	18,75	20,00	20,63	21,25	18,75	18,75	20,00	18,82	18,67
Z [%]	46,25	49,07	53,49	52,33	51,16	40,48	40,59	41,38	40,00

L_c – calibrated length; L_0 – initial length; a - thickness; b – width; L_t – total length; S_0 – initial area; F - force ; L_{0f} – final initial length; a_f -final thickness ; R_p – yield stress; R_m – tensile stress; A – elongation ; Z - eduction in area;

a) b) c)

a) CDT samples at the tensile test;
b) HBT samples at the tensile test;
c) PWTT samples at the tensile test

Fig. 5. Samples for the tensile test obtained from the samples taken after applying the 3 different techniques of renewal by welding

It can be noticed in table 5 that the tensile trength had the biggest value, 571,43 N/mm^2 in the case of HBT samples, given to the specificity of the renewal technique, and the minimal value was of 490,67 N/mm^2 for the PWTTT3 sample.

Table 6.

Differences between experimentally the results obtained and the values indicated in the standard ASTM A 387-99

Sample Code	Values obtained test		Steel standardized values SA 387 Gr12			Difference	Difference	
	R_c [N/mm^2]	R_m [N/mm^2]	R_c [N/mm^2]	$R_{m\ min}$ [N/mm^2]	$R_{m\ max}$ [N/mm^2]	R_{cmin} [N/mm^2]	$R_{m\ min}$ [N/mm^2]	$R_{m\ max}$ [N/mm^2]
HBT1	459,18	571,43	295	450	580	164,18	121,43	-8,57
HBT 2	397,11	514,2	295	450	580	102,11	64,2	-65,8
HBT 3	382,03	484,7	295	450	580	87,03	34,7	-95,3
CDT1	373,42	498,68	295	450	580	78,42	48,68	-81,32
CDT 2	376,48	500,38	295	450	580	81,48	50,38	-79,62
CDT 3	379,01	500,49	295	450	580	84,01	50,49	-79,51
PWTT1	371,26	503,86	295	450	580	76,26	53,86	-76,14
PWTT 2	377,16	496,14	295	450	580	82,16	46,14	-83,86
PWTT 3	378,77	490,67	295	450	580	83,77	40,67	-89,33

3.5. Assessment of the samples obtained at the renewal by welding applying the analyzed techniques, by trying to determine the resilience

In order to assess the effect of the different renewal techniques mentioned over the plasticity characteristics of the samples, they have been exposed to the resilience test according to SR EN 875/1997[19].

3.5.1. The samples obtained after the controlled deposition technique

Analyzing the cross-sectional area as a function of the absorbed energy it has been noticed the fibrous, crystalline or mixed aspect from different zones of the joints obtained by the controlled deposition technique, as one can see in figs. 6, 7, 8.

The values resulted from the impact test on the samples obtained by the controlled deposition technique are indicated in table 7.

a)

b)

Fig. 6. Specimens from base material – Controlled Deposition Technique
a) Specimen aspect; b) cross-sectional area analysis

a)

b)

Fig. 7. Specimens from weld - Controlled Deposition Technique
a) Specimen aspect; b) cross-sectional area analysis

a) Specimen aspect

b) cross-sectional area

Fig. 8. Specimens from heat affected zone – the "Controlled Deposition Technique " case

Table 7.

Impact test values– for CDT case

The area ➔	Basic metal			Heat affected zone (HAZ)			Weld Bead		
Specimen no. ➔	1	2	3	1	2	3	1	2	3
b [mm]	10	10	10	10	10	10	10	10	10
a_c [mm]	8	8	8	8	8	8	8	8	8
S_o[mm2]	80	80	80	80	80	80	80	80	80
KV [J]	250	252	250	98	92	62	94	82	84
KCV [J/cm^2]	312,5	315	312,5	122,5	115	77,5	117,5	102,5	105
a_f[mm]	5,5	5,5	5,5	6,5	8	5	4	4	4,5
b_f [mm]	4,5	5	5	7,5	7	6	6	5,5	5
S_f mm^2]	24,75	27,5	27,5	48,75	56	30	24	22	22,5
S_d [mm^2]	55,25	52,5	52,5	31,25	24	50	56	58	57,5
b_1 [mm]	8,4	8,5	8,7	9,5	9,2	9	9,4	9,6	9,3
T [%]	16	15	13	5	8	10	6	4	7
C_r [%]	30,94	34,38	34,38	60,94	70,00	37,50	30,00	27,50	28,13
F_b [%]	69,06	65,63	65,63	39,06	30,00	62,50	70,00	72,50	71,88

b - width, a_c –thickness; S_o- area; KV - tenacity; KCV – resilience; a_f –fragile thickness; b_f - fragile width ; S_f - fragile aria mm^2] S_d – ductile area;

3.5.2. The samples obtained after the half bead technique

Analyzing the cross-sectional as a function of the absorbed energy it has been noticed the fibrous, crystalline or mixed aspect from different zones of the joints obtained by the half bead technique, as one can see in figs. 9, 10, 11.

The values resulted from the impact test on the samples obtained by the half bead technique are indicated in table 8.

a) b)

Fig. 9. Specimens from base material – Half Bead Technique
a) Specimen aspect; b) cross-sectional analysis

a) b)

Fig. 10. Specimens from weld bead - Half Bead Technique
a) Specimen aspect; b) cross-sectional analysis

a) Specimen aspect b) cross-sectional analysis

Fig. 11. Specimens from heat affected zone - Half Bead Technique (HBT)
a) Specimen aspect; b) Breaking section analysis

Table 8.

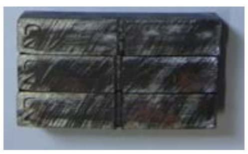
Impact values – for HBT case

The area	Basic metal			Heat affected zone			Weld bead		
Specimen no.	1	2	3	1	2	3	1	2	3
b [mm]	10	10	10	10	10	10	10	10	10
a_c [mm]	8	8	8	8	8	8	8	8	8
S_o[mm2]	80	80	80	80	80	80	80	80	80
KV [J]	254	242	256	160	180	140	86	78	80
KCV [J/cm^2]	317,5	302,5	320	200	225	175	107,5	97,5	100
a_f[mm]	6	5	5,5	4,5	4	4,5	4,4	4	4
b_f [mm]	4,5	5	5	4	4	4	4,5	4	5
S_f mm^2]	27	25	27,5	18	16	18	19,8	16	20
S_d [mm^2]	53	55	52,5	62	64	62	60,2	64	60
b_1 [mm]	8,3	8,4	8,6	9	9	9	9,2	9	9,1
T [%]	17	16	14	10	10	10	8	10	9
C_r [%]	33,75	31,25	34,38	22,50	20,00	22,50	24,75	20,00	25,00
F_b [%]	66,25	68,75	65,63	77,50	80,00	77,50	75,25	80,00	75,00

3.5. 3. The samples obtained after the renewal followed by post welding heat treatment

The values resulted from the impact test on the samples obtained by the renewal followed by post welding heat treatment is indicated in table 9.

Analyzing the cross-sectional as a function of the absorbed energy it has been noticed the fibrous, crystalline or mixed aspect from different zones of the joints obtained by the half bead technique, as one can see in figs. 12, 13, 14.



a) Specimen aspect

b) cross-sectional analysis

Fig. 12. Specimens from base material– renewal followed by post welding heat treatment

a) Specimen aspect

b) cross-sectional analysis

Fig. 13. Specimens from weld bead - renewal followed by post welding heat treatment

a) Specimen aspect

b) cross-sectional analysis

Fig. 14 Specimens from heat affected zone - renewal followed by post-welding heat treatment

Table 9.

Impact test values – for the PWTT case

Area	Basic metal			The area thermally influenced			Weld bead		
Specimen no.	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
b [mm]	10	10	10	10	10	10	10	10	10
a_c [mm]	8	8	8	8	8	8	8	8	8
S_o[mm2]	80	80	80	80	80	80	80	80	80
KV [J]	218	218	216	214	194	192	60	68	74
KCV [J/cm^2]	272,5	272,5	270	267,5	242,5	240	75	85	92,5
a_f[mm]	6,5	6,5	6,5	6,5	6,5	6	6	6,5	5,5
b_f [mm]	7,5	7	7	8	6,5	6,5	6	7	6
S_f mm^2]	48,75	45,5	45,5	52	42,25	39	36	45,5	33
S_d [mm^2]	31,25	34,5	34,5	28	37,75	41	44	34,5	47
b_1 [mm]	8	8	7,5	8,6	8,4	8,5	9,5	9,3	9
T [%]	20	20	25	14	16	15	5	7	10
C_r [%]	60,94	56,88	56,88	65,00	52,81	48,75	45,00	56,88	41,25
F_b [%]	39,06	43,13	43,13	35,00	47,19	51,25	55,00	43,13	58,75

In fig. 15 there are presented the variation of impact test values for the samples taken after applying all the 3 techniques of renewal, and in figs. 16, 17, 18 there are indicated the impact test variations for base material, Heat affected zone (HAZ), respectively, weld bead.

Analyzing the results from fig. 15, one can notice a normal distribution of the impact test values in all the samples taken.

Analyzing fig. 16, it can be notice that the impact test values in base material are in range (216-256) J. They are diminishing from HBT to renewal followed by heat treatment.

Fig. 17 shows that, in the zone heat affected zone, the lowest impact test values obtained were for the samples taken at the controlled deposition technique (62 J), and the highest (214 J), for the samples taken at the renewal followed by post welding heat treatment.

Figure 18 shows that for weld bead, the impact test values are the highest (94J) in the case of controlled deposition technique and the lowest values (60 J) in case of renewal followed by post welding heat treatment.

The impact test values obtained in the weld bead are almost similar with those indicated in the quality certificates of the filler material, so isn't the case to change the renewal technologies.

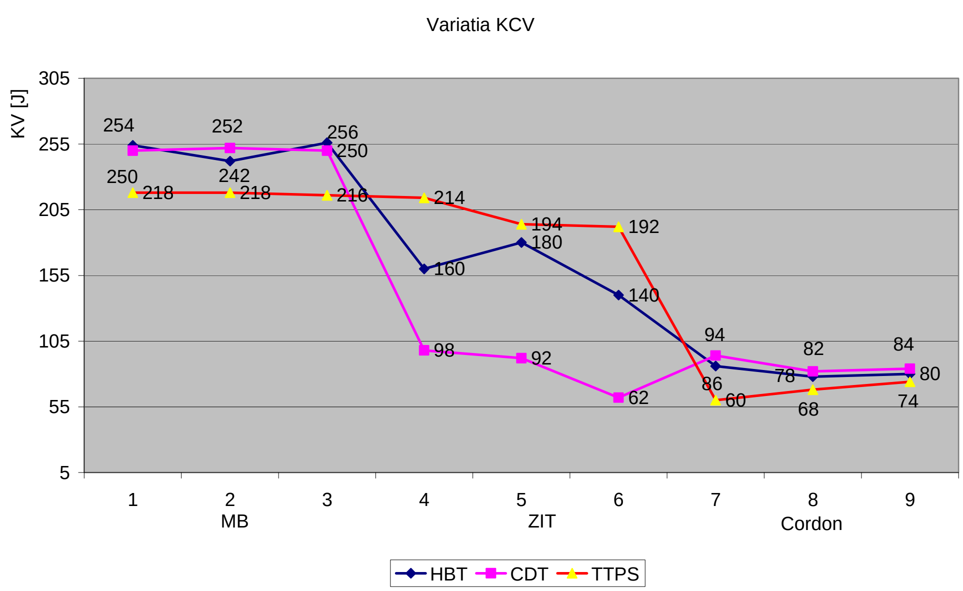


Fig. 15. The variation of the impact test values in the 3 different cases of renewal

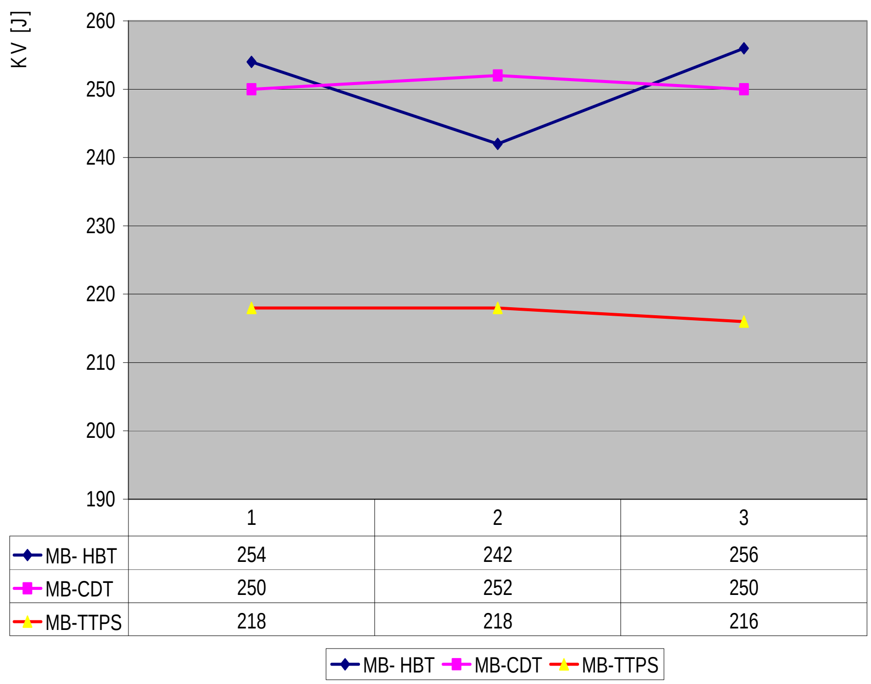


Fig. 16. The variation of the impact test values on the test specimens take from base material

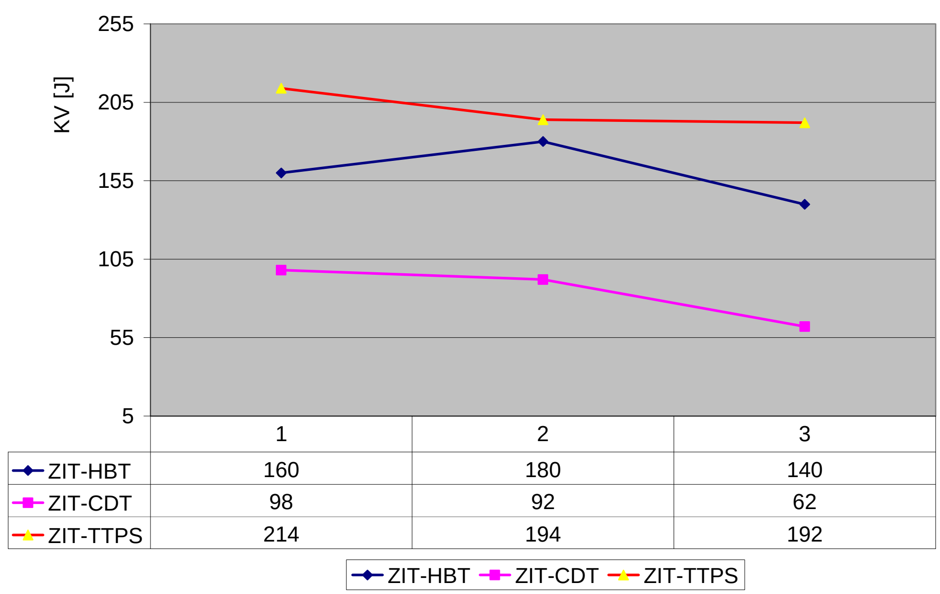


Fig. 17. The variation of the impact test values on the test specimens take from heat affected zone

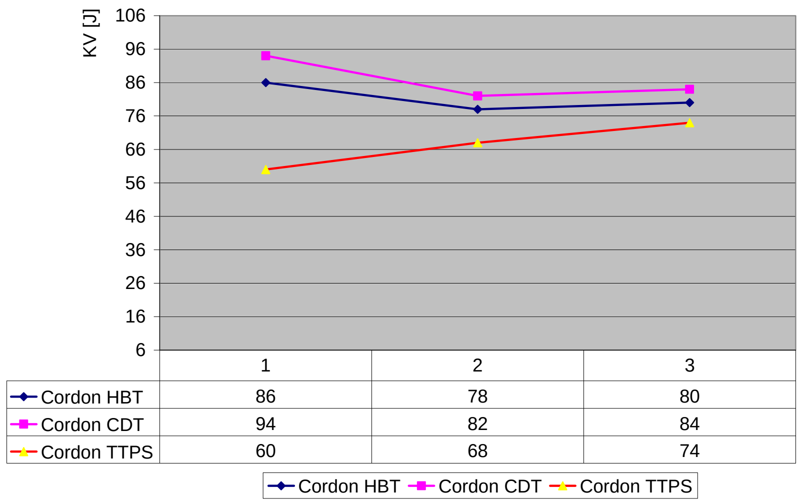


Fig. 18. The variation of the impact test values on the test specimens take from weld bead

4. Conclusions

The following conclusions can be drawn from the research and experiments:

- The most applied techniques of renewal by welding are those synthetically presented in Table 10.

It can be noticed that there are some difficulties in applying the techniques presented here, as follows for:

- Half Bead Technique: it is difficult to control the removal of half of the layer, also the depth measurement;
- Consistent Layer Technique: the temperature in the respective area must not exceed Ac_1; it is difficult to be measured;
- Alternate Temper Bead Technique: it is difficult to determine the welding parameters;
- Controlled Deposition Technique: it is difficult to increase the linear energy of the next layer with 1.2-1.8;
- Weld Toe Tempering Technique: it is difficult to deposit the additional layer right in the middle of the joint.

- the tensile test specimens having the highest tensile strength were those taken form the HBT, aprox. 572 N/mm^2.

- comparing the tensile strength values of the specimens obtained after applying the renewal by welding techniques with those indicated in the standards, one can notice that the obtained differences do not surpass normal limits even the high values can be noticed for the samples taken at the post welding heat treatment technique.

- the post welding heat treatment technique led to a decrease of the basic material resilience value until 38 J, in comparison with the material that was not heat treated.

- in the heat affected area, the lowest value of impact test (62J) was obtained on sample made with Controlled Deposition Technique. The higher value (214J) was obtained in sample made with renewal by welding followed by post welding heat treatment technique.

- in the weld bead, the higher value of impact test (94J) was obtained on sample made with Controlled Deposition Technique and the lowest value of 60J on sample made with renewal by welding followed by post welding heat treatment technique.

Table 10

Characterization of the techniques used for renewal by welding

Crt. No.	Renewal techniques	Way of achieving	Comments
1	Half Bead Technique;	Deposition followed by removal of half of the layer;	Difficult to control the removal of half of the layer; Use process SMAW.
2	Alternate Temper Bead Technique	Layers deposited with controlled linear energy.[9], [10]	Not requiring the removal of material. Use usually the TIG-automate process; Apply to steel type C or C-Mo-Mn.
3	Consistent Layer Technique	Layers deposited with controlled linear energy.[11],[12], [13]	Consists in the deposition of layers of size small enough for the layer deposited to subsequently perform a TT reversion. The process used is TIG or SMAW
4	Controlled Deposition Technique; Ontario Hydro, CEGB, University of Tennessee.	Layers deposited with controlled linear energy.[1], [2], [14]	Is obtained by increasing the diameter of the added material in order to enable the linear energy to increase 1.2 ... 1.8 times from one layer to another. Process used is SMAW.
5	Weld Toe Tempering Technique	Depositing an additional layer (of slaughter) on the last layer[3],[15], [16],	Difficult to determine the dimensions of additional layer and positioning it on the last layer. Difficulties in achieving the expected result.

The final conclusion is that in some situations, when higher values of the mechanical resistance or joint resilience are desired, according to the experimental results obtained for the analyzed case, applying this technique of renewal will lead to avoiding the post welding heat treatment.

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