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EVALUATION OF TECHNICAL CONDITION AND REPAIR OF CASING OF CATALYTIC CRACKING REGENERATOR R-202

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The main features of the performed technical diagnostics of damaged petrochemical equipment are considered for evaluation of its reparability. It is noted that in order to detect defects, the nature of their development, and the subsequent possibility of performing repair and restoration works, an individual approach to selection of control means and methods is required in most cases. The work gives an example of development and implementation of repair and welding technologies for restoration of integrity and service characteristics of vessel bodies taking into account the results of technical diagnostics and investigation of mechanical properties. 7 Ref., 3 Tables, 7 Figures.

Keywords: *repair of regenerator casing, visual and ultrasonic testing, welded joints, cracks, repair-welding technology*

Evaluation of reparability of damaged petrochemical equipment is a rather complicated problem, as it requires not only a thorough assessment of the technical condition of structures, but also of metal properties after long-term service under the conditions of exposure to aggressive process and concomitant media, as well as broadly varied technological parameters.

Regenerator operation conditions

Working pressure, MPa:	
above, not more than	0.14
below, not more than	0.17
calculated	0.35
Working temperature, °C:	
medium, not more than	700
wall	150
calculated	300
Working medium	flue gases, air, steam, microspherical zeolyte-containing catalyst

As the nature of defects emergence, their type and nature of their development differ by their variety, an individual approach should be applied for their detection and assessment in each concrete case. This requires:

- clarification of the cause of defect emergence, their type and nature of their development;
- assessment of the level of equipment damage and detection of the main damage sites;
- determination of the properties of base metal and welded joints of equipment in the sites and beyond the affected zones.

Analysis of the results of the above studies can provide a reply to the question of repairability of this structure, and in case of a positive reply, a technical decision on its restoration can be taken, and then development of the technology of damaged equipment repair can be started. Such an approach will allow avoiding errors in development of the repair technology that may lead to deterioration of technical condition of metal structures, and can make them nonrepairable in some cases.

In this work, the approach to solution of this problem proposed by PWI specialists is shown in the case of preparation for repair-restoration operations for the damaged casing of catalytic cracking regenerator R-202 in PJSC «LINIK» plant (Lisichansk).

The need to perform this work was caused by the fact that through-thickness cracks were revealed in the regenerator casing during routine checkup of its technical condition. The cracks formed exclusively in welded joints and zones adjacent to them. In this connection, engineering services of PJSC «LINIK» Company contacted PWI with a request to look into this problem and provide scientific-technical assistance in restoration of serviceability of the damage apparatus for the period of not less than four years.

At the first stage of the work, the problem associated with determination of technical feasibility of repair-restoration operations was addressed. For this purpose PWI specialists analyzed technical documentation and results of previous diagnostic examinations, performed visual inspection of the affected areas of the regenerator, clarified the reasons, determined the time period of defect initiation and propagation in the form of cracks [1].

Analysis of technical documentation and results of diagnostic examination. When studying the technical documentation, a lot of attention was giv-

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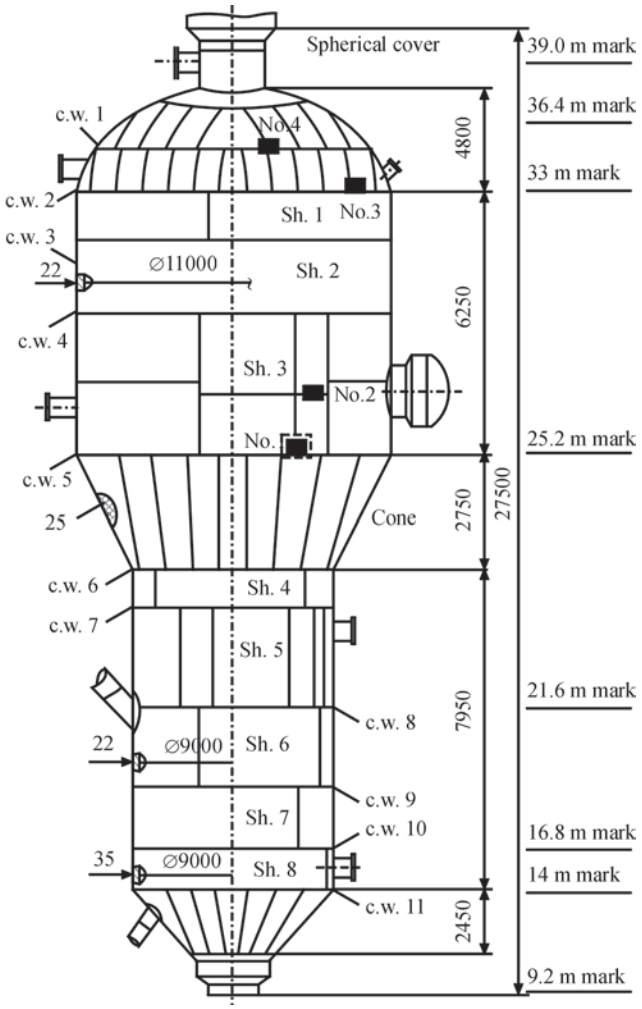

Figure 1. Design of the casing of R-202 regenerator with indication of areas (■) of cutting out control samples (characteristic locations where cracks formed)

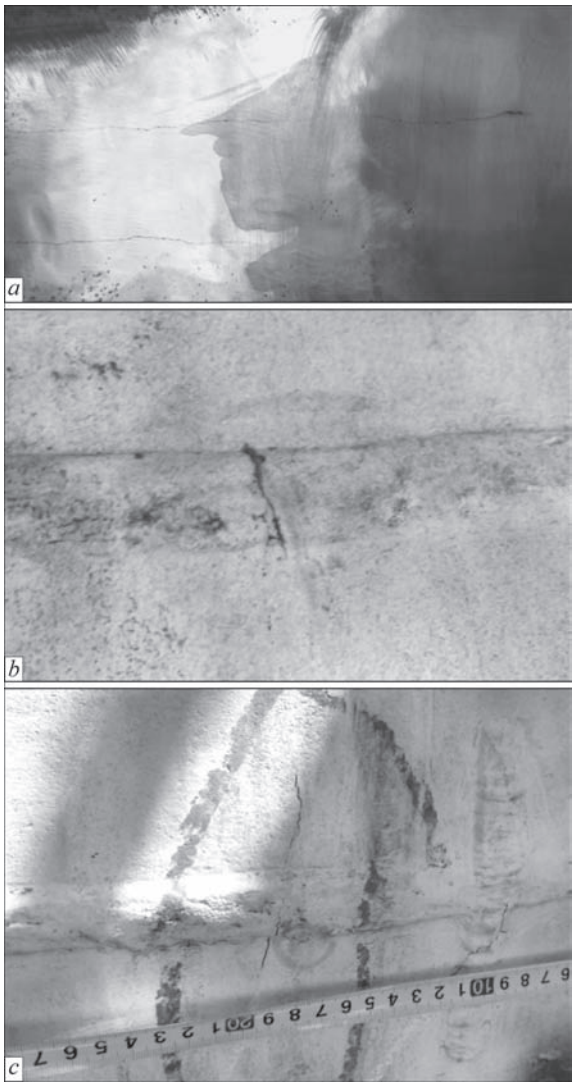

Figure 2. Examples of typical crack formation in welded joints made in shop conditions at enlarging the rings of a shell of 11 thou mm diameter (*a*); in circumferential welds of assembly joints in regenerator upper part (*b*) and in areas of repair welding up (*c*)

en to features of mounting assembly and information on routine repairs of the structure. It was found that mounting assembly of the regenerator was performed using enlarged elements, which were manufactured in one of the Russian enterprises. Expansion rolling of the rings and their assembly with application of welding were performed without subsequent heat treatment, either in the manufacturing plant, or in site. The regenerator was commissioned in 1993.

Surveys of service personnel participating in regenerator assembly in the period of its mounting, revealed certain difficulties during abutment of enlarged elements, leading to the need for their pretension before welding. The largest misfits during assembly of enlarged elements were observed in the regenerator upper part, where the casing diameter was equal to 11 thou mm in the points of its geometric transitions (Figure 1). Considering this fact, as well as casing element thickness being 20–22 mm in these areas, it is obvious that pretension, as well as generation of welding strains in the joints induced considerable residual stresses. This accounts for the fact that the largest number of cracks formed in exactly these locations.

Analysis of the results of diagnostic examination of the regenerator casing, performed from 2002 till 2010 with the frequency of once per two years, showed that before 2010, no defects preventing further operation of the regenerator, were revealed in the casing. Massive cracking in the regenerator casing (in the points of welding-in nozzles into the apparatus casing, in circumferential welded joints of 11 thou mm diameter shell and upper cover) started presumably in 2008–2010. This was indicated by the results of monitoring the regenerator technical condition, performed in 2010.

An attempt to perform repair of cracked areas of regenerator casing by the staff and with the technology, developed by the repair service of the company, operating this facility, did not allow solving this problem. After completion of the repair, monitoring the

condition of the regenerator casing showed that new cracks started initiating and old cracks, covered by patches, began propagating in the locations of welding-on the patches and in welded up defective areas. By 2013 the number and size of the cracks reached a critical value that cast a doubt on the possibility of further safe operation of the apparatus. In this connection, in 2013 PWI experts performed detailed visual inspection and ultrasonic testing of welded joints of regenerator casing. Its results showed the following.

Visual inspection of regenerator casing. Visual inspection of welded joints was conducted, when a considerable part of defects had already been overlaid by patches, that somewhat complicated selection of locations with the most characteristic types of welded joint damage. On the other hand, even in this case, additional cracklike defects were found in plant welded joints made at enlarging of the rings before their expansion rolling (Figure 2, *a*).

Absolute majority of the detected defects were located in assembly circumferential joints and on their intersections in the regenerator upper part. The only exceptions were defects in the areas of repair welds or patches, which propagated beyond the heat-affected zone (HAZ) (Figure 2, *b*, *c*).

Detected defects had one characteristic feature, associated with initiation and further propagation of cracks only in the areas of higher residual stresses, formed as a result of site and repair welding. This feature of defect development allowed a certain narrowing of the scope of inspection of the structure surface, and focusing on welded joints in the regenerator upper part, where higher residual stresses are present after welding and straightening of the abutted elements.

Determination of boundaries of damaged areas in welded joint near-weld zones prone to cracking with application of ultrasonic testing. In order to detect and assess the discontinuities, ultrasonic testing of welded joints was performed and the following approaches were used:

- pulse-echo method for relatively fast detection of cracks and their approximate localization [2–4];
- time-of-flight diffraction method (TOFD) for quantitative evaluation of crack height [5–7].

Ultrasonic testing performed with application of standard pulse-echo method revealed that there is no delamination in base metal of regenerator casing.

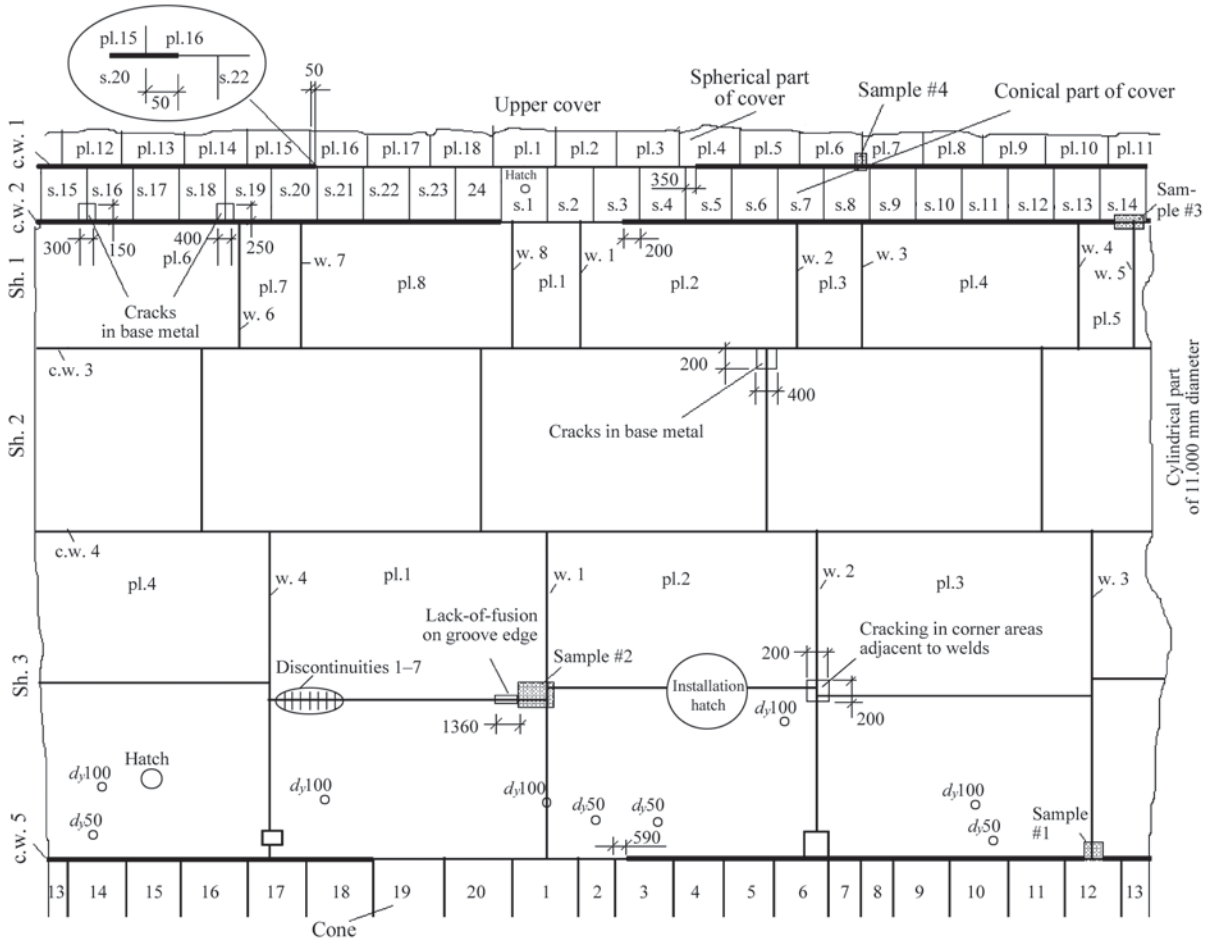

Figure 3. Fragment of regenerator casing with indication of locations of concentration of cracklike discontinuities: circumferential weld areas marked by bold lines have discontinuity density of 30–50 discontinuities per one meter

Table 1. Chemical composition of metal samples Nos 1–4

Sample number	C	Si	S	P	Mn	Cu	Cr	Ni
1	0.058	0.573	0.020	0.021	1.50	0.188	0.090	0.112
2	0.072	0.573	0.023	0.024	1.60	0.197	0.094	0.117
3	0.052	0.548	0.023	0.021	1.47	0.179	0.095	0.109
4	0.074	0.629	0.032	0.027	1.44	0.099	0.099	0.094
GOST 19281–89	≤ 0.12	0.5–0.8	≤ 0.035	≤ 0.030	1.3–1.7	≤ 0.30	≤ 0.30	≤ 0.30

Table 2. Mechanical characteristics of metal samples Nos 1–4

Sample number	σ_y, MPa	σ_t, MPa	δ_5,%	ψ, %
1	359–363	494–495	33.4–35.2	68.3–70.7
2	426–426	564–564	29.6–31.2	68.4–68.5
3	444–464	582–594	28.6–31.6	67.0–68.5
4	408–409	526–529	30.9–34.2	58.9–61.2
Initial state	387–398	540–578	30.0–33.5	55.7–55.3
GOST 19281–89	345	480	21	–

On the other hand, systemic cracklike discontinuities were detected in welded joints with circumferential welds c.w.1, c.w.2, c.w.5 (Figure 3). Density of cracks in some areas of welds was more than 20–30 discontinuities per one meter. Cracklike discontinuities were also found in the other areas of the above-mentioned joints, but not with such a high density. The largest dimensions of cracklike discontinuities were assessed by the value of 100–120 mm from the circumferential weld towards the base metal. Circumferential weld c.w.5 has predominant cracking towards shell Sh.3 for not more than 100 mm distance in the weld, and not more than 50 mm in the base metal. Crack propagation towards the conic part is insignificant and equal to about 20–35 mm.

In welded joints c.w.3, c.w.4, where numerous cracklike discontinuities were also detected, the dimensions and nature of crack propagation were somewhat different. In such joints discontinuities develop from inside the casing, and the length of the largest discontinuities is equal to about 50–60 mm to each side of the weld.

In the regenerator lower cylindrical part, c.w.6–c.w.11, no cracklike discontinuities were detected.

The following stage of work performance involved assessment of the actual state of metal (structure, mechanical properties) in welded joints after long, more than 131 thou h., operating time in service. For this purpose metal samples were taken from regenerator casing in those locations, where cracking is most often found (see Figure 1). These were further on used to prepare samples for metallographic examinations and mechanical testing (static rupture and impact bending test). Results of testing metal samples showed the following:

- it was confirmed that regenerator metal structures are made from 09G2S steel (Table 1);
- during operation no noticeable changes occurred in the metal structure at more than 150 mm distance from the present welds;
- metal preserved its static strength, ductility and impact toughness on the level of requirements made to steel 09G2S (Tables 2, 3);
- during operation micro- and macrocracks formed in the weld metal and in the base metal located at up to 150 mm distance from weld axis, on the inner and outer surfaces of the welded joints (Figure 4);
- intergranular nature of crack propagation (Figure 5) is indicative of the fact that these are stress corrosion cracks;
- at 150 mm and greater distance from the weld metal 09G2S steel preserved good ability to resist cold cracking.

These studies led to the conclusion that regenerator casing metal in the zones, where damaged welded joints are located, has accumulated local damage during operation. The width of these zones does not exceed 150 mm from weld axis. Thus, it becomes ob-

Table 3. Impact toughness of metal samples Nos 1–4

Sample number	*KCU*, J/cm^2 at temperature, ^{o}C		
	20	–20	–40
1	255–333	188–304	234–346
2	160–176	116–120	83–111
3	150–156	92–110	84–89
4	90–93	78–84	55–61
Initial state	191–196	120–136	63–105
GOST 19281–89	59	–	34

vious that the technical decision to repair the regenerator casing should envisage mandatory removal of metal located at not less than 150 mm distance from weld axis. In view of that, repair of circumferential welds with massive cracking was performed by the method of step-by-step cutting out and replacement of defective areas of the casing by plate inserts. This technology was used to perform repair of welded joints c.w.5, c.w.2 and c.w.1 in regenerator casing areas marked in Figure 6.

In areas with isolated short cracks, they were removed by grinding with subsequent welding up of the formed groove.

At step-by-step method of defective area replacement, plates of 09G2S steel, pre-expanded to fit the shell radius, were placed and welded in the openings cut out and prepared by mechanical methods. Considering that the defective shells had considerable damage on a length equal to not less that 3/4 of their total length, they were divided into an equal number of areas.

The length of the cut-out areas was commensurate with the length of plates, making up the shell, and it was corrected proceeding from the requirements, that the locations of vertical welds in the points of joining of the inserts, should be shifted to 150–200 mm distance relative to plant welds present on the shell. Numbers of areas, into which the repaired shells were divided, was précised proceeding from the results of their control from the inside of the regenerator. The width of plate inserts was 300 mm. The sequence of welding-in the plate inserts into the regenerator casing is shown in Figure 7.

The work started as follows: after removal of the lining, the inner and outer surfaces of the casing, where metal was replaced, was cleaned from contamination, then scraped on not less than 50 mm width to each side from the boundaries of the anticipated opening to conduct nondestructive testing. Scraping was performed to metallic luster by mechanical method using sanding machines fitted with abrasive wheels and disc wire brushes.

Nondestructive testing to determine the boundaries of cracked area was performed using visual-optical, penetrant and ultrasonic techniques.

Results of nondestructive testing were used for marking the repaired area of regenerator casing for cutting out.

Cutting out of the area damaged by cracks was conducted by air-plasma cutting. As the work was performed in winter time, before cutting out the defective area, it was preheated by gas torches up to the temperature of 50–70 °C.

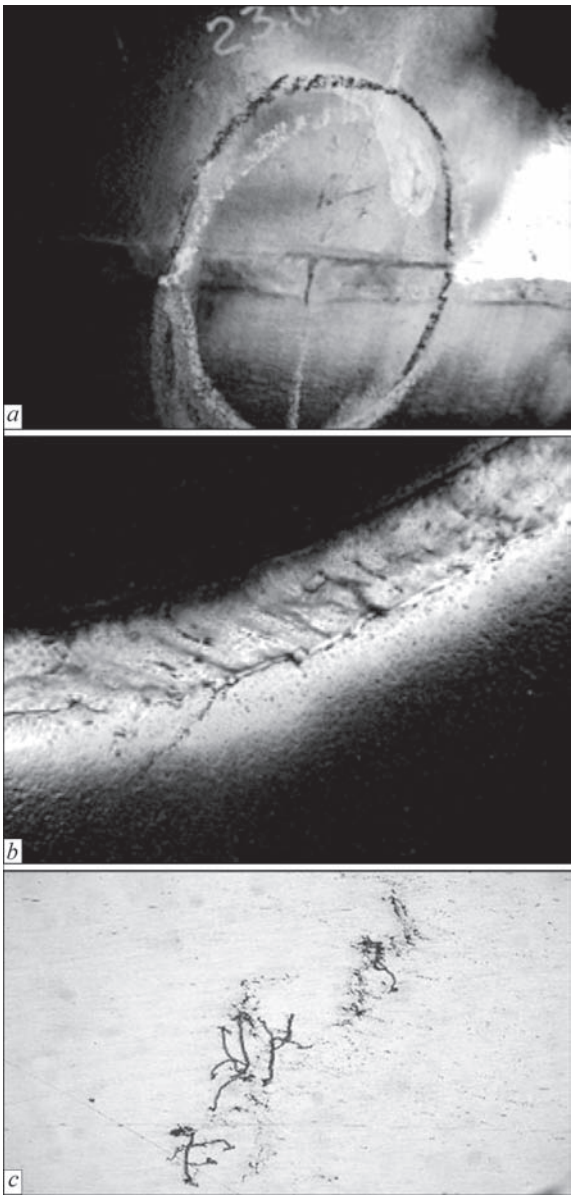

Figure 4. Macro- (*a*, *b*) and microcracks (*c*) formed on inner (*a*) and outer (*b*) surfaces of welded joints

Technological openings were cut out in such a way that their length was by 300 mm, and width — by 6–10 mm greater than the dimensions of plates to be welded in.

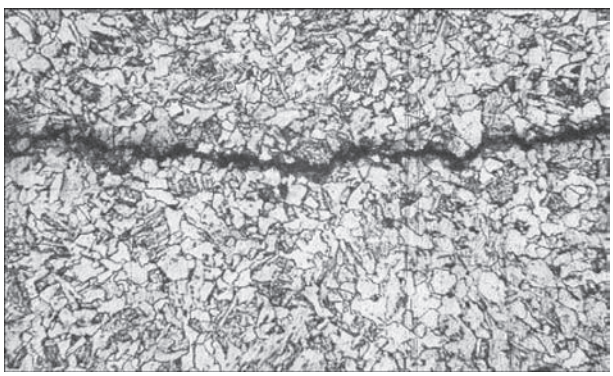

Figure 5. Microstructure (×320) of metal of sample No.1 in the crack formation zone

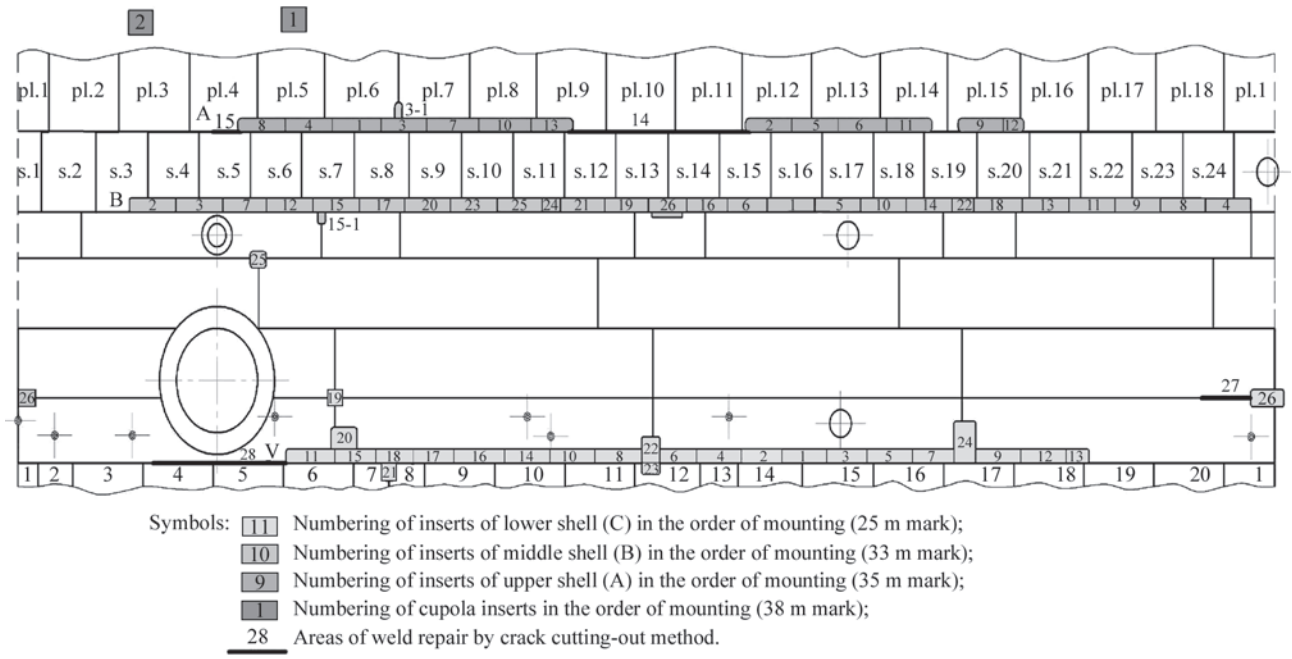

Figure 6. Schematic of placing the inserts

After cutting out the technological opening, mechanical method was used to scrape the cut surface to the depth of 0.5–1.0 mm, and then the completeness of defect removal was controlled visually and by dye penetrant technique.

If remaining cracks were revealed during inspection, they were mechanically cut out and nondestructive testing was repeated. After complete removal of the defects, the formed grooves were welded up, using the following procedures.

Before welding, each of the areas where remaining cracks were cut out, was heated to the temperature of 120–150 °C. The welding process proper was conducted by manual arc method with 3.2 mm electrodes of LB-52U grade, when making the weld root layer, and with 4.0 mm electrodes of OK 48.00 grade, when making the filling and face layers of the weld. Reverse polarity direct current (RPDC) welding was performed in the following modes: I_w = 90–120 A; U_a = 24–28 V in welding with 3.2 mm electrodes and I_w = 140–170 A; U_a = 24–28 V — with 4.0 mm electrodes.

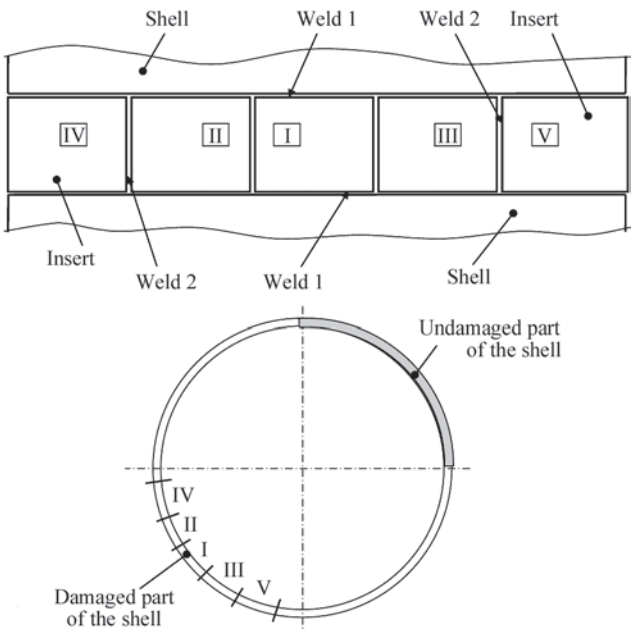

Figure 7. Sequence of welding-in the inserts at repair of regenerator R-202

After restoration of the integrity of technological opening edges, air-plasma cutting was used to make a groove on them for welding the plate inserts to the regenerator casing. Then the edges were mechanically scraped to the depth of 0.5–1.0 from the edge surface. The surface of the elements to be welded was also scraped to metallic luster both from the casing outside and inside. Scraping was performed with a sanding machine to not less than 20 mm distance from each edge. At the final stage of preparation of regenerator casing and plate inserts for assembly and welding the groove geometry and quality of edge preparation were checked. The design elements of welded joints connecting the plate insert to regenerator casing and of the two adjacent plate inserts corresponded to joints C12 and C21, specified in GOST 14771–76.

During assembly, the plate inserts were mounted in the openings prepared for welding in the regenerator casing and tack-welded. Prior to tack welding and during welding the joints were heated up to the temperature of 120–150 °C. Such a preheating temperature was accepted proceeding from the fact that welding was performed in winter time, when air temperature dropped below –20 °C.

Welding was performed without interruption. Interpass temperature was regularly monitored and maintained within 100–180 °C during filling of the groove. In the case of forced interruptions, welded joint temperature was kept at the level of 100 °C.

The welding process was conducted in the following sequence.

First stick electrodes were used to perform from inside of the regenerator manual arc welding of root layers of the weld in the upper and lower horizontal butt joints. The ends of plate insert 150–200 mm long were left unwelded. Welding was conducted from the insert middle to its ends by back-step method in 100-150 mm sections, shifting the start and end of the second pass steps by 25–40 mm relative to the first pass. Weld root was made by «double-layer» method.

After making complete inside horizontal welds, the roots of horizontal welds were treated with a sanding machine from the outside to clean sound metal. Then welding of horizontal welds from the outside of regenerator casing was performed. The sequence of making the weld outside part was the same, as when welding it from the inside of the regenerator casing.

The root beads were made with 3.2 mm LB-52U electrodes. Welding was performed in the following mode: I_w = 100–130 A, v_w = 6–7 m/h. The second and subsequent layers of outer weld were performed by mechanized welding in a gas mixture of 80 % Ar + 20 % CO_2 with 1.2 mm wire of OK Aristorod 12.50 grade in the following mode: I_w = 160–190 A, U_a = = 24–28 V, v_w = 10–14 m/h. In areas difficult-of-access for mechanized welding, the groove was filled by manual arc welding with 4.0 mm stick electrodes OK 53.70 (48.00) in the following mode: I_w = 150–160 A, v_w = 7–9 m/h.

After completion of welding of the upper and lower horizontal welds, the welded joints were heated up to the temperature of 200–220 °C (temperature of low-temperature tempering), soaked at this temperature for 1 h, then covered by a heat-insulating belt, under which they were kept up to complete cooling.

Then air-plasma cutting was used to cut out the defective part of regenerator casing to the left and right from insert 1 to place plate inserts (coupons) II and III. Edge grooving and their scraping to metallic luster were performed from outside and inside to not less than 20 mm distance from each edge. Inserts II and III were placed into design position and fastened by welding assembly tacks. From the inside horizontal welds were made, leaving 200–300 mm unwelded sections at the edges of abutment of plates II and III to plates I, IV and V.

After welding inserts I, II and III into regenerator casing, welding of vertical welds, joining inserts I and II, I and III to each other, was started. Welding of vertical welds began to be performed, mainly, from the inside of regenerator casing. In some cases, the sequence of welding the vertical weld was purposefully used to adjust the position of plate insert relative to regenerator casing. These were exactly the considerations, proceeding from which the welding sequence was changed, when it became necessary to «draw-in» the ends of plate insert inside the regenerator casing, and the vertical weld began to be made from outside of the casing.

The root and near-root layers of vertical welds (from the first to the third one), were made with 3.2 mm electrodes of LB-52U grade in the following mode: I_w = 90–120 A, U_a = 22–24 V, v_w = 6–7 m/h. After deposition of these weld layers, scraping of weld root layer to clean (defectfree) metal was performed by mechanical method from the weld face side. Filling of the groove was started after visual inspection of the condition of the scraped weld surface. The groove was filled by a combined method: fourth, fifth, and sixth layers were made by manual arc welding with 4.0 mm electrodes of OK 53.70 (48.00) grade; welding of subsequent layers of the weld was performed by mechanized process in shielding gas mixture with 1.2 mm solid wire of OK Aristorod 12.50 grade. The following modes were used: I_w = 150–160 A, U_a = = 24–26 V, v_w = 7–9 m/h — for manual arc welding; I_w = 140–150 A, U_a = 23–24 V, v_w = 7–9 m/h – for mechanized welding in a gas mixture.

After making the vertical weld, «closing» of the horizontal welds (in the unwelded sections) was performed, i.e. in that part, which was left unwelded before making the vertical welds. The procedure of making the horizontal welds in the «closing» locations was conducted with the same welding materials in the same sequence and modes as the main horizontal welds, which joined the plate inserts and regenerator casing to each other.

After welding the vertical welds and «closing» sections, the area of regenerator casing, where this work was performed, was heated up to the temperature of 200–220 °C, and kept at this temperature for 1 h with subsequent covering with heat-insulating belt up to complete cooling. After complete cooling of welded joints, their surface was prepared by mechanical method for nondestructive testing performance. Welded joint quality was controlled by visual-optical and ultrasonic techniques.

The above operations, methods and sequence of their performance were realized in repair of the other areas of regenerator casing, requiring replacement of damaged metal. Alongside application of this method, replacement of the following shell assembly welds

was performed c.w5 of 23 m length (18 plate inserts were welded in,), c.w. 2 of 30 m length (24 plate inserts were welded-in) and c.w. 1 of 16 m length (13 plate inserts were welded-in).

Performance of repair operations was followed by pneumatic tightness testing of the regenerator casing. During such testing no leaks or visible deformations were observed in the zone of structural element repair. This is an indication of the high quality and reliability of repair welded joints.

Conclusions

1. To detect and assess the discontinuities in welded joints of casings of petroleum-processing equipment it is rational to apply UT, using pulse-echo method for relatively rapid detection of cracks and their approximate localizing, as well as TOFD method for quantitative assessment of crack height.

2. Program of performance of diagnostic examination, which, by NDT requirements is developed before the start of operations, should allow correction, depending on current examination results.

3. Before taking the technical decision on repair of petroleum-processing equipment, metallographic studies of welded joint metal and adjacent base metal areas should be performed that will allow assessment of the level of their damage, as well as establishing the nature and scope of damage beyond the weld zone.

4. At reconditioning equipment, with damage not only of welded joints, but also of adjacent zones of base metal, it is recommended to perform repair with complete replacement of damaged areas.

5. A necessary condition for further reliable operation is application of welding technologies, providing minimizing of residual stresses in welded joints and the structure as a whole that is achieved by step-by-step cutting out of damaged fragments of the casing and welding-in plate inserts with a certain sequence of making the welds.

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