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REPAIR OF 20CRMNSIVAL STEEL PUMPING UNITS WITH THE USE OF WELDING TECHNOLOGIES

РЕМОНТ КОРПУСОВ НАСОСНЫХ АГРЕГАТОВ ИЗ СТАЛИ 20ХГСФЛ С ПРИМЕНЕНИЕМ СВАРОЧНЫХ ТЕХНОЛОГИЙ

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Abstract. 20CrMnSiVaL low-alloy cast steel is widely used for tanks, machines and devices (pumps, compressors, hydraulic boxes and other) in the oil and gas industry. A large amount of such equipment operates under conditions of high pressure, corrosive effect of the working environment, a large temperature difference, mechanical loading due to moving parts.

During its operation the elements of oil and gas are eroded due to temperature and power loads, corrosion, and other factors. Most constructive elements of gas and oil equipment are repaired by welding. A highly concentrated heat source and deformation capacity are the cause of residual stresses. They affect the performance and accuracy of manufacturing elements.

One of the main problems concerning the improvement of the quality of machines is the enhancement of housing repair technology. The housings are made of cast steel using electric arc welding.

In this work we employed the finite element method in the program ANSYS. We performed an analysis of stress-strain state in the model of the welded joint

simulating the machine body. We considered and implemented the technology of repair by welding and different types of treatment. We conducted a comparative study of mechanical properties. In this paper we also present the results of residual welding estimation in samples welded using various technologies.

We compared traditional technologies of heat treatment and deformation processing – ultrasonic and vibration treatment.

Аннотация. Для изготовления корпусов машин и агрегатов (насосов, компрессоров, гидравлических коробок и т.д.), используемых в нефтегазовой отрасли, широко применяется низколегированная литейная сталь феррито-перлитного класса марки 20ХГСФЛ. Значительное количество такого оборудования работает под одновременным воздействием высоких давлений, коррозионного и эрозионного воздействия от рабочих сред, значительного перепада температур, механических нагрузок от движущихся частей.

При эксплуатации нефтегазопромыслового оборудования с течением времени часто происходит разрушение элементов корпуса вследствие воздействия температурных и силовых нагрузок, коррозии и других факторов. Большинство конструктивных элементов корпусов нефтегазопромыслового оборудованияремонтируются с применением сварочных операций. Высококонцентрированный источник тепловой энергии и различная деформационная способность деталей являются причиной возникновения значительных остаточных напряжений, которые влияют на точность изготовления и работоспособность элементов.

Одной из острых задач, касающихся повышения качества машин и агрегатов, является совершенствование технологии ремонта корпусов, изготовленных из литейных сталей с применением электродуговой сварки.

В данной работе с применением метода конечного элемента в программном комплексе ANSYS был произведен анализ напряженно-деформированного состояния в модели сварного соединения, имитирую-

щего корпус машины, рассмотрены и реализованы технологии проведения ремонта с применением сварки и различных видов обработки, выполнены сравнительные исследования механических свойств. Также в работе приводятся результаты расчета уровня остаточных сварочных напряжений в образцах, сваренных по различным технологиям.

Для сравнения рассмотрены как традиционные технологии термической обработки, так и деформационные способы – ультразвуковая и вибрационная обработка.

Key words: machine surface repair, welding steel foundries, evaluation of the stress-strain state, welding stresses, mechanical properties, weld, ultrasonic treatment, vibration treatment.

Ключевые слова: ремонт корпусов машин, сварка литейных сталей, оценка напряженно-деформированного состояния, сварочные напряжения, механические свойства, сварное соединение, ультразвуковая обработка, вибрационная обработка.

Nowadays one of the essential problems in the development of petroleum engineering is the improvement of machine and device efficiency. The problems of the saving of material, energy and labour resources are also important.

One of the key tasks concerning the enhancement of the quality of machine and device repair is the improvement of repair technology with the use of manual arc welding. At the moment arc welding is the only welding process that is highly applied in the repair of oil and gas equipment.

Temperature and deformation processes and phase transformations are the cause of significant residual stresses. These stresses lead to distortion of welded constructions, loss of strength, and reduction of the corrosion resistance of the metal. This adversely affects the operation of equipment.

Currently, in order to repair machine bodies the traditional repair technology is applied with the use of manual arc welding by electrodes of brands UONI

13/55, UONI 13/65, type 50A, E60 with concomitant heating of the defective part.

In practice, this technology has low performance of repair and the complexity of the heat treatment process. This technology often gives rise to cracks in the weld and the heat-affected zone (HAZ). After repair welding joints rather quickly go out of service. During the first months after repair cracks appear in the zone of fusion with the base metal (Figure 1).

Figure 1. Crack in the weld zone of the welded joint

The average lifetime of weld metal of valve seat metal is 300 - 400 hours. As a rule, after welding repair pumping equipment does not meet the technical specifications.

We analyzed equipment before and after repair and assumed that the cause of the destruction of welded constructions of 20CrMnSiVaL steel is the high level of residual stresses, phase transformations and low efficiency technology stress relief. The application of preheating before welding contributes to the hot spot area spreading in the weld zone and, thus, development of brittleness. All this causes a brittle fracture of metal at the HAZ (Figure 1).

To determine the residual welding stresses and strains in the butt joint of 20CrMnSiVaL steel we used the finite element method.

The numerical analysis model was adopted from real constructions. The sample form of defects was chosen in accordance with instructions for repairing buildings machines (Figure 2).

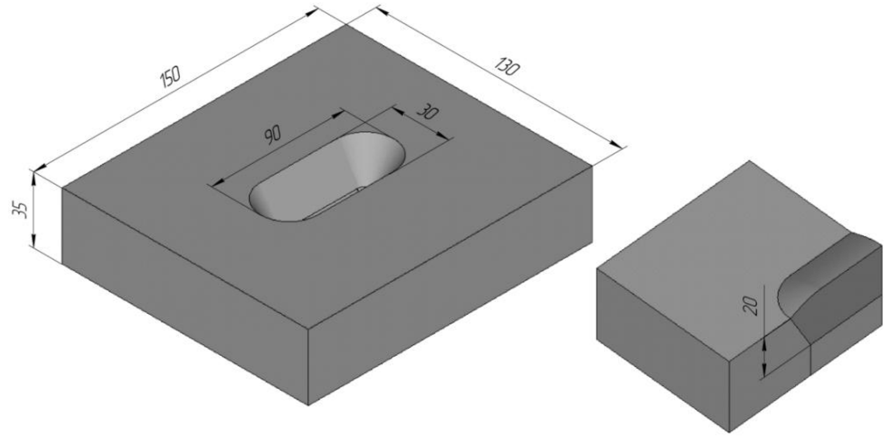

Figure 2. Dimensional model of the sample

First, we performed thermal analysis. Then we conducted a structural behavior analysis of the sample during the cooling of welded joint at the weld completion temperature. The element of the numerical studies model matched 20CrMnSiVaL steel. The model has the following dimensions: width – 130 mm, length – 150 mm, depth – 35 mm. We took the weld properties identical to those of the base metal.

At the stage of thermal analysis we simulated the cooling of welded joint and determined changes in temperature by the volume of the sample. We used the linear isoparametric eight-node finite element while constructing the finite element mesh of the geometrical model (Figure 3).

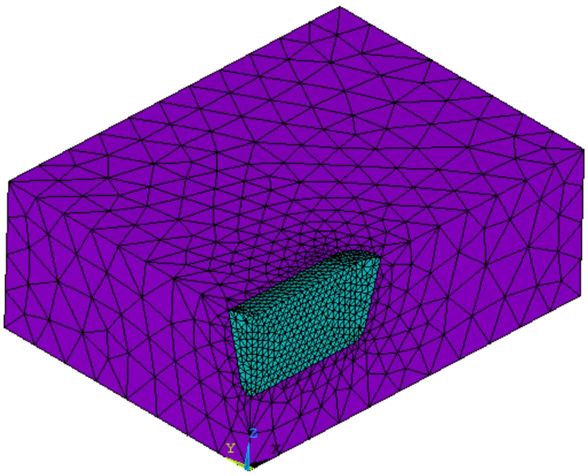

Figure 3. Finite element model of quarter of welded sample

When simulating the cooling of the weld, we assumed that the heat transfer to environment is realized through convective heat transfer between the surface of the seam and the sample with the air.

The initial temperature of the weld was set 1600°C, the ambient temperature was 20 °C.

As a result of the thermal analysis, we obtained the temperature distribution over the entire model and changes in temperature fields during the cooling of the weld.

Due to the large thickness of metal, in the HAZ a bulk metal layer is formed, which is prone to grain growth due to overheating at a temperature higher than 900 °C.

The changes in temperature fields, which we got as a result of thermal analysis, were applied to the model in the form of load. The calculations found that the distribution of equivalent stresses in the simulation of welding of crack in a sample of 20CrMnSiVaL steel (Figure 4).

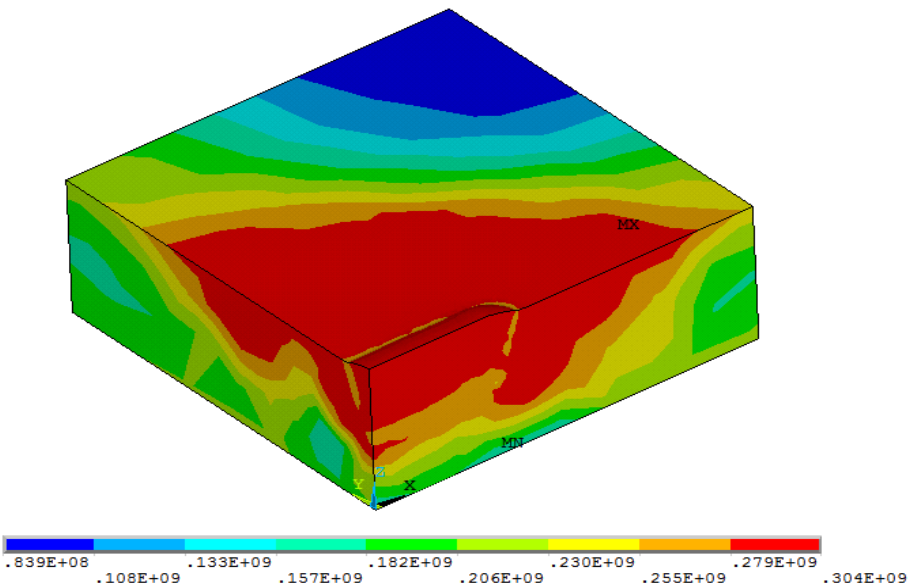

Figure 4. Distribution of the equivalent stress, MPa

In Figure 5 operating stresses graphics are presented which occur in the weld cross section and on the metal surface.

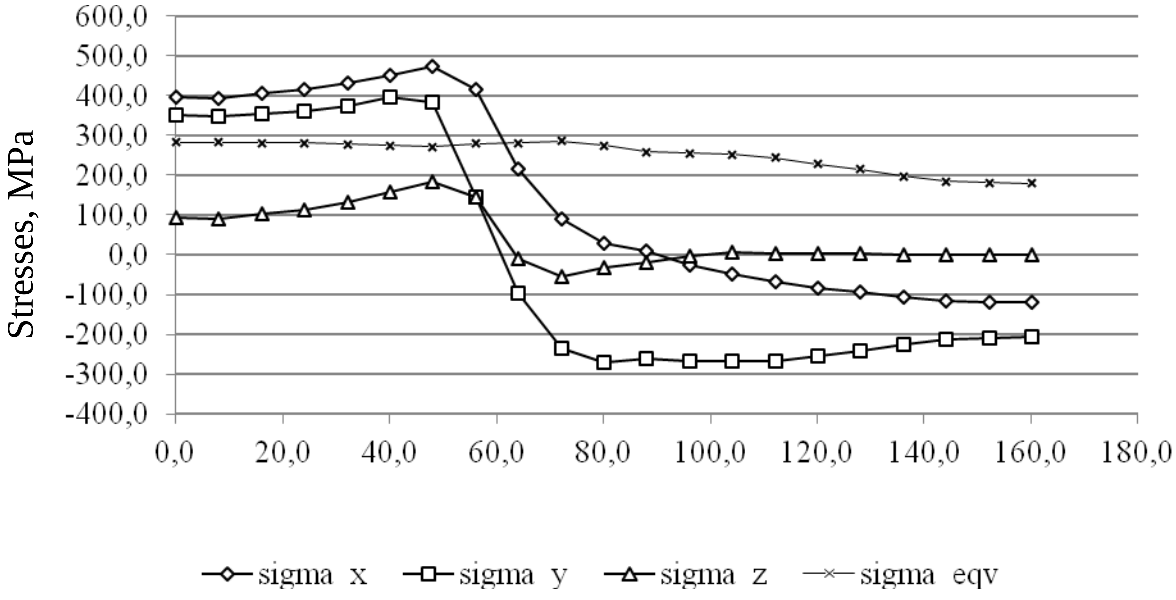

Figure 5. Stresses in the cross-section of the metal surface

This study showed that the greatest concentration of stresses and strains arise in the area of the weld and fusion zone. Considering the property changes of the metal in the heat affected zone, residual welding stresses can lead to distortion of the structure in case of its insufficient rigidity and causes premature failure during its operation.

To solve this problem, we considered various processing technologies through the example of 20CrMnSiVaL steel. The welding was performed using electrodes UONI 13/55 with the following processing:

1) welding without processing;
2) with 250 °C preheating;
3) with ultrasonic treatment during and after welding 25…27 kHz;
4) with concomitant cooling;
5) with vibration treatment 50 kHz.

Manual arc welding was performed by 3 mm diameter electrodes. The welding current was equal to 72-90 A. The studies were conducted on plates cut from the pump housing. The pump casing was made of 20CrMnSiVaL steel. The plate has the following measurements: length - 110 mm, width - 65 mm, thickness 4.4 mm.

We used the forenamed technologies due to the following reasons:

- Preheating reduces welding stresses and improves the structure and properties of metals (this technology is generally used) [1];

- Cooling during welding grinds grain, increases the strength properties and impact toughness in the heat affected zone. Cooling during welding reduces the heat affected zone [2];

- Welding with concomitant vibration treatment reduces welding stresses in the weld metal and the HAZ. It reduces the heterogeneity of the weld metal structure and the heat affected zone. Vibration treatment improves the mechanical properties of the weld metal and improves the welded joint endurance. It increases the corrosion resistance of the weld metal [3-8];

- Ultrasonic processing has a complex effect on the weld. It reduces the stress concentration in the weld joint and creates a layer with increased resistance to cracking and other on the treated surface [9].

After welding we carried out researches on the influence of preheating, concomitant cooling, vibration and ultrasonic treatment on mechanical properties of the weld metal in accordance with GOST 6996.We conducted an X-ray structure analysis of the samples to determine the residual stress in the weld.

We conducted tensile tests using the machine IR 5113-100.The samples were prepared in accordance with GOST 6996, 3 samples were made for each processing. We determined the mechanical characteristics of the weld zone. For this purpose, we performed a cervical in the samples so that the metal would be destroyed precisely in the weld zone. Deformation rate was 1 mm / min. Test temperature was 20°C.The results of the static tensile tests are shown in the diagram (Figures 6 and 7).

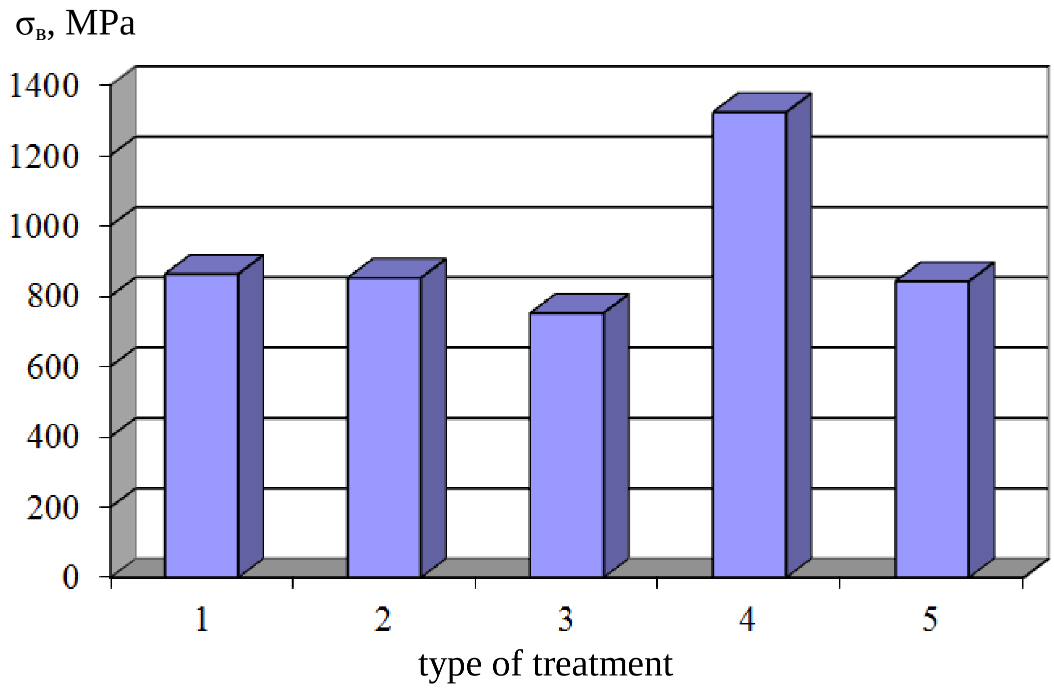

Figure 6. Dependence diagram of yield strength (temporary resistance) of the weld on the type of treatment (1 - welding without processing, 2 - welding heated at 250°C, 3 - welding with ultrasound treatment during and after welding; 4 - welding with concomitant cooling, 5 - vibration welding treatment)

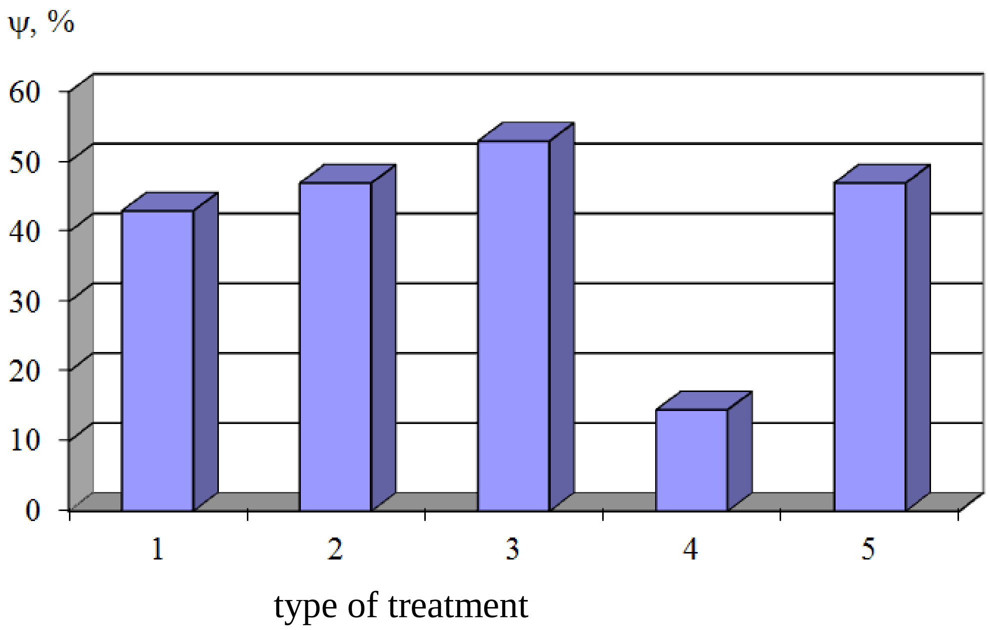

Figure 7. Dependence diagram of relative sample contraction under static tension on the type of treatment during welding (1 - welding without processing, 2 - welding heated at 250°C, 3 - welding with ultrasound treatment during and after welding; 4 - welding with concomitant cooling, 5 - vibration welding treatment)

Considering that tensile strength of the 20CrMnSiVaL steel is less than 600 MPa, the preferred treatment is ultrasonic. Ultrasonic treatment allows to increase the ductility of the weld margin by12 percent, in comparison with the current technology with preheating. At the same the tensile strength of the weld is reduced and weld strength becomes higher than the strength of the base metal.

We measured the hardness using the video microscope Axiovert – 100 A with MHT microhardness tester and KS-300 image analysis system. Indentation load is equal to 100 g. Exposure time under load is 10 sec. Rate of the pyramid uplift is 5 g /sec. For each state we took at least six hardness measurements. Processing of the results was done using hardware methods installed in Microsoft Excel with confidence level of 75%. Relative hardness measurement error does not exceed 5%. We presented the results in the chart (Figure 8).

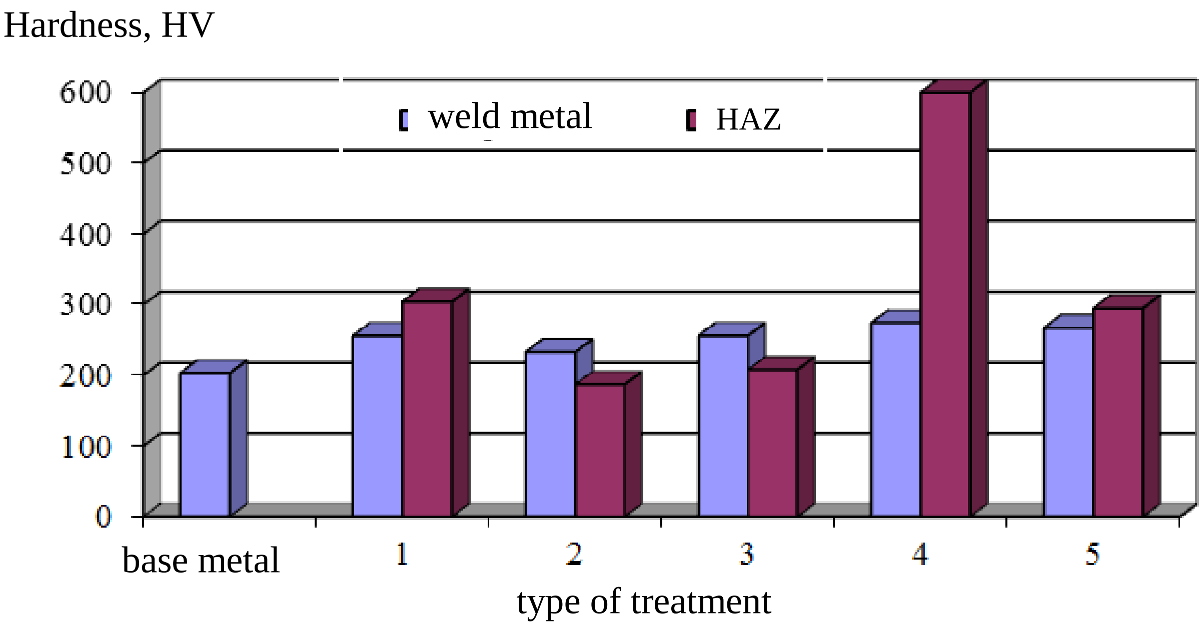

Figure 8 – Dependence diagram of the hardness of the base metal, weld metal and heat affected zone on the type of treatment (1 - welding without processing, 2 - welding heated at 250 °C, 3 - welding with ultrasound treatment during and after welding; 4 - welding with concomitant cooling, 5 - vibration welding treatment)

During the cooling process in the weld zone martensite structure is formed, ductility is reduced and a complex stress state is formed due to additional welding stresses. The hardness of the weld and heat affected zone increases. This leads to a high probability of cold cracking.

Ultrasonic treatment does not reduce the hardness in comparison with preheating and at first glance it deteriorates the technological joint strength. But there are two positive points: the harder the metal surface is, the higher its resistance to erosive destruction is; elimination of heating allows to reduce the heat-affected zone including the brittle interlayer generated by overheating.

An X-ray analysis of the samples was done to determine the level of residual welding stresses. We used X-ray diffractometer DRON 4-07, which allows to sent data to the personal computer. We used the SoK radiation with Bragg-Brentano focusing and Soller slits on the primary beam and a graphite crystal - a monochromat on the diffracted beam. The experimental data was processed with the use of "Maud" software. The algorithm uses the Ritfeldas method (powder full-profile method). The results of the analysis are shown in Figure 9.

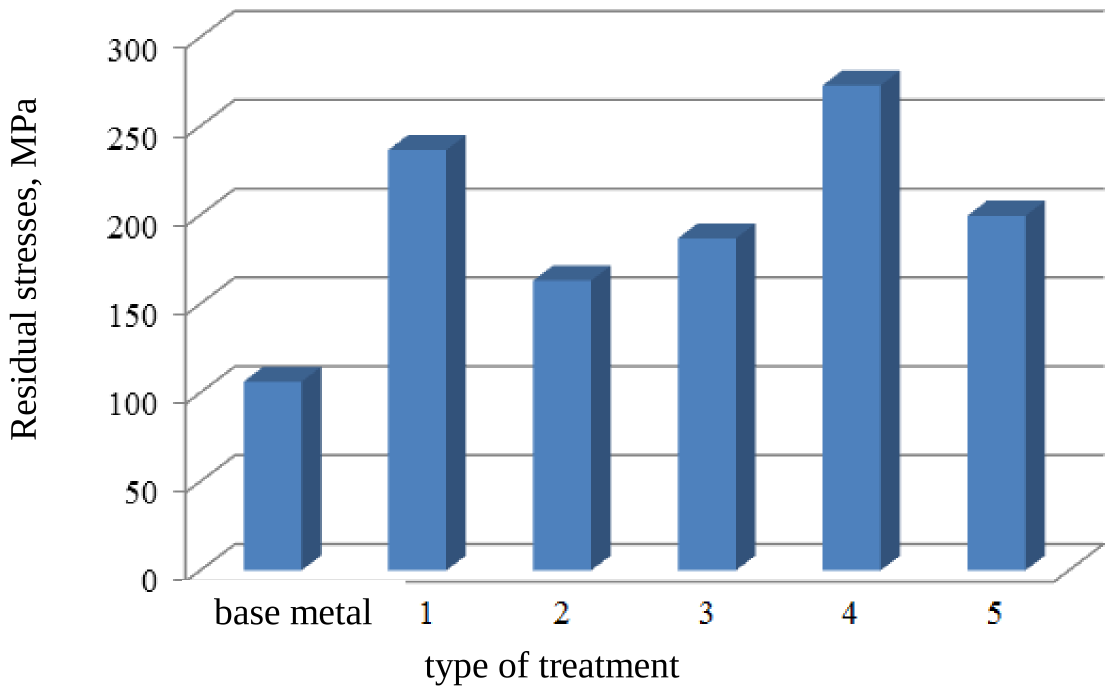

Figure 9. The results of calculation of residual stresses (1 - welding without processing, 2 - welding heated at 250 °C, 3 - welding with ultrasound treatment during and after welding; 4 - welding with concomitant cooling, 5 - vibration welding treatment)

The diagram shows that the minimum level of residual stress is 163,2 MPa. The residual stress of the sample with ultrasonic treatment is 186 MPa. Stress is equal to 199,6 MPa in the samples using vibratory treatment. In the samples with vibration treatment the stress rate is 199,6 MPa. In other processing methods internal stress exceeds 200 MPa, which means that the probability of cold cracking is very high.

Conclusions

1 The results show that it is possible to improve the repair pump housings of 20CrMnSiVaL steel by changing the energy consuming preheating before welding to ultrasonic treatment of the welded joint.

2 To upgrade the technological strength of the welded joint. We should limit the heat rate. This reduces the hot spot area in the HAZ. We recommend using the ultrasonic impact treatment of welds.

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