UDC 620.196.2

MANUFACTURING TECHNOLOGY UPGRADING OF WELDED SHELLS OF VESSELS FOR OIL AND GAS REFINING

D.V. Karetnikov [1], R.G. Rizvanov [2], Ya.A. Kolesnikov, O.V. Evsyutina

Ufa State Petroleum Technological University, Ufa, Russia
e-mail: [1] DenisKar@yandex.ru, [2] rifriz@mail.ru

Abstract. *The possibility of modernization of welding operations in technological process of welded joints manufacturing in devices for oil and gas refining is considered as the purpose of improvement of mechanical properties of welded joints and decrease in level of residual welding stresses on an example of welding under flux of square butt joints of plates from steel 09Mg2Si.*

The methods of carrying out the experimental studies with the description of the chosen modes of welding and accompanying processing are resulted. The results of tests of welded specimens on static stretching, impact strength, and also results of metallographic and hardness research are presented.

Keywords: *submerged arc welding, welded seam, vibrating processing, mechanical properties, microstructure, residual stresses*

Optimization of technological process of manufacturing the equipment as a whole covers problems of accuracy, productivity and profitability simultaneously ensuring operational reliability of details in parts of machines. Its importance especially increases in connection with wide automation of apparatuses-building manufacture.

The majority of the vessel type oil and gas equipment is made by welding because today to provide impermeability of connection of big diameter vessels is possible just by arc welding, its type and characteristics depending on the type of material, thickness of a detail and the kind of connection required. Despite the wide nomenclature of existing welding processes (manual arc welding, gas metal arc welding, submerged arc welding etc.) all above-mentioned processes have common local character of heating, high speeds of heating to the temperatures exceeding temperatures of metal melting (3000 °C at gas and 4000 °C at arc welding), that causes significant temperature stress and deformations, inhomogeneous structural transformations in a seam and heat-affected zones and other factors negatively influencing working ability of the weldied joint [6]. Therefore considering specificity of oil refining branch, the above-mentioned equipment is required to have high level reliability. The general indicators of reliability of the vessel type oil and gas equipment depend on similar indicators of welded joints, as the weakest parts from the point of view of presence of defects, concentrators of stress, inhomogeneous properties of metal and other negative factors.

Today the basic ways of prevention and dealing with the above-mentioned negative factors are the application of various types of thermal operations (preliminary and accompanying heat-treatment, annealing). Specific features of thermal operations, especially large-sized designs, are the high expenses of labor and power resources, and negative influence on ecology. Introduction of alternative methods of processing, obviously less power-intensive, is restrained by the factor that the majority of the oil and gas equipment is subordinated to Rostehnadzor, and accordingly should be made on existing certified technologies. Thus for certification of technological process of welding a considerable quantity of experimental studies and processing of their results by numerical methods with high degree of trust is necessary to be carried out.

One of the most perspective methods, allowing to skip the application of thermal operations in technological process of manufacturing of welded constructions is the application of vibrating processing, both low-frequency, and ultrasonic, depending on the goals and features of the constructions.

Originally experiences on application of the above-mentioned methods took place in practice of foundry manufacture where elastic oscillations were applied to get the fine-grained structure at moulding. Works of many authors devoted to research the influence of ultrasonic oscillations on structure and technological properties of a welded seam show that. But there is much less data on the influence of accompanying low-frequency vibration on the structure and technological properties of a welded seam although ongoing studies in this field testify to its efficiency and possibility of real application in practice [3, 4, 7, 9 - 11]. Advantages of application of low-frequency vibration in comparison with ultrasonic are: more effective removal of residual stresses, possibility of application of more simple, and accordingly more reliable and cheap equipment that simplifies process of introduction of the method in real manufacturing. At the same time it is necessary to consider the fact that with the increase in frequency of disturbance over 300 - 500 Hz damping of oscillations also considerably increases in the hardened metal. Therefore at vibrating processing of welded seams of remote elements of massive designs it is recommended to use low-frequency processing [7].

Probably the factor, having additional braking effect on introduction of the method of accompanying vibrating processing, is openness of the question concerned the mechanism of influence of elastic oscillations of both low and high frequency on crystallizing metal at moulding and welding. The main minus of existing set of hypotheses – hypotheses of hydraulic pressure, shrinkage during hardening, viscous friction and many others is the absence of explanation from the point of view of parameters of the mode of accompanying vibrating influence, such as frequency, amplitude, vibro-speed and vibro-acceleration. Explanations are basically theoretical and not proved experimentally.

From the literary data it follows that input of elastic oscillations in crystallizing metal of a welding bath, both of high and low frequency promotes not only formation of fine-grained structure, but also improves some technological and operational characteristics of metal of a welded seam [1 - 4, 7, 9 - 11]. Thus the elementary estimation of key parameters of vibrating processing allows to make a conclusion concerning the basic difference in mechanisms of low-frequency and ultrasonic influence. So if at low-frequency processing disturbance frequency varies within 50 - 200 Hz, and the value of the amplitude providing real efficiency of processing is in the range from 0,6 to 1 mm then at ultrasonic processing disturbance frequency with the purpose to decrease acoustic effect is above 25 kHz, the amplitude does not exceed 0,01 mm. Thereby at ultrasonic processing disturbance frequency varies in one range with the speed of crystals growth, and accordingly due to own frequencies of crystals matching the disturbance frequency of vibrating processing, the mechanism of vibrating processing will be of a resonant character [2]. As a hypothesis about the basic mechanism of accompanying low-frequency vibrating processing we made the assumption stated in works [1, 2, 12], about cavitation destruction of crystal front, according to which it was accepted that the process of cavitation occurs on the gas bubbles which allocated on crystal front because solubility in the solid phase is lower than in the liquid. Crystallization centres thrown by cavitation to the melt become the attraction for formation of fine-grained structure. Herewith it is also considered that the speed of cooling increases with input of vibrating oscillations to the melted metal, owing to the growth of its heat transfer.

To confirm the hypothesis of the efficiency of accompanying low-frequency vibrating processing on crystallizing metal of a welding bath we made five butt double-sided submerged arc weld joints from plates with the sizes 150x500 and the thickness of 10 mm from steel 09Mg2Si with various parametres of vibrating processing. Welding modes are presented in Table 1.

Table 1. Modes of welding of plates:
I_{weld} – welding current, amperes; d_{el} – the diameter of the electrode, millimetres; U_{arc} – the arc voltage, volts; V_{weld} – welding speed, meters per hour; V_{wire} – wire feed rate, meters per hour

	I_{weld}, A	d_{el}, mm	U_{arc}, V	V_{weld}, meter/h	V_{wire}, meter/h
Upper seam	700 - 750	3	32 - 34	31 - 33	80 - 85
Lower seam	640 - 680	3	28 - 30	27 - 30	75 - 80

Processing of vibrating oscillations was carried out by means of pneumatic vibrator VSH-10. Modes of accompanying vibrating processing are presented in Table 2.

Table 2. Modes of vibrating processing

Vibrating freq, Hz	Amplitude, mm	Vibro-speed, mm/s
0	0	0
50	0.8 - 1	3.1 - 4.1
100	0.8 - 1	6.2 - 8.3
150	0.8 - 1	12.5 - 16.7
200	0.8 - 1	17.1 - 20.9

The specimens have been cut out after welding from the zone of welded joints of the plates for research to define the value of residual stresses, to analyse microstructure of the metal of the welded joint, to test various sites of welded joint metal for an impact bend and static strength.

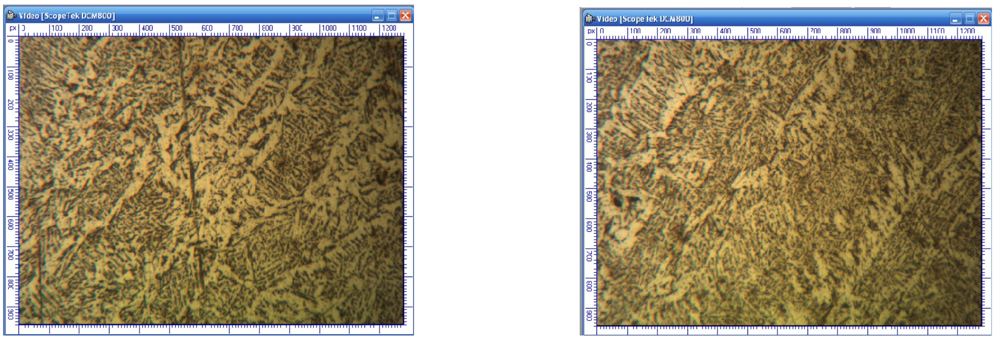
In [8] it is shown that for cyclic loading it is possible to express dependence of endurance strength on the size of grain with the formula similar to dependence of yield strength on the size of grain:

$$\sigma = \sigma_{iR} + K_R \sqrt{d},$$

where σ_{iR} and K_R – constants, d – average diameter of grain.

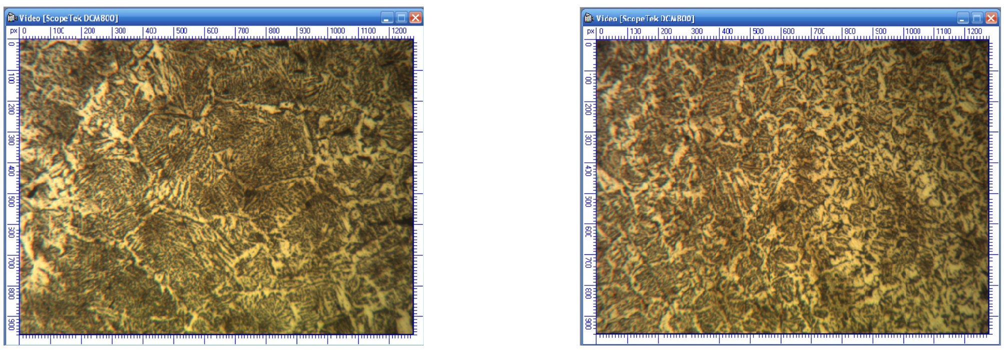
Based on mentioned above, for obtaining the maximum resource of a welded seam, formation of a seam with the minimum average size of grain on all sites of welded joint and providing minimum possible level of residual stresses is the most appropriate.

The analysis of microstructure of metal of welded joint was carried out through optical microscope EC METAM PB-21 with 300 time increase. The microstructural analysis of specimens carried out by both visual and calculation method (by means of program SIAMS), has revealed considerable grinding (reduction of the average area of grain) of metal of welded joint. In figure 1 the microstructure of metal of a welded seam at different modes of processing is presented. In Fig. 2 the microstructure of heat affected zone metal is presented at different modes of processing.



a) b)

Fig. 1. The microstructure of a welded seam from a steel 09Mg2Si:
a) – without vibration; b) – with vibration frequency 150 Hz at vibro-speed 9,5-12,5 mm/s



a) b)

Fig. 2. The microstructure of a heat affected zone
of welded joint from a steel 09Mg2Si:
a) – without vibration; b) – with vibration frequency 150 Hz at vibro-speed 9,5 - 12,5 mm/s

From the visual analysis of the pictures presented in Fig. 1 and 2, determination in orientation of microstructure, owing to reduction of its dispersion, which is the factor positively influencing the strength at variable (cyclic) loadings is obvious. Results of calculation of the average area size of grain in program SIAMS for different sites of welded joint depending on processing modes are presented in Table 3.

Table 3. Results of calculation of the average area of the size of grain in program SIAMS for different sites of welded joints depending on processing modes

Vibrating freq, Hz	Average grain size, μm ^{2}			
	Main metal	Heat affected zone	Welded seam №1	Welded seam №2
0	34	50	47	46
50	34	34	35	39
100	36	33	36	40
150	34	34	35	36
200	36	37	38	39

From the analysis of the data presented in Table 3, it is obvious that the maximum level of the average area of grain of metal decrease in heat affected zone and a welded seam is reached at frequency of accompanying vibrating processing of 150 Hz and equals to 32 % for heat affected zone and 25 % for welded seam in comparison with non-vibrated specimens.

Other important factor influencing the strength of welded joints at cyclic loadings is existence of technological defects of welded joints (slag inclusions, pores, incomplete penetration etc.) [6]. Therefore after welding of plates the 100 % radiographic control has been carried out. The analysis of radiographical pictures has shown that the total area of projections of pores on the area with the length of 50 mm and 10 mm width is minimum at 100 Hz frequency of accompanying vibrating. Therefore, accompanying vibrating processing makes positive impact on dispersion of nonmetallic inclusions, their quantity and the way of arrangement in a seam. It is assumed that the mechanism of reduction of quantity of pores and considerable grinding of nonmetallic inclusions is similar to the mechanism of grinding of crystallizing metal structure, and first of all is connected with intensification of processes of degassing and removal of nonmetallic inclusions with increase of intensity of vibration processing. The estimation of the total percentage area of pores projections results on the area of a welded seam with the length of 50 mm and 10 mm width depending on modes of accompanying vibrating processing is presented in Fig. 3.

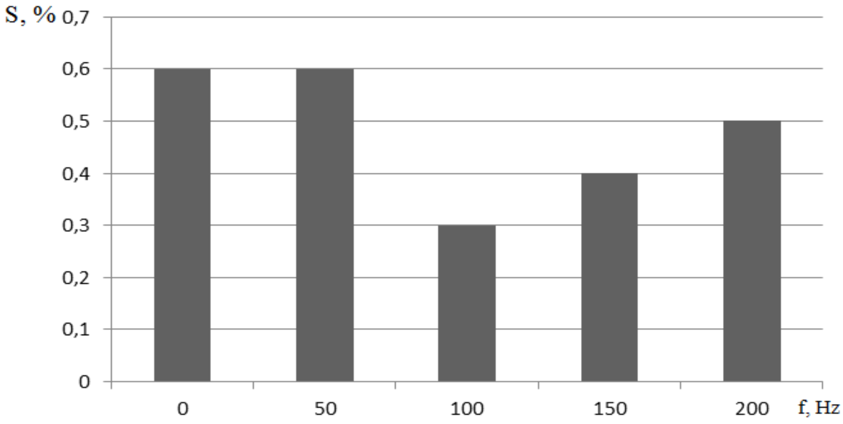


Fig. 3. Diagram of dependence of the total percentage area of projections of pores (s) on the area of a welded seam with the length 50 mm and 20 mm width

Considering that majority of welded vessels for oil and gas refining made of low-alloy steels during their operation-life suffered from simultaneous influence of many cyclically changing loadings (pressure differences, fluctuations of external and internal temperature etc.), significant negative influence on their constructive strength and durability is made by residual welding stresses and distortion. Studies to determine the influence of modes of accompanying vibrating processing on the level of residual welding stresses were carried out by X-ray - diffractometric method on microscope DRON-4. 10x15 mm sized specimens have been cut by an electroerosion method out of the welded plates. The diagram of dependence of level of residual stresses on frequency of accompanying vibrating processing is shown in Fig. 4.

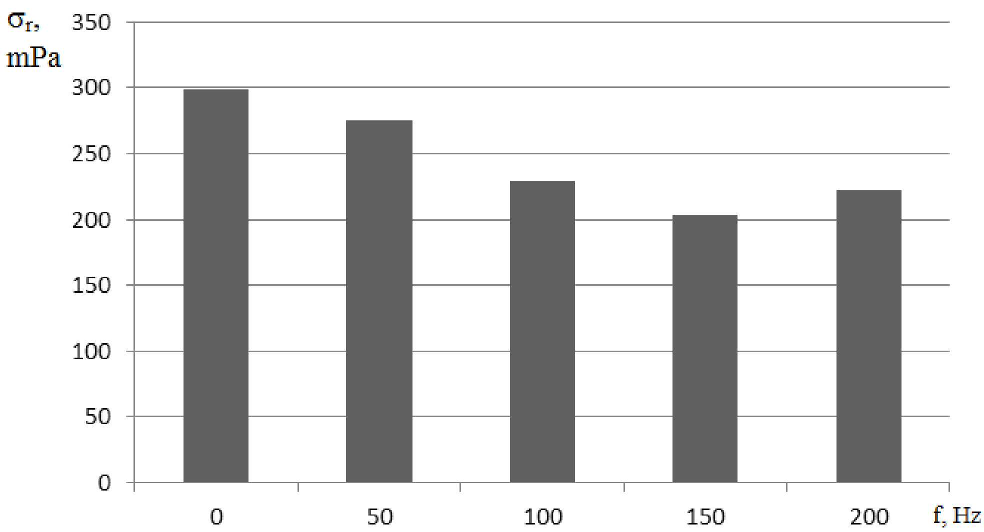


Fig. 4. The diagram of dependence of level of residual welding stresses (σ_r) on frequency of accompanying vibrating processing

It is obvious from Fig. 4 that accompanying vibrating processing results to lower level of residual stresses, and maximum efficiency of processing is reached at 150 Hz frequency. It does not only reduce the level of welding distortion of the design, but also allows to extend the device resource that is proved to be true in the data presented in work [4] where the author carried out research of influence of modes of vibrating processing on low-cycle endurance strength of butt arc welded joint made of low-alloy steels. In the work it is established that low-frequency local vibrating processing promotes the number of loading cycles increase before destruction of the specimens, hence local vibrating processing during welding positively influences low-cycle endurance strength.

To estimate the influence of modes of vibrating processing on the strength of a welded seam and entire welded joint the specimens have been made of the welded plates in accordance with standard GOST 6996 and mechanic testing for static stretching has been performed. The diagram of ultimate strength and yield strength of welded joint dependence on frequency of accompanying vibrating processing is presented in Fig. 5. The diagram of ultimate strength and yield strength of welded seam dependence on frequency of accompanying vibrating processing is presented in Fig. 6.

It is obvious from Fig. 5 and 6 that dependence of ultimate strength and yield strength of welded joint on frequency of vibration is maximal on 150 Hz frequency. On similar frequency the maximal decrease was also reached in the average area of grain in welded seam and heat-affected zones. Based on above it is possible to assume that peak efficiency of accompanying vibrating processing is reached at disturbing frequency of 150 Hz and vibro-speed in the range of 9,4 - 12,5 mm/s.

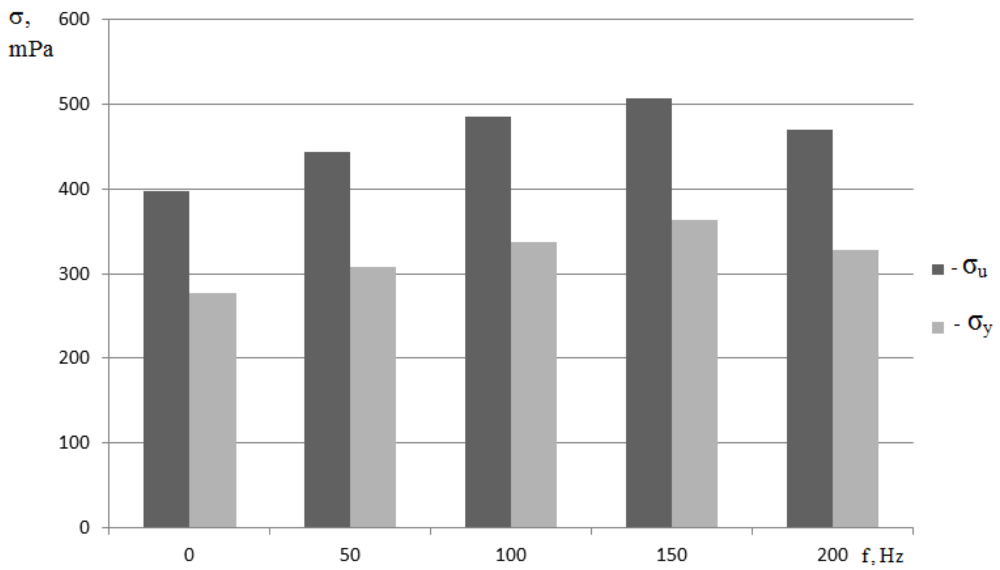


Fig. 5. The diagram of ultimate strength (σ_u) and yield strength (σ_y) of welded joint made of steel 09Mg2Si dependence on frequency of accompanying vibrating processing

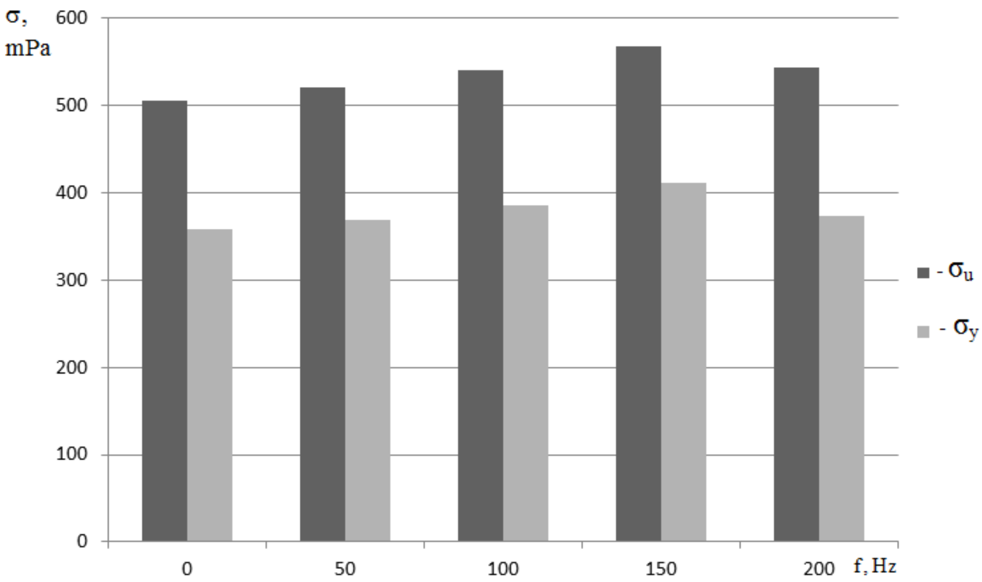


Fig. 6. The diagram of ultimate strength (σ_u) and yield strength (σ_y) of welded seam made of steel 09Mg2Si dependence on frequency of accompanying vibrating processing

Thus experimentally obtained data are presented in works [3, 4, 9 - 11] showing that peak efficiency of vibrating processing of welded joint made by manual metal arc welding and gas metal arc welding (GMAW) is reached at disturbing frequency of 50 Hz and amplitude of 1 mm. The increase in optimal disturbing frequency from 50 to 150 Hz with the given method used for processing the welded joints carried out by submerged arc welding, in our opinion, is caused by necessity to increase intensity of vibrating influence owing to the presence of slag crust and a layer of not fused flux that are slowing down the speed of cooling of a seam. It is shown in [5] that with increase in degree of overcooling, the critical size of a grain germ decreases, and therefore the number of the centres of crystallisation increases which leads to forming more fine-grained structure.

From the point of view of microstructure the increase of strength properties occurs first owing to decrease in the average area of grain, second owing to quantity increase of pearlite phases in metal of welded joint with increase in intensity of vibrating processing. The estimation of the ratio change of quantity of ferrite phase to pearlite phase was carried out in accordance with GOST 8233 on the basis of computer analysis of pictures of the microstructure of various zones of welded joint in program SIAMS. The results of that estimation are presented in Table 4.

From Table 4 it is obvious that with increase in intensity of vibrating processing there is a decrease of points of ferrite-pearlite structures of various zones of welded connection which means quantity redistribution of pearlite and ferrite phases towards pearlite phase quantity increase. Considering such features of complex mechanic properties of pearlite as high strength and hardness [5], point decrease of ferrite-pearlite structures leads to increase in strength and decrease in characteristics of impact strength. Herewith it is necessary to consider that for welded vessels made of low-alloy steels the minimum value of impact strength for specimens with the U-shaped concentrator for various zones of welded joint at temperature +20 °C should be equal to 50 J/cm^2 by OST 26 291

Table 4. Results of determination of ferrite-pearlite ratio structure (points) in program SIAMS

№	Frequency of vibration, Hz	Ferrite-pearlite phase quantity ratio, points			
1	0	Main metal	Heat affected zone	Welding seam №1	Welding seam №2
2	50	7.5	7.6	7.9	7.5
3	100	7.5	7.3	7.2	7.1
4	150	7.5	7.1	7.0	6.6
5	200	7.5	7.2	7.2	6.5

The results of determination of impact strength level are presented in Table 5 for specimens with the U-shaped concentrator, made in accordance with standard GOST 6996.

Table 5. Results of determination of impact strength level of specimens depending on frequency of accompanying vibrating processing

№	Frequency of vibration, Hz	KCU, J/cm^2
1	0	72
2	50	67
3	100	59
4	150	58
5	200	56

From Table 5 it is obvious that accompanying vibrating processing increases the strength characteristics of welded joint, without essential decrease of impact strength.

Other important question while researching character of influence of modes of accompanying vibrating processing on characteristics of welded joints is to get the dependence of efficiency of processing from its intensity determined by the level of vibrating amplitude. From the data presented above it is possible to make a conclusion that vibrating processing at submerged arc welding is most effective at disturbance frequency of 150 Hz. In work [13] while carrying out the numerical modeling of influence of amplitude of vibration on the level of residual stresses it was established that with increase of amplitude of vibration there is an increase in intensity of removal of the level of longitudinal residual stresses. But experimentally obtained data in work [7] show that at increase in amplitude of vibration over 1 mm capture of air by the fused metal surface and its saturation by various gases accordingly begins that negatively affects properties of welded joint as a whole. Thus for carrying out experiments for the estimation of influence of amplitude of vibration feature on efficiency of accompanying vibrating processing, the range of amplitude from 0,2 to 1,4 mm at disturbance frequency of 150 Hz has been chosen. Welding modes are similar to the modes presented in Table 1. Modes of accompanying vibration processing are presented in Table 6.

Table 6. Modes of vibration processing

№ of experiment	Frequency of vibration, Hz	Amplitude, mm
1	150	0.2
2	150	0.6
3	150	1.0
4	150	1.4

After that test specimens have been made out of the welded plates for the test on static strength in accordance with standard GOST 6996. The diagram of dependence of ultimate strength and yield strength of welded joint depending on intensity of accompanying vibrating processing is presented in Fig. 7.

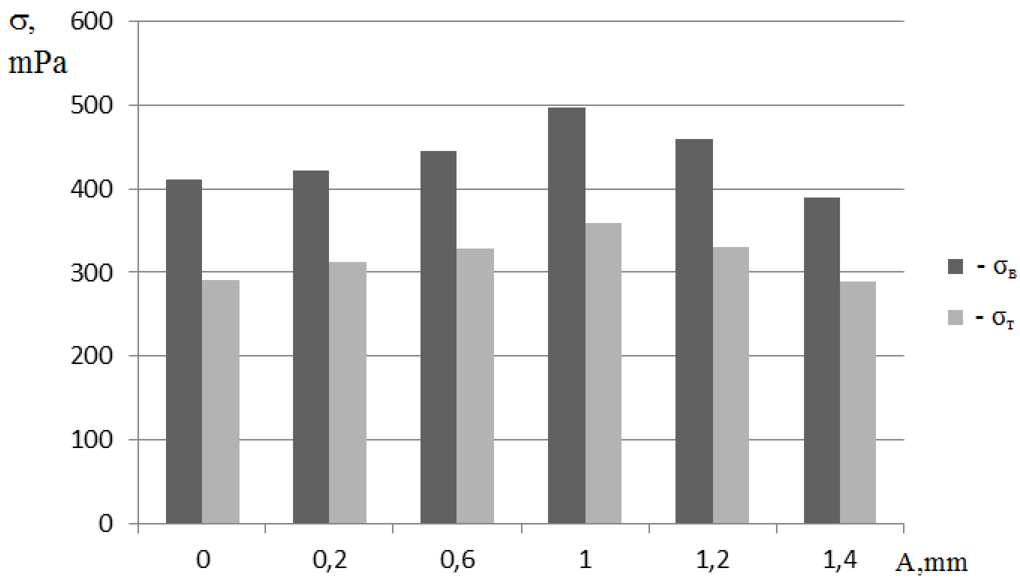


Fig. 7. The diagram of dependence of ultimate strength and yield strength of a welded seam from steel 09Mg2Si on amplitude of accompanying vibrating processing

From the diagram presented in Fig. 7, it is possible to draw a conclusion that optimum value of amplitude of the accompanying vibrating processing, providing its greatest efficiency is equal to 1 mm. Decrease in values of ultimate strength and yield strength of welded joint processed with amplitude of 1,4 mm is caused by the raised formation of pores, due to violation of integrity of slag crust and air capture by near-surface turbulent flows.

Thus the data presented above indicate the efficiency of the method of accompanying vibrating processing. The carried out patent search shows the presence of origin on the given subjects both in Russia, and in Western countries, but the analysis of the data of the open sources has not revealed the facts of introduction of the given technology in manufacturing processes. Presumably the starting impulse of wide introduction of the given technology will be necessity to increase competitiveness of produced goods from the point of view of economic and operational indicators.

Conclusions

1. The accomplished patent and literary review has shown the absence of facts of industrial application of low-frequency accompanying vibrating processing.

2. The accomplished studies show the efficiency of application of the method of accompanying vibrating processing as it can reduce the level of residual welding stresses and distortion and also improve mechanic properties of welded joints.

3. It is established that optimum parametres of accompanying vibrating processing during submerged arc welding of butt joints from steel 09Г2С are disturbing frequency of 150 Hz and amplitude of vibrating processing of 1 mm.

References

1. Ефимов В.А., Эльдарханов А.С. Влияние вибрации на теплофизические особенности затвердевания слитков // Процессы литья. 1995. № 3. С. 30 - 41.

2. Ефимов В.А., Эльдарханов А.С. Технологии современной металлургии. М.: Новые технологии, 2004. 784 с.

3. Зарипов М.З. Модернизация технологии изготовления сварных аппаратов из стали 12Х18Н10Т с применением вибрационной обработки: Дисс. к.т.н. Уфа, 2010. 132 с.

4. Карпов А.Л., Файрушин А.М., Ризванов Р.Г., Зарипов М.З. Повышение качества изготовления сварных нефтехимических аппаратов применением вибрационной обработки в процессе сварки // Башкирский химический журнал. 2005. Том 12. № 1. С. 27 - 29.

5. Лахтин Ю.М. Металловедение и термическая обработка металлов. Учебник для вузов. 3-е изд. М.: Металлургия, 1983. 360 с.

6. Николаев Г.А., Куркин С.А., Винокуров В.А. Сварные конструкции. Прочность сварных соединений и деформации конструкций: Учебное пособие. М.: Высшая школа, 1982. 272 с.

7. Ибрагимов И.Г., Ямилев И.Г., Салмин А.Н. Совершенствование технологии выполнения сварного узла труба трубная решетка кожухотрубчатых теплообменных аппаратов, изготовленных из мартенситных сталей // Нефтегазовое дело. 2009. Том 7. № 1. С. 194 - 197. URL: http://www.ngdelo.ru/2009/1/194-197.pdf

8. Терентьев В.Ф., Оксогоев А.А. Циклическая прочность металлических материалов: Учебное пособие. Новосибирск: Изд-во НГТУ, 2001. 61 с.

9. Ризванов Р.Г., Файрушин А.М., Карпов А.Л., Зарипов М.З. Исследование влияния виброобработки в процессе сварки на свойства сварных соединений нефтегазового оборудования из стали 09Г2С // Нефтегазовое дело. 2007. Том 5. № 1. С. 183 - 186.

10. Ризванов Р.Г., Файрушин А.М. Установка для вибрационной обработки базовых деталей нефтехимических аппаратов в процессе их изготовления / III конгресс нефтегазопромышленников России. Секция Н «Проблемы нефти и газа». Уфа, 23-25 мая 2001 г.: Научные труды. Уфа.: Изд-во «Реактив», 2001. С. 332 - 333.

11. Файрушин А.М. Совершенствование технологического процесса изготовления корпусов аппаратов с применением вибрационной обработки: Дисс. к.т.н. Уфа, 2003. 121 с.

12. Эльдарханов А.С. Кавитационное разрушение границы затвердевания // Процессы литья. 1996. № 3. С. 16 - 24.

13. Yang Y.P., Jung G., Yancey R. Finite element modeling of vibration stress relief after welding // Presented at the American Society of Materials. Reprint. 2005. URL: http://www.vsrtechnology.net/wp-content/uploads/yang_jung_yancey.pdf

UDC 620.196.2

MANUFACTURING TECHNOLOGY UPGRADING OF WELDED SHELLS OF VESSELS FOR OIL AND GAS REFINING

D.V. Karetnikov [1], R.G. Rizvanov [2], Ya.A. Kolesnikov, O.V. Evsyutina

Ufa State Petroleum Technological University, Ufa, Russia

e-mail: [1] DenisKar@yandex.ru, [2] rifriz@mail.ru

Abstract. *The possibility of modernization of welding operations in technological process of welded joints manufacturing in devices for oil and gas refining is considered as the purpose of improvement of mechanical properties of welded joints and decrease in level of residual welding stresses on an example of welding under flux of square butt joints of plates from steel 09Mg2Si.*

The methods of carrying out the experimental studies with the description of the chosen modes of welding and accompanying processing are resulted. The results of tests of welded specimens on static stretching, impact strength, and also results of metallographic and hardness research are presented.

Keywords: *submerged arc welding, welded seam, vibrating processing, mechanical properties, microstructure, residual stresses*

References

1. Efimov V.A., El'darkhanov A.S. Vliyanie vibratsii na teplofizicheskie osobennosti zatverdevaniya slitkov (The effect of vibration on the thermophysical characteristics of ingots solidification), *Protsessy lit'ya - Casting processes*, 1995, Issue 3, pp. 30 - 41.

2. Efimov V.A., El'darkhanov A.S. Tekhnologii sovremennoi metallurgii (Modern metallurgical technology). Moscow, Novye tekhnologii, 2004. 784 p.

3. Zaripov M.Z. Modernizatsiya tekhnologii izgotovleniya svarnykh apparatov iz stali 12Kh18N10T s primeneniem vibratsionnoi obrabotki (Modernization of technology production of welded apparatus from steel 12Kh18N10T using vibratory processing). PhD thesis. Ufa, 2010. 132 p.

4. Karpov A.L., Fairushin A.M., Rizvanov R.G., Zaripov M.Z. Povyshenie kachestva izgotovleniya svarnykh neftekhimicheskikh apparatov primeneniem vibratsionnoi obrabotki v protsesse svarki (Improving production quality of welded petrochemical apparatus using vibration during welding), *Baskirskii khimicheskii zhurnal*, 2005, Volume 12, Issue 1, pp. 27 - 29.

5. Lakhtin Yu.M. Metallovedenie i termicheskaya obrabotka metallov: uchebnik dlya vuzov (Physical metallurgy and heat treatment of metals. Textbook. 3 ed.). Moscow, Metallurgiya, 1983. 360 p.

6. Nikolaev G.A., Kurkin S.A., Vinokurov V.A. Svarnye konstruktsii. Prochnost' svarnykh soedinenii i deformatsii konstruktsii: Uchebnoe posobie (Welded structures. Strength of welded joints and deformation of structures. Textbook). Moscow, Vysshaya shkola, 1982. 272 p.

7. Ibragimov I.G., Yamilev I.G., Salmin A.N. Sovershenstvovanie tekhnologii vypolneniya svarnogo uzla truba trubnaya reshetka kozhukhotrubchatykh teploobmennykh apparatov, izgotovlennykh iz martensitnykh stalei (Technology perfection of welded knot performance the pipe trumpet lattice of shell and tube heat exchanger made from martensit steels), *Neftegazovoe delo - Oil and Ghas Business*, 2009, Vol. 7, Issue 1, pp. 194 - 197. URL: http://www.ngdelo.ru/2009/1/194-197.pdf

8. Terent'ev V.F., Oksogoev A.A. Tsiklicheskaya prochnost' metallicheskikh materialov: Uchebnoe posobie (Cyclic strength of metallic materials: Textbook). Novosibirsk, NGTU, 2001. 61 p.

9. Rizvanov R.G., Fairushin A.M., Karpov A.L., Zaripov M.Z. Issledovanie vliyaniya vibroobrabotki v protsesse svarki na svoistva svarnykh soedinenii neftegazovogo oborudovaniya iz stali 09G2S (Research of influence vibrating processing in welding on weldment properties of petrochemical devices from low-alloy steel), *Neftegazovoe delo - Oil and Ghas Business,* 2007, Volume 5, Issue 1, pp. 183 - 186.

10. Rizvanov R.G., Fairushin A.M. Ustanovka dlya vibratsionnoi obrabotki bazovykh detalei neftekhimicheskikh apparatov v protsesse ikh izgotovleniya (Unit for vibrational processing of base details of petrochemical apparatus in during their manufacture), *III kongress neftegazopromyshlennikov Rossii. Sektsiya N «Problemy nefti i gaza». Nauchnye trudy*. (*Materials of the III Congress of Russian oil-gas producers. Section H "Oil and gas problems"*). *Ufa*, *23-25 may 2001.* Ufa, Reaktiv, 2001. PP. 332 - 333.

11. Fairushin A.M. Sovershenstvovanie tekhnologicheskogo protsessa izgotovleniya korpusov apparatov s primeneniem vibratsionnoi obrabotki (Improving the process of manufacturing the apparatus casing with the use vibrating processing). PhD thesis. Ufa, 2003. 121 p.

12. El'darkhanov A.S. Kavitatsionnoe razrushenie granitsy zatverdevaniya (Cavitational destruction of solidification boundary), 1996, Issue 3, pp. 16 - 24.

13. Yang Y.P., Jung G., Yancey R. Finite element modeling of vibration stress relief after welding. Presented at the American Society of Materials. Reprint. 2005. http://www.vsrtechnology.net/wp-content/uploads/yang_jung_yancey.pdf