MACHINE BUILDING AND MACHINE SCIENCE

UDC 621.791.793:669.15–194.2:539.4 https://doi.org/10.23947/2687-1653-2021-21-1-89-95

On detection of crack-like welding defects by existing quality control methods

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Introduction. The research materials devoted to the operability assurance of welded structures of hazardous technical devices — components of oil and gas production equipment are summarized. The factors determining the operational strength of welded joints and structures are systematized and diagrammed. The causes for the decrease in their service properties are described. We have defined the role of volumetric and crack-like welding defects, which were not detected during quality control at the manufacturing stage and in determining the residual life while in operation, in ensuring the life cycle of the structure. Measures to improve the practice of detecting crack-like defects under visual-and-dimensional and ultrasonic methods of quality control of welded joints are proposed.
Materials and Methods. In accordance with SNiP 2.05.06–85, the structures of main oil and gas pipelines, vertical cylindrical tanks, and other oil and gas production equipment (OGPE) are made of dead-killed and semikilled low-carbon and low-alloy steels with tensile strength of up to 686.5 MPa. Regardless of the class and strength level of steel, it should be well welded by all methods prescribed by standard process documentation (SPD). At the same time, regardless of the state of supply, the carbon equivalent $C_{экв}$ should not exceed 0.46 %. The research methods are calculation-experimental ones. To calculate the stress-strain state of welded joints, the following methods were used:
— finite elements (FEM),
— fracture mechanics using the stress intensity coefficient K_t.
Methods of mathematical statistics were used to estimate the geometric dimensions of crack-like welding defects. Welding defects were detected by standard quality control methods prescribed by the SPD and GOST standards.
Results. Welded structures operating in the fatigue mode are considered. Some factors characteristic of welded joints are analyzed. It is shown how they affect the formation of strength performance properties. The role of dangerous crack-like defects, which with high probability can be formed in welded joints in the manufacture of structures and during operation, is established. Often, the reason is a decrease in mechanical properties due to aging and loss of plasticity caused by accidental mechanical actions. Note that it is impossible to identify these defects by existing quality control methods, both during the control process under production and during diagnostics while in operation. This reduces the accuracy of predicting the operational life of the welded structure.

Discussion and Conclusion. It is proposed to include the following requirements in the SPD:
— to the quality of welded joints of hazardous technical devices of OGPE,
— to detection of sharp crack-like defects with a radius of curvature in the range of 0.1-0.25 mm.
However, the reliability of detection of such defects by the control methods used remains low due to the human factor. To increase the reliability of detection of sharp crack-like defects, the directions of improvement of ultrasonic quality control of welded joints are determined.

Keywords: welding, welds, structural strength, welding defects, non-destructive testing, visual and dimensional control, ultrasonic testing, validity.

For citation: V. A. Peredelsky, V. Y. Harchenko, A. L. Chernogorov, et al. On detection of crack-like welding defects by existing quality control methods. Advanced Engineering Research, 2021, vol. 21, no. 1, p. 89–95. https://doi.org/10.23947/2687-1653-2021-21-1-89-95

Introduction. Scientific studies [1-7], as well as standards[1], regulatory[2] and specification documents[3] of relevant organizations are devoted to the problems of determining the strength of the operated welded metal structures. Factors that determine the strength characteristics of weld joints are numerous and diverse. The destruction of welded metal structures under operation depends on:

— operating conditions (level of calculated loads, loading scheme, joint effect of various forces, action of unaccounted loads, etc.);

— structural and technological causes.

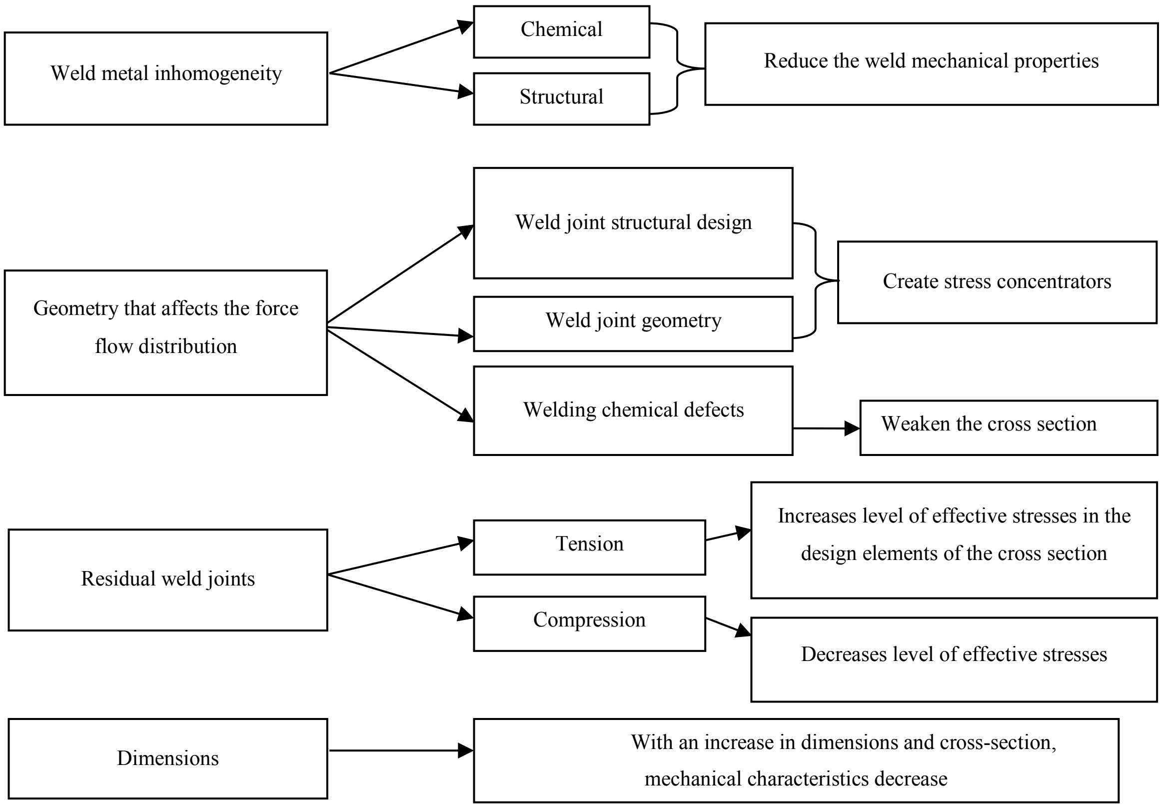


Fig. 1. Factors determining the operational strength of weld joints and structures

The generalization of numerous studies suggests that the load-bearing capacity of welded structures is affected by the following conditions.

I. Heterogeneity of the metal structure and mechanical properties of the weld and the near-weld zone.

II. Welding defects, mainly, crack-like ones. These are undercuts, cracks, rolls, sharp inclusions, faulty penetration, incomplete fusion, etc. (Fig. 2).

[1] Gas-shielded arc welding. Welded joints. Main types, design elements and dimensions. Federal Agency for Technical Regulation and Metrology. Moscow: Standartinform; 2001. 37 p. (In Russ.)

[2] RD-25.160.10-KTH-001-12. Welding technology instruction for the construction and repair of steel vertical tanks of "Transneft" JSC. 112 p. URL: https://www.studmed.ru/rd-25-160-10-ktn-001-12-instrukciya-po-tehnologii-svarki-pri-stroitelstve-i-remonte-stalnyh-vertikalnyh-rezervuarov-chast-1_5cb8180807a.html (accessed: 10.10.2020). (In Russ.)

[3] Gazprom Industry Standard 2-2.4-083-2006. Regulatory documents for the design, construction and operation of Gazprom facilities. Instructions on non-destructive methods of quality control of weld joints during the construction and repair of field and main gas pipelines. URL: https://files.stroyinf.ru/Index2/1/4293831/4293831880.htm (accessed: 10.10.2020). (In Russ.)

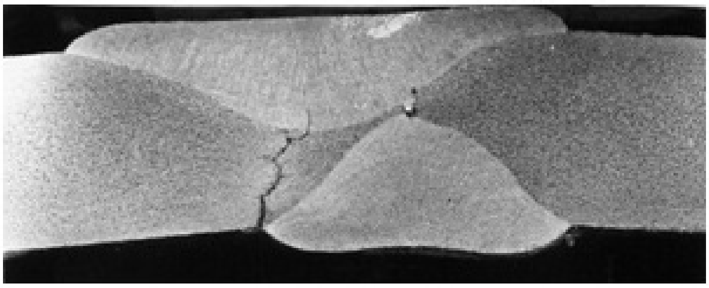


Fig. 2. Defects in the butt weld joint

III. Imperfection of the geometry of the weld cross-sections. The decrease in strength is mostly due to the sharpness of the interface between the base and the deposited metal (Fig. 2, 3): the smaller the transition radius *r* and the greater the angle of approach θ from the base to the deposited metal, the lower the fatigue strength of the weld joint. This pattern is valid even in the absence of welding defects.

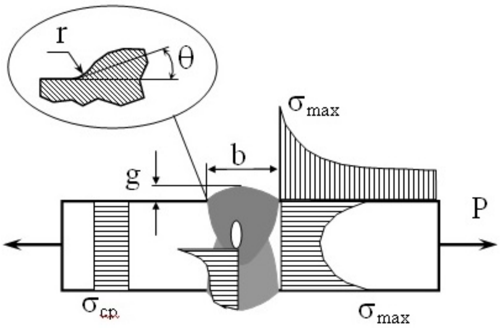


Fig. 3. Stress distribution in the interface zone of the base and deposited metal, at the apex of sharp defects

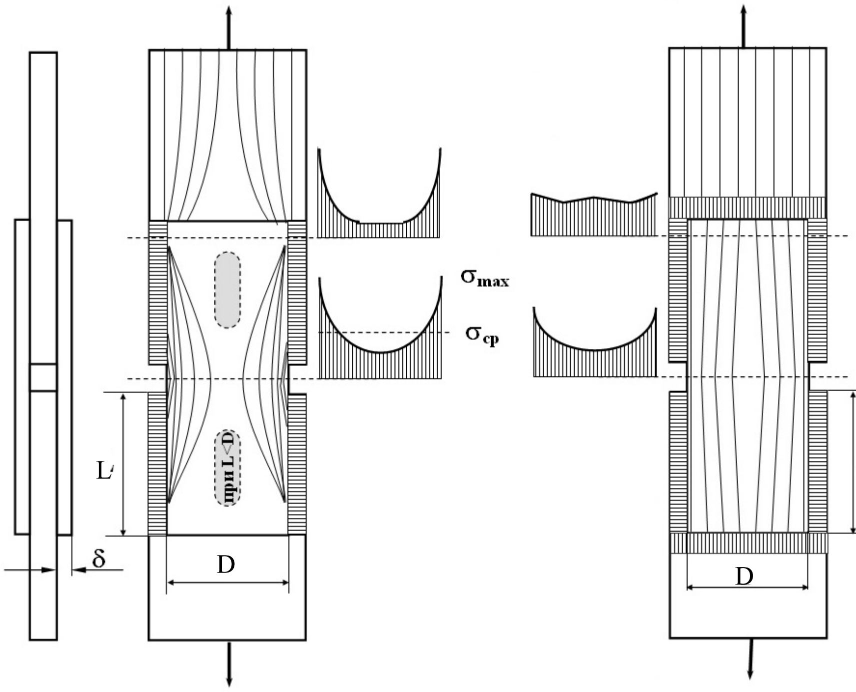
The weld joint design is determined by:

— the shape and dimensions of the butt edges of the parts;

— relative position, configuration, length of welds;

— type of weld joint according to GOST.

Fig. 4 shows the stress distribution in lap joints with flank and composite welds.



a) *b*)

Fig. 4. Stress distribution in lap joints: *a*) with flank welds; *b*) with composite weld

Table 1 shows the values of the theoretical stress concentration coefficient $K_н$ depending on the length and width of the tie plate:

$$K_{Н} = \frac{6max}{6ср} = 6{,}6 \cdot \frac{D}{L} \cdot \mathrm{cth}\left(4{,}6\frac{D}{L}\right). \quad (1)$$

Table 1

$K_н$ values depending on the length and width of the tie plate

D/L	0.2	1.0	2.0	4.0
$K_Н$	1.45	2.01	3.37	6.61

IV. Residual welding stresses (RWS).

V. Absolute dimensions of the parts to be welded (scale factor).

Welded joints in metal structures, even without welding defects, usually contributes to a decrease in operational properties. Butt weld joints are the least dangerous in this sense. Lap joints and T-joints create a stress concentration caused by sharp changes in the working cross-sections [8, 9]. However, for the manufacture of many structures, butt joints are not enough.

Residual welding stresses can change the overall power flow distribution pattern. RWS, interacting and summing up with stresses from external loads, affect the performance of weld joints. This effect can also be positive, for example, if the vectors of RWS and stresses from external loads are multidirectional (tension + compression, etc.).

Welded joints have the greatest impact on the fatigue of structures. Disturbing factors (Fig. 1) cause destruction at stresses that can be transmitted by elements of metal structures without weld joints[1].

In numerous papers devoted to the impact of welding defects on the performance of joints, recommendations are given to reduce harmful effects. At the same time, it is noted that some defects should be classified as harmless. For example, single small pores practically do not affect the fatigue strength of weld joints. In this case, the regulations on the presence of pores are designed to provide not the strength, but the acceptable presentation of the product.

Traditionally, welding defects are understood as any imperfections in the geometry and discontinuities of the material of the welds and the heat-affected zone (HAZ). Thus, the geometry of the local interface zone of the base and deposited metals can also be considered a defect.

Materials and Methods. The study of the documents regulating the presence and size of welding defects has shown that they practically do not require the geometry of the sections of weld joints at the junction of the weld and the base metal. However, it is here that destruction occurs due to the formation and growth of crack-like defects [2, 4, 10]. When developing standards (for example, for main pipelines operating under static and re-static loads), it is important to consider not only the size of the defect that weakens the working section of the weld, but also its sharpness, which determines the local stress concentration at the defect mouth.

In [8], methods for predicting the stability of weld joints during fatigue work with account for the actual geometry of the welds and the probability of defects are presented. This approach is appropriate for the development of industry standards for the admissibility of welding defects considering the loading and responsibility of metal structures. These methods provide the determination of statistically valid characteristics of the weld joint quality.

In metal structures under static loads, defects in welds appear if their dimensions are so significant that they actually weaken the working cross-sections of the joints. To determine the strength of the joints and the acceptable dimensions of the defects, a static strength calculation for permissible stresses is performed.

It is advisable to approach the calculations of weld joints operating in the re-static load mode with crack-like defects, with regard to fracture mechanics. In this case, the stress intensity factor K_t [3, 10–12] is used:

$$K_t = \sigma\sqrt{\pi l}, \quad (2)$$

[1]Harchenko VYa, Assaulenko SS, Peredelsky VA. On the requirements for the quality of weld joints and their classification in machine-building structures. In: Proc. VII Sci.-Pract. Conf. on Innovative technologies in mechanical engineering and metallurgy. Rostov-on-Don: DSTU Publ. Center; 2015. P. 341–346. (In Russ.)

where σ — nominal voltages; *l* — half-length of the equivalent crack describing a typical size of crack-like defects defect (e.g., the undercut depth, the depth of faulty penetration, etc.).

In this case, defects with a radius at the vertex *R* of less than 0.25 mm can be conventionally classified as crack-like defects. These are the defects for which $R > 0.25$ mm can be conventionally considered blunt.

Research Results. One of the factors that determine the operational properties of welded structures are crack-like defects, such as: faulty penetrations, undercuts, inter-roll incomplete fusions, microcracks.

During visual and measuring control, it is very difficult to detect sharp defects with small measured values (0.1-0.25 mm). This is due to the low sensitivity of the measuring instrument and the human factor since the measurements are performed using the controller in manual mode [13].

Radiography and ultrasound are the two main non-destructive physical testing methods for detecting internal defects. Under studying the particularly critical structures, these methods often duplicate each other since they have different sensitivity and reliability. To bring out sharp, undetectable defects (e.g., cracks), an ultrasound control[1] is preferred [14, 15]. However, it is often done manually. Accordingly, the results may be affected by the human factor, so this method is not sufficiently reliable.

Major challenge in assessing the product quality may arise for specialists already at the preparation stage, when choosing the method of ultrasonic testing (e.g., when using the mirror-shadow method, the echo technique, or the shadow method). To choose, you need to know the methods of operation, as well as to consider the characteristics of the converters in accordance with GOST R 55725-2013[2]. Such knowledge is not always demonstrated even by third-level specialists, which is revealed during certification.

Equipment and quality control specialists should be able to correctly configure the flaw detector according to standard samples (SS-1, SS-2, SS-3) and according to the enterprise standard samples (ESS). Such templates are made of a material similar to the material of the object under control. The samples should correspond to the object in thickness and (if required) in radius (when checking small diameter pipes). However, the practice of conducting certification activities indicates that in some cases, specialists are not able to perform this work efficiently.

During the control process, the speed and step of scanning the object are also important. If the scanning speed is too high, the operator risks missing the defect or inaccurately determining its coordinates, the depth of occurrence and the boundaries of the discontinuity. The scanning speed standards are specified in the regulatory documentation. However, in the field, the control procedure is complicated by temperature difference, which depend on the time of year, venue, etc. For example, depending on the environment temperature, the temperature of the object under control changes, and this can affect the viscosity of the contact liquid. On the other hand, at low temperature, heating of the controlled area is required. This changes some of the physical properties of the object under control and, accordingly, the passage of ultrasound in the product, etc.

The main problem in summing up the results of the control and issuing conclusions is a free and subjective interpretation of the data obtained on the number of defects, depth and area of their occurrence. Much depends on the experience of the operator, his ability to distinguish the signals of defects from false or superficial ones.

Discussion and Conclusions. It is required to restrict the influence of the human factor to increase the reliability of the results of visual-measuring and ultrasonic quality control of weld joints. To achieve this goal, we consider it appropriate to organize additional training in the process of periodic mandatory assessment of the qualifications and certification of control specialists. Teachers should be experts of welding production. In short-term training programs, it is required to summarize information on the impact of sharp crack-like welding defects on the strength characteristics of welded structures and their operational life.

[1] GOST 55724–2013. Non-destructive testing. Welded joints. Ultrasonic methods. Federal Agency for Technical Regulation and Metrology. Moscow: Standartinform; 2019. 28 p. (In Russ.)

[2] GOST P 55725–2013. Non-destructive testing. Piezoelectric ultrasonic transducers. General technical requirements. Federal Agency for Technical Regulation and Metrology. Moscow: Standartinform; 2019. 16 p. (In Russ.)

During certification, it is required to use special simulators for ultrasonic testing and samples of weld joints of structural elements with artificially created defects that simulate their real size, shape and location in test samples. This will provide obtaining an objective assessment of the reliability and informativeness of ultrasound control.

References

1. Luk'yanov VF, Zhabin AN, Prilutskii AI. Normativnaya baza tekhnicheskogo regulirovaniya v svarochnom proizvodstve [Regulatory framework for technical regulation in welding production]. Rostov-on-Don: DSTU Publ. Centre; 2008. 302 p. (In Russ.)

2. Hesse A-C, Nitschke-Pagel T, Dilger K. On the effect of weld defects on the fatigue strength of beam welded butt joints. Procedia Structural Integrity. 2018;13:2053–2058.

3. Gorev VV, Uvarov BYu, Filippov VV, et al. Metallicheskie konstruktsii. V 3 t. [Metal structures. In 3 vol.], 3rd ed., VV Gorev (ed.). Moscow: Vysshaya shkola; 2004. Vol.1. 551 p. (In Russ.)

4. Gumerov AG, Yamaleev KM, Zhuravlev GV, et al. Treshchinostoikost' metalla trub nefteprovodov [Fracture toughness of metal of pipes of oil pipelines]. Moscow: Nedra-Biznestsentr; 2001. 231 p. (In Russ.)

5. Gosavi PD, Sarkar KK, Khunte SK, et al. Microstructure and mechanical properties correlation of weld joints of a high strength naval grade steel. Procedia Structural Integrity. 2019;14:304–313.

6. Shen W, Qiu Y, Xu L, et al. Stress concentration effect of thin plate joints considering welding defects. Ocean Engineering. 2019;184:273–288.

7. Papatheocharis T, Sarvanis GC, Perdikaris PC, et al. Fatigue resistance of welded steel tubular X-joints. Marine Structures. 2020;74:102809.

8. Luk'yanov VF, Parkhomenko AA, Rogozin DV. Otsenka ustalostnoi prochnosti svarnykh soedinenii s uglovymi shvami na osnove analiza lokal'nogo napryazhennogo sostoyaniya [Evaluation of fatigue strength of weld joints with angular seams based on the analysis of the local stress state]. Welding and Diagnostics. 2010;6:16–19. (In Russ.)

9. Kurkin AS, Makarov EL. Metodika rascheta resursa svarnykh konstruktsii s nalichiem defektov [Methods of calculating the service life of welded structures with defects]. Welding and Diagnostics. 2012;5:41–44. (In Russ.)

10. Hu Y, Yan R, Shen W, et al. A novel semi-analytical method for notch stress and fatigue strength analysis of tube-flange welded joints. International Journal of Fatigue. 2020;141:105860.

11. Poletaev YuV, Poletaev VYu, Rogozin DV. Vliyanie nadreza na sklonnost' svarnykh soedinenii k mezhzerennomu razrusheniyu [Notch effect on the liability of welded joints to intergranular fracture]. Vestnik of DSTU. 2015;3(82):28–34. (In Russ.)

12. Primož Štefane, Sameera Naib, Stijn Hertelé, et al. Effect of crack length on fracture toughness of welded joints with pronounced strength heterogeneity. Procedia Structural Integrity. 2018;13:1895–1900.

13. Shubochkin AE, Prilutsky MA, Susman GV, et al. O pogreshnosti izmereniya geometricheskikh parametrov svarnogo soedineniya s ispol'zovaniem shablonov [On the error of measuring the geometric parameters of the welded compound using templates]. Welding and Diagnostics. 2019:6:41–45. (In Russ.)

14. Aleshin NP, Chernyshev GG, eds. Svarka. Rezka. Kontrol'. Spravochnik v 2 t. [Welding. Cutting. Control. Reference book in 2 vols.] Moscow: Mashinostroenie; 2004. 480 p. (In Russ.)

15. Albuquerque V, Silva C, Moura E, et al. Thermal aging effects on the microstructure of Nb-bearing nickel-based superalloy weld overlays using ultrasound techniques. Materials & Design. 2012;36:337–347.

Submitted 23.12.2020

Scheduled in the issue 19.01.2021

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Claimed contributorship

V. A. Peredelsky: basic concept formulation; text preparation; formulation of conclusions. V. Ya. Harchenko: basic concept formulation; academic advising; analysis of source material; the text revision; correction of the conclusions. A. L. Chernogorov: performing calculations of the stress-strain state of welded joints; the text revision. S. V. Tihonov: formation of references; analysis of the research results.

All authors have read and approved the final manuscript.