LEVEL OF EFFECT OF PREPARATION AND ASSEMBLY FOR WELDING ON QUALITY OF WELDED JOINTS FOR INDUSTRIAL PIPELINES

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Investigations were carried out, and contribution of the effect of preparation and assembly for welding on the level of quality the welded joints in different dimension-type pipelines was estimated based on the experience of manufacture of welded industrial pipelines by using mathematical modelling and information technologies.

Keywords: *manual arc welding, preparation and assembly for welding, industrial pipelines, welded joints, defectiveness, reasons of reject, dominant factors, quality level*

The good perspectives for application of sufficiently complex models, reflecting multiple-factor and interaction of the effects taking place in the different technologies, is provided by the current level of computer technologies. Computer application for mathematical modelling makes its available for wide range of users connected with investigation as well as development and optimizing of engineer solutions [1–3].

Welding-assembly production (WP), in comparison to heavy machine-building enterprises oriented to gross production of uniform products, delivers with the help of welding the single and small branch products having different orientation to designation as well as internal content, i.e. methods of manufacture, structures being applied, welded materials and welding consumables. Therefore, it is virtually impossible to use classical mathematic statistics, applied for quality control in the gross (serial) production and assembly manufacture. A series of tasks is to be solved in this connection and first of all the task of production systematization for application of mathematical statistics apparatus. It was determined that a grouping on main elements of production is to be taken as a basis in formation of population of the welded joints. A steel grade, pipeline diameter or length of welded joint in a metal structure, thickness of welded material, welding procedure and method of testing were taken as grouping criteria (GC). An algorithm taking into account WP peculiarities was developed on this basis. For example, welded joints of 350–500 mm diameter and 6–8 mm wall thickness made using a method of manual arc welding (MAW) compose an uniform base population (BP) of the joints and objects, in which welding of these joints is carried out, are a space of random events with determined limits [3].

Mathematic description of BP formation is given by following model:

$$\mathrm{CAC} \in \sum \mathrm{OC} \in \sum \mathrm{WP} \in \sum \mathrm{GE} \in \sum \mathrm{GC}, \qquad (1)$$

where $\mathrm{WP} = \sum_{i=1}^{k} \mathrm{PE}_i$; $\mathrm{PE} = \sum_{j=1}^{m} \mathrm{GC}_j$;

or in matrix form

$$N_{\mathrm{BP}_i} = \begin{vmatrix} \mathrm{PE}_1 + \mathrm{PE}_2 + \ldots + \mathrm{PE}_i \\ \mathrm{GC}_{11} + \mathrm{GC}_{21} + \ldots + \mathrm{GC}_{i1} \\ \mathrm{GC}_{12} + \mathrm{GC}_{22} + \ldots + \mathrm{GC}_{12} \\ \ldots + \ldots + \ldots + \ldots \\ \mathrm{GC}_{1j} + \mathrm{GC}_{2j} + \ldots + \mathrm{GC}_{ij} \end{vmatrix},$$

where CAC is the construction-assembly complex; OC is the object of construction; PE is the production element; GE are the groups of elements; N is the number of elements included in BP; k, m is the amount of elements of production and GC, respectively.

The welded joint or area of joint of 300 mm length is taken as a BP unit. Production elements and their groups for each joint population should not vary significantly and form i-th construction-assembly series of the joints manufactured during specific working cycle under determined factor conditions of specific assembly organization. Concept introduced by us differs from known determination for lot of production according to GOST 15895–70 by the fact that the products can be manufactured at different objects and in different time. Mandatory requirement in manufacture of the base lot is a presence of unique technical documents.

The next task consists in a development of unified criteria for defectiveness measurement. Criteria of weld quality on reject fraction, fraction of total defectiveness in percents and relative area of defects g per test area are given in separate studies. Application of such criteria under assembly conditions is complicated on several reasons. Firstly, a relation of the criteria with existing normative documentation for quality evaluation is absent. Secondly, the calculations of relative area of girth welds are complicated. Besides, area of the defects g masks the possibility to detect such a dangerous defect as through worm-hole breaking system in whole. In comparison with the shallow long lack of penetration, g of the through worm-hole is less than in lack of penetration. Calculation formulae set general and unacceptable defectiveness in accordance with the requirements of ISO 3834 and SNiP. A complex criterion was set for evaluation of defectiveness structure and its relations on the whole by base population of the joints allowing evaluating defects on their length L (L_g — general defects being found, L_r — rejected, requiring removal) as well as on amount D (D_g — amount of general defects being found, D_r — rejected). Quality status of welding production, its processes and conditions can be characterized based on information about L and D (or simultaneously) over the specified test cycle (month, quarter, year etc.). Such a criterion is representative for each particular technology, performer and construction organization in whole. Numerical expression of this criterion and its structure are termed by us as a statistical formula of defectiveness (FD) [3–5]. General expression of BP FD is

$$\sum\sum\begin{vmatrix} L_g, & D_g \\ L_r, & D_r \end{vmatrix} = P(x_g,\ x_r) + \\ + S(y_g,\ y_r) + LP(z_g,\ z_r) + \ldots\ , \tag{2}$$

where P, S, LP are the pores, slag inclusions and lack of penetrations, respectively; x_g, y_g, z_g and x_r, y_r, z_r are the general and rejected amount and length of defects, respectively.

Partial expressions for L_g and L_r look like

$$L_g = \sum_{i=1}^{n} L_g^i/n = \sum_{i=1}^{n} P_g^i/n + \\ + \sum_{i=1}^{n} S_g^i/n + \sum_{i=1}^{n} LP_g^i/n + \ldots; \tag{3}$$

$$L_r = \sum_{i=1}^{n} L_r^i/n = \sum_{i=1}^{n} P_r^i/n + \\ + \sum_{i=1}^{n} S_r^i/n + \sum_{i=1}^{n} LP_r^i/n + \ldots \tag{4}$$

Formula (3) provides information on general defectiveness and (4) on unacceptable one according to SNiP.

The partial expressions of defectiveness formula are similar to expressions (3) and (4) for criteria D_g and D_r. Thus, a structure of defectiveness due to specific causes according to BP FD is determined in the following way:

$$D_g = \sum_{i=1}^{n} D_g^i/n = \sum_{i=1}^{n} P_g^i/n + \\ + \sum_{i=1}^{n} S_g^i/n + \sum_{i=1}^{n} LP_g^i/n + \ldots, \tag{5}$$

where n is the amount of tested areas.

It is well-known that the level of weld quality is affected by variety of different factors. Among them are preparation and assembly, qualification of performers, welding consumables, welding and auxiliary equipment, welding procedure, work organization, qualification of engineers, failure of working rhythm, flaw detection testing, heat treatment, welding conditions, season etc. Additional investigations were carried out for these factors. They allowed determining that preparation and assembly for welding, qualification of performers, welding consumables, welding procedure and welding equipment [4–5] are the factors dominating in formation of defectiveness (90 to 97 %).

However, the level of effect of each factor on quality level is different due to variety of joint dimension-types, different welding consumables, materials to be welded, methods and conditions of welding. Therefore, the main reasons of defects' formation during welding can be determined only under specific industrial conditions for specific BP of the joints.

Welding engineering can be optimized due to strengthening and modernizing of its weak sections through determining the level of effect of that or other industrial factor on quality of the joints of specific dimension-types. The level of quality of each factor, in turn, is determined by its main parameters which can have positive as well as negative effect. The negative parameters of the factor are, as a rule, the reason for defectiveness (reject) formation in welding (Figure 1). The level of defectiveness causes of which are specific factors and their parameters serves an optimality criterion. Thus, the important principle for monitoring of welding quality on a feedback of factor–cause–defect algorithm is realized.

The investigations were carried out in welding of the joints of different dimension-type industrial pipelines by methods of MAW, CO_2 mechanized welding, argon-arc welding (MAAW) and welding in CO_2 + + Ar mixture. Data obtained by non-destructive testing (NDT) methods, i.e. visual (VT), X-ray (XRT) and ultrasonic (UST), were used for defectiveness determination.

Figure 1 shows an algorithm of investigations. Welded joint with specific negative factor parameters were manufactured experimentally and during pre-object trainings of welders from different WP. The aim of investigations is to determine the types of defects and their amount formed during the moment of action of specific causes and the defectiveness structure depending on cause and DC in a series of causes acting on the objects of welding operations.

Classification of WP in BP and development of quantitative units of defectiveness measurement allowed creating a computer system for registration, monitoring and analysis of quality of welding operations and welded joints. A database and information about quality state of works being performed and defectiveness of welded joints was developed based on NDT data. Figure 2 shows an example of system window for processing of operative information about quality state of welding operations.

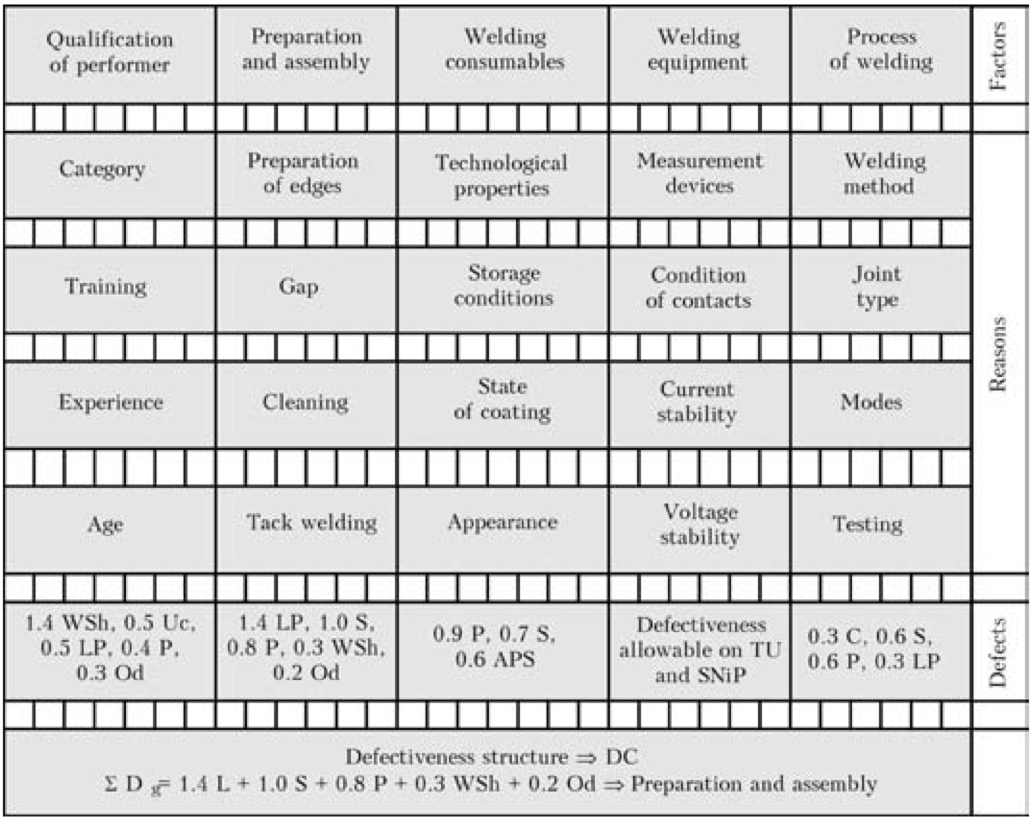

Figure 1. Algorithm for determination of dominant causes (DC) of defectiveness formation in welded joints on their structure: WSh — defects of weld shape; Uc — undercuts; APS — accumulation and chains of pores and slag; C — cracks; Od — other defects

Type of defectiveness representing specified DC and, as a result, specific industrial factor of welding technological process are to be determined for practical conditions. Probability of DC representation was determined based on statistical data of NDT carried out per cycle not less than one year using computer technologies and mathematical modelling:

$$P(\mathrm{DC}) = p_1/p_2 \text{ at } 0 < P(\mathrm{DC}) < 1, \qquad (6)$$

where p_1 is the amount of practical confirmations of specific DC; p_2 is the amount of all DC;

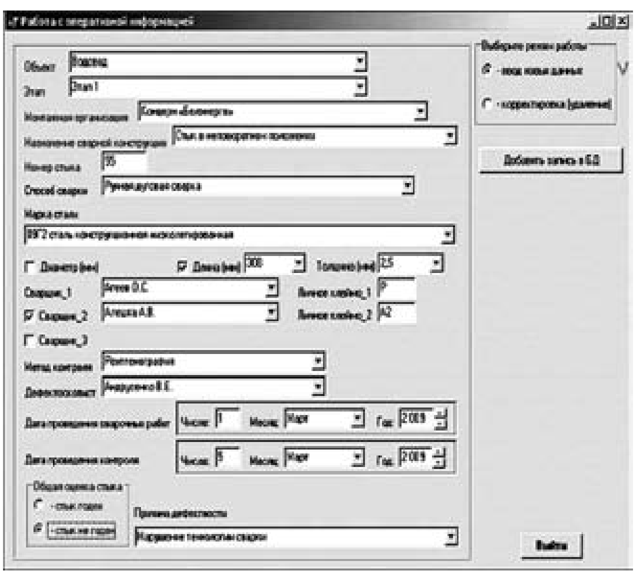

Figure 2. Main system window for processing of operative information on quality state of welding operations

$$P(\mathrm{DC}) = (A/\sum(\mathrm{FC}))\cdot 100\ \%, \qquad (7)$$

where Σ (FC) is the amount of all probable repeats of cause; A is the amount of practical confirmations of given cause.

For example, 2053 cases on «Preparation and assembly for welding» factor (PAW) were detected during 2009 when DC of formation of unallowable defectiveness was found by its negative parameters. 1754 cases among them were confirmed by expert judgment. Probability of DC representation by cause

$$P(\mathrm{DC})_{\mathrm{PAW}} = 1754/2053 = 0.85.$$

The causes of defectiveness in factor–cause–defect chain were analyzed using arrays of BP quality history for the period of not less than two years [6–8]. The main causes and defectiveness found in the test area at a moment of indicated cause effect were determined from the reports of the operator-inspectors or by expert judgment. The causes and defectiveness were processed and classified using computer equipment (Figures 3 and 4).

Preparation and assembly for welding is one of the dominant factors determining output level of the quality of welded joints. However, investigations of specific contribution and quantitative evaluation of its effect on quality of specific dimension-types of welded joints are virtually absent.

The reject, made by this factor, results in specific defects which are generated by main causes (negative

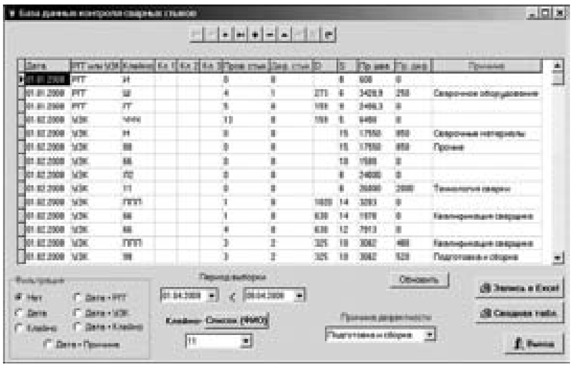

Figure 3. Example of system window for operation with database on quality of welded joints and causes of reject

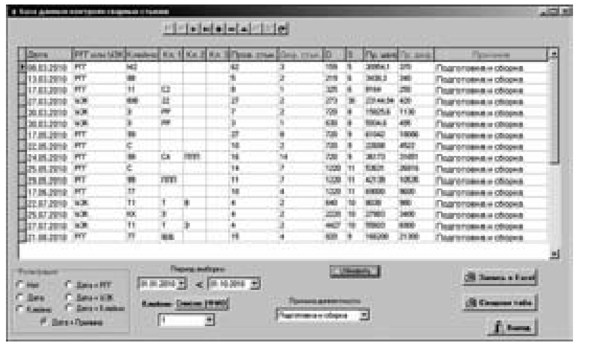

Figure 4. Example of obtaining of output information on PAW factor

parameters) of the reject on this factor, i.e. improper preparation of edges (root face angle, rounding radius), violation of gap dimensions (alignment) between the elements to be welded, low-quality cleaning (presence of rust, dents, chips and oils), tack welding etc. Investigation results are given in Table 1.

Establishment of dependencies of defectiveness formation and relation with causes of its formation is an important task solving which allows taking preventive measures on their warning before beginning of welding-assembly operations, improving technological processes and performing monitoring of welding quality on-line. Experimental investigations showed no functional relation between the causes of defectiveness formation and its amount, however, an important statistical relation was determined between the defectiveness structure and cause of its formation.

The following expressions are obtained using results of study of causes of defectiveness on PAW factor and formulae (3) and (6):

$$PAW_1 = P(0.8) + S(1.3) + LP(1.4) + WSh(0.25) + Od(0.2);$$

$$PAW_2 = P(0.6) + S(0.9) + LP(1.7) + WSh(0.4) + Od(0.3);$$

$$PAW_3 = P(1.1) + S(1.4) + LP(1.3) + WSh(0.3) + Od(0.25);$$

$$PAW_4 = P(0.8) + S(1.0) + LP(1.5) + WSh(0.5) + Od(0.2);$$

$$F_{PAW} = P(0.8) + S(1.0) + LP(1.4) + WsH(0.3) + Od(0.2),$$

where PAW_1 is the preparation of edges; PAW_2 is the gap (alignment); PAW_3 is the cleaning; PAW_4 is the tack welding; F_{PAW} is the structure of defectiveness on PAW factor.

Thus, it was determined by experiment that each negative parameter of studied factor is the cause of formation of unique peculiar only to it defectiveness structure [9–11] (Figure 5).

Defects of LP (1.4 per area of testing), S and P type and their inclusions as well as different WSh defects dominate in defectiveness structure due to causes of PAW factor.

Therefore, the causes of defectiveness formation on PAW factor in the welded joints of industrial pipelines allow making proved solutions on improvement of its parameters, reduction of specific contribution of reject and increase of quality level of the welded joints. Besides, total specific contribution of factor effect on quality level of the welded joints of specific dimension-types under different methods of welding, grades of welded materials and conditions of welding process can be determined.

Table 2 shows investigation results of effect of PAW factor on quality level (defectiveness) of the welded joints of industrial pipelines of different dimension-types. It can be seen that this level varies from 95.1 to 90.7 %. It was determined that the reject is significantly lower in mechanized and automatic methods of welding then in MAW. It follows form the Table that the specific contribution of effect of preparation and assembly on quality level of the welded joints increases with a rise of pipeline diameter independently on methods of welding. Thus, only 61 joint from 1250 joints were rejected in MAW of pipeline of 57 mm diameter, 11 joints (or 18 %) among them were rejected due to causes of factor being studied. At the same time, 167 joints in total from 1790, among which 57 (or 34.1 %) due to causes of studied factor, were rejected in welding of pipelines of 500 mm in diameter, i e. welding of big diameter joints is connected with complication of technology of welded joint manufacture.

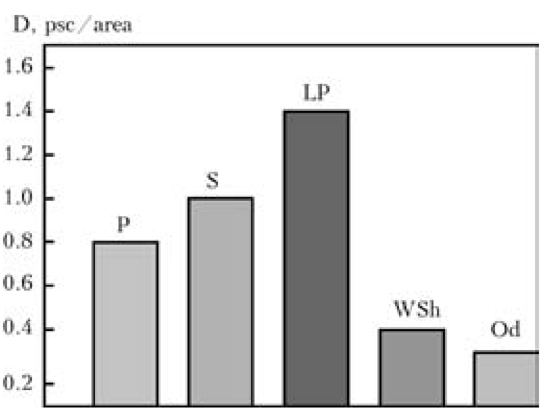

Figure 5. Diagram of defectiveness D being formed due to causes of PAW factor in welding of industrial pipelines of 57 to 500 mm diameter

Table 1. Defectiveness found due to causes of PAW factor, pcs

Method of welding	Amount of joints welded	Tested areas of 300 mm length	Pores and their clusters	Slag inclusions	Lacks of penetration	Defects of weld shape	Other defects
MAW	2450	7320	5850	8050	10980	2930	1830
MAW in CO_2	1600	4200	2940	4100	5900	1350	920
MAW in CO_2 + Ar	2100	5460	4370	4920	7650	1640	1100
MAAW	1820	5100	4590	4450	6650	1530	1020
Total	7970	22080	17750	21520	31180	7450	4870

Table 2. Effect of PAW factor on quality level of the welded joints of industrial pipelines

Method of welding	Steel grade	Thickness of steel, mm	Pipeline diameter, mm	Amount of butt-welded joints, pcs	Amount of rejected joints, pcs	Quality level, %	Total amount of joints rejected on PAW factor, pcs	Specific contribution of PAW factor, %
MAW	09G2	2.5	57	1250	61	95.1	11	18.0
MAW in CO_2 + Ar	20Kh	4.0	89	1270	73	94.3	18	24.6
MAAW	14KhGS	4.0	89	5740	360	93.7	84	23.3
MAW in CO_2 + Ar	20Kh	6.0	112	4300	290	93.3	73	25.3
MAW	14KhGS	6.0	112	2790	215	92.3	64	29.7
MAAW	14KhGS	10.0	289	2900	235	91.9	74	31.5
MAW	20Kh	10.0	289	1500	132	91.2	44	33.2
	14KhGS	14.0	500	1790	167	90.7	57	34.1
Total				21540	1533	92.7	425	27.7

Increase of diameter of pipelines complicates the process of PAW itself that is the main reason of reject growth. Even insignificant deviations of the gap (or alignment) between the elements being welded from that is required by technical regulations result in formation of unallowable defects. Welding in this case is carried out, as a rule, in several passes and after each a cleaning of deposited layer from scale and slag, performance of quality control and other actions are necessary.

CONCLUSIONS

1. The dominant factors, generating from 90 to 97 % of defects being formed, were determined as a result of investigations and based on data of NDT of quality of the welded joints in technological pipelines.

2. Cause-effect relationships of defectiveness formation in the welded joints were determined that allow taking preventive measures for warning reject due to causes of presence of this factor and control of welding quality on the feedbacks of factor–cause–defect algorithms.

3. Specific contribution of effect of preparation and assembly for welding on output quality level of the welded joints depending on dimension-types of pipelines and methods of welding was calculated. This allows quickly making proved control decisions on improvement of specific technological processes and assurance of the necessary quality of the welded joints.

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