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STUDY OF THE OPERATING TIME OF THE PROTECTIVE COATING OF SURFACES OF ASSEMBLY AND WELDING EQUIPMENT

The **subject** of the study is the issues related to determining the service life of protective coatings protecting the surfaces of assembly and welding fixtures from the effects of welding spatter and mechanical wear when performing certain assembly and welding operations of welded metal structures. The development in Ukraine of various industries, especially the precision engineering industry (instrument making), is characterized by a transition to market management methods, increasing demand for competitive and liquid products. This can be achieved by the systematic and rapid introduction of technically new products, improving their quality, increasing labor productivity, and automating production. Welded metal structures are widely used in the designs of modernized and new types of products, the high-quality production of which is impossible without the use of assembly and welding equipment. The reliability and durability of these devices depends on the protection of their surfaces to the effects of welding spatter and scoring during assembly and welding operations. Analytical and experimental studies of the resistance of protective coatings to an experimental welding drop of metal showed that of the most tested coatings, the most durable is the developed protective coating containing a mixture of molybdenum disulfide powder, graphite powder, epoxy varnish and certain solvents. **Purpose**: determination of the service life of the developed protective coating when exposed to a number of significant factors, including the effects of real welding spatter. **Tasks**: to identify the main - significant technological factors affecting the service life of the protective coating; develop a planning matrix based on a full factorial experiment; to conduct experimental studies of the resistance of the coating to the effect of an experimental metal drop under the influence of significant technological factors, to obtain the equations of regression of resistance; conduct analytical and experimental studies to determine the temperature of the experimental drop of molten metal; conduct analytical studies of the temperature of a real welding spray; conduct a study of the resistance to friction; conduct analytical studies to determine the quantitative characteristics of the reliability and durability of the proposed coating composition. **Results:** the article presents the research data by the authors of the service life of the proposed protective coating that protects the surfaces of assembly and welding fixtures when exposed to welding spatter and coating wear when moving metal structures in the fixture. The quantitative characteristics of the reliability and durability of the coating are obtained. **Conclusions:** A methodology has been developed for determining the service life of protective coatings protecting the surfaces of assembly and welding fixtures from the effects of welding spatter during welding operations and coating wear when moving elements of the welding structure in the fixture during assembly.

Keywords: assembly and welding equipment; protective coatings; welding spatter; protective film thickness; types of welding; likelihood of uptime; failure rate; failure intensity; life time.

Introduction

The solution of the urgent task of technological support of reliable operation and increase of the service life of assembly-welding technological equipment used for the manufacture of welded metal structures of various shapes, sizes, weights and various purposes. The main negative factor affecting the tool life is the effect of welding spatter on the surface of fixtures during assembly and welding operations. Different enterprises solve this problem in different ways: by using protective screens, water emulsions, lubricants, protective coatings, paints and varnishes and other protective equipment, without which assembly and welding equipment, after its first use, may lose accuracy or completely fail. The analysis of literature data and industrial studies showed that the most resistant to welding spatter are coatings (suspensions) based on molybdenum disulfide powders. A number of coatings on this basis have been developed using various film-forming. It was established that the optimal composition, which withstood the maximum number of experimental metal drops on a pilot plant until burnout, is a composition containing two parts, one of which is molybdenum disulfide powder and graphite powder, and the other film-forming component is epoxy varnish. This composition is diluted with a mixture of solvents to obtain the desired molar consistency.

A method of analytical calculation with experimental verification of the developed coating is proposed taking into account the influence of significant technological factors close to the actual operating conditions of the assembly and welding equipment. A method of analytical calculation based on the matrix of a complete factorial experiment is proposed and experiments are carried out to determine the resistance of the coating to an experimental metal drop depending on certain factors and regression equations are obtained. A methodology has been developed for determining the temperature of an experimental metal drop, and analytical studies have been carried out to determine the temperature of a real welding spray. The conversion factor for the transition from an experimental metal drop to a real welding spray is determined. The service life of the coating when exposed to welding spatter is determined. Investigations of the resistance of the coating to mechanical wear were carried out, and the service life of the coating was determined under the combined action of metal sprays and wear. A methodology has been developed and quantitative characteristics of the reliability and durability of the proposed protective coating have been determined.

Analysis of recent articles and publications

Recently, the development of industries such as defense, space, radio-electronic, computing and others in Ukraine is characterized by a transition to market management methods, increased demand for competitive and liquid products by the systematic and rapid introduction of technically new products, modernization of existing ones by improving their quality, increasing labor productivity automation of production. All this leads to an increase in the volume of work and the cost of technological preparation of production. One of the main elements in the designs of modernized and new types of products is welded metal structures, the production of which requires the use of a large number of special assembly and welding equipment. The cost of designing and manufacturing assembly and welding equipment for the complexity of individual products reaches 20 - 25% of the total cost of manufacturing this product [1, 2].

One of the effective ways that can significantly reduce material and labor costs is the use of adaptable technological equipment that allows you to assemble devices for various purposes from the same elements repeatedly. This is especially advisable in enterprises with pilot and small-scale production, as well as in the development of new products and the manufacture of an experimental batch. A gamut of standardized parts and assembly units of universal assembly devices for assembly-welding works (UDAW) with mounting grooves 8 was developed; 12; 16 mm [3, 4]. The design feature of this tooling is that the elements of the tooling kits are interchangeable, this allows you to use them repeatedly for a long time creating devices for various metal structures.

However, taking into account the operating features of assembly and welding equipment, its service life largely depends on the means of protecting its surfaces. Much attention has been and is being paid to the issue of improving the reliability and durability of this equipment, which is confirmed by the analysis of literature data.

The authors of this article conducted studies of the performance of assembly and welding equipment, identified the main factors affecting the tool life, identified failures and investigated experimental data on the creation of coatings based on molybdenum disulfide, graphite, epoxy varnish and a mixture of solvents [5–14].

The values of each component included in the composition of the coating, their ratio and application technology were established.

Molybdenum disulfide is an antifriction filler. Its use reduces the coefficient of friction and wear during friction, which arises as a result of frequent disassembly and assembly of devices and when installing parts of metal structures in devices. In addition, molybdenum disulfide has a positive effect on the resistance of the coating to the destructive effect of drops of molten metal.

Graphite, like molybdenum disulfide, is a filler in the coating. The main purpose of graphite in the coating is to give it the property of electrical conductivity, which provides a reliable current path to the welded nodes through coated elements of technological equipment, increasing the stability of burning of the electric arc and the stability of its excitation. Graphite as well as molybdenum disulfide increases the resistance of the coating to welding spatter.

Epoxy varnish is introduced into the coating composition as a binder at the stage of its preparation and deposition on the surface of the substrate, and then, after polymerization, it is film-forming, which provides reliable adhesion to the substrate (adhesion) and the required coating strength (cohesion).

Xylene, acetone, ethylcellosol are technologically auxiliary substances that act as solvents of the components of the epoxy varnish (polyester, epoxy resin, etc.). The method of their use ensures the quality of the applied coating, characterized by obtaining a coating of a certain molar consistency, the formation of a protective film of uniform thickness, and the absence of streaks and surges.

The surface substrate is the degreasing and removal of corrosion products, followed by phosphating in a phosphate solution.

It was experimentally stated that the optimum resistance of the developed coating to welding spatter and wear during friction is determined by a ratio of epoxy varnish and filler (MoSg and graphite) close to 1: 2. The best quality of the applied coating is determined by the total amount of solvents up to 50% of the total weight composition.

Preparation of a protective coating and its application require the use of certain equipment and qualified specialists. The coating on the parts is carried out in suspension by spray guns with a nozzle diameter of 0.8 mm - 1.2 mm. The nozzle distance from the part is within 300 mm. Spraying is carried out in a fume hood, coating consumption per 1 m_2 of surface is up to 300 g. Drying (curing) of the coating is carried out in a special cabinet with temperature control, in steps according to the specified mode. The total curing time of the coating is within 3–3.5 hours. After drying, the parts are cooled in indoor air.

The purpose of this work is analytical and experimental studies of the service life of the developed protective coating, depending on the effects of welding spatter and mechanical displacements of the welding elements during the assembly of the welded structure, taking into account the influence of a set of familiar technological factors. Development of methods and quantification of reliability and durability of the developed protective coating.

The service life of the developed coating is defined as the ratio of the resistance of the coating to the influence of real welding sprays, "m_p" to the average number of sprays bombarding the same elementary site during one year of operation of the fixture "N" [5, 7].

Resistance "m_p" was determined from the resistance of the coating obtained experimentally by "m_e" multiplied by the conversion coefficient "K_m", which allows you to switch from experimental metal droplets (formed on a special installation) to real welding spatter.

The determination of the "m_e" value was carried out on the basis of the method of mathematical planning [16, 17]. The resistance of the coating to metal droplets was determined in an experimental setup.

For specific experimental design conditions, 5 significant technological factors were studied at two levels: type of welding – x_1 (manual arc and semi-automatic in a carbon dioxide CO_2 environment); grade of the main material of devices – x_2 (steel 20 and cast iron VCh-50-32); spatial arrangement of the surface of the fixture relative to the welding zone – x_3 (vertical and horizontal); distance of the fixture surface from the welding zone – x_4 (350 and 50 mm); thickness of applied coating film – x_5 (30 and 10 microns).

The intervals of variation of factors at the upper and lower levels are given in table 1.

The planning matrix was built on the basis of the application of a full factorial experiment, including 32 experiments (table 2).

Table 1. *Significant technological factors*

Code	Factors				
	x_1	x_2	x_3	x_4	x_5
Main level (x^{i_o})	–	–	–	200	20
Range of variation ($\triangle x^i$)	–	–	–	150	10
Upper level (+)	Manual arc welding	Steel 20	Vertical	350	30
Lower level (-)	Welding in a CO_2 environment	Cast iron VCh-50–32	Horizontal	50	10

Table 2. *Experiment planning matrix*

No. experience	Factors						Optimization parameters y = me (number of weld drops)
	x_0	x_1	x_2	x_3	x_4	x_5	
1	+	+	+	+	+	+	480
2	+	-	+	+	+	+	430
3	+	+	-	+	+	+	470
4	+	-	-	+	+	+	410
5	+	+	+	-	+	+	420
6	+	-	+	-	+	+	350
7	+	+	-	-	+	+	400
8	+	-	-	-	+	+	330
9	+	+	+	+	-	+	250
10	+	-	+	+	-	+	200
11	+	+	-	+	-	+	195
12	+	-	-	+	-	+	175
13	+	+	+	-	-	+	185
14	+	-	+	-	-	+	140
15	+	+	-	-	-	+	150
16	+	-	-	-	-	+	115
17	+	+	+	+	+	-	310
18	+	-	+	+	+	-	260
19	+	+	-	+	+	-	270
20	+	-	-	+	+	-	235
21	+	+	+	-	+	-	250
22	+	-	+	-	+	-	200
23	+	+	-	-	+	-	210
24	+	+	-	-	+	-	110
25	+	+	+	+	-	-	80
26	+	-	+	+	-	-	65
27	+	+	-	+	-	-	72
28	+	-	-	+	-	-	50
29	+	+	+	-	-	-	67
30	+	-	+	-	-	-	30
31	+	+	-	-	-	-	35
32	+	-	-	-	-	-	15

The significance of the factors was evaluated by regression coefficients based on the calculation of confidence intervals. By implementing the full factorial experiment, we obtained a linear regression equation:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5.$$

In our case

$$y = m_p = 217,7 + 21,7x_1 + 11,8x_2 + 29,5x_3 + 103,5x_4 + 76,3x_5.$$

$$\triangle b = \pm 3,84.$$

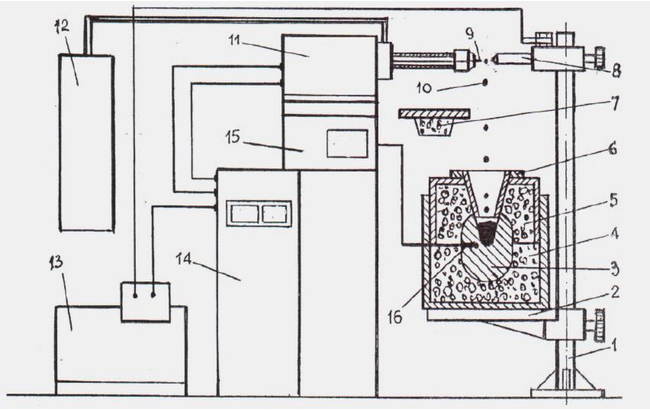
It is established that the average value of the resistance of the proposed coating composition under the influence of technological factors in experimental conditions is in the range of 160 325 drops of metal. Deviations of calculated values of coating resistance from experimental ones did not exceed.

Having determined the resistance of the coating to the action of metal droplets under experimental conditions, to go to real, i.e. determination of the resistance of the coating to the effects of real welding spatter (m_p), it is necessary to solve two problems. The first is the determination of the temperature of experimental drops of metal $T_{e.d}$; the second is the determination of the temperature of real welding spatter $T_{r.w.s}$.

The temperature coefficient was determined by the ratio of the temperature of the experimental droplets $T_{e.d}$ to the temperature K_t of the actual welding spatter $T_{r.w.s}$.

$$K_t = \frac{T_{e.d}}{T_{r.w.s}} .$$

The temperature $T_{e.d}$ was determined experimentally using the calomerization method in a special installation of fig. 1, installing the colorimeter block at various distances from 50 to 1000 mm from the welding arc.



1 – tripod; 2 – base table; 3 – calorimeter block; 4 – case; 5 – cover; 6 – funnel; 7 – cork; 8 – non-consumable electrode; 9 – a melting electrode; 10 – drops of molten metal; 11 – wire feed mechanism; 12 – CO_2 cylinder; 13 – welding converter; 14 – control cabinet; 15 – measuring device; 16 – temperature sensor.

Fig. 1. Installation diagram for the determination of experimental metal droplets

$T_{e.d}$ was determined from the equation through the amount of heat received by the calorimeter block and the average specific heat content of metal droplets in the block.

$$T_{e.d} = T_m + \left[\frac{S_{y_h} - (C_{mb}T_m + W_m)}{C_{mb}}\right],$$

Where T_m is the melting temperature of the metal, °C; S_{y_h} – average specific heat content of welding droplets for various *h*, cal.g; C_{mb} – the average specific heat of the metal from normal temperature to the melting point, cal/g grad; W_m – latent heat of melting, cal/g grad.

The calculation data of the experimental drops of molten metal are given in table 3.

Table 3. *The calculated temperature values of the experimental metal drop*

Drop span *h*, mm	**Average specific drop heat S_{y_h} , cal.g**	**The temperature of the experimental drop, $T_{e.d}$, °C**
50	662,0	3928
120	632,0	3730
240	611,0	3592
360	590,0	3454
480	580,0	3388
600	570,0	3322
1000	560.0	3256

The temperature of real welding spatter $T_{r.w.s}$ was determined analytically using the dependence of the amount of heat lost by the welding drop in the arc gap due to radiation. It was found that welding sprays, in contrast to metal droplets in the arc gap, in addition to emitting, give off heat $Q_{w.s}$ due to convection and thermal conductivity are determined from the expression:

$$Q_{w.s} = F_{w.s} \cdot \alpha_c (T_{w.s} - T_m) + F_{w.s} \cdot C_0 \varepsilon (\frac{T_{w.s}{}^4}{100^4} - \frac{T_m{}^4}{100^4}),$$

where $F_{w.s}$ – heat transfer surface welding spatter, m^2; α_c – contact coefficient of heat transfer, determined by blowing welding balls of molten metal in the shape of a ball, $\frac{kcal}{m^2 \cdot grad \cdot g}$; $T_{w.s}$ – the initial temperature of the spray, $°C$; T_m – medium temperature, $°C$; C_0 – absolute blackbody emissivity, $\frac{kcal}{m^2 \cdot grad \cdot g}$; ε – reduced degree of blackness of the system.

By a known $Q_{w.s}$ the change in temperature $T_{w.s}$ in the time interval is determined:

$$T_{w.s} = \frac{4{,}187 R_{w.s}^3 \cdot \gamma C_m \cdot T_{w.s.in} - Q : \Delta t}{4{,}187 R_{w.s}^3 \cdot \gamma C_m},$$

where $R_{w.s}$ – the average radius of the spray, m; γ – specific weight of the material spray kg/m^2; C_m – specific heat capacity spray, $\frac{kcal}{kg \cdot grad}$; $T_{w.s.in}$ – welding spray temperature at the initial moment of the time interval Δt $°C$; Δt – the numerical value of the time intervals, h.

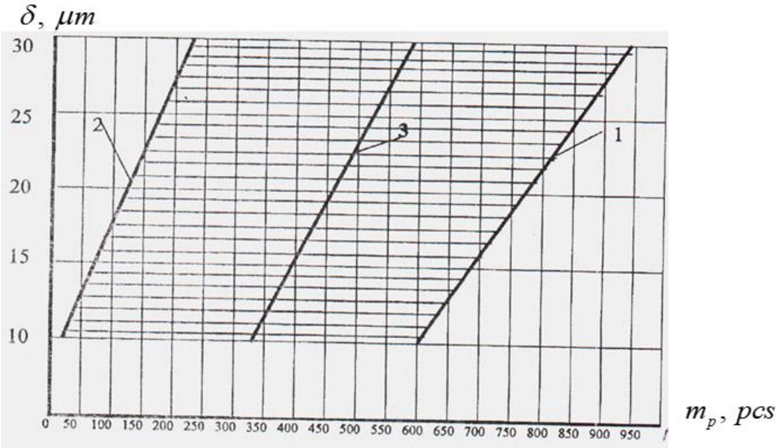
The data for the calculation are given in table 4.

Table 4. *Data for calculating the temperature of the welding spray*

V	Rc	Nu	α_c	Δt	Q	$Q \cdot \Delta t$	$T_{s.in}$	$T_{s.fin}$
					9,18	0,0073	2300	2197
					7,81	0,0062	2197	2109
					6,78	0,0054	2109	2033
					5,98	0,0047	2033	1966
1,2	115,3	7,21	106,7	0,0008	5,35	0,0042	1966	1906
					4,82	0,0038	1906	1852
					4,39	0,0035	1852	1803
					4,02	0,0032	1803	1758
					3,70	0,0029	1758	1716
					8,74	0,0131	2300	2104
					6,33	0,0094	2104	1962
					4,92	0,0074	1962	1851
					4,04	0,0060	1851	1760
0,48	46,1	5,1	75,48	0,0015	3,40	0,0051	1760	1683
					2,93	0,0043	1683	1617
					2,58	0,0038	1617	1559
					2,29	0,0034	1559	1507
					2,05	0,0030	1507	1460

As a result of analytical and experimental studies, it was found that the final temperature of the welding spray during manual arc welding and various span distances varies from 2197 to 1716 $°C$, and for semi-automatic welding in CO_2 from 2104 to 1460 $°C$.

The average temperature coefficient K_t = 1.95, and the average resistance of the developed protective coating "m_p" is 325 - 600 drops of metal (fig. 2).



1 – welding in a CO_2 environment; 2 – manual arc welding; 3 – average value of accuracy

Fig. 2. The resistance of the protective coating me to the effects of welding spatter

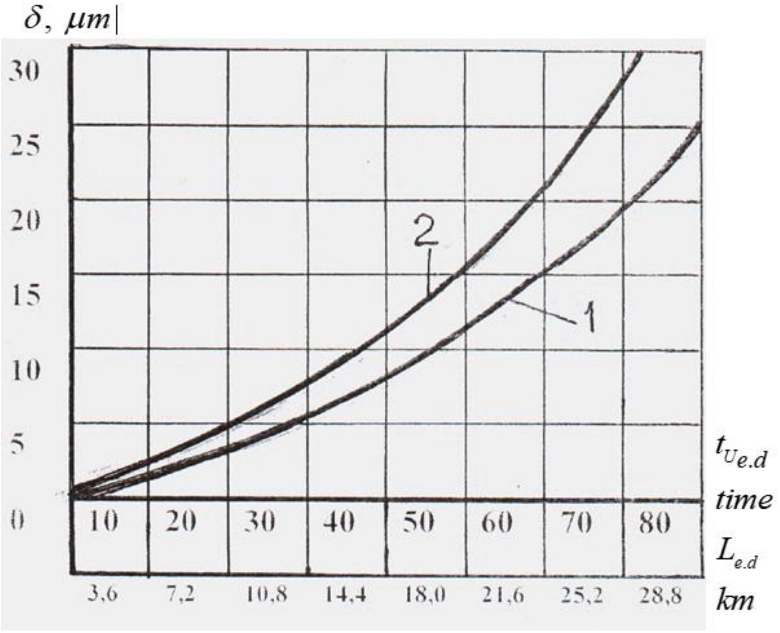
Based on analytical and experimental studies, the operating time of the proposed protective coating is obtained: when performing welding or assembly – welding operations, which is for various surfaces from 4 to 15 years with a single application.

The wear time of the coating during mechanical friction of metal elements on the surface of fixture tu is determined by the ratio of the length of the path of the surfaces of friction pairs obtained under experimental conditions (L_{ex}) to the average path of metal elements in the fixture in real conditions (L_p) for one year operation equal for base plates up to 1300 m, base and support-hull tooling elements up to 1800 m.

To determine Lex the friction pairs were prepared: steel 20X coated and steel ST3 uncoated, cast iron VCh-50-32 coated and steel ST3 uncoated.

The tests were carried out on a MIG - 1 machine [5] at a pressure of 0.5 MPa and a displacement velocity of 0.1 m / s (40 double strokes per min.).

The graph of coating wear during experimental studies is shown in fig. 3.



1 – steel ST3 (uncovered) on steel 20X (coated); 2 – steel ST3 (uncovered) on cast iron VCh-50-32 (coated)

Fig. 3. Schedule changes in the thickness of the protective coating during mechanical friction

Mathematical models of wear curves " δ " of the developed coating, depending on the base material of the friction pairs and the operating time (*t*), are determined from the equation

$$y = C_0 + C_1 t_{u1} + C_2 t_{u2} + C_3 t_{u3}.$$

To determine the coefficients C_0, C_1, C_2, C_3, we applied the method of sigular arrangement (SVD), which consists in the following: at given times $t_{u1} < t_{u2} < t_{u3}$ and obtained experimental results $y_{u1} ... y_{un}$, we can assume:

$$y = c_1 \varphi_1(t_u) + c_2 \varphi_2(t_u) + ... + c_k \varphi_k(t)(t)_u.$$

Having compiled a plan matrix $\alpha = \varphi : (t_i)$, $i = \overline{1, \Pi}$; $j = \overline{1, K}$ consider the column vector $\overline{y_u} = \begin{Bmatrix} y_{u\,1} \\ ... \\ y_{u\,n} \end{Bmatrix}$; $\overline{C} = \begin{Bmatrix} C_1 \\ ... \\ C_k \end{Bmatrix}$ and having made a number of mathematical transformations, we find the values C_1, C_2, C_3 that are given in table 5.

Table 5. *The calculated data of wear factors*

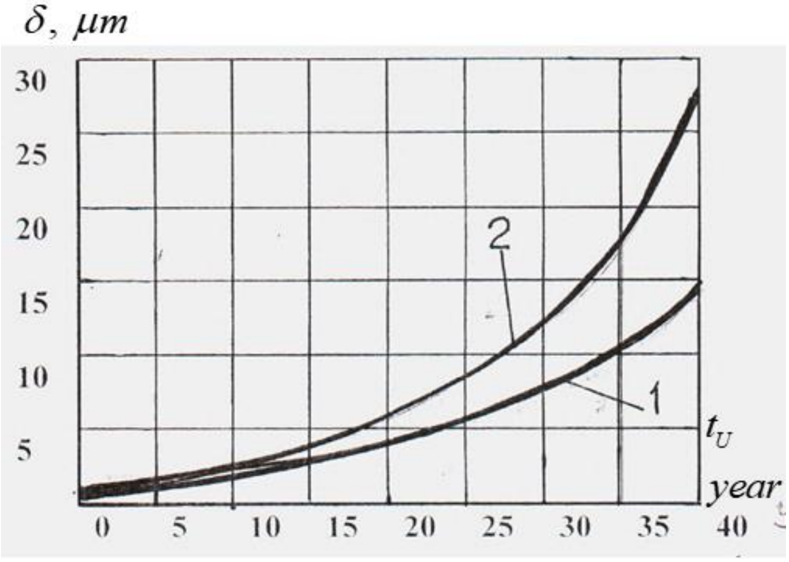
No. of experiment	Friction pairs	C_0	C_1	C_2	C_3	$\delta = y_u = f(t_u)$
1	ST3 steel (uncoated) on steel 20X (coated)	0	2,6	-0,3	0,4	$y_{u\,1}$
2	Steel ST3 (uncovered) for cast iron VCh-50-32 (coated)	0	3,6	0,4	0,2	$y_{u\,2}$

Then the mathematical models of wear curves have the form:

$$\delta_1 = y_{u1} = 2,6\left(\frac{t_1}{20}\right) - 0,3\left(\frac{t_1}{20}\right)^2 + 0,4\left(\frac{t_1}{20}\right)^3;$$

$$\delta_2 = y_{u2} = 3,6\left(\frac{t_2}{20}\right) - 0,4\left(\frac{t_2}{20}\right)^2 + 0,2\left(\frac{t_2}{20}\right)^3.$$

The processing of the results on a computer showed that the operating time of the proposed coating during mechanical friction and the proper operation of fixtures in the assembly of welded metal structures for various groups of tooling elements is 25-30 years or more (fig. 4).



1 – steel ST3 (uncovered) on steel 20X (coated); 2 – steel ST3 (uncovered) on cast iron VCh-50-32 (coated)

Fig. 4. The service life of the protective coating during assembly operations

The concept of reliability and durability can be formulated by the main characteristics, with the help of which it is possible to quantitatively evaluate the reliability of the coating composition [16, 17]. These characteristics are: the probability of uptime – $P(\tau)$, the failure rate – $\alpha(\tau)$, the failure intensity – $\lambda(\tau)$, the average uptime – T, the readiness factor K_r.

In these studies, the term τ is considered in two cases: the time during which the assembly of metal structures and the tacking of elements (τ_w) and the time during which the final welding of the metal structure is performed (τ_c).

According to statistics, the main characteristics of reliability are estimated by the following equations:

Uptime probability $\overline{P_{as}}(\tau_{as})$ and $\overline{P_w}(\tau_w)$

$$\overline{P_{as}}(\tau_{as}) = \left|\frac{N_{as} - n_{as}(\tau_{as})}{N_{as}}\right|;$$

$$\overline{P_w}(\tau_w) = \left|\frac{N_w - n_w(\tau_w)}{N_w}\right|.$$

Failure rate $\overline{\alpha_{as}}(\tau_{as})$ and $\overline{\alpha_w}(\tau_w)$

$$\overline{\alpha_{as}}(\tau_{as}) = \frac{n_{as}(\tau_{as})}{N_{as}\Delta\tau_{as}};$$

$$\overline{\alpha_w}(\tau_w) = \frac{n_w(\tau_w)}{N_w\Delta\tau_w}.$$

Failure intensity $\overline{\lambda_{as}}(\tau_{as})$ and $\overline{\lambda_w}(\tau_w)$;

$$\overline{\lambda_{as}}(\tau_{as}) = \frac{n_{as}(\tau_{as})}{N_{c_{as}}\Delta\tau_{as}};$$

$$\overline{\lambda_w}(\tau_w) = \frac{n_w(\tau_w)}{N_{cw}\Delta\tau_w},$$

where N_{as}, N_w – the number of samples placed under observation, pcs.; n_{as}, n_w – the number of samples that failed in time (τ_{as}) or (τ_w), pcs.; $\Delta\tau_{as}$, $\Delta\tau_w$ – selected value of the time interval, years; $N_{c_{as}}$, N_{c_w} – the average number of working samples in the time interval, pcs.

Average time of trouble-free work $\overline{T_{as}}$ and $\overline{T_w}$

$$\overline{T_{as}} = \frac{\sum_{i=1}^{\frac{\tau_{k_{as}}}{\Delta\tau_{k_{as}}}} n_{as_i}\tau_{as_i}}{N_{as}};$$

$$\overline{T_w} = \frac{\sum_{i=1}^{\frac{\tau_{k_w}}{\Delta\tau_{k_w}}} n_{w_i}\tau_{w_i}}{N_w},$$

where n_{as_i}, n_{w_i} – the number of samples that failed in the i-th interval, pcs.; τ_{as_i}, τ_{w_i} – average time of the i-th interval, years; $\tau_{k_{as}}$, τ_{k_w} – number of all failed samples over time N_{as} and N_w, pcs.

As a result of statistical studies and mathematical processing, the statistical characteristics of coatings reliability $\overline{P}$, $\overline{\alpha}$, $\overline{\lambda}$ are shown in fig. 5.

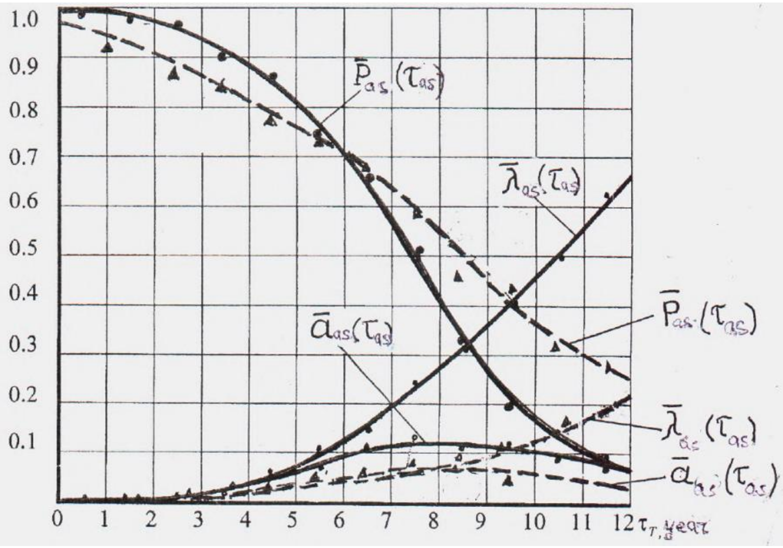


Fig. 5. Statistical characteristics of the reliability of the coating

The average values of the operating time of coatings "$\bar{x}$" and the standard deviation "σ" are determined from the expressions

$$\bar{x} = \bar{T} = \frac{1}{N}\sum_{i=1}^{k} n_i x_i = C + hu ,$$

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{k} n_i (x_i - \bar{x})^2} = h\sqrt{\frac{hu}{N-1} - (\bar{u})^2} ,$$

where C is the middle of the middle interval; h is the length of the interval (1 year); $\bar{u}$ – interval number.
The calculation data are given in table 6.

Table 6. *Data for the calculation of the operating time "$\bar{x}$" and standard deviation "σ"*

Initial data			Calculation		
intervals τ , years	**mid interval**	**number of failures *h*, pcs.**	***u***	***hu***	**(*hu*)^2**
Assembly operations					
1-2	1,5	1	-6	-6	36
2-3	2,5	2	-5	-10	100
3-4	3,5	2	-4	-8	65
4-5	4,5	3	-3	-9	81
5-6	5,5	10	-2	-20	400
6-7	6,5	14	-1	-14	196
7-8	7,5	16	0	0	0
8-9	8,5	16	1	16	256
9-10	9,5	13	2	26	676
10-11	10,5	10	3	30	900
11-12	11,5	6	4	24	576
12-13	12,5	4	5	20	400
13-14	13,5	2	6	12	144
14-15	14,5	1	7	7	49
Total		100		68	3878
Assembly operations					
1-2	1,5	2	-3	-6	36
2-3	2,5	3	-2	-6	36
3-4	3,5	8	-1	-8	64
4-5	4,5	37	0	0	0
5-6	5,5	30	1	30	900
6-7	6,5	10	2	20	400
7-8	7,5	6	3	18	324
8-9	8,5	4	4	16	256
Total		100		64	2016

After processing the results of statistical studies, it was found that the average value of the operating time of the coating during assembly operations is x_{as} = T_{as} = 8 years for welding operations x_c = T_c = 5 years, standard deviation σ_{as} = 6 years, σ_c = 4.5 years.

When assessing the analytical characteristics of the reliability and durability of a coating, wear failures are the main ones, the time of occurrence of which obeys the truncated normal distribution law.

The failure rate in this case is determined by the well-known equation:

$$\alpha(\tau) = c \cdot e^{\frac{-(\tau - \mathrm{T}_1)^2}{2\sigma}},$$

where c is the constant of the truncated normal distribution, which is determined from the expression

$$c = \frac{\sqrt{\dfrac{2}{P}}}{\sigma\left[1 + \varphi(\dfrac{\mathrm{T}_1}{\sigma\sqrt{2}})\right]},$$

where σ – standard deviations; φ – probability interval.

After carrying out certain calculations, we obtained for assembly operations c = 0.101, for welding operations c=0,099.

For our case, we get the following failure rates

$$\alpha_{as}(\tau_{as}) = 0{,}101 e^{\frac{-(\tau_{as} - 8)^2}{72}},$$

$$\alpha_w(\tau_w) = 0{,}099 e^{\frac{-(\tau_w - 5)^2}{40{,}5}}.$$

There is a relationship between $\alpha(\tau)$ and $P(\tau)$

$$P(\tau) = 1 - \int_0^\tau \alpha(\tau) d\tau.$$

Substituting the values $\alpha(\tau)$ and c and making a series of mathematical transformations, we obtain

For assembly operations

$$P_{as}(\tau_{as}) = \left[\frac{1 - \varphi\left(\dfrac{\tau_{as} - T_{as}}{\sigma_{as}\sqrt{2}}\right)}{1 + \varphi\left(\dfrac{T_w}{\sigma_{as}\sqrt{2}}\right)}\right] = \left[\frac{1 - \varphi\left(\dfrac{\tau_{as} - 8}{8{,}46}\right)}{1{,}945}\right].$$

For welding operations

$$P_w(\tau_w) = \left[\frac{1 - \varphi\left(\dfrac{\tau_w - T_w}{\sigma_w\sqrt{2}}\right)}{1 + \varphi\left(\dfrac{T_w}{\sigma_w\sqrt{2}}\right)}\right] = \left[\frac{1 - \varphi\left(\dfrac{\tau_{as} - 5}{6{,}34}\right)}{1{,}788}\right].$$

For probabilistic determination of the failure rate of the coating between $\lambda(\tau)$, $P(\tau)$ and $\alpha(\tau)$ there is a dependence

$$P(\tau) = e^{\int_0^\tau \lambda(\tau) d\tau},$$

$$\alpha(\tau) = \lambda(\tau) e^{\int_0^\tau \lambda(\tau) d\tau},$$

$$\lambda(\tau) = \frac{\alpha(\tau)}{P(\tau)} = \frac{c \cdot e^{-\frac{(\tau - \mathrm{T}_1)^2}{2\sigma^2}}}{P(\tau)}.$$

Having completed a number of mathematical transformations, we obtain for our case:

For assembly operations

$$\lambda_{as}(\tau_{as}) = \frac{\sqrt{\dfrac{2}{P}} e^{-\frac{(\tau_{as} - T_{as})^2}{\sigma_{as}^2}}}{\sigma_{as}\left[1 - \varphi\left(\dfrac{\tau_{as} - T_{as}}{\sigma_{as}\sqrt{2}}\right)\right]} = \frac{0{,}8 e^{-\frac{(\tau_{as} - 8)^2}{72}}}{6\left[1 - \varphi\left(\dfrac{\tau_{as} - 8}{8{,}46}\right)\right]}.$$

For welding operations

$$\lambda_w(\tau_w) = \frac{\sqrt{\dfrac{2}{P}} e^{-\frac{(\tau_w - T_w)^2}{\sigma_w^2}}}{\sigma_w\left[1 - \varphi\left(\dfrac{\tau_w - T_w}{\sigma_w\sqrt{2}}\right)\right]} = \frac{0{,}8 e^{-\frac{(\tau_w - 5)^2}{40{,}5}}}{6\left[1 - \varphi\left(\dfrac{\tau_w - 5}{6{,}34}\right)\right]}.$$

The reliability characteristics of obtaining analytically are presented in the form of graphs (fig. 6).

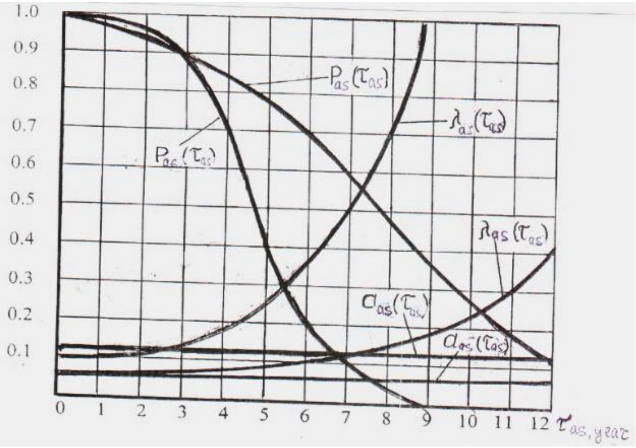


Fig. 6. Analytical characteristics of the reliability of coatings

The average failure-time of protective coatings in the probabilistic version is found from the equation

$$T=\int_0^{\infty}\tau\alpha(\tau)dt=C\int_0^{\infty}\tau e^{-\frac{(\tau-T_1)^2}{2\sigma^2}}d\tau.$$

Performing a series of mathematical transformations, we obtain for our case:

When performing assembly operations

$$T_{as}=T_{as}+C_{as}\sigma_{as}^2 e^{\frac{-T_{as}^2}{2\sigma_{as}^2}}=9,6 \text{ years.}$$

When performing welding operations

$$T_w=T_w+C_w\sigma_w^2 e^{\frac{-T_w^2}{2\sigma_w^2}}=5,5 \text{ years.}$$

The considered characteristics make it possible to evaluate the reliability of coatings, but do not allow to establish a relationship between the time components of the operation cycle, not taking into account the time spent on preventive measures and repairs ensuring the durability of the elements of assembly and welding equipment. To solve this issue, a performance coefficient k_p is introduced, which is determined from the expression:

$$k_p=\frac{T}{T+T_p},$$

where T – uptime, h; T_p – the time it takes to restore the failed element, h.

In the process of conducting research on the performance of assembly and welding equipment, one of the main issues in the operation of equipment is the reliability and durability of protective equipment (protective coating) when exposed to welding splashes during welding and mechanical wear during the assembly of welding metal structures in the device.

The method of graphic summation of developments proposed coating protects surfaces during execution of welding operations and the assembly process determined that the average time to failure of the protective coating is 5 – 6 years. It is theoretically revealed and experimentally proved that to ensure an 8 – 10 – year service life of the working surfaces of equipment placed near the welding zone, 2-time coating is necessary, respectively.

Conclusions

Based on experimental studies, it was determined that the resistance of the proposed protective coating against the impact of welding splashes is described by a multi – factor linear polynomial, and the resistance of the coating during mechanical movement is described by a cubic parabola. Based on experimental studies, it was found that the operating time of the working surfaces of assembly and welding equipment during assembly work (assembly and tacking metalwork elements) is 6–15 years, and when performing assembly and welding operations (tacking and final welding) from 4 to 8 years. Mathematical dependences of the probability of failure-free operation, the frequency and intensity of failures are obtained. The average uptime of the coating is 6 years. It is theoretically determined and experimentally confirmed that to ensure an 8–10-year service life, two-time coating application is necessary.

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ДОСЛІДЖЕННЯ НАПРАЦЮВАННЯ ЗАХИСНОГО ПОКРИТТЯ ПОВЕРХОНЬ СКЛАДАЛЬНО-ЗВАРЮВАЛЬНОГО ОСНАЩЕННЯ

Предметом дослідження в статті є питання, пов'язані з визначенням терміну служби захисних покриттів, що оберігають поверхні складально-зварювальних пристосувань від впливу зварювальних бризок і механічного зносу при виконанні певних операцій по збірці і зварюванні зварних металоконструкцій. Розвиток в Україні різних галузей промисловості, особливо галузі точного машинобудування (приладобудування), характеризується переходом на ринкові методи господарювання, підвищення попиту на конкурентоспроможну і ліквідну продукцію. Цього можна досягти систематичним і швидким впровадженням технічно нових виробів, підвищення їх якості, збільшенням продуктивності праці, автоматизацією виробництва. У конструкціях модернізованих і нових видах виробів широко застосовуються зварні металоконструкції, якісне виготовлення яких неможливо без застосування складально-зварювального оснащення. Надійність і довговічність даних пристосувань залежить від захисту їх поверхонь впливу зварювальних бризок і задирам при виконанні складальних і зварювальних операцій. Аналітичні і експериментальні дослідження стійкості захисних покриттів впливу експериментальної зварювальної краплі металу показали, що з більшості апробованих покриттів найбільш довговічним є розроблене захисне покриття, що містить суміш порошку дисульфіду молібдену, порошку графіту, епоксидного лаку і певних розчинників. **Мета:** визначення терміну служби розробленого захисного покриття при впливі ряду значущих чинників, в тому числі впливу реальних зварювальних бризок. **Завдання:** виявити основні – значущі технологічні чинники, які впливають на термін служби захисного покриття; розробити матрицю планування на підставі повного факторного експерименту; провести експериментальні дослідження стійкості покриття впливу експериментальної краплі металу при впливі значущих технологічних факторів, отримати рівняння регресії стійкості; провести аналітичні та експериментальні дослідження з визначення температури експериментальної краплі розплавленого металу; провести аналітичні дослідження температури реальної зварювальної бризки; провести дослідження стійкості покриття при терті; провести аналітичні дослідження щодо визначення кількісних характеристик надійності і довговічності запропонованого складу покриття. **Результати**: в статті представлені дані досліджень авторами терміну служби запропонованого захисного покриття, що оберігає поверхні складально-зварювальних пристосувань при впливі зварювальних бризок і зносу покриття при переміщенні елементів металоконструкцій в пристосуванні. Отримано кількісні характеристики надійності і довговічності покриття. **Висновки**: Розроблено методологію щодо визначення терміну служби захисних покриттів, що оберігають поверхні складально-зварювальних пристосувань від впливу зварювальних бризок при виконанні зварювальних операцій і зносу покриття при переміщенні елементів зварювальної конструкції в пристосуванні при складанні.

Ключові слова: складально-зварювальна оснастка; захисні покриття; зварювальні бризки; товщина захисної плівки; види зварювання; ймовірність безвідмовної роботи; частота відмов; інтенсивність відмов; строк служби.

ИССЛЕДОВАНИЕ НАРАБОТКИ ЗАЩИТНОГО ПОКРЫТИЯ ПОВЕРХНОСТЕЙ СБОРОЧНО-СВАРОЧНОЙ ОСНАСТКИ

Предметом исследования в статье являются вопросы, связанные с определением срока службы защитных покрытий, предохраняющих поверхности сборочно-сварочных приспособлений от воздействия сварочных брызг и механического износа при выполнении определенных операций по сборке и сварке сварных металлоконструкций. Развитие в Украине различных отраслей промышленности, особенно отрасли точного машиностроения (приборостроения), характеризуется переходом на рыночные методы хозяйствования, повышения спроса на конкурентоспособную и ликвидную продукцию. Этого можно достичь систематическим и быстрым внедрением технически новых изделий, повышения их качества, увеличением производительности труда, автоматизацией производства. В конструкциях модернизированных и новых видах изделий широко применяются сварные металлоконструкции, качественное изготовление которых невозможно без применения сборочно-сварочной оснастки. Надежность и долговечность данных приспособлений зависит от защиты их поверхностей воздействию сварочных брызг и задирам при выполнении сборочных и сварочных операций. Аналитические и экспериментальные исследования стойкости защитных покрытий воздействию экспериментальной сварочной капле металла показали, что из большинства апробированных покрытий наиболее долговечным является разработанное защитное покрытие, содержащее смесь порошка дисульфида молибдена, порошка графита, эпоксидного лака и определенных растворителей. **Цель**: определение срока службы разработанного защитного покрытия при воздействии ряда значимых факторов, в том числе воздействию реальных сварочных брызг. **Задачи**: выявить основные – значимые технологические факторы влияющие на срок службы защитного покрытия; разработать матрицу планирования на основании полного факторного эксперимента; провести экспериментальные исследования стойкости покрытия воздействию экспериментальной капли металла при влиянии значимых технологических факторов, получить уравнения регрессии стойкости; провести аналитические и экспериментальные исследования по определению температуры экспериментальной капли расплавленного металла; провести аналитические исследования температуры реальной сварочной брызги; провести исследование стойкости покрытия при трении; провести аналитические исследования по определению количественных характеристик надежности и долговечности предложенного состава покрытия. **Результаты**: в статье представлены данные исследований авторами срока службы предложенного защитного покрытия, предохраняющего поверхности сборочно-сварочных приспособлений при воздействии сварочных брызг и износа покрытия при перемещении элементов металлоконструкций в приспособлении. Получены количественные характеристики надежности и долговечности покрытия. **Выводы**: Разработана методология по определению срока службы защитных покрытий предохраняющие поверхности сборочно-сварочных приспособлений от воздействия сварочных брызг при выполнении сварочных операций и износа покрытия при перемещении элементов сварочной конструкции в приспособлении при сборке.

Ключевые слова: сборочно-сварочная оснастка; защитные покрытия; сварочные брызги; толщина защитной пленки; виды сварки; вероятность безотказной работы; частота отказов; интенсивность отказов; срок службы.

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