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INVESTIGATION OF CHARACTERISTIC OF POWDER WIRE WITH THE CUO/AL EXOTHERMIC MIXTURE

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Summary. *The paper the results of research is presented and the level of influence of the parameters of surfacing and the amount of exothermic mixture in the composition of self-shielding flux-cored wire on the deposition rate factor and spattering factor are analyzed. The analysis of the experiment was performed using the Taguchi method, in addition, to determine the influence of individual factors on the studied parameters (a_d, ψ_S), analysis of variance (ANOVA) is fulfilled. It was found that for the deposition rate factor, according to the degree of influence the factors are distributed in the following order − WFS, B, CTWD, U_a, and for the spattering factor − U_a, B, CTWD, WFS. According the analysis of variance (ANOVA) of the experiment results are determined that the greatest impact on the deposition rate factor (a_d) has the wire feed speed (WFS − 53.98%), the amount of exothermic mixture in the core of flux-cored wire (B − 27.3%) and contact tip to work distance (CTWD − 22.75%) have less influence, and the influence of the arc voltage (U_a) can be neglected since its contribution is only 5.82%. The arc voltage (U_a) has a high influence on the spattering factor (ψ_S), whose contribution is more than half (60.19%), the amount of exothermic mixture in the charge of flux-cored wire (B) has less influence, whose influence is (22.38%), while contact tip to work distance (CTWD) and wire feed speed (WFS) have minor influence and are respectively 11.55% and 5.88%. Technologically acceptable modes of surfacing are determined (contact tip to work distance CTWD = 35 mm; flux-cored wire feed speed WFS = 124 m / h; arc voltage U_a = 28V) and amount of exothermic mixture in the core of flux-cored wire, which significantly influences on the indexes of deposition rate factor and spattering factor. Models of the 2nd order of dependence on the two most significant factors for the indexes a_n and ψ_p are constructed.*

Key words: *surfacing, S-FCAW, exothermic mixture, deposition rate factor, spattering factor, welding parameters, Taguchi method, ANOVA.*

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Formulation of the problem. At present, a wide range of surfacing materials is used, which allow to get options for combining the properties of welded metal, resistant to various types of wear. One of the methods of surfacing is surfacing with self-shielding flux-cored wire (S-FCAW). Among the advantages of S-FCAW, there is high productivity, quality and the ability to achieve a high degree of doping of the weld metal, high deposition rate factor, visual arc control and others [1, 2]. However, with the use of S-FCAW there is a lag behind the melting of the core from the shell, which causes deterioration of the welding parameters and reduces the effectiveness of protection of the deposited metal from the air [2, 3], the components of the core can enter the weld bath, passing the stage of the drop, which leads to the contamination of the weld metal exogenous nonmetallic inclusions. The important parameters of the S-FCAW quality are the welding-technological characteristics: the fusion coefficient, deposition rate factor, spattering of the electrode metal, which are strongly influenced by the melting point of the core of the wire, the granulometric and chemical composition of the charge of the filler, the environment of the melting zone, the range of technologically acceptable welding modes [2, 3]. It is known [4, 5] that the melting kinetics of S-FCAW is influenced by the introduction into the composition of the core of the exothermic mixture based on the scale of iron and aluminum powder. However, data on the influence of exothermic mixtures of another composition on the characteristics of melting of S-FCAW in the literature are absent. Thus, the expansion of the

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list of exothermic mixtures in the manufacture of powder wires, the determination of the welding characteristics of the S-FCAW in the technologically acceptable region of surfacing regimes, and also the optimal content of the amount of exothermal mixture of CuO / Al in the core of the powdered wire, is important for the development of new surfacing materials and improvement of the known ones.

Analysis of the available research results. An important reserve for improving the melting characteristics of S-FCAW is the addition of exothermic mixture [5 − 8]. One of the main characteristics of S-FCAW is the deposition rate factor and spattering factor. Metal losses while spraying and burning can range from 25 to 30% [10]. The deposition rate factor and fusion coefficient, as well as the spattering losses are determined by the size and frequency of the droplet transition by the transfer of electrode metal, as well as the composition of S-FCAW filling agent and some other factors. In paper [5], the results of the investigation of Fe_2O_3/Al mixture influence on the characteristics of S-FCAW melting are characterized particularly the increase of the deposition rate factor due to iron recovery, and the reduction of spattering losses due to the improvement of the protection of the molten metal, are presented. Unfortunately there is no information about the use of copper oxide with aluminum CuO/Al as the component of the exothermic mixture in S-FCAW structure which has higher thermal effect than Fe_2O_3/Al mixtures (4.12 kJ / g against 3.97 kJ / g) [8], as well as its influence on the deposition rate factor and spattering factor.

The objective of the paper is the determination of the priority and nature of the influence of technologically acceptable modes of surfacing and CuO/Al exothermic mixture in the composition of S-FCAW filling agent on the quality of its melting performance**.**

Statement of the problem. For investigations, S-FCAW with the exothermic mixture 4 mm in diameter were prodused. As the gas slag-forming component, the slag basis was used: marble - fluorspar - rutile. The surfacing was carried out by one-pass rollers on plates with low carbon steel S 235 J2G2 EN 10025-2 (St3ps) 10x100x200mm in size on the welding machine using power supply with a rigid voltage-ampere characteristic. Coefficient of the wire filling is 0,32-0,34. S-FCAWs which filler charge corresponded to the composition shown in Table. 1 were investigated.

Table 1

Compositionof S-FCAW, %

The name of the component \ Experimental composition		1	2	3
Gas slag creating	Fluorspar GOST 4421-73	24	24	24
	Rutilovy concentrate GOST 22938-78			
	Calcium carbonate GOST 8252-79			
Alluring and deoxidizers	Titanium powder PTM TU 14-22-57-92	19	19	19
	Ferrosilicon FS-75 GOST 1415-78			
	Ferromanganese FMN-88A GOST 4755-91			
	Metal Chrome X99 GOST 5905-79			
	Ferovanadiy FVd-50 GOST 27130-94			
	Powder cobalt PK-1u GOST 9771-79			
Iron powder PZhR-1 GOST 9849-86		37	27	17
Oxide of copper powder-like GOST 16539-79		16,7	25	33,3
Aluminum powder PA1 GOST 6058-73		3,3	5	6,7

Criterion «the more, the better» for the indicator of the deposition rate factor (α_d) and criterion «the smaller, the better» for the indicator of spattering rate (ψ_s) the qualitative characteristics of which can be expressed by equations (1) and (2) are chosen in this paper:

$$SN_b = 10 \cdot \left(\log \left(\sum \left(\frac{Y^2}{S_i^2} \right) \right) \right); \tag{1}$$

$$SN_b = -10 \cdot \left(\log \left(\sum \left(\frac{1/Y^2}{S_i^2} \right) \right) \right); \tag{2}$$

where S_i^2 is dispersion:

$$S_i^2 = \frac{1}{N_i - 1} \cdot \sum_{u=1}^{N_i} \left(Y_{i,u} - \bar{Y}_i \right); \tag{3}$$

$\bar{Y}_i$ is the average value:

$$S_i^2 = \frac{1}{N_i} \cdot \sum_{u=1}^{N_i} \left(Y_{i,u} \right); \tag{4}$$

i is the amount of experiments; u is the experiment number; N_i is the number of tests for the experiment i.

The necessary number of tests N during the experiment is determined by the classical structure of the fractional factor experiment plan by the following dependence:

$$N = Z^{k-p}; \tag{5}$$

where Z is the number of levels at which the factors values varies during the experiment implementation; k is the number of factors influencing the parameter of the investigated object optimization; p is the fragmentation degree of the experiment plan.

Taking into account that Z = 3, k = 4, p = 1, then the number of experiments N = 9. The value of the factors of the surfacing process at different levels is given in Table 2.

Table 2

Selected factors and their levels

Code	Factor	Low level (1)	Average (2)	High level (3)
A	Percentage of exothermic mixture in powder wire B, %	6	9	12
B	Contact tip to work distance CTWD, mm	35	40	45
C	Wire feed rate WFS, m / h	98	111	124
D	Arc voltage U_a, V	28	31	34

The experimental scheme of factors using the orthogonal array L9 and the values of factors is shown in Table. 3. At the same time, the rate of surfacing SS was assumed to be a constant value, and was equal to SS = 18.5 m/h.

Experiments are carried out to investigate the influence of the parameters of the welding modes and the amount of exothermic mixture on the deposition rate factor of (α_d) and the spattering rate (ψ_s). The results of the experiment and calculations (α_d^c, ψ_s^c) are given in Table 4.

Table 3

The plan of the experiment of full factor analysis using the orthogonal array by the method [9]

№	Coded values				Actual values			
	Factor A	Factor B	Factor C	Factor D	B, %	CTWD, mm	WFS, m / h	U_a, V
1	1	1	1	1	6	35	98	28
2	1	2	2	2	6	40	111	31
3	1	3	3	3	6	45	124	34
4	2	1	2	3	9	35	111	34
5	2	2	3	1	9	40	124	28
6	2	3	1	2	9	45	98	31
7	3	1	3	2	12	35	124	31
8	3	2	1	3	12	40	98	34
9	3	3	2	1	12	45	111	28

Table 4

Results of research

№	Welding current I_{awc}, A	Deposition rate factor, g / A • h		Spattering factor, %	
		Experimental, α_d	Calculated, α_d^c	Experimental, ψ_s	Calculated, ψ_s^c
1	240	16,20	15,93	9,7	9,54
2	300	16,36	16,90	8,3	9,61
3	360	16,84	16,59	16,3	15,24
4	300	16,12	15,08	18,2	19,38
5	360	14,07	16,58	12	11,34
6	360	12,25	12,79	13	12,58
7	360	17,13	16,89	6,8	6,02
8	360	10,22	9,96	14	13,99
9	340	13,32	13,58	3,2	3,61

The results of the factor influence analysis on the deposition rate factor (α_d) are given in Table 5 and Fig.1

Table 5

Table of reviews of the deposition rate factor (α_d) for the ratio S / N

Level	B, %	CTWD, mm	WFS, m/h	U_a, V
1	24,33	24,34	22,05	23,6
2	23,34	22,86	23,64	23,57
3	22,45	22,93	24,44	22,95
Delta	1,64	1,63	2,47	0,73
Rank	2	3	1	4

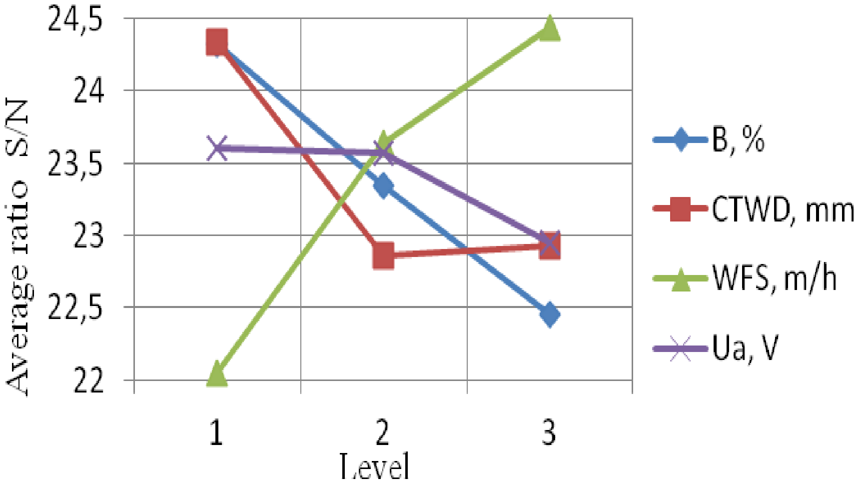


Figure 1. The graph of signal-to-noise ratio (S/N) for the index of the deposition rate factor by factors and level

The analysis of the ratio of signals/noise characteristics of the indicator (α_d) shows (Fig. 1, Table 5) that the main influence has the wire feed speed (factor C). In this case, the degree of influence factors, ascending decreasing, are distributed in the following order − C, A, B, D. The least effect has the arc voltage U_a (factor D). The optimum in the experiment for the indicator of the specific deposition rate factor (α_d) has the choice of the factor C with level 3, that is, WFS = 124 m/h, the percentage of exothermic mixture in the powder wire is B = 6% (level 1), contact tip to work distance is CTWD = 35 mm (level 1), and the arc voltage is U_a = 28 V (level 1).

The results of the analysis of the above given factors influence on the spattering factor (ψ_s) are given in Table 6 and in Fig. 2

Data analysis (Figure 2) shows that the main factor is the factor D − arc voltage (U_a). By the degree of influence the factors are distributed in the following order − D, A, B, C. Optimal, in our experiment, for the indicator of the specific surfacing performance is the factor D choice (arc voltage) − U_a = 28 V (level 1). The smallest value of the spattering factor was obtained with the values of other factors: the percentage of exothermic mixture in the powder wire B = 12% (level 3); contact tip to work distance − CTWD = 45 mm (level 3); wire feed speed is WFS = 111 m / h (level 2).

Table 6

Table of reviews of the spattering factor (ψ_S) for the ratio S/N

Level	B, %	CTWD, mm	WFS, m/h	U_a, V
1	-20,79	-20,53	-21,65	-17,14
2	-23,02	-20,96	-17,90	-19,10
3	-16,56	-18,88	-20,83	-24,12
Delta	6,46	2,09	3,75	6,98
Level	2	4	3	1

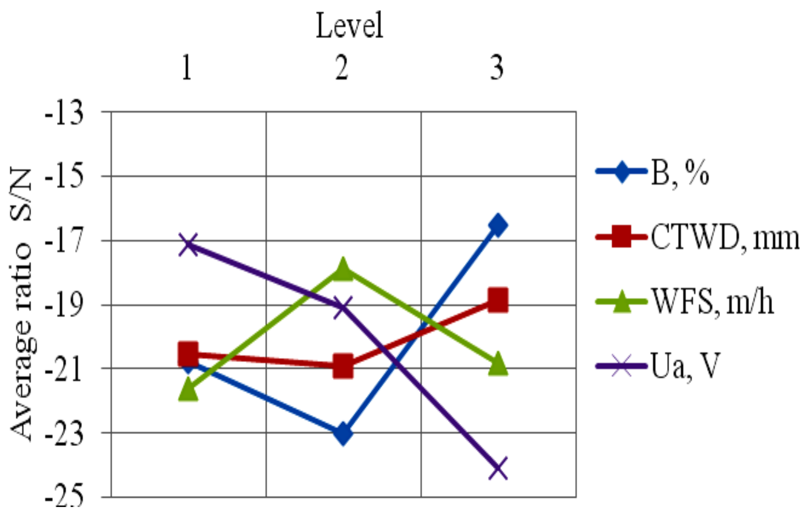


Figure 2. The graph of signal-to-noise ratio (S/N) for the index of the spattering factor (ψ_S) according to factors and level

However, the considered method can determine only the impact of certain factors on the indicator investigated in general, while the quantitative characteristics of certain factors can be determined by means of the dispersion analysis (ANOVA). The use of dispersion analysis helps to check formally the value of all the main factors and their interaction, by comparing the average square, with the estimation of experimental errors at certain levels of confidence. ANOVA analysis was performed with 95% confidence level and 5% significant level. The percentage of the influence of each parameter on the surfacing indicator is shown in the last column of Table 7.

The results of the analysis show that the highest influence on the deposition rate factor (α_d) has the wire feed speed (WFS) and is 47.01%. The influence of the exothermic mixture in the core of the powder wire (B) and the contact tip to work distance (CTWD) is less 27.30% and 22.75%, relatively. There is no significant influence on the arc voltage (U_a). The contribution of this parameter is only 2.94%, which can be considered as «noise».

Table 7

Results of analysis of variance (ANOVA) of the effect on the deposition rate factor (α_d)

Factor	Value	Number of freedom degrees	Adj MS	Adj MS	Contribution %
A	B, %	2	12,7808	10,791	27,30
B	CTWD, mm	2	10,6510	10,401	22,75
C	WFS, m/h	2	22,0102	28,451	47,01
D	Ua, V	2	1,3760	3,062	2,94
	Error	0			
	Sum	8	46,8180		100

The percentage of the contribution of each parameter on the rate of spraying factor (ψ_s) is given in Table 8.

Table 8

Results of analysis of variance (ANOVA) of the effect on the spattering factor (ψ_s)

Factor	Value	Number of freedom degrees	Adj MS	Adj MS	Contribution %
A	B, %	2	61,549	31,1102	34,06
B	CTWD, mm	2	0,916	0,4977	0,51
C	WFS, m/h	2	8,969	4,4257	4,96
D	U_a, V	2	109,262	53,8221	60,47
	Error	0	0		
	Sum	8	180,696		100

The high influence on the spattering factor (ψ_s) of these factors, has the arc voltage U_a (factor D) with 60.47% contribution. Less impact has the amount of exothermic mixture in the charge of powdered wire (factor A) 34.06%. The low effect have WFS (factor C) and CTWD (factor B) 4.96% and 0.51% relatively, the effect of these indicators is classified as «noise».

Comparing the results of the dispersion analysis (ANOVA) for the two indicators, it can be concluded that the wire feed speed (WFS) and the arc voltage (U_a) have the opposite effect for both indicators. Being the main factors for one indicator, for the other it does not have a significant impact. In turn, such factor as the percentage of exothermic mixture in the powder wire (B) has a significant effect on both indicators. CTWD has the average contribution to the surfacing rate, but has little effect on the spattering factor. Therefore, we use the optimal values of this parameter, and the value of the wire feed speed (WFS), with the condition of reaching the highest value of the deposition rate factor (α_d), in this case they be equal WFS = 124 m/h, CTWD = 35mm. And the optimum value of the voltage on the arc is taken for the case of reaching the minimum spattering (ψ_s) having the value Ua = 28V.

In order to obtain regression models for the two most important factors, the deposition rate factor (α_d) and the spattering factor (ψ_s), second-order dependencies were derived. As a plan, the central composite plan was used as a plan. The analysis was carried out by means of Statistica 6.1 program.

According to the results of the dispersion analysis (ANOVA), the parameters of the wire feed speed (WFS) and the amount of exothermic mixture in the powder wire (B) were important for the deposition rate factor.

Derived mathematical model is as follows:

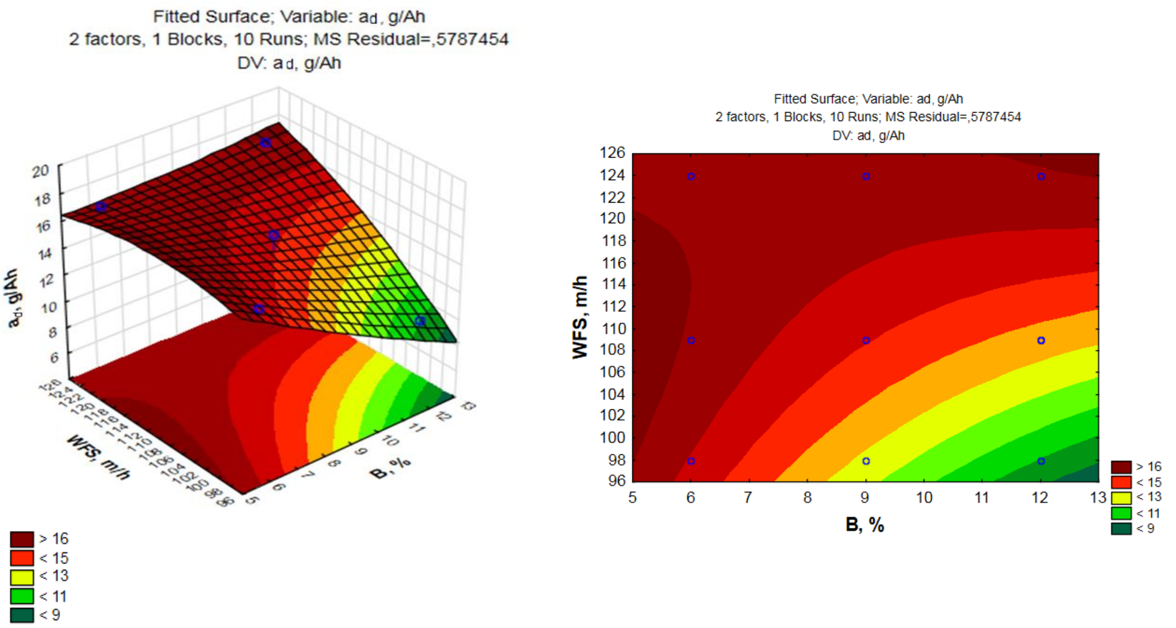
$$a_d = -6{,}39286 - 5{,}243 \cdot B + 0{,}71005 \cdot WFS + 0{,}01731 \cdot B^2 - 0{,}00417 \cdot WFS^2 + 0{,}04017 \cdot B \cdot WFS. \quad (3)$$

Fig. 3 shows the dispersion analysis tables (ANOVA) for the residual sum of squares (SSResidual). It is evident from Fig. 3, a that almost all the coefficients have high statistically significant effects (level p <0,05). Approximation validity R-sqr = 0,95294 − the overall quality of the model is good. The value of the confidence interval is set at 95%. The response surface and contour graph of the obtained mathematical model are shown in Fig. 4.

ANOVA; Var.:ан, г/Ач; R-sqr=,95294; Adj:,89412 (3k factor ЭС-Vпд-Uxx)
2 factors, 1 Blocks, 10 Runs; MS Residual=,5787454
DV: ан, г/Ач

Factor	SS	df	MS	F	p
(1)ЭС, %(L)	13,41034	1	13,41034	23,17140	0,008562
ЭС, %(Q)	0,05033	1	0,05033	0,08697	0,782736
(2)Vпд, м/год(L)	21,54615	1	21,54615	37,22907	0,003651
Vпд, м/год(Q)	1,09446	1	1,09446	1,89108	0,241074
1L by 2L	9,91207	1	9,91207	17,12682	0,014395
Error	2,31498	4	0,57875		
Total SS	49,19621	9			

Figure 3. Results of calculating the significance of the model by the residual sum of the squares



a) b)

Figure 4. Surface of response (a) and contour chart (b) of the deposition rate factor (α_d) from the wire feed speed (WFS) and the amount of exothermic mixture in the core of the powder wire (B)

The obtained graphs show that the highest values of the deposition rate factor will have the powder wires when surfacing with the highest wire feed speed and the content of the exothermic mixture in the range of 6 − 13%. At low values of wire feed speed WFS, there is no activation of the exothermic reaction, and the oxidant (CuO) enters the slag, thereby reducing the surfacing rate.

Taking into account the influence of the voltage on the arc and the percentage of the exothermic mixture in the core of the powder wire on the spraying factor, the mathematical model of the 2nd order of the spattering factor ψ_S dependence on these factors was constructed.

Figure 5 shows the dispersion analysis table (ANOVA) for the residual sum of squares (SSResidual). From Fig. 5 it is possible to conclude that almost all coefficients have high statistically significant effects (level p <0,05). Approximation validity R-sqr = 0,97552 – the overall quality model is good. The value of the confidence interval is set at 95%.

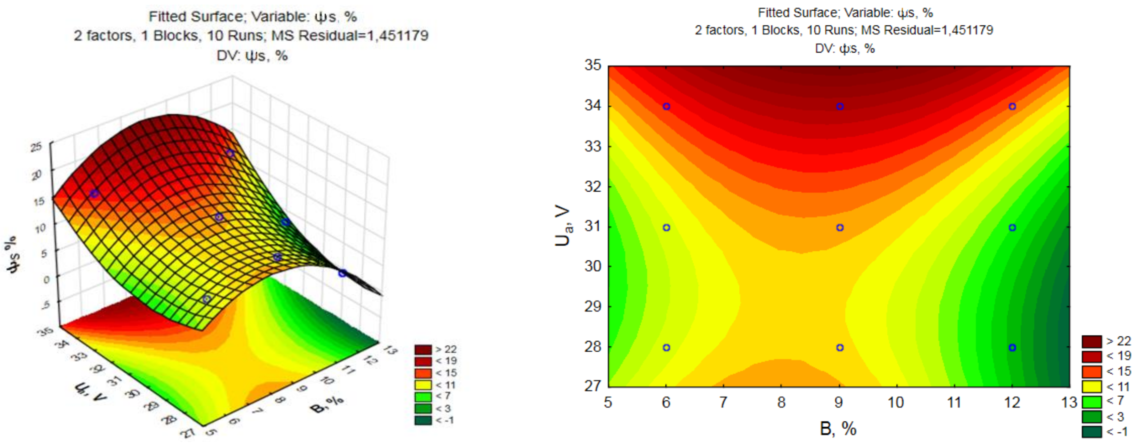
ANOVA; Var.:фр; R-sqr=,97552; Adj:,94493 ([No active dataset])
2 factors, 1 Blocks, 10 Runs; MS Residual=1,473949
DV: фр

Factor	SS	df	MS	F	p
(1)ЭС, %(L)	21,3499	1	21,3499	14,48482	0,019007
ЭС, %(Q)	46,8294	1	46,8294	31,77137	0,004876
(2)U, B(L)	106,4962	1	106,4962	72,25230	0,001051
U, B(Q)	16,0182	1	16,0182	10,86752	0,030029
1L by 2L	6,3640	1	6,3640	4,31763	0,106276
Error	5,8958	4	1,4739		
Total SS	240,8840	9			

Figure 5. Results of calculating the significance of the model by the residual sum of the squares

Derived mathematical model is as follows:

$$\psi_s = 267{,}3762 + 4{,}8960 \cdot B - 19{,}0263 \cdot U_a - 0{,}5293 \cdot B^2 + 0{,}3096 \cdot U_a^2 + 0{,}1301 \cdot B \cdot U_a . \qquad (7)$$



a) b)

Figure 6. Surface of response (a) and contour chart (b) of the spattering factor (ψ_S) from the amount of exothermic mixture in the core of the powder wire (B) and the arc voltage (U_a)

Analysis of the graphs of the spraying factor dependencies (Fig. 6) shows that the proportion of the exothermic mixture in the powder wire (B) has multivalued effect. Technologically acceptable values of the spraying coefficient for the arc voltage are within the range 27.5 ... 30.5 V, with further increase, the spattering factor increases. This can be caused by the growth of the arc length resulting in the deterioration of its protection, and more intense displacement of the drop on the electrode ends. The influence of the exothermic mixture amount has a local extreme nature. Comparing S-FCAW melting parameters at technologically acceptable regimes, using the exothermic mixture of CuO / Al system and the known Fe_2O_3/Al [5], we noticed the decrease of the deposition rate factor (α_d) to 1%, and the spraying losses are within the same limits (6 ... 8)%.

From the above mentioned data, we can come to the conclusion that for further research, the investigation of the exothermal CuO / Al system mixture amount influence, including the effect on the metal properties is needed [13, 14].

Conclusions. Using the above mentioned methods of the experiment results analysis make it possible to give qualitative and quantitative characteristics of each factor influence on the investigated parameters. The effect of the exothermic mixture on the investigated parameters is 27% and 34%, therefore it is essential and significant. The influence of other factors varies from the significant values (60% and 47%) to (2.94% and 0.51%), the latter can be classified as «noise». The influence of significant factors on the investigated parameters (α_d,ψ_s) is formalized in mathematical form enabling to predict the powder wire characteristics from the two most significant factors.

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ДОСЛІДЖЕННЯ ХАРАКТЕРИСТИК ПОРОШКОВОГО ДРОТУ З ЕКЗОТЕРМІЧНОЮ СУМІШШЮ CUO/AL

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Резюме. *Наведено результати досліджень, проаналізовано рівень впливу параметрів наплавлення та кількості екзотермічної суміші в складі самозахисних порошкових дротів на коефіцієнти наплавлення та розбризкування. Аналіз експерименту виконано з використанням методу Тагуті. Крім того, для визначення впливу окремих факторів на показники, що досліджуються (a_d, ψ_S), проведено дисперсійний аналіз (ANOVA). При цьому встановлено, що для коефіцієнта наплавлення за ступенем впливу чинники розподілилися в наступному порядку – WFS, B, CTWD, U_a, а для показника коефіцієнта розбризкування – U_a, B, CTWD, WFS. За допомогою дисперсійного аналізу (ANOVA) результатів експерименту визначено, що найбільший вплив на показник коефіцієнта наплавлення (a_d) чинить швидкість подачі дроту (WFS − 53,98%), менший вплив чинять кількість екзотермічної суміші в осерді порошкового дроту (B − 27,3%)та виліт електрода (CTWD − 22,75%). Впливом напруги на дузі (U_a) можна нехтувати, так як його внесок складає лише 5,82%. Високий вплив на коефіцієнт розбризкування має напруга на дузі (U_a), чий внесок складає більше половини (60,19%), менший вплив має кількість екзотермічної суміші у шихті порошкового дроту (B), чий вплив складає (22,38%). Водночас виліт дроту (CTWD) та швидкість подачі дроту (WFS) чинять незначний вплив та складає відповідно 11,55%, та 5,88%. Визначено технологічно прийнятні режими наплавлення (виліт дроту CTWD= 35мм; швидкість подачі порошкового дроту WFS = 124 м/год; напруга на дузі U_a = 28В) та кількість екзотермічної суміші в осерді порошкового дроту, що суттєво впливає на показники коефіцієнтів наплавлення та розбризкування. Для показників a_d та ψ_S побудовано моделі 2-го порядку залежності від двох найбільш значущих чинників.*

Ключові слова: *наплавлення, СПД, екзотермічна суміш, коефіцієнт наплавлення, коефіцієнт розбризкування, параметри зварювання, метод Тагуті, ANOVA.*

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