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INCREASING OF EFFICIENCY OF MANUAL ARC WELDING AND SURFACING OF ENGINEERING PRODUCTS

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Summary. *The data on the exothermic mixture amount in the electrodes coating influence on their heating and melting are given. Experimental methods found that exothermic reactions in the stage of heating and melting take place at the electrode coating contained more than 35% of the exothermic mixture. It is proved that when there is 58% of the iron scale in the electrodes coating as compared to electrodes containing the same amount of iron powder, the electrode melting rate is increased by 18 – 20%, the coating melting mass speed – 31 – 34% and the electrode melting coefficient – 11 – 14%. It is proved that the exothermic mixture adding (up to 53,4%) into the electrodes coating leads to effective efficiency heating increasing: basic metal ($\eta_{b.m.}$) from 0,715 to 0,815 and an electrode (η_e) from 0,28 to 0,415. The obtained results can be used in the welding electrodes performance improving development.*

Key words*: electrode, exothermic mixture, welding, surfacing, efficiency.*

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Statement of the problem. The method of manual arc welding performance increasing is discussing. The aim of research – to determine the exothermic mixture percentage and the electrodes coating thickness influence on the melting process intensification.

Currently manual arc welding (surfacing) with coated electrodes is one of the widely used processes. In the industrialized countries, the work performed using manual arc welding amount is 20 – 25% of the total, it is 60 – 70% in Ukraine [1 – 3]. Especially high rate observed in the construction industry, where it can exceed 80 – 85% [1]. According to 2014 year statistics data the arc welding with coated electrodes volume in 10...15 years will be 40 – 50%.

For welding and surfacing a wide range of electrodes is used. However, their productivity is quite low – *2,7 kg/h*, surfacing and melting rate do not exceed respectively, *8,5 – 10,0 g/h*·A and *13 – 15 m/h*.

This obliges to pay serious attention to the manual arc welding improvement, which primarily relates to the welding electrodes – one of the main factors determining the efficiency and welding technology [3].

The welding processes productivity increasing and the search for new raw materials types for their manufacture is one of the main tasks facing the welding and surfacing materials developers. One of the primary ways to increase manual arc welding (surfacing) productivity is the iron powder adding into the electrodes coating. When the iron powder content in the electrodes coating within the values 15 – 25% it is welding-technological properties improving without significantly changing the deposition rate. The highest performance is achieved when the electrode coating content of iron powder is 60 – 70% with increasing the electrode coating thickness at the same time. However, the «high-performance» electrodes proportion, used in our country, is very small due to the need to use in this case, the power source having a no-load voltage value of *80 V*, the iron powder deficiency, their quality production providing complexity in production lines «electrode press – conveyor calcining furnace» (approximately 1% of the total electrodes number). Further electrodes progressive brands production growth is also limited by scarcity (as in the world market, and in our country), a number of raw materials such as iron powder, rutile concentrate and others.

One of the ways to solve this problem is to use the effect of exothermic reactions by the introduction of the materials used exothermic mixes as appropriate oxidants (scale, hematite, manganese ore et al.) And reductants (ferrotitanium, ferrosilicon, aluminum powder, etc.) while heating and melting, which process is already exothermic before the electrode rod melting [4].

Iron oxides, added into the electrode coating in the scale form, allow the use of the effect of increasing the iron powder bulk density and its positive effect on the electrode manufacturability. Furthermore, as an exothermic reaction result during electrode coating melting, the reduced iron is fed into the seam, improving the welding process performance and extracted heat to accelerate the melting of the coating and the electrode as a whole.

The purpose of this study is to investigate the influence of the exothermic amount of the mixture and the coating thickness of the electrodes on the performance of manual arc welding, welding characteristics of the electrodes, the physic-chemical and mechanical properties of the weld metal and the surfaced metal.

The scale, the exothermic mixtures main component, is used in welding and steel production and it is typically 70 – 80 exothermic mixture mass percent and the final account quality of the weld metal or melted metal depend on its physic-chemical properties. Study [5] showed that the scale composition is a waste press-forging production of machine-building plants, depending on the grade of forged steel varies within fairly narrow limits, comprises, %: 58 – 63 FeO, 31 – 36 ($Fe_2O_3 + Fe_3O_4$) and the total oxygen quantity, calculated on its content in FeO and $Fe_2O_3 + Fe_3O_4$, ranges from 23,0 – 23,8%.

Such elements as Mn and Si is almost completely oxidized and their oxides content in the scale is within the calculated limits, and containing oxides of Ni, Cr, Mo, V less than their lower limit. Therefore, these elements in the heating process and forging are not completely oxidized, they are also found in the scale in the unoxidized form. Thus, scale, taken after forging preforms made of alloyed steel can be efficiently used in surfacing and welding of low and high alloyed steels if necessary alloying of the weld metal without adding of these elements corresponding in their number in the ferro-alloys form or metal powders.

Melting speed or the electrode performance, which is estimated primarily varying the length or the mass of the molten electrode per unit time, is the welding process important characteristic and depends on many factors, the main of which are: the welding current, the coating formulation and the current polarity kind.

When added into the coating exothermic mixture additional heat electrode released by a chemical reaction between the iron oxides and deoxidizers-elements. The heat greatest amount released during reaction of aluminum oxide with iron and the lowest – when reacting with manganese oxide of iron.

When added into the electrode coating and the active elements of iron-oxides reductants exothermic process occurs with additional heat release. Since any process of reduction is exothermic, the determination of the place of its occurrence is an important issue. In those cases, when heating the electrode coating and the interaction of iron oxides with the elements deoxidizers-formed mixture was exothermic, exothermic process occurs in the coating before the melting of the electrode rod. With insufficient for the formation of an exothermic mixture of iron oxides and deoxidizers-elements in the coating of the electrodes, an exothermic process occurs at the stage of forming and drop transferring. Thus, in the first case, there will be a rapid melting of the coating and the electrode rod, and the second – only increase the heating temperature of the electrode metal without increasing the melting rate of the electrode.

Analysis of the available results of investigations. The method of manual arc welding performance increasing is discussing. The aim of research – to determine the exothermic mixture percentage and the electrodes coating thickness influence on the melting process intensification. In that work exothermic mixture is a mechanical mixture of iron oxide, aluminum powder and alloying elements in the form of ferroalloys (ferromanganese and ferrotitanium). Due to the fact that in the coating composition investigated electrodes are: gas-slag-forming component (marble), and iron oxide Fe_2O_3, contained of the scale and rutile concentrate which dissociate in the stage of heating and melting the coating with the release, respectively, the CO_2 and free oxygen, part reductants (mainly aluminum and titanium) will interact with them, without forming an exothermic mixture. The unreacted portion of the element – iron oxide with reductants – is exothermic mixture.

In the interaction of aluminum with iron oxides, the following exothermic reactions occur:

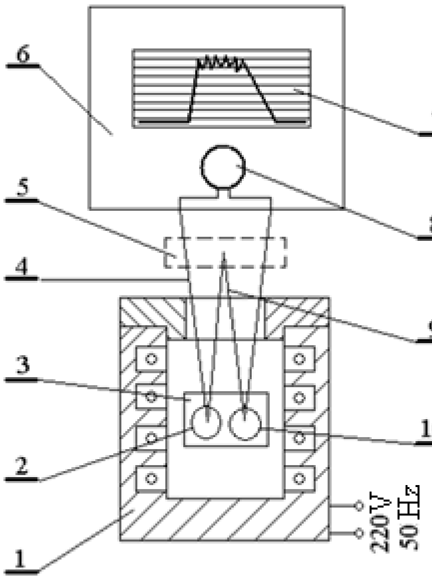
$$\begin{gathered} 3\,FeO + 2\,Al = Al_2O_3 + 3\,Fe + 880{,}9\ \text{kJ/mol.} \\ 215{,}55 + 53{,}96 = 101{,}96 + 167{,}55, \\ 79{,}98\% + 20{,}02\% \longrightarrow 37{,}83\% + 62{,}17\%, \\ \Delta H_{298} = 1674{,}6 - 793{,}7 = 880{,}9\ \text{kJ/mol.} \end{gathered} \tag{1}$$

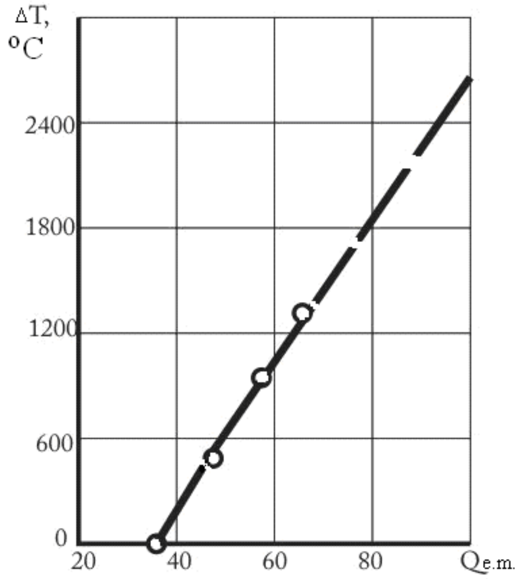
$$\begin{gathered} Fe_2O_3 + 2\,Al = Al_2O_3 + 2\,Fe + 852\ \text{kJ/mol.} \\ 159{,}70 + 53{,}96 = 101{,}96 + 111{,}70, \\ 74{,}25\% + 25{,}25\% \longrightarrow 47{,}72\% + 52{,}28\%, \\ \Delta H_{298} = 1674{,}6 - 822{,}6 = 852\ \text{kJ/mol.} \end{gathered} \tag{2}$$

$$\begin{gathered} 3\,Fe_3O_4 + 8\,Al = 4\,Al_2O_3 + 9\,Fe + 3345{,}2\ \text{kJ/mol.} \\ 694{,}65 + 215{,}84 = 407{,}84 + 502{,}65, \\ 76{,}29\% + 23{,}71\% \longrightarrow 44{,}79\% + 55{,}21\%, \\ \Delta H_{298} = 6698{,}2 - 3353 = 3345{,}2\ \text{kJ/mol.} \end{gathered} \tag{3}$$

Results of investigations. From the comparison of the results of reactions (1 ± 3) it follows that the greatest amount of heat is released during the interaction of aluminum with ferrous oxide, and the smallest – with the interaction of manganese with ferrous oxide.

The presence in the investigated electrodes of the exothermic mixture and the temperatures developed by the exothermic reactions was determined according to the scheme indicated in Fig. 1.

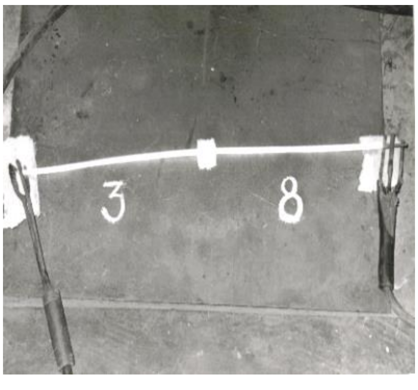




a) b)

Figure 1. Measuring temperature scheme, resulting in the electrode coatings are heated and melted (a), and the increase in the electrode coatings temperature *T* (b) depending on the exothermic mixture percentage *($Q_{e.m.}$)*

To determine the exothermic process location and conditions directly in the electrode coating we produced electrodes with a rod of *5,0 mm* diameter and the same coating weight coefficient ($K_m = 0,6$). Electrodes with the same amount of scale and the iron powder in the coating are welded to each other, and then inserted into the electrode holders which are connected to the welding transformer DCT-1000. In the short circuit formed by the electrodes studied current passed before the completion of the exothermic reaction, after which the power source is disconnected. The results are shown in Figures 1 – 3, from which it follows that the investigated electrodes comprise an exothermic mixture and exothermic reactions in the solid phase of the electrode coating takes place only when the content of it in over 35% of the exothermic mixture and the more intense, the larger it is contained in coating the electrodes. Conducted research found that when the electrode coating content of the exothermic mixture consisting of slag and the aluminum powder, 35 to 64% of the temperature increase of 1280^{0}C and is sufficient for complete melting ferroalloys (Fig. 1 b).



a) b)

Figure 2. The electrode coatings type with different scale (indices 8, 9) or iron powder (indices 3, 4) content when they are heated by electric current: a – 29,2%; b – 43,8%

a) b)

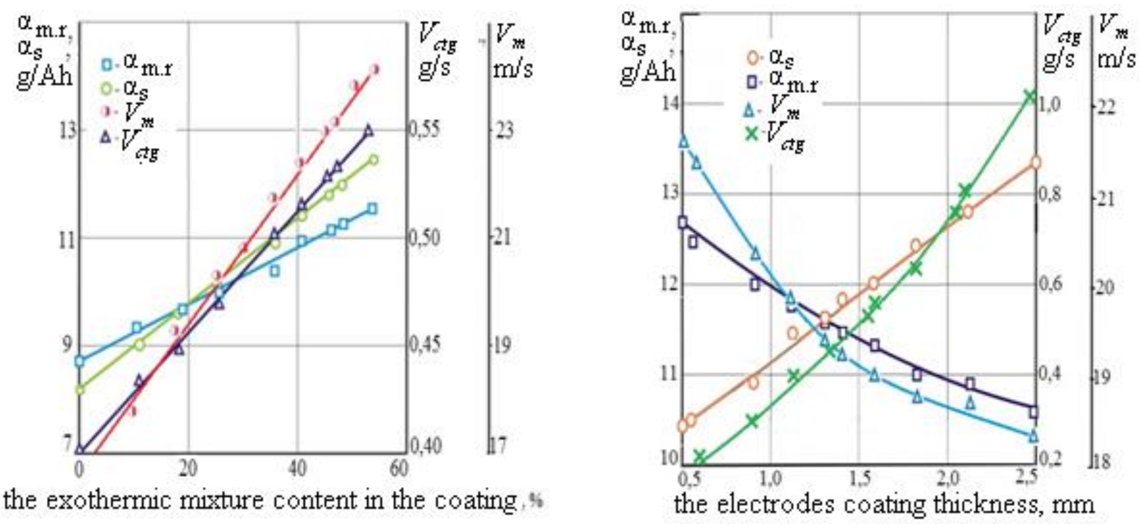
Figure 3. The exothermic process flowing in the electrode coating (a) containing 58,4% scale (index 6) and its appearance after the process completion (b)

From Fig. 3 b it follows that an exothermic process occurs in the electrode coating in the solid phase (the electrode rod is melted).

When the electrodes coating content of the oxide scale within 58,4% (Fig. 3 a, b) as compared with electrodes containing the same amount of iron powder, the electrode melting rate increased by 18 – 20%, the coating mass melting rate – 31 – 34%, and the electrode melting rate – to 11 – 14%.

For exothermic mixture amount influence to technological characteristics melting electrodes research, electrodes with a diameter of *5,0 mm* and a coating weight coefficient of *0,6* were fabricated. Melting electrodes was performed under the same values of the force (*290 A*) and the welding current density (*24,8 A/mm*^{2}) and voltage power supply idle stroke *60 V*.

Calculated melting electrodes indicators depending on the number of the exothermic mixture in a coating (Fig. 4 a) show that the introduction of the electrode coating exothermic mixture to 53,4% leads to an increase of the melting rod coefficients ($\alpha_{m.r} = 8{,}7 – 11{,}4$ *g/A·h*) surfacing ($\alpha_s = 8{,}2 – 12{,}5$ *g/A·h*), the electrode melting rate (*17 – 23 m/h*) and the electrode coating melting rate (*0,4 – 0,6 g/s*).



a) b)

Figure 4. Melting electrodes coefficients depending on the the exothermic mixture content in the coating of electrodes (a) and the electrodes coating thickness (b)

To determine the effect of coating thickness with electrodes with the exothermic mixture process ability their melting, electrodes fabricated with rod diameter of *5,0 mm* and a coating thickness of *0,5 – 2,6 mm*, which corresponded to a change in coating weight ratio of *0,17* to *1,14*. Exothermic mixture content in the test electrodes was 44,4% by weight of the coating.

Increasing the electrodes coating thickness (Fig. 4 b) increases the surfacing rate ($\alpha_s = 10{,}4 - 13{,}4$ *g/A·h*) to reduce melting rod coefficient ($\alpha_{m.r} = 12{,}8 - 10{,}5$ *g/A·h*) increase the mass speed coating melting (*0,18 – 1,03 g/s*), lower electrode melting rate (*21,5 – 18,2 m/h*).

Due to the fact that in all the compositions studied electrodes percentage exothermic mixture was the same, but varied only its weight amount, the increase occurred only reduced iron from its oxides and productivity melt coating electrodes.

Despite the reduction of the melt web, to increase the electrodes coating thickness, the deposited metal amount is increased, which is possible only if the strongly reducing iron from its oxides. Decrease the $\alpha_{m.r.}$ with increasing coating thickness indicates that the heat formed during the exothermic reaction is consumed mainly in the melting of the coating, increasing its bulk melting rate (*0,18 – 1,03 g/s*). Furthermore, the coating of the heat transferred from the rod, whereby the rod reduces its heating and melting rate. Due to the fact that in all the compositions studied electrodes percentage exothermic mixture was the same, but varied only its weight amount, the increase occurred only reduced iron from its oxides and productivity melt coating electrodes.

From the above it follows that the electrodes with the exothermic mixture in a coating containing 44,4% of the exothermic coating mixture, allow to reach surfacing electrodes coefficient *11,8 – 12,5 g/A h*; melting rate – *21,5 – 25 m/h*; optimum welding current, due to increased melt rate and the absence of overheating during welding, electrode diameter *5,0 mm – 300 A*.

The main efficiency factors for electrodes are:

a_s – surfacing coefficient, which is *8 – 9,5 g/A·h* for existing marks of electrodes with no iron powder in their coating.

Coefficients $\alpha_s, \alpha_{elrd.m.}, V_m, V_{ctg}$ have been calculated by the following formulas:

$$\alpha_{elrd.m.} = \frac{G_{elrd} \cdot 3600}{I_s \cdot t},$$

where $\alpha_{elrd.m.}$ – electrode melting coefficient, *g/A·h*; G_{elrd} – total mass of the electrode core and metallic components of the coating, *g*; I_s – current of surfacing, *A*; t – time of electrode burning, *sec*.

$$V_m = \frac{L_{elrd}}{t},$$

where V_m – linear melting rate for electrode, *mm/sec*; L_{elrd} – length of molten electrode, *mm*.

$$V_{ctg} = \frac{G_{mtn.ctg}}{t},$$

where V_{ctg} – mass melting rate for electrode coating, *g/sec*; $G_{mtn.ctg}$ – mass of molten coating, *g*

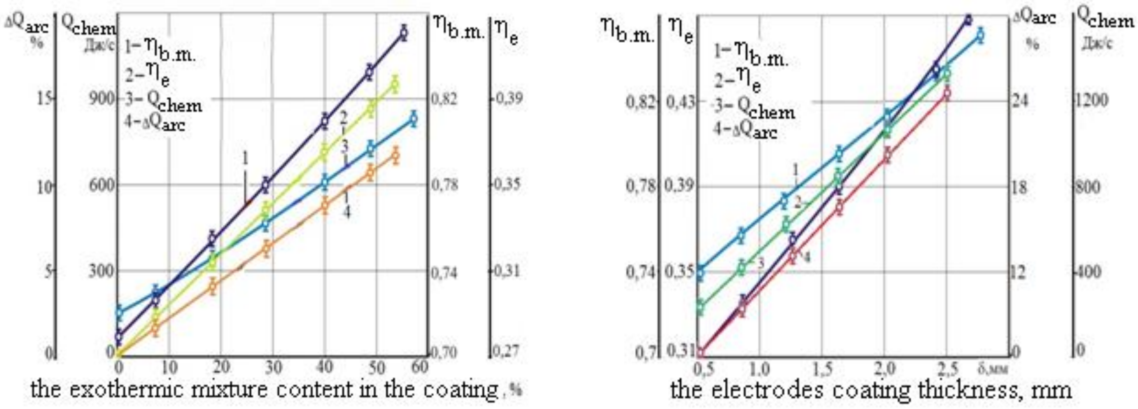
$$\alpha_s = \frac{G_{mtn.met.} \cdot 3600}{I_s \cdot t}$$

where a_s – surfacing coefficient, *g/Ah*; $G_{mtn.met.}$ – mass of molten metal, *g*.

Influence of the thermal effect of the exothermic process occurring during the melting of the electrodes with the exothermic mixture in a coating determined experimentally by melting the electrodes at a constant current of opposite polarity at values of welding current of *290 A* and a voltage of the power supply idle stroke – *60 V*. Determination of the influence of the exothermic amount of the mixture and the coating thickness of the electrodes with an exothermic mixture of products for heating and melting an electrode was performed by the method of calorimetric [6 – 8].

There are the electrodes with a diameter of the rod electrodes *5,0 mm* in two versions were made: one – with different content in a coating of the exothermic mixture at a constant coating coefficient value, and the other – with a different coating thickness *(0,5 – 2,6) mm*, which corresponds to a change in coating coefficient value between 0,17 and 1,14 at a constant amount in the exothermic coating mixture (44,4%).

The calculated values of the effective efficiency heating electrode *(η_e)* and the base metal *($\eta_{b.m.}$)* and the related characteristics are shown in Figure 5.



a) b)

Figure 5. The exothermic mixture amount in the electrodes coating (a) and the coating thickness (b) effect on the melting thermal characteristics

The exothermic mixture adding to the electrodes coating to 53,4% (Fig. 5 a) modifies η_{bm} from *0,815* and *0,715* and η_e from *0,28* to *0,415*. Increasing the amount of weld metal coverage and arc thermal power (at almost the same amount of slag on the plate) shows that additional heating plates occurs primarily by increasing the electrode metal content for the same period of time and by increasing the arc thermal capacity.

With the change of the electrodes coating thickness *(0,5 to 2,6) mm* (Fig. 5 b) increases the exothermic mixture content; increasing the heat and reduced iron content at the exothermic reaction.

The amount of deposited metal and slag on the base metal at increased calorimetry, respectively, from *17,5* to *21,0 g* and *2,0* to *13,0 g*, resulting in a change of $\eta_{b.m.}$ and from *0,74* to *0,84*; η_e proportional increase from *0,31* to *0,47*, in spite of the reduction in their rate of melting occurs due to increased thermal capacity of the arc and the specific costs of heat (K_e + K_{ehim}) for the electrode melting.

Due to the fact that the increase of the exothermic mixture in the test electrodes, i.e. the metal component of the coating is due to a corresponding decrease in the content gas-slag-forming coating part, the reduced heat losses in melting the coating, since iron enthalpy lower than the slag and increases the proportion of the heat coming to the melting of the rod and also to heating of the drops.

The researches have shown that the adding of the exothermic coating mixture increases the rate of melting of the electrode due to: increase the arc thermal capacity; heat generated by the exothermic reaction in the solid phase; reducing the costs of coating melting and improve the arc processing characteristics.

Averaged data of mechanical properties and chemical composition made by different parties designed electrodes weld metal [4] show that these electrodes and mechanical properties in the weld metal content of sulfur and phosphorus fully satisfy the requirements of GOST 9467-75 types E46 to the electrodes (ET-3), E50A (ET-2) and E60 (ET-4) (Tables 1 – 3).

Table 1

The weld metal chemical composition

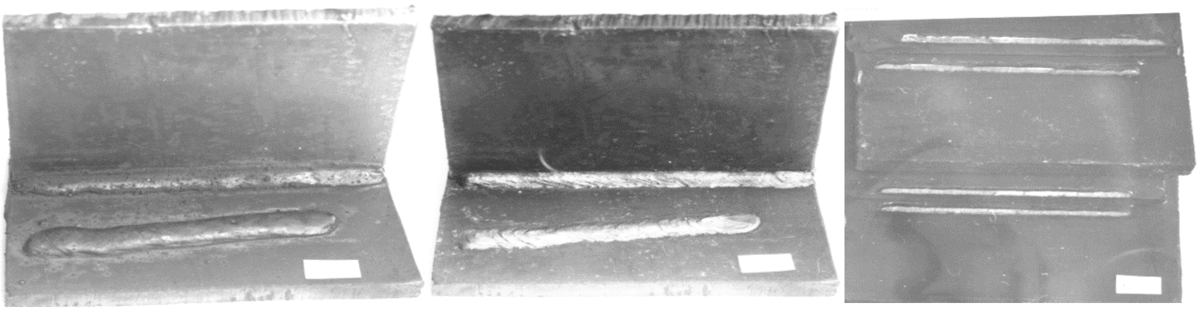
The electrode type	Content of elements, %						
	C	Mn	Si	Al	Ti	S	P
ET-2 (E50A)	0,10 – 0,12	0,71 – 0,90	0,15 – 0,25	0,01 – 0,04	0,04 – 0,09	0,023 – 0,030	0,028 – 0,033
ET-3 (E46)	0,05 – 0,10	0,40 – 0,60	0,14 – 0,26	0,06 – 0,08	0,01 – 0,03	0,020 – 0,030	0,023 – 0,030
ET-4 (E60)	0,10 – 0,13	1,31 – 1,49	0,28 – 0,35	0,02 – 0,06	0,04 – 0,07	0,027 – 0,032	0,026 – 0,032

Checking designed electrodes weldability showed the following: the arc is excited easily and stably lit; coating melts uniformly, spraying small (Figure 6 a); the forming roller – smallscaly (Fig. 6b); the slag crust separation – light; the deposition rate *– 11,8 – 12,5 g/A·h*; the melting rate *– 21,5 – 25 m/h.*

Table 2

Gas composition of weld metal

Content of gases					
In cm^3 per 100 g of metal			Percentage		
Carbon monoxide	Nitrogen	Hydrogen	Oxygen	Nitrogen	Hydrogen
82,5-86,7	13,5	4,0 – 4,2	0,059 – 0,062	0,0169	0,00036



a) b) c)

Figure 6. Bead appearance and a fillet weld (a) weld bead smallscaly formation (b) kinks fillet welds (c) formed researched *(d_e = 5,0 mm)* electrodes type ET-2 with exothermic mixture in a coating

Table 3

Composition of nonmetallic inclusions in the weld metal

Total number of nonmetallic inclusions	Dioxide Si	Protoxide gland	Oxide Aluminium	Protoxide Manganese	Oxide calcium	Dioxide Titanium	Other
0,08	15,96	1,86	66,13	4,57	3,12	5,34	3,08

Checking of welding-technological properties of the developed electrodes for engineering plants showed the following:

- Arc easily excited and steadily burns;
- Coating melts evenly, sprinkling small;
- Forming roller – finely scaly;
- Separation of the slag crust – light;
- Electrodes are not very sensitive to the presence of scale and rust on the surface of the deposited metal;
- Coefficient of surfacing – *11,1 – 13,0 g/A·h*;
- Melting rate – *21,5 – 25 m/h.*

Conclusion. A good method to increase the efficiency of manual arc welding and surfacing is the introducing of exothermic mixture into the coating of electrodes (slag, ferroalloys and aluminum powder in amounts sufficient to form it).

In order to make electrodes for surfacing process, it is advisable to use the scale of the alloyed steel (that is a reject of press forging) as a component of exothermal mixture.

Developed are electrodes containing the exothermic mixture in their coating for surfacing of die steels, which provide the increased efficiency of manual arc surfacing by *1,3* to *1,7* times in comparison with the similar existing electrodes.

The developed methods for experimental determination of the exothermal process running in a hard phase makes it possible to find the presence or lack of exothermal mixture in the coating of electrodes.

With variation of the content of exothermal mixture in the coating of the electrodes from 35 to 64%, the rise of temperature in it was 1280°C.

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ РУЧНОГО ДУГОВОГО ЗВАРЮВАННЯ ТА НАПЛАВЛЕННЯ ДЕТАЛЕЙ МАШИНОБУДУВАННЯ

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Резюме. *Обговорено метод підвищення ефективності ручного дугового зварювання та наплавлення. Визначено вплив кількості екзотермічної суміші у складі покриття та впливу товщини покриття електродів на процес інтенсифікації процесу плавлення. Підвищення продуктивності зварювальних процесів та пошук нових видів сировини для їх виробництва є одним із основних завдань розробників зварювальних та наплавних матеріалів. Одним із основних способів підвищення продуктивності ручного дугового зварювання (наплавлення) є додавання в покриття електродів порошку заліза. Найвища продуктивність досягається, коли вміст порошку заліза в електродному покритті становить 60 – 70% при одночасному збільшенні товщини електрода. Наведено дані щодо впливу кількості екзотермічної суміші в покритті електродів на їх нагрівання та плавлення. Експериментальними методами встановлено, що екзотермічні реакції в стадії нагрівання та плавлення відбуваються в електродному покритті, що містить понад 35% екзотермічної суміші. Доведено, що коли у покритті електродів 58% залізної окалини в порівнянні з електродами, що містять таку ж кількість порошку заліза, швидкість плавлення електрода збільшується на 18 – 20%, швидкість плавлення покриття – на 31 – 34%, а коефіцієнт плавлення електрода – на 11 – 14%. Доведено, що додавання екзотермічної суміші (до 53,4%) у покриття електродів призводить до підвищення ефективності нагрівання основного металу ($\eta_{b.m.}$) від 0,715 до 0,815 і електрода (η_e) – від 0,28 до 0,415. Отримані результати можуть бути використані для поліпшення ефективності зварювальних електродів.*

Ключові слова: *електрод, екзотермічна суміш, зварювання, наплавлення, ефективність.*

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