

Aerosol fluxing in electro arc metallization

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Abstract. The main structural and technological factors of electric arc metallizers, which significantly affect the quality of their operation, are considered. The results of experimental studies on the adhesion strength, porosity, microhardness and comparative wear resistance of coatings obtained by electroarc metallization are presented. Optimal modes of coating with electroarc metallization are determined. It is established that the use of aerosol fluxing during electric arc metallization provides an increase in adhesion-cohesive strength by 25 ... 30%, an increase in microhardness to 40%, a decrease in porosity by 20 ... 25%.

1. Introduction

In the world practice of restoring the details of machinery and corrosion protection of aluminum and zinc pipes, equipment and metal structures, electric arc metallization (EM) has become very popular, as one of the most technologically productive, high-quality and universal methods of metal coating. However, along with clearly positive sides, EM has certain drawbacks. This perennial problem is the speed and oxidation of dispersed metal in a heterophase stream. Without overcoming these EM problems, it is impossible to further improve the physical and mechanical properties of metal coatings. Despite the extensive volume of studies carried out to modernize EM over the historical period of its use (over 100 years), these problems remain unresolved.

2. Materials and methods.

To solve technical problems, the method of aerosol fluxing and the laws of gas dynamics were used. The design developments were based on TAFA equipment. The following filler materials (wire) were used in the experiments:

1. Sv-08, flux № 1 - Na₂CO₃, Na₃AlF₆, Na₂B₄O₇
2. Sv-08, flux № 2 - Na₂CO₃, Na₃AlF₆, H₃BO₃
3. Sv-08, flux № 4 - Na₂CO₃, Na₃AlF₆, Na₂B₄O₇
4. Sv-08, flux № 5 - Na₂CO₃, Na₃AlF₆, Na₂B₄O₇, NH₂CON₂
5. Sv-08, flux № 6 - Na₂CO₃, Na₃AlF₆, Na₂B₄O₇, H₃BO₃
6. Sv-08 (without flux)



7. Sv-08 + X20N80 (without flux)
8. Steel 45 (without flux)

3. Results of the research.

We have developed two models of supersonic metal sprayers — EAM-11SHD-machine-tool (electro arc metallization) and EAM-12SHD-manual (electro arc metallization) are developed. They are considered a new generation of electro arc metallization (EM) equipment.

Designers and creators of electro arc metallization (EM) equipment of TAFE firm followed up one and the same objective, i.e. supersonic outflow of metal and air flow and contraction of spray-cone angle of spray pattern, obtaining increase of physical and mechanical properties of coatings without application of arc activation complicated devices, i.e. burning of hydrocarbon fuel or flammable gases.

The work was begun from gas dynamic calculation of air jet outflow via shaped nozzle (Fig. 1).

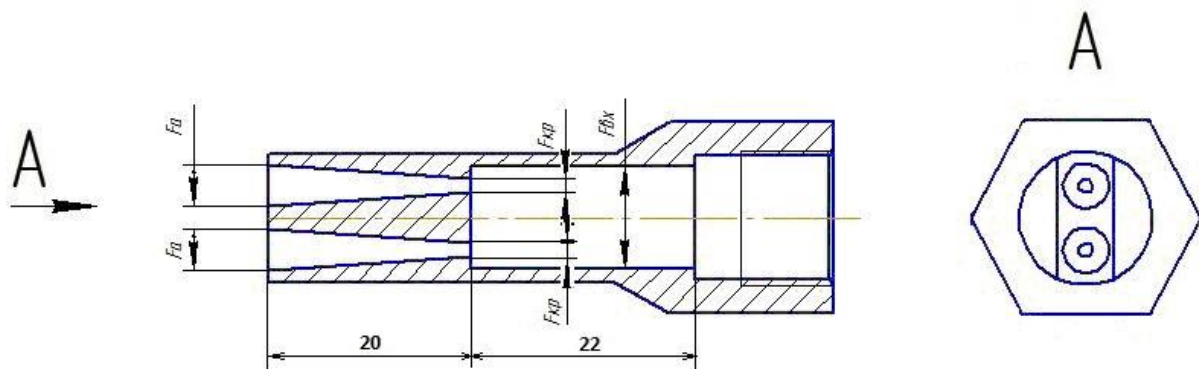


Figure 1. Supersonic nozzle of metal sprayer EAM-11SHD (electro arc metallization)

1. Basic data for calculation:

- P_0 – total pressure in main (kg/sm^2);
- F_{mp} – minimum passage section at gas outflow (sm^2);
- μ – jet flow coefficient ($\mu \approx 0,85 \dots 0,9$);
- T_0 – air temperature ($T_0 \approx 290^\circ\text{K}$);
- R – gas constant (for air $R=29,3$);
- K – adiabatic k-value ($K=1,4$);
- A – flow coefficient ($A \approx 0,023 \text{ 1/s}$);
- $g = 9,8 \text{ m/s}^2$.

2. Calculation of sonic velocity or gas critical velocity at supersonic outflow from nozzle:

$$C = \sqrt{K \cdot g \cdot R \cdot T_0} = \sqrt{1,4 \cdot 9,8 \cdot 29,3 \cdot 290} = 340 \text{ m/s}.$$

This condition is realized at correlation of receiver pressures (main) and ambient medium P_H : $\frac{P_0}{P_H} \geq 1,89$. If $\frac{P_0}{P_H} < 1,89$ – outflow is subsonic and calculation is done according to other dependences.

In commonly used schemes (Fig.1) correlation $\frac{F_{en}}{F_{mp}} > 1,5 \dots 2$ must be provided. When this condition

is not observed the occurring losses result in decrease of total pressure P_0 by 20...30% because of energy losses at transfer of supersonic flow to subsonic flow.

Let's examine section parameters F_{en} .

In outlet it corresponds to: $F_{en} = 0,785 \cdot 7,5^2 = 44 \text{ mm}^2$.

Passage section in nozzle F with account of shadowing of electrode wire $\varnothing 2\text{mm}$:

$$F_{mp}=0,785 \cdot 7^2 - 2 \cdot 7 = 24,5 \text{ mm}^2.$$

There is correlation: $\frac{F_{en}}{F_{mp}} = \frac{44}{24,5} = 1,8$, that satisfies normal conditions of jet system operation.

Air consumption:

$$G = \mu \cdot A \cdot P_o \cdot F_{KP} = 0,85 \cdot 0,023 \cdot 7 \cdot 0,245 = 0,0335 \frac{\text{kg}}{\text{s}} \approx 33 \frac{\text{g}}{\text{s}}.$$

Taking into consideration the design features of nozzle EAM-11SHD (electro arc metallization) (electrode wire location in it) gas flow in the nozzle changes from sonic (at $F_{KP}=24,5\text{mm}^2$) to supersonic, because at outlet section we have $F_a=0,785 \cdot 7^2=38,5\text{mm}^2$

With application of table of gas dynamic functions (A.A. Dimentyeva and others) [1] we obtain:

$$q(\lambda)=q(\lambda)=\frac{F_{mp}}{F_a}=\frac{24,5}{38,5}=0,63, \text{ from which } \lambda=1,6.$$

$V_a=340 \cdot 1,6=540 \text{ m/s}$ (without taking into consideration heat supply for the sake of arc burning)

This calculation of supersonic velocity of air jet from nozzle is done without consideration of heat supply from electric arc. Supersonic velocity is $V_a=540 \text{ m/sec}$ – of cold air.

It is known that arc temperature is about 6000°C [2]. On the ground of gas dynamic calculation it is possible to suggest that V_a increases no less than 3 times.

In connection with development of supersonic metal sprayers the task of metallization distance optimization (H_D) was assigned. For this task the experimental tests of function of dependence of adhesive-cohesive resistance of EM (electro arc metallization)-coatings from metallization distance at supersonic and subsonic mode were carried out.

As optimal value of supersonic metallization distance is accepted maximum result of adhesive-cohesive resistance of EM (electro arc metallization)-coatings.

At subsonic metallization H_D was accepted 120 mm, at supersonic metallization H_c it was improved to 160 mm.

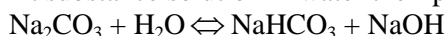
Increase of maximum velocity of air flow being measured device PDGP-1 [3] provides the metallization quality improvement at reconditioning of engines crankshafts and other elements which metallization is possible only at the distance more than 120 mm.

Comparative laboratory tests of supersonic metal sprayer EAM-10SHD (electro arc metallization) showed at metallization distance 160 mm. increase of adhesive-cohesive resistance by 25%, coating density by 23%, operation ratio of filler material by 15% in comparison with subsonic level of air jet outflow.

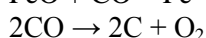
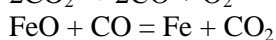
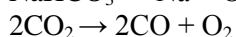
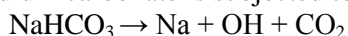
To solve the problem of decrease of oxidation potential at EAM (electro arc metallization) and metal alloying being melted by arc, the method of aerosol fluxing [4, 6, 7], was applied, the essence of which is in the following.

The essence of aerosol fluxing (AF) consists in that in the dispersed metal jet at EM (electro arc metallization), aerosol in the form of different substance water solution is introduced.

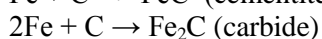
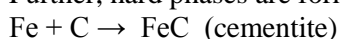
At substance solution in water their predissociation takes place, for example:



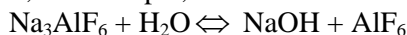
Getting into the high temperature zone of electric arc and dispersed metal jet the predissociated sodium carbonate is subjected to thermal dissociation.



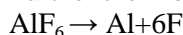
Further, hard phases are formed at the contact with melted ferrum:



Thus, in aerosol fluxing (AF) process the carbothermic process and reconditioning process take place. At aerosol fluxing (AF) some other substances compositions to obtain analogical effect are used, for example, at lithium aluminum hydride solution its dissociation takes place:

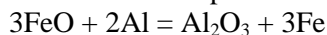


Further thermodissociation:



Metallotherapy runs with heat emission because of energy-releasing reaction of deoxidization of ferrous oxide by aluminium with emission of about 200 kkal. of heat.

Aluminothermic process running is seen from the flowing reaction:



At application of aluminothermic effect, i.e. FeO deoxidization reaction by aluminium, increase of temperature of metal particles in heterophase flow takes place because of the same reason of energy-releasing reaction of deoxidization of ferrous oxide by aluminium with heat emission.

It is known [3], that the temperature in contact of melted metal particle at its collision with substrate characterizes energy condition of atoms (T):

$$T = f(T_{\Pi}, T_K, E_K, E_T),$$

where T_{Π} – template temperature;

T_K – metal drop temperature;

E_K – kinetic energy of metal drop;

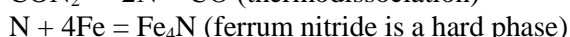
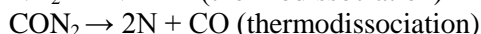
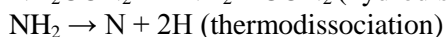
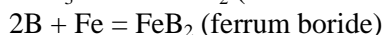
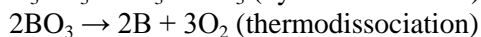
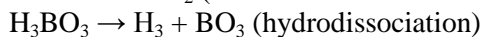
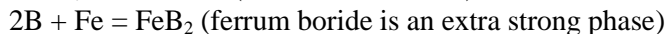
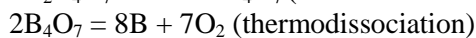
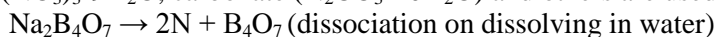
E_T – kinetic energy of heterophase flow.

That is why to obtain the hardening effect of coating adhesion with substrate, as well as particles in coating is necessary to increase T and E. This is proved by the works of V.V Kudinov on research of interaction separate particle with substrate, from them it follows that adhesion resistance mainly can be increased by increasing the temperature of metals particles in contact with substrate and velocity V of particles [5].

Increase of adhesive-cohesive resistance of electro arc metallization EM – coating at the account of carbothermic (C) metallothermic (Al) ferrum deoxidization is the first solvable problem by means of aerosol fluxing.

The second application of method of aerosol fluxing (AF) is alloying of metalize layer to increase its resistance, hardness and wear resistance. It is obtained by application of some additional substances to prepare aerosol, containing boron, nitrogen, chrome.

The process runs identically to the described above reactions. For it the substances soluble in water, for example borax ($\text{Na}_2\text{B}_4\text{O}_7$), boric acid (H_3BO_3), carbamide (NH_2CON_2), chromic nitrate $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, carbonate ($\text{N}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$) and others are used.



For experimental tests according to aerosol fluxing (AF) the developed hydro-disperser presented in Figure 2 was used.

It is a steel cylinder where by means of air fed into metal sprayer it is dispersed to midst state of flux water solution. In this form as it shown in the figure heterophase flow moves into electrical circuit, arc, metal sprayer, where thermodissociation of the dissolved substances and other phase transformations [8-12].

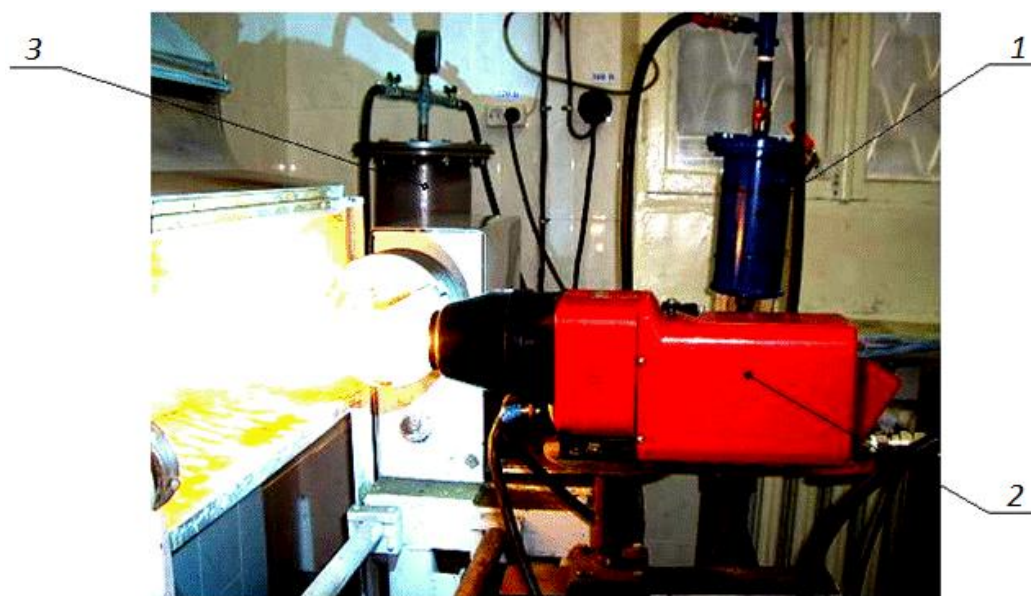


Figure 2. Electro arc metal sprayer working together with hydro-disperser for aerosol fluxing (AF):
1 – hydro-disperser; 2 – metal sprayer; 3 – filter for compressed air cleaning.

Results of the experimental tests

The generalized results of experimental tests are presented in the table.

Table – Experimental tests results

№	№ flux	Concentration , g/l	Solution consumpt ion, mm/min	Adhesion, cohesion, kgs/mm ²	Porosity, %	Microhardn ess, HV	Comparative wear resistance, %*
1	1	60	10	5,4/5,2	3,8	560	100
2	2	50	5	5,4/5,3	3,6	540	50
3	4	60	10	5,5/5,3	4,1	560	100
4	5	60	10	4,4/2,5	4,5	560	110
5	6	60	5	5,0/4,8	5,2	580	90
6	Sv -08			2,3/2,1	6,0	212	35
7	Sv -08+ X20H80			3,4/4,0	6,1	280	45
8	Steel 45			3,0/2,8	6,2	510	100

*Wear resistance of coating from Steel 45 without aerosol is 100% conventionally

From the table is seen that the maximum results of adhesive-cohesive resistance, microhardness and wear resistance are obtained at application of fluxes № 1, № 4, № 5, № 6 at concentration 60 g/l. Not only flux content but also substance concentration in aerosol and flux consumption influence considerably on the coating properties.

Application of aerosol fluxing also positively influences the reaction of metal coating in friction couple. Figures 3, 4 present diagrams of counterface (block) wear and friction coefficient for different metal coatings at their testing for wear resistance on friction machine.

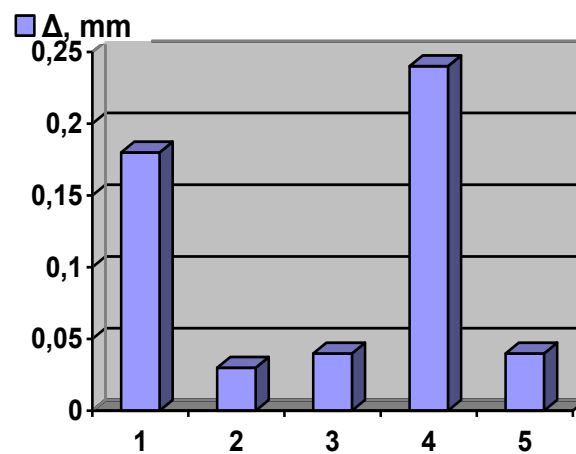


Figure 3. Block wear for different metalized coatings: 1 – Sv-08 (without aerosol); 2 – Sv-08 + aerosol № 5; 3 – Sv-08 + aerosol № 4; 4 – Sv-08 + X20H80 (without aerosol); 5 – Steel 45 (without aerosol)

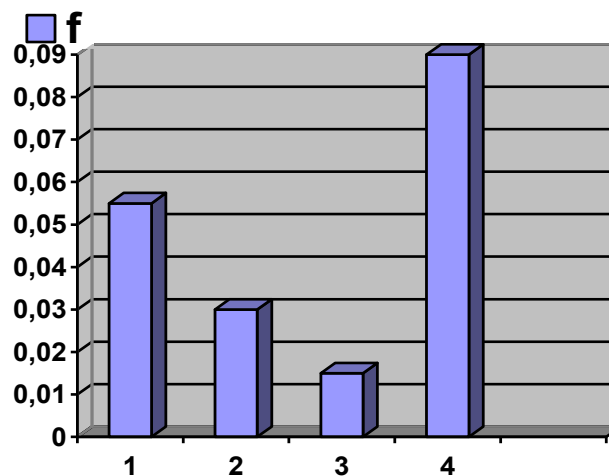


Figure 4. Friction coefficient for different metalized coatings: 1 – Sv-08 (without aerosol); 2 – Sv-08 + aerosol № 4; 3 – Sv-08 + aerosol № 6; 4 – Sv-08 + X20H80 (without aerosol)

4. Conclusions.

1. According to the gas dynamic calculation of the developed nozzle of electro arc metal sprayer supersonic velocity of air flow is 540 m/s without taking into account arc burning temperature.
2. Experimentally by means of the developed in State Scientific Institution of All Russian Research 3. Technological University device PDGP-1 maximum velocity of air flow at the distance of 160 mm from the point of crossing electrode wires is defined. On this basis the accepted earlier metallization distance from 120 to 160 mm was adjusted. It extends the applicability of electro arc metallization (EM).
3. Improvement of physical and mechanical properties of electro arc metallization (EM) coatings is achieved at the account of deoxidization of ferrum by aluminium and carbon (metallo-carbothermy) and its alloying with boron, nitrogen, carbon at aerosol fluxing.
4. Application of aerosol fluxing at electro arc metallization (EM) provides increase of adhesive-cohesive resistance by 25...30%, microhardness increase to 40%, porosity decrease by 20...25%.

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