

INFLUENCES OF SURFACE-ACTIVE SUBSTANCES ON SPECIFIC POWER CONSUMPTION AND ON SURFACE ROUGHNESSES OF METAL PRODUCTS UNDER PLASMA VACUUM ARC TREATMENT

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The use of the vacuum arc for cleaning of the material surfaces and for removal of various contaminations is an actual problem in view of essential advantages of this cleaning method in comparison with chemical, mechanical and other ones and, first of all, in view of absolute environmental safety of vacuum arc method [1-5]. However, in the case of vacuum arc cleaning of some kinds of the hot rolled metals covered with relative thick (6-12 microns) layers of oxide, the roughness of the surfaces after cleaning sometimes exceeds the necessary limit of 10-14 microns. Cleaning of such steels of thick layers and removal of the scale is accompanied by the large power inputs. It is a reason of necessity of improvement of plasma vacuum arc technology and of the study of the interaction mechanisms of cathode plasma of the vacuum arc with the material surfaces.

1. Introduction

It has been shown [6] that how the cathode plasma interacts with the cathode surface points to the fact that the elementary cathode spots (ECS) exist on the surface with scale in the form of compact structurally ordered groups for long lifetime; such groups were called group cathode spots (GCS). The measurements of the dependence of GCS size on current demonstrated that GCS has a configuration in which the elementary cathode spots are located along the GCS contour according to the law independent of current. This configuration is undoubtedly connected with forming a characteristic micro relief on the eroded surface in the form of an axially symmetrical columnar jut of melted metal (protrusion). Surface roughness after treatment is due to protrusion formation. The effect of a high-intensity magnetic field leads to protrusion disappearance. Assuming that the magnetic field influences the ECS formation by way of changing the density of near-surface plasma, one can suggest that it is possible to change a GCS structure and, accordingly, a surface microrelief by way of depositing substances with special characteristics on the surface [7]. More perspective are the substances with lower work function, low evaporation heat and high ionization efficiency in the gas phase. The effect of surface-active substances on surface plasma interaction with surface was experimentally studied for KOH, NaOH, Ba(OH) \cdot 8H $_2$ O и Ba(NO $_2$) $_2$ \cdot 2H $_2$ O. A significant increase in surface roughness and power consumption was observed. The effect of those compounds on a mechanism of vacuum arc discharge interaction with surface, on specific power consumption for vacuum arc descaling of metals and on surface roughness has been considered.

2. Effect of surface-active substances on specific power consumption and surface roughness

The samples of steels SUS304 and SUS430T were used to study the effect of special chemical compounds deposited directly before vacuum-arc treatment on roughness and specific power consumption. The chemical composition of steels is given in Table 1.

Chemical composition of steel

Table 1.

| Steel quality | Components, % | | | | | | |
|---------------|---------------|-----|-------|------|-----|-----------|----------|
| | C | Mn | P | S | Si | Cr | Ni |
| SUS 304 | 0,08 | 2,0 | 0,045 | 0,03 | 1,0 | 18,0-20,0 | 8,0-10,5 |
| SUS 430 | 0,12 | 1,0 | 0,04 | 0,03 | 1,0 | 16,0-18,0 | 0,75 |

The KOH or NaOH water solution (10-20 weight %) was used as a chemical compound to be

deposited; these compounds were uniformly deposited on the sample surface with their further complete drying. The experiments were carried on for the cleaning rate 0.35-6 m/min and the vacuum-arc discharge currents 140-340 A, which corresponds to the surface density of charge 6 C/cm².

The ratios of specific charge and surface roughness for different ways of vacuum arc treatment are given in Table 2.

The dependence of specific power consumption and surface roughness on a way of vacuum arc treatment

Table 2

| Compound | Steel quality | Charge density | Specific power consumption kWt/h m ² | Roughness Ra | Roughness Rmin | Decrease in specific power consumption |
|----------|---------------|----------------|---|--------------|----------------|--|
| Без CB | SUS304 | 80,91 | 5,82 | 10,2 | 58,5 | — |
| KOH 10% | SUS304 | 39,8 | 2,71 | 5,4 | 31 | 2,1 |
| KOH 20% | SUS304 | 39,3 | 2,57 | 4,3 | 25,4 | 2,3 |
| KOH 25% | SUS304 | 42,5 | 2,8 | 4,0 | 30,7 | 2,1 |
| Без CB | SUS430 | 89,7 | 5,98 | 11,9 | 51,8 | — |
| KOH 20% | SUS430 | 39,5 | 2,63 | 3,8 | 19,2 | 2,3 |
| KOH 25% | SUS430 | 51,3 | 3,42 | 4,1 | 21,4 | 1,7 |
| NaOH 10% | SUS430 | 45,1 | 2,85 | 7,8 | 34,1 | 2,0 |
| NaOH 20% | SUS430 | 44,0 | 3,0 | 6,8 | 31,0 | 2,0 |
| NaOH 25% | SUS430 | 52,6 | 3,65 | 8,3 | 36,5 | 1,6 |
| NaOH 20% | SUS430 | 55,5 | 3,8 | 4,6 | 24,2 | 1,5 |

As seen from Table, the optimal concentration of water solution of KOH or NaOH alkali is 20%. As it should be expected, a decrease in total power consumption on steel quality and substance to be deposited is 1.5–2.4 times and the roughness 1.5–3.2 times owing to reducing the electron work function on the scale surface by the surface-active substances and increasing a flow of neutral particles evaporated from the surface, as well as owing to changing GCS structure from linear to circular.

The characteristic Talyrond traces of the SUS430 steel surface treated by the cathode spots of vacuum arc discharge are presented in Fig. 1.

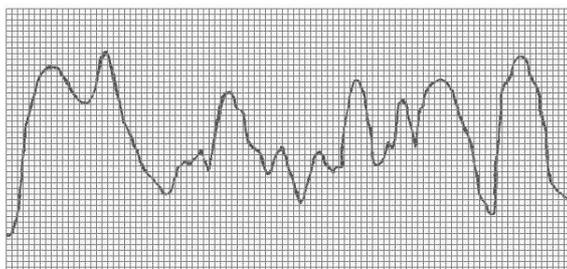


Fig. 1a

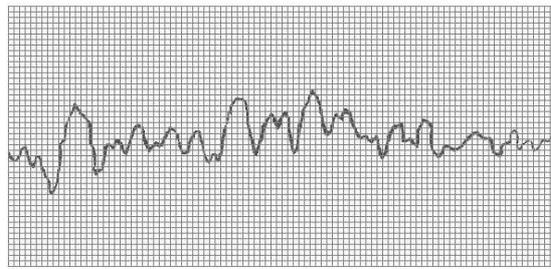


Fig. 1b

3. Experimental method and results

An experimental setup for study of the cleaning process consists of a vacuum chamber with a system of electrodes inside, a power unit of direct current for discharge, a system of vacuum pumping with a rotation pump and a system of water circulation for anode cooling. The samples were made in the form of a square 100×100×3 mm from SUS 430 steel with 5 mm scale. The sample to be tested was a cathode. Along the perimeter the sample surface was masked with a ceramic plate to avoid discharge at the sample edge. The open surface has the form of a regular square with the area 100 cm², 60 cm² and 40 cm².

The following substances were selected – KOH, NaOH, LiOH, Ba(OH)₂, KCl and NaCl. We assumed that the ECS formation probability is defined, on the one hand, by the density of near-surface plasma that is created by already existing ECSs and, on the other one, the minimal threshold density of near-surface plasma that initiates a new ECS [8]. Therefore, the substances promoting more effective plasma generation in ECS of vacuum arc discharge were selected to cover the surface. KOH and NaOH

are approximately one type with slightly different work function of metal (2.22 and 2.35 eV), similar energy of evaporation (1.4 and 1.48 eV) and boiling temperature (1570 and 1660 K). LiOH and Ba(OH)₂ are decomposed at rather low temperature (before the corpuscular particle flows starts to develop). However, they form stable oxides Li₂O and BaO with very low work function, high boiling temperature and rather high energy of evaporation (3.19 eV and 3.82 eV). NaCl and KCl were selected to study how Cl (gas with high affinity to electron) influences on the probability of ECS formation.

The experimental setup to study the probability of ECS formation on the surface of hot-rolled steel covered by the above-indicated substances is shown in Fig. 2. The cathode (sample) is a plate of 60×20 mm from hot-rolled steel SUS 430; this plate is divided into two identical parts with a line of 0.5

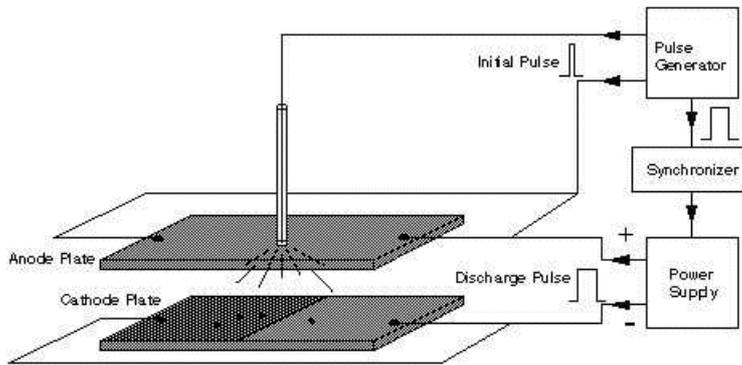


Fig. 2

mm in thickness. One part of this plate was covered by one of the above-indicated substances the other was clean. The anode made from copper has the same form as the cathode; at the center of the anode there is a hole for an initiating electrode. The distance between the anode and cathode was 30 mm. The initiating pulse duration was 5 ms. The parameters of the discharge pulse were so that only one clearly delineated crater be formed for one pulse. The discharge pulse duration was 1 ms and the discharge current amplitude was 15 A.

in that case only one GCS can be formed on the oxidized surface of SUS 430 steel. The result of cathode spot formation (discharge initiation) was registered as a separate crater of erosion on the surface. The number of craters on the every part from the separating line was counted for 30 discharges. The number of craters on the both parts without substance deposition was almost identical. The probability of CS formation on one part of the plate was defined as the ratio of the crater numbers on one part and the total number of craters on the plate. For KOH deposited on one part the probability of charge initiation and, hence, ECS formation was higher than that on the clean part. The formation probability has the maximal value for the 10% concentration of the KOH water solution, which corresponds to the surface concentration of substance 0.001 g/cm². As the quantity of the SAS water solution (volume units) per a surface area was always the same there is unambiguous relation between the concentration of the SAS water solution and the surface concentration of this SAS for all the experiments. The maximum of the considered dependence is a rather important experimental fact for further interpretation of the results.

The dependence of surface roughness and rate of substance removal from the surface on substance concentration have been studied for stably burning vacuum arc discharge. In this case, the power source operated in the mode of direct current. The voltage was 200 V, arc current was 55 and 100 A. the anode was a copper rod of 20 mm in diameter. The anode-cathode distance was 40 mm. The discharge was initiated with a high-voltage initiating electrode. The work pressure could be regulated from 5 to 50 Pa. It was shown that the surface roughness is almost independent of pressure within the pressure range 5–20 Pa. (Fig. 3). Moreover, the surface roughness is independent of discharge current, which is in agreement with the linear dependence of the number of cathode spots on discharge current.

It should be noted that the cleaning rate linearly depends on discharge current within the experimental range of current values. This rate was defined as follows. The samples with the exact value of the surface area to be treated were used for tests. The time of complete sample cleaning was measured for a fixed value of discharge current. The cleaning rate was defined as the ratio of cleaned surface area and time.

After descaling the surface roughness of the sample was measured with a profilometer (Mitutoyo SurfTest 401). The dependences of surface roughness and cleaning rate on KOH and NaOH concentration are shown in Figs. 3b–3c. The roughness rapidly decreases with concentration increase and has the value approximately 2.5 times less than that for zero concentration. For further increase in concentration the roughness weakly increases. The maximum of cleaning rate is more pronounced for the 10% concentration of substance; this maximum is approximately 1.8 times higher than that far from the

maximum. The discharge voltage for KOH deposition is 1.5–2.0 V higher than that without KOH and has the maximal value for 10% KOH.

KCl and NaCl used instead of KOH and NaOH lead to decreasing the cleaning rate and increasing the surface roughness, as expected. The effect of different concentration of Ba(OH)₂ and LiOH on cleaning rate and roughness was studied as well. It has been found that Ba(OH)₂ does not change the cleaning rate but the roughness somewhat increases. The roughness increases more significantly for LiOH (almost in 1.6 times).

Thus, among the surface-active substances KOH, NaOH, LiOH, Ba (OH)₂, KCl and NaCl the most favorable results were obtained for KOH and NaOH. For the 10% concentration of SAS the surface roughness is approximately 2.5 times less than that without surface-active substances.

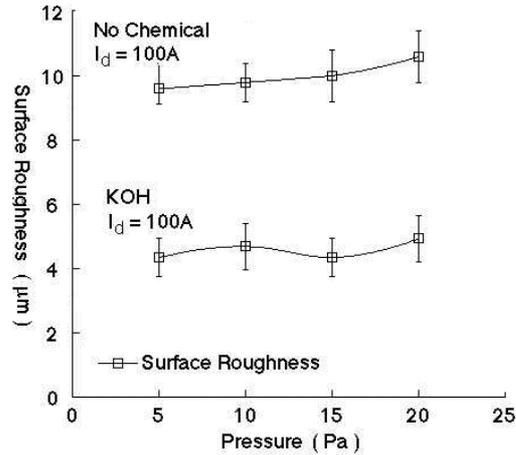


Fig. 3a

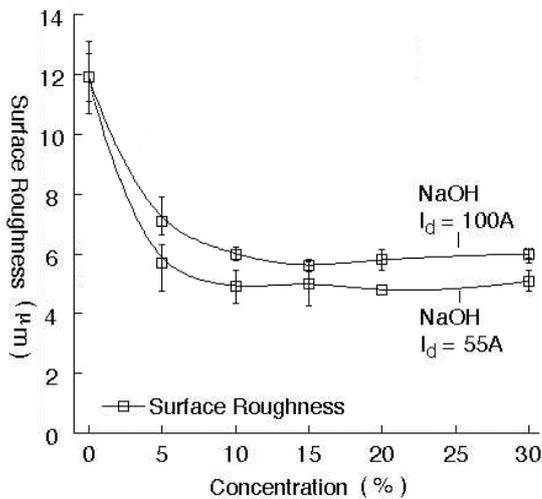


Fig. 3b

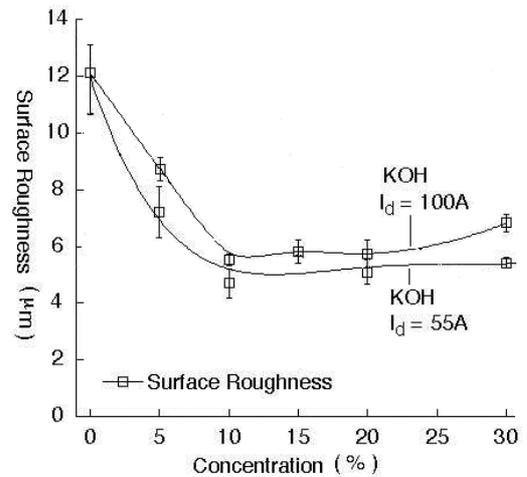


Fig. 3c

Reference

1. V.E. Bulat, A.M. Mirkarimov, R.B. Nagaibekov, S.L. Pozharov, U.Kh. Rasulev. TATF 96 Proceedings, P.155-157.
2. U.A. Arifov et.al. European Patent № 0468110. Date of filling: 24.07.90
3. S.L. Pozharov et. al. Russian Federation Patent by proposal № 93003651/12 Date of filling 21.01.93.
4. H.D. Steffens. In: "Proceedings of the Ninth International Thermal Spray Conference", Hague, 1980, P.420
5. A. Itoh, K. Takeda, M. Ito and M. Koga. Proceedings of the National Thermal Spray Conference, Longbeach, 1990, P.20
6. W. Petasch. Surf. Coat. Technol., 1997, **97**, 176.
7. K. Kiyokawa, A Itoh., H. Matsuoka, M. Tomimatsu and K. Sugiyama. Thin Solid Films, 1999, **345**, 119.
8. S.L. Pozharov, A.M. Mirkarimov, I.V. Soldatov. JTF, 1998, **68** (11), 57.