

**PLASMA POLISHING OF STAINLESS STEELS –
THE ELECTROLYTE CONCENTRATION VS. GLOSS LEVEL**

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Abstract

The technology of plasma polishing in electrolyte is considered as environmental friendly alternative to the common electrochemical polishing process. The solutions of the electrolyte use no acids or toxicants, but the environmental safe, low concentrated aqueous solutions of various inorganic salts are used instead. The dependence of the gloss level of the treated surface upon the electrolyte concentration as well as upon the voltage is examined in this paper. The specimens of stainless steel were used for plasma polishing in ammonium sulphate based electrolyte. The influence of the voltage on the overall properties of the process is discussed, as well.

Key words

Plasma, polishing, electrolyte, concentration, voltage, gloss level

INTRODUCTION

Regarding the rapidly increasing demands of customers for the quality of surface finishing on the one hand, and ever stricter environmental and health requirements on the other hand, the manufacturers are forced to close the old plants and invest in the new modern methods of surface treatment. An alternative to the conventional electrochemical process is a non-standard method of surface polishing using the effect of plasma discharge in electrolyte, i.e. the technology of plasma polishing in electrolyte. It is based on the physical phenomena taking place on the surface of the treated object immersed in electrolyte, under the influence of direct current at the voltage of hundreds volts when a vapour-plasma envelope is generated above the treated surface, i.e. a thin film of ionised vapour and gas resulting from the local boiling of electrolyte. When compared to the classical electrochemistry, it is a qualitatively and quantitatively different process.

The schematics of the plasma polishing can resemble the common electro-polishing, at first glance. However, there are some major differences. The metal part to be treated, is immersed into the electrolyte and is anodically polarised, i.e. connected to the plus pole of the electric

current supply. The counter electrode is connected to the minus pole of the power supply. The main differences are in the voltage value and in the chemical composition of the electrolyte. The high concentrated mixture of acids, used at electro-polishing, is displaced by low-concentrated aqueous solution of chemically neutral salts. A thin gaseous film is forming on the entire treated surface due to high value of the voltage between the electrodes. The film is formed from evaporated water and gas (oxygen) and it is electrically nonconductive and separates the metal surface from the electrolyte. In this way, the electric current is broken so the electric circuit gets disconnected. Nevertheless, if the voltage between the electrodes is high enough (a few hundreds of volts), the gaseous film becomes ionized due to high value of the electric field in the thin film. Therefore, the electric current flows through this film in the form of glow discharge. Columns of the glow discharges act on the metal surface. The discharge columns always runs toward the peaks of the surface profile since the distance between the metal surface and the wall of electrolyte is here shortest. In this way the surface peak is quickly removed. When the material of the peak is removed, the column of discharge moves to another surface peak where the thickness of the vapour-gas film is less. In this way the surface becomes smoother (1). If a proper chemical composition of the electrolyte and suitable parameters of the process are used, the treated surface becomes glossy. One of the advantages of this technology is in the possibility to treat metal parts with complex and irregular shape. Furthermore, there is no shielding effect as it is in the case of electrochemical polishing – all metal surface is treated uniformly including through holes. Next advantage of the plasma polishing process is in the harmless composition of the electrolyte. The electrolytes are based on environmental harmless solution of various inorganic salts. The aqueous solutions of concentrations 4÷6 % are prepared by dissolving granulate in the water without extra demand on its quality.

There are a few basic parameters of the process which affecting the properties of the process itself, as well as the properties of the treated surface. The process's parameters, which can be independently varied, are: the voltage, the treatment time, the temperature and the concentration of the electrolyte. All these parameters determine the value of the density of electric current, which is the major dependable process parameter. The value of the material remove rate of the process depends principally just on the value of the current density, so in this way, the process's parameters indirectly influences the properties of the treated surface, as well. The impact of two main parameters of the process, the concentration of the electrolyte and the voltage, on the gloss level of the treated surface is examined in this article.

CURRENT-VOLTAGE CHARACTERISTICS OF THE PROCESS

The voltage on the electrodes of the electrolytic circuit determines the nature of the physical processes carried out. The typical current-voltage characteristics of the anode process is shown in Fig. 1 (1). The curve shows several sections which correspond to different stages of the process. The process of common electrolysis takes place in the A-B section of the characteristics. Generation of gas bubbles on the electrodes is observed – O₂ at the anode, H₂ at the cathode. The bubble boiling near the active electrode at higher voltage complements the process of electrolysis. Upon further increasing the voltage, islets of vapour-gas film are formed on the surface of the active electrode.

The B-C section of the current-voltage characteristics is characterised by pulsation of the electric current. It occurs if the voltage is above a certain supercritical value, when the current density is about 10÷16 Acm⁻². A film of vapour and gas, which is periodically formed around the active electrode, periodically stops the current passing through the electrolytic circuit. The point B characterises the moment when the islets of film-boiling merge into a continuous layer, which pushes the electrolyte off from the surface of the active electrode and breaks the electrical circuit. After some time, the integrity of the vapour film is damaged due to gravitational force.

After the collapse of the vapour-gas film on the active electrode, the electric contact between the electrolyte and the electrode is restored and the process is periodically repeated.

The intensity of the electric field at the voltage value exceeding point C is high enough to ionise the environment of the vapour-gas film. The mode of stationary vapour-plasma envelope around the active electrode is initiated. After the creation of the ionised vapour film, the current density drops sharply to the tenth order of the values typical for point B. The surface of the active electrode may be intensely heated, but only in some cases. The section of current-voltage characteristics between points C and D is the heating zone. The temperature of the active electrode in the area after the point D decreases and is close to the boiling point of the electrolyte solution. This area is called the electro-hydrodynamic mode of the process and just this area is used for plasma polishing. It is necessary to point out, that the heating zone exist only at some circumstances, and the polishing process runs in most cases since voltage value just after the point C. However, the more the voltage close to the value given by point C, the less the process stability. The position of the point C varies for the electrolytes of different composition, concentrations and temperature (1).

MATERIALS AND PROCEDURES

The specimens used for this experimental study were made of a rolled sheet of X10 CrNi 18/8 austenitic stainless steel. The thickness of the sheet was 3 millimetres. The specimens of dimensions 50 mm × 50 mm has been cut from the sheet using water jet cutter. Two holes of diameter 5 mm were drilled at two adjacent corners of the specimen. The holes were used to fix the specimen to its holder during plasma polishing. To unify all specimens' surface properties, the surface of the specimens was blasting treated. White Fused Alumina FEPA F 040 of average (median) grain size 0,355 - 0,500 μm was used for this purpose. The initial (before polishing) gloss level of the specimen had the average value of 7.5 GU and the surface roughness Ra had the average value of 1.7 μm.

The gloss level of the treated specimen has been measured using a benchtop glossmeter Novo Curve, Rhopoint Instruments, UK. This glossmeter is a unique instrument with specially designed optics for accurately measuring curved surfaces and small areas. The gloss meter uses 60° measurement angle, which is suitable for all gloss levels, and it conforms to ASTM D523 and to ISO 2813. The gloss level was measured at the geometric centre of each specimen five times and the average values of these data were then calculated.

Aqueous solution of ammonium sulphate was used for the electrolyte. Three different concentration of the electrolyte have been chose – 6%, 9%, and 12% to determine the influence of the concentration on the resulting gloss level of the specimens. During the plasma polishing process, the electrolyte is self-heated by the heat released by the process, and must be therefore cooled by a cooling circuit using heat exchanger. Forced circulation of the electrolyte provides uniform distribution of the electrolyte's temperature in the vessel. The temperature of the electrolyte was kept constant at the value 60 °C for all specimens. The treatment time lasted 2.5 minutes and the immersion depth of the specimens under the electrolyte level was always the same – 100 mm.

The voltage between the electrodes varied within a quiet wide range. As described above, there is a critical value of the voltage below which the process become unstable – a value close to the point C on the current-voltage characteristics (see Fig. 1). Therefore, the experiment started with the higher possible voltage of 350 V. This value is limited only by the design of the electrical part of the equipment. The voltage was then gradually reduced in some steps until the occurrence of intense pulsation of the electric current. This is the lower limit of the usable voltage range and its value depends on other process parameters, especially on the concentration of the electrolyte solution.

RESULTS

The measured gloss level of three sets of specimens after plasma polishing can be found in Table 1. There are the average values given in the table. The voltage drop between each next specimen was 30 V except the last one in the case of 6% concentration of the electrolyte, since the critical value of the process stability was reached at 235 V. This value of the voltage was afterwards used also for next two concentrations, where the critical value of the process stability was reached at the voltage value of 200 V.

Voltage [V]	Gloss level [GU] at various electrolyte concentrations		
	6%	9%	12%
350	22.1	7.9	3.3
320	29.3	15.1	7.5
290	33.9	26	19.3
260	66.9	39.9	23.2
235	69.5	47.1	24.2
200	—	51	0.8

Graphical representation of the obtained data is shown in Fig. 2. There are three gloss versus voltage curves for each used concentration of the electrolyte.

DISCUSSION

Analysing the above results of the accomplished experiment a few conclusions can be drawn. At first, the higher concentration of the electrolyte solution has a negative impact on the gloss level. The electrolyte concentration of about 6% is usually used for stainless steel polishing at our workplace. The higher concentrations in this experiment was used only to study

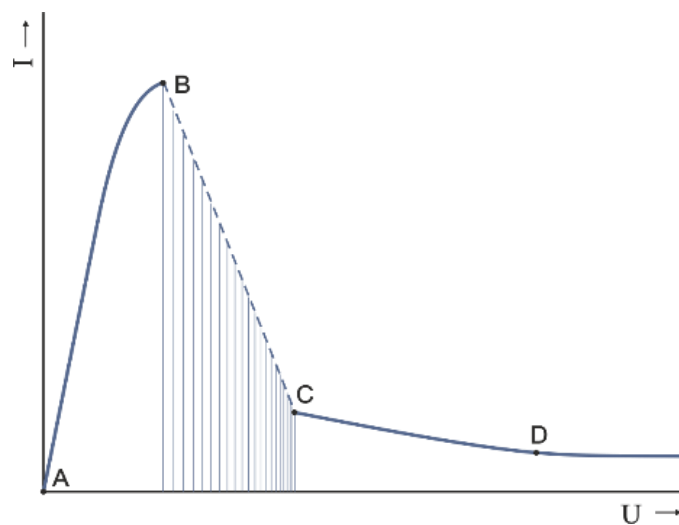


Fig. 1 Typical current-voltage characteristics of the anodic process (1);
B – formation of continuous vapour-gas film around the active electrode,
C – formation of stable vapour-plasma envelope around the active electrode,
D – formation of hydrodynamic phenomena in electrolyte, induced by a strong electric field

the influence of the electrolyte concentration on the process properties. However, the references to the usage of lower concentration of the electrolyte are published. For example, the concentration of ammonium sulphate 5% is reported by the authors of (2), the concentration of 4% is reported in (3) and even the concentration of 3% ammonia sulphate is mentioned in (4).

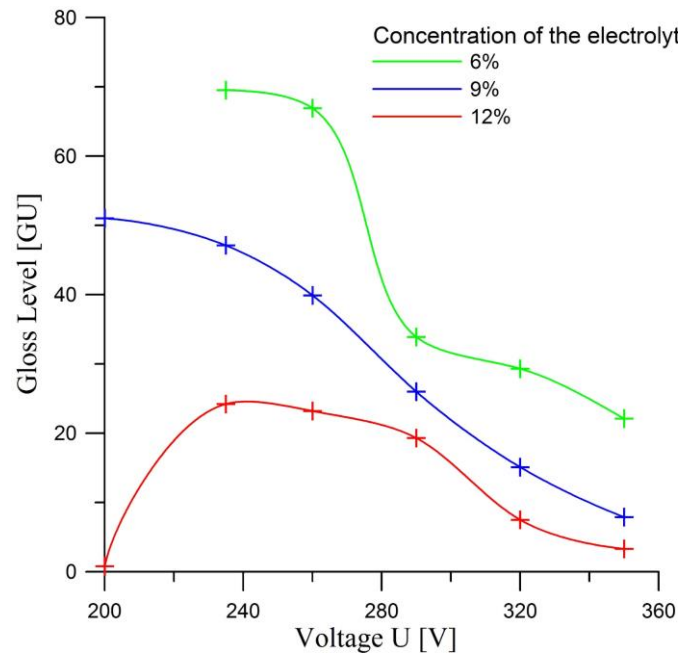


Fig. 2 The resulting gloss level of the polished surface versus voltage at electrolyte concentration 6%, 9% and 12%

Notwithstanding, a low concentration of the electrolyte has a negative impact on the stability of the electrolytic-plasma process due to the increased series resistance of the electric circuit (1). If the integrity of the vapour-plasma envelope around the treated surface is become corrupted, the electrolyte is locally in direct touch with the metal surface, i.e. a micro-short circuit is forming. However, the electrolyte is then rapidly evaporated in the place of the short circuit due to high local intensity of the electric current. The integrity of the vapour-plasma envelope is recovering in this way. The micro-short circuit described above leads to a voltage drop. The voltage drop on the vapour-plasma envelope slows down the recovery of its integrity at the location of the micro-short circuit. Any larger voltage drop on the vapour-plasma envelope leads to the instability of the electric circuit, which can give rise to oscillations due to the negative dynamic resistance of the vapour-plasma envelope. Such oscillation of the system formed by the power source and the vapour-plasma envelope will initiate the protective circuits and the power source will be switched off. Based on our experience, the concentrations below 6% pose a problem of process stability, particularly in the case of polishing objects with various internal cavities and holes. Such holes cause turbulent flows of the electrolyte through the hole, which can rapidly rise the occurrence of the micro-short circuits. The largest number of micro-short circuits occurs at the start of the process when the vapour-plasma envelope is being formed, which takes some time (estimated tenths of a second).

The value of the voltage between electrodes significantly affects the gloss level of the polished surface as it can be seen in Fig. 2. Higher value of the voltage then the minimal needed value the gloss level decreases. This is in accordance with the surface roughness dependence on the voltage value (5). The voltage has also effect on the plasma-polishing process stability. The closer is the voltage to the point C on current-voltage characteristics the higher is the probability that the voltage drop caused by micro-short circuits will decrease the voltage value

below this point C. In this case, the value of the voltage is not enough to maintain the stable ionisation of the vapour-gas envelope and oscillations occur.

CONCLUSIONS

The experiment results indicate that the maximum surface gloss is achieved at a lower concentration of electrolyte. The selected electrolyte concentration of 6% represents a compromise between this requirement and the need for process stability. The concentrations below 6% pose a problem of process stability, particularly in the case of polishing the objects of free-form shapes with various internal cavities and holes. To get the maximal gloss level, the voltage should be set at minimal possible value with regard to the process stability.

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