POST-DISCHARGE PHENOMENA ON SURFACES

A. Goldman
Laboratoire de Physique des Décharges (CNRS)
Ecole Supérieure d'Electricité
91190 - Gif-sur-Yvette, France

R.S. Sigmond
Electron and Ion Physics Research Group
Norwegian Institute of Technology
N-7034 Trondheim - NTH, Norway

ABSTRACT

Corona corrosion is used to investigate post-discharge phenomena on surfaces. The results show that an intermittent irradiation of the sample can have a much larger effectiveness than a permanent irradiation. They are discussed in terms of two mechanisms in competition, an intensifying mechanism playing essentially at the beginning of the post-discharge phase and a damping mechanism developing together with this phase.

1. INTRODUCTION

The influence of intermittent operating conditions on the surface phenomena produced by an ionized gas is hereafter studied by means of corona corrosion of aluminium (1), (2), (3), but similar results should be obtained in plasma treatment applications, since corrosion or treatment processes are governed by the same basic phenomena. For more details, let us say that anodic corrosion with perforating pits of aluminium foils 15 µm thick has been chosen for the study, since the duration to complete the perforating pits provides an easy means to measure the discharge reactivity.

The experiments were performed with a point-to-plane Trichel corona discharge, using the aluminium samples as plane anodes. The activation of the gas by this kind of discharge can be assumed to provide to the surface, without significant heating or kinetic energy:

. a flow of negative ions (4), with a maximum current density $j_0$ at
the center of the anode and decreasing values

\[ j_r = j_0 \left( \frac{r^2}{d^2} + 1 \right)^{-5/2} \]  

as the distance \( r \) from the center increases (\( d \): gap length) \( 5 \). A flow of non-charged populations of species, in different states of activation [excited states (6), dissociated species, radicals]

for a part of them (7) ; preferentially conveyed towards the anode by energy and momentum transfer from the ions, these neutral species create an electrically induced gas flow, often called electric wind.

In a small central area of 3-4 mm diameter, the corrosion follows more complicated laws due to the important rôle played there by the neutrals; but outside this region, the time \( t_p \) for a perforating pit to proceed through the 15 \( \mu \)m anodic aluminium foil varies, under dc conditions, with the current density \( j \) as \( 8 \):

\[ t_p (h) = 100 \cdot j (\mu A/cm^2)^{-0.37} \]  

Taking into account the relation \( [1] \) for \( j \), we see that the corrosion will progress with a pits perforated area whose diameter will grow with time as

\[ \delta = (at^{1.08} - 1)^{1/2} \]  

In these conditions, it will be possible to appreciate the influence of intermittent conditions on the discharge reactivity by simply measuring the corresponding variations of \( \delta \).

2. EXPERIMENTS

Two series of experiments have been carried out under intermittent operating conditions, with the same gap length (\( d = 7 \) mm) and the same mean current (\( I = 100 \) \( \mu \)A) in a 80% \( N_2 \) - 20% \( O_2 \) mixture, at 50% relative humidity, renewed by a 5.6 \( 1/h \) flow in vessels whose volumes were \( \sqrt{2} \) l for mode \( A \) (see below) and \( \sqrt{6} \) l for mode \( B \). The experimental set-up are schematized in Fig. 1.

With the set-up shown in Fig. 1 (A), the intermittent conditions were provided (mode A) by pulsing the discharge supply. The discharge exposure pulse time \( t_d \) was fixed at 100 ms for all experiments, but the
current and the electric wind could not be fully developed during this time interval; the charge flow carried by each individual pulse was only 6.3 μC, which means that a square pulse should have lasted only 63 ms. With this working mode, the corrosion perforated area took a circular shape of diameter $\delta$. The curve (A) of Fig. 2 shows how this diameter varies with the duration $t_o$ between the discharge exposure pulses for a constant total charge flow $Q = 2.3$ C.

With the set-up of Fig. 1 (B), the intermittent conditions were provided (mode B) by driving the sample on a rotating disc which brought it one time per revolution under the discharge. With this working mode, the current and the electric wind are permanently fully developed, but a centrifugal gas flow, induced by the rotation movement, operates additionally to the local electric wind and, during a revolution, the sample suffers the spatial variations of the discharge current density (equation [1]). The variable used for these experiments is the rotation speed which simultaneously affects the discharge exposure pulse duration $t_d$ and the duration $t_o$ between the discharge exposure

---

Fig. 1 - Schematic set-up providing intermittent discharge exposure conditions with a pulsed discharge supply (mode A) or with the sample $S$ on a rotating disc bringing it one time per revolution under the discharge (mode B).
Fig. 2 - Extension of the corrosion perforated area as a function of
the time interval \( t_0 \) between the discharge exposure pulses.

(A): diameter of the perforated area in mode A, with \( Q = 2,3 \) C.
(B): width of the perforated area in mode B, with \( Q = 1 \) C.

Pulses. Assuming square discharge exposure pulses with a constant cur-
rent density \( j_0 = I/2 \ d^2 \) deduced from eq. [1], we find that \( \tau_d \)
and \( \tau_o \) are linked by a ratio \( \alpha = \tau_d / (\tau_d \cdot \tau_o) \) defining a duty cycle
which can be evaluated to 4% in our case. With this working mode, the
corrosion perforated area takes an annular shape of radius \( R \) (distance
equal to 80 mm between the gap axis and the rotating axis), and of width
\( w \). The curve (B) of Fig. 2 shows the variations of this width as a
function of \( \tau_o \) for a constant total charge flow \( Q = 1 \) C, that is to
say 2.3 times smaller than in mode A, and with a number of discharge ex-
posures no more constant.
3. DISCUSSION

Both working modes clearly show that an important intensifying effect is obtained on corrosion phenomena when rest times are introduced in the exposure conditions to the discharge reactivity.

Let us first discuss the results obtained with the pulsed supply [ curve (A) of Fig. 2 ] , since it implies one parameter less, the centrifugal gas flow induced by the rotation movement. The intensifying effect which is shown by this curve should be explained by a disruption effect in the surface electrochemical equilibrium, allowing chemical prolonged effects of the reactive species still coming from the gas (9) or laying on the surface. Furthermore, electrochemical effects are expected from the presence of residual ions (and associated surface potential) on the superficial layers, heavily charged with physisorbed and chemisorbed species which give them a lowered conductivity.

These intensifying processes are impeded by other phenomena which are illustrated by the decreasing slope of the curve beyond $t_o \sim 350$ ms and which can be interpreted as representative of an incubation phenomenon slowing down the discharge activity. To be coherent with the results, this incubation phenomenon has to become more and more efficient as the time interval $t$ between the discharge pulses is increased; it should be associated to a passivating process coming in competition with the corrosion process during this time interval.

The same explanations are valuable for the results obtained with the rotating system [ curve (B) of Fig. 2 ]. But here appears, in spite of a total charge flow more than two times lower, an additional intensifying effect which might be due:

- to a larger efficiency, during the discharge pulses, of the activated neutrals which are brought by an electric wind fully established, but modified by the rotation movement,

- to effects (sweeping effects on the surface, drying effects, ...) of the centrifugal gas flow induced by the rotation movement.

4. CONCLUSION

Further investigation is needed for a better knowledge of the chemical kinetics phenomena involved in the important intensifying effects of the discharge activity observed on aluminium surfaces under intermittent exposure conditions. Such conditions can in fact be met in practical cases where alternative supply or movement is provided and could be provoked if the present results should be proved valuable to be transposed to beneficial uses.
ACKNOWLEDGMENT

We acknowledge technical assistance from R. Baumgartner (Laboratoire de Physique des Décharges, CNRS/ESE).

REFERENCES


