ANODIC ARC ROOT BEHAVIOR OF A TRANSFERRED ARC MOVING ORTHOGONALLY TO A PLANE SURFACE

SOBRINO J.M.*, COUDERT J.F.**, FAUCHAIS P.**

* CETIM, 52 avenue Félix Louat, BP 67, 60304 SENLIS Cedex, FRANCE
** LMCTS - URA CNRS 320, Faculté des Sciences, 123 avenue Albert Thomas, 87060 LIMOGES Cedex, FRANCE.

ABSTRACT

An especially designed experimental set-up was constructed to study transferred arc root behavior in the case of an argon arc struck in air at atmospheric pressure between a 40° thoriated tungsten cathode tip and a flat anode. The current intensity was fixed at 40 A. The electrodes were moved at a monitored relative translation velocity. A synchronization system was used to correlate fluctuations in voltage as a function of time with instantaneous photographs of the arc and the traces left by the arc root on the anode surface. The influence of the different factors on the arc root jumps was systematically studied e.g. the relative translation velocity (60, 120, 240 mm/s), the anode-cathode distance (5 and 7 mm), the roughness of the anode surface (Ra=0.15 to 3.25 μm), the nature of the anode material (copper or grey cast iron) and the presence of an auxiliary argon sheath gas striking the anode surface directly.

Increasing the translation velocity, the roughness of the anode surface or the anode-cathode distance resulted in an increase in both the frequency and length of the arc root jumps. On the other hand, the presence of a sheath gas around the plasma column strongly influenced the arc attachment. The jump frequency dropped noticeably when there was a reduction in the sheath gas flow rate, whereas the jump length increased. The important differences noted in the behavior of the arc root when a copper or a grey cast iron anode were used led to differences in the electrical and thermal conductivity of the two materials. The shape of the voltage signals was also representative of a change in the arc root attachment. Some of the results of the experiment are presented here.

INTRODUCTION

For several years now, CETIM, in collaboration with the Plasma/Laser/Materials Laboratory of the University of Limoges, has been studying thermal surface treatments applied to steel, cast iron and aluminium alloys using a plasma torch. The initial studies demonstrated the heat treatment capacities of the plasma torch [1,2], emphasizing its numerous advantages (flexibility of use, high flow density, easy robotization, compactness, etc). Two examples are surface quenching by blown electron arc torch and surface remelting by transferred arc. While the treatments were being studied, we developed precision tools and testing apparatus based on the study and understanding of the phenomena involved. We studied the behavior of a transferred arc during surface dressing of cast iron. In certain cases, irregularities occur during the treatment, resulting in the presence of surface craters and unmelted zones. This was arbitrarily attributed to the treatment tool. It was supposed that it was due to haphazard attachment of the arc root to the anode, resulting in overheating of the metal in certain places. The aim of this preliminary study was to demonstrate the relationship between treatment irregularities and development of the arc voltage in the course of time, where each attachment of the arc root at a given point is accompanied by a virtually linear increase in the arc voltage, combined with elongation of the arc column during translation.

EXPERIMENTAL SET UP

The transferred plasma torch was designed, drafted and produced by the PLM laboratory in Limoges (Figure 1). It has a water-cooled 40° tip thoriated tungsten cathode with a diameter of 4 mm. The plasma gas is injected axially around the perimeter of the cathode. We used an argon flow rate of 2 l/min. The injection of an auxiliary gas was designed to protect the part being treated from oxidation by the ambient air. The gas flow strikes the anode directly around the perimeter of the zone in which the arc root is attached. The flow rates used were 4 to 10 l/min of argon or a mixture of argon and hydrogen.The anode, which corresponds to the part to be treated, is made of either copper or cast iron in order to modify the thermal and electrical properties of the metal. It consists of a 5 mm thick flat plate on which the transferred arc forms. The other side is water-cooled. The effect of the initial surface condition was studied by varying the roughness of the plate within an Ra range of 0.15 to 3.25 µm. A motorized system ensures a relative translation movement between the torch and the anode. The translation velocities can vary from 1.5 mm/sec to 240 mm/sec. The distance between the electrodes was 5 or 7 mm and the intensity of the arc current was fixed at 40 A for all the tests.

EXPERIMENTAL METHODOLOGY AND ASSESSMENT

In order to situate the experimental conditions under which the studies took place, it is important to give a brief reminder of the different transferred arc morphologies which can occur. Figure 2 shows the development of the anodic arc attachment . To go from case (a) to case (d), it is necessary to increase the arc current intensity, decrease the anode/cathode distance, or increase the plasma gas flow rate. In each case, there is an increase in the rigidity of the arc which can be defined as its capacity to retain its shape and impact despite the external constraints imposed upon it. One of these constraints, for example, is the relative displacement of the torch and the part. Cases (a) and (b) show an intermittent, constricted, sometimes multiple anodic attachment. The arc moves randomly along the anode. The cathode plasma jet is not dominant near the anode. We could say there is an anodic jet flow with intermittent attachment. In cases (c) and (d), the anodic attachment is less distinct. The plasma flow is dominated by the cathode jet around the anode. This time, we have a cathode jet flow.

In order to visualize what happens to the anode during relative displacement of the torch and part, we adopted operating conditions designed to produce an arc shape similar to that of case (b). Figure 3 shows descriptively what happens when there is an arc root attachment at one point during displacement. The arc is elongated as seen in the diagram. The part of the plasma column dominated by the cathode jet keeps its shape and direction. An anodic attachment "lug" is formed which becomes elongated during displacement. The arc voltage increases substantially up to a critical value. The arc root then jumps back into the axis of the cathode in order to minimize the instantaneous voltage. On the basis of these observations, we therefore developed a continuous control method based on the detection of arc root jumps on the part. To do so, we considered three different observations of displacement of the arc on the anode. The first concerns the continuous recording of the instantaneous arc voltage as a function of time. This was recorded using a digital oscilloscope (operated at a 1 msec/pt sampling rate). The second is a video recording of the shape of the arc during displacement using a video camera with a high shutter speed (1/10000). The third is the pattern of the traces left on the anode by the arc root. These three observations were compared using a synchronization system which enabled us to correlate the voltage signal with the arc photographs obtained using the video recorder, and with the treatment traces on the part. The results were then depicted on a single sheet (Figure 4), showing, from top to bottom:

- the test parameters and static voltage
- the numbered arc photographs
- the alternation of black and white rectangles whose length corresponds to 1/25th of a second i.e. the frequency of the video shots.
- the voltage signal recorded using the oscilloscope; the numbers refer to the photographs mentioned above indicating the instant at which the shot was taken.
- a dashed line showing the static voltage
- the traces left on the anode by the arc root
- the time scale
- the metric scale.

RESULTS AND DISCUSSION

Let us take the example given in the Figure 4. The arc photographs allow us to easily explain the morphological variations and the arc jumps during displacement and therefore the influence on the voltage signal. The first and last three sets of images each correspond to a voltage ramp. For each ramp, it can be clearly seen that the arc root moves away from the axis of the plasma column which remains rigid as a result of acceleration of the plasma gases in this zone. The arc root remains "attached" to a particular zone. It remains static and does not follow the displacement of the cathode. The arc stretches until the voltage reaches a critical value, at which point the arc root jumps in order to minimize the instantaneous voltage. It comes back into the axis of the cathode (photograph n° 4). These explanations can be easily verified by the traces on the anode produced by the arc. Between points 1 & 3, and 4 & 6, the treatment is interrupted, with overheating at points 1 and 4. If we follow the traces, we can see that there is an irregularity in the treatment between 4 and 6 cm on the metric scale, corresponding to a very large and very short voltage jump.

Figure 5 shows the three different types of anode traces which can be obtained, together with their respective voltage signals. Two representative parameters can be used to compare the results produced for two or more operating conditions. These are the length of the interruptions to the treatment and the number of jumps per unit length; the amplitude on the other hand, remains relatively constant and is related to the length of the jumps. Table I qualitatively shows the influence of variations in several control parameters on these two particular parameters.

	Length of interruptions in the treatment	number of jumps per unit length
Increase in the displacement velocity	↗	↗
Increase in the roughness of the anode	↗	↗
Increase in the anode/cathode distance	↗	↗
Presence of an auxiliary gas	↗	↘
Passage from copper to cast iron	↗	↗

Table I: Influence of control parameters on the length of interruptions in the treatment and the number of jumps per unit length.

It is interesting to note that the presence of an auxiliary sheath gas decreases the frequency of the arc root jumps but increases their length. Using cast iron instead of copper for the anode results increases the length and frequency of the jumps, mainly due to differences between the thermal and electrical conductivity of these two materials.

CONCLUSION

We have shown here that it is possible to control the regularity of displacement of the arc on the part, which affects the quality of the metal surface remelting. Under optimized treatment conditions, the voltage signal is regular and of very low amplitude (< 0.5 V) around the average voltage. A study of the fluctuations of the arc root on the part helped us to understand the anodic attachment phenomena which occur during treatment of a real part. We were thus able to show the variable influence of the main control parameters. A more detailed use of the data sheets showing the correlation between the arc image, the voltage signal and the anode traces for a given interval of time brought to light other interesting results. These demonstrate other types of correlation with, for example, voltage signals presenting non-linear voltage ramps or different velocities between the cathode and the arc root. A closer study of these results will be the subject of a forthcoming publication on the interpretation of the physical phenomena which govern the behavior of transferred arcs and anodic attachment.

REFERENCES

[1] Sobrino, Dublanche, Grimaud, Coudert, Fauchais, Duchateau, Mongis, Peyre, Brunet. *Application des torches à plasma d'arc dans le traitement thermique de durcissement par trempe superficielle des aciers et des fontes.* ATTT Congress 1992. Strasbourg. FRANCE. 24, 26 June 1992. p. 297-316.

[2] Sobrino, Mongis, Dublanche, Grimaud. *Evolutions autour de la refusion superficielle des fontes par plasma d'arc.* ATTT Congress 1994 - Nice, FRANCE. 26, 28 September 1994. p. 245, 256.

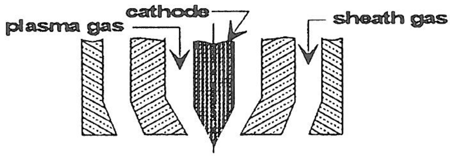

Figure 1 : Scheme of the plasma torch

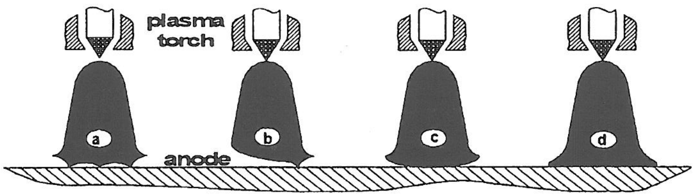

Figure 2 : Development of the anodic arc root attachment

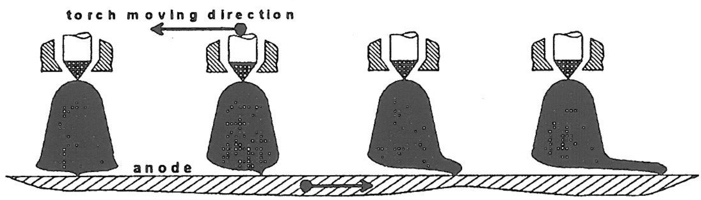

Figure 3 : Elongation of the arc during displacement

plasma gas : 2 l/mn	sheath gas : 0 l/mn	arc current : 40 A
arc length : 5 mm	disp. velocity : 60 mm/s	voltage : 17.45 V

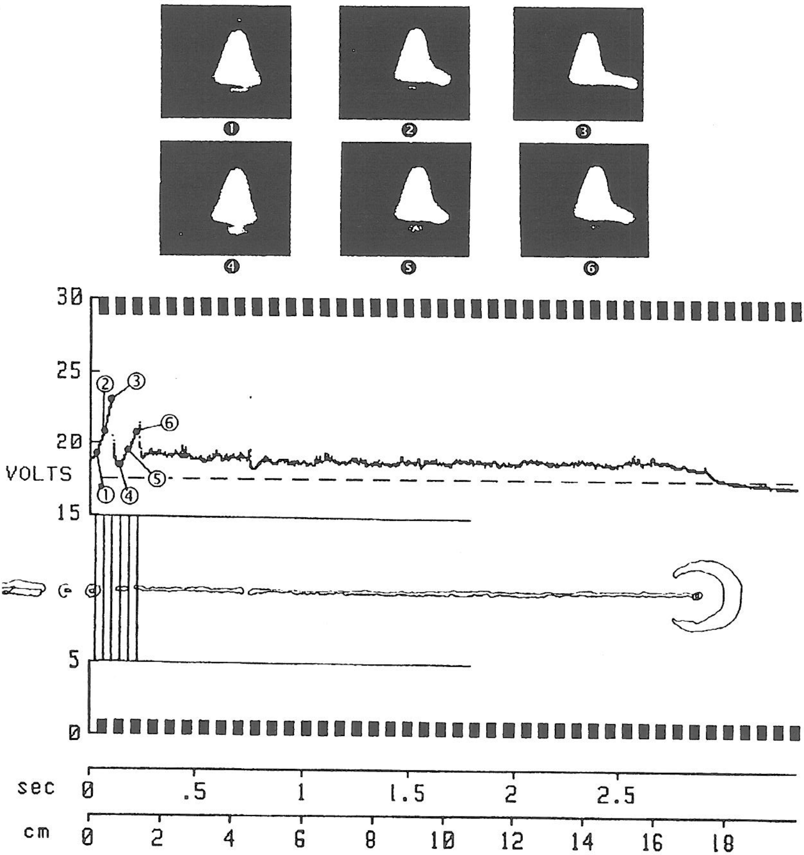

Figure 4 : Correlations between photographs, voltage signal and trace of the arc root

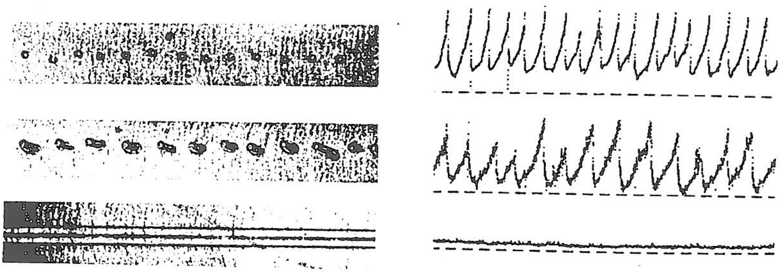

Figure 5 : Different types of anode traces with their respective voltage signals