EROSION OF NON-REFRACTORY CATHODES IN ARC PLASMA DEVICES

A.E. Guile
Department of Electrical and Electronic Engineering
University of Leeds, Leeds LS2 9JT, England

Keywords: Cathode erosion

ABSTRACT

Arcs were rotated between water-cooled electrodes by a magnetic field in air up to several bar. Cathode erosion rates were measured by weight loss after arcing at currents up to 800A over a wide range of arc velocity and of water cooling flowrate. The non-linearities in cathode erosion rate with arc duration, current, velocity and water flow rate point to a critical role of cathode oxide films.

1. INTRODUCTION

This paper describes a 4-year experimental investigation into the erosion of non-refractory cathodes in plasma devices in which an arc rotates for very long times driven by a transverse magnetic field.

Apparatus shown in Fig. 1 was constructed in which a radial arc could be driven between concentric electrodes by an axial magnetic field, in gas at pressures up to several bars. The cathode ring could be readily detached from a housing cooled by water at 10 bar pressure, and weight loss after a period of arcing was found by a balance weighing down to 10^{-8}kg.

For all except the initial low-current experiments, the axial length of the cathode was 1.8cm. The inter-electrode gap was 2mm. The cathodes were polished initially with 180 grit emery paper, and then with 400 grit emery paper or a proprietary brand of polishing material, both of which were found by scanning electron microscopy to give a similar finish deviating from flatness by about 2μm. Before arcing, each cathode was washed in a degreasing fluid and after drying it was weighed.

2. EXPERIMENTAL

Early experiments at 45A using o.f.h.c. copper cathodes showed an initial gain in weight due to oxidation for some seconds, followed by an increasing loss with time(1). For arcs of some minutes duration the velocity was varied over about a ten to one range, and the erosion rate was found varying in a somewhat sinusoidal manner with velocity as is shown in Fig.2 for arc currents of 45, 100 and 220A. Until then it had been generally supposed that increase in arc velocity would lead to a decrease in erosion rate[2],whereas these new results[1] showed that in some ranges the erosion rate could increase by about an order of magnitude when velocity was increased, and this was shown[3] to be true of other materials beside copper.

For each arc current there was a limited range of arc velocity over which the arc could rotate stably. Just below the lower end of this range, the arc could frequently switch to a low velocity mode which causes gross damage to both electrodes[4]. It has been shown[5] that these large drops in velocity to a value far below that which is normally encountered in a magnetic field[6],[7], can occur at arc currents from tens to thousands of amperes and for arc lengths which can exceed 1cm, and they must be avoided by using a sufficiently strong transverse magnetic field. The upper limit of velocity at each arc current arises from arc extinction after a very short duration.

Fig. 2 shows the cathode erosion rate as a function of arc velocity measured over the widest range of velocity which could be obtained between these two limits, at a series of arc currents between 45 and 800A. The power limitation of the motor/generator set caused the duration of each individual arc to be reduced from several minutes at 45A to 1.5 seconds at 800A, but by subjecting each cathode to a number of arcs, the total arcing duration reached those shown in the caption of Fig. 2. It can be seen that far from erosion rate falling with increase in arc velocity, there is a tendency at higher arc currents for the opposite to occur.

It had been generally supposed that the loss of weight of the cathode was proportional to arc current I and duration t, the rate of loss often being quoted in gm/coulomb. Measurements on copper cathodes showed however [9] that cathode erosion rate is not in fact independent of time but is proportional to t^n where $0 < n < 0.8$. For most cases $n \simeq 0.5$ and using this to correct the data of Fig.2 in order to standardise the erosion rate at all currents to a common arc duration of 5 minutes, showed that at two different velocities, the erosion rate is proportional to $I^{1.2}$ which is very similar to the result[8] that the minimum erosion rate for o.f.h.c. copper is proportional to $I^{1.15}$.

It was also found that at 800A, a different mode could exist with the arc roots confined to a narrow region instead of spreading over the cathode surface. The narrow track was then covered with a much thicker than normal oxide film, and the erosion rate was usually at least ten times higher than that in normal mode. It is clear that more work needs to be done at currents of 1kA and above in order to identify the conditions which cause this transition to a higher erosion mode, which may be connected with the similar discontinuity also found just below 1kA on the copper contacts of contacts operating in air[10]. Means must be found of avoiding this high erosion mode when designing high-power plasma chemistry devices.

When the cathode cooling rate was increased over a 30:1 range, the erosion rate curve, instead of falling continuously, exhibited as many as four peaks with as much as a four to one variation between a minimum and a maximum as shown in Fig. 3. Thermocouples embedded in the cathode[11] showed oscillations in temperature with cooling rate most of which can be seen from Fig. 3 to correspond with the erosion rate. From erosion rate/temperature results an activation energy for erosion of copper cathodes has been obtained, and a present examination[12] of the implications of this is beginning to clarify the relative roles of the oxide film and of the properties of the cathode metal in the arc erosion process.

Time did not permit detailed examination of the effects of changes in gas and in pressure, though for 100A arcs, raising the air pressure from 1 to 5.3 bar caused the copper erosion rate to fall by a factor between 3 and 5 for a range of arc velocities, whereas the same increase in pressure caused the erosion rate of a silver/copper alloy cathode to increase by about 3 to 5 times. This markedly different result for two materials illustrates that much remains to be understood in the arc cathode erosion process and the many factors which influence it.

The cathode materials which were tested during this research programme were:-

(a) o.f.h.c. (oxygen-free-high-conductivity) copper.
(b) e.t.p. (electrolytic-tough-pitch) copper.
(c) phosphorous-deoxidised copper.
(d) vacuum-cast o.f.h.c. copper.
(e) silver/copper of various compositions including the eutectic.
(f) sintered tungsten/silver.
(g) sintered tungsten/copper.
(h) silver.
(i) silver/cadmium oxide.
(j) copper/zirconium.
(k) a vacuum interrupter material.
(l) aluminium bronze of three compositions.
(m) leaded brass.
(n) naval brass.
(o) a heat treatable aluminium alloy.

For the experimental conditions which could be examined and which are described in this paper, the best overall erosion rates seemed to be obtained using o.f.h.c. copper, and it was this material which was tested over the widest possible ranges of the variables involved and all results in this paper are for o.f.h.c. copper. Time did not permit examining other materials in such detail.

3. DISCUSSION

The complex variations in the cathode erosion rate of o.f.h.c. copper with velocity, current, time, water flow and gas pressure, together with optical and scanning electron microscopy of the surfaces, pointed to influence of oxide films, and this led to the investigations described in the paper given in Session 3 of the General Sessions of the present Symposium. In this latter paper it has been shown that the erosion rate of copper cathode for rotating 45A arcs can vary by almost ten to one as the thickness of the oxide layer is varied. Thus some of the non-linear changes in cathode erosion rate shown in the present paper to occur with a number of variables, appear to be due to the changes in the cathode oxide film. This film will be very thin if the initial copper cathode surface is well polished, but the resultant low erosion rate will increase as the oxide film becomes thicker, and although after a certain thickness the erosion rate may diminish, it can remain higher than that for a well-polished cathode. Thus very long arcing durations may lead to a thick oxide film which might have an unacceptably high erosion rate unless it is controlled by efficient cooling. The results on water cooling indicate that at least for some systems and geometries it cannot necessarily be assumed that a greater throughput of cooling water will lead to reduced cathode wear. Nor is it true that increased magnetic field will necessarily reduce the erosion rate: on the contrary the rate may increase at the higher fields and velocities, though a damaging high-erosion mode at low velocities must be avoided by having a sufficiently high magnetic field.

ACKNOWLEDGEMENT

The author wishes to thank Dr A H Hitchcock and Tioxide International Limited.

REFERENCES

1. A E Guile and A H Hitchcock, J. Phys. D. 7, 597 (1974)
2. K Mosley, A E Guile and D Dring, J. Electrochem. Soc., 119, 1316, (1972)
3. A E Guile and A H Hitchcock, Proc. 3rd. Int. Conf. on Gas Discharges, IEE London, Conf. Pub'n 118, 534, (1974)
4. A E Guile and J G J Sloot, Proc. 3rd. Int. Conf. on Gas Discharges, IEE London, Conf. Pub'n 118, 544, (1974)
5. A E Guile and J G J Sloot, Proc. IEE, 122, 669, (1975)
6. A E Guile and K A Naylor, Proc. IEE, 115, 1349, (1968)
7. A E Guile, V W Adams, W T Lord and K A Naylor, Proc. IEE, 116, 645, (1969)
8. A H Hitchcock and A E Guile, Proc. IEE, 763, (1975)
9. A E Guile and A H Hitchcock, J. Phys. D., 8, 427, (1975)
10. H W Turner and C Turner, Proc. 2nd. Int. Conf. on Gas Discharges, IEE London, Conf. Pub'n. 90, 203, (1972)
11. A E Guile and A H Hitchcock, Proc. IEE, 122, 579, (1975)
12. A E Guile, A H Hitchcock, A K Vijh and K Dimoff, to be published.

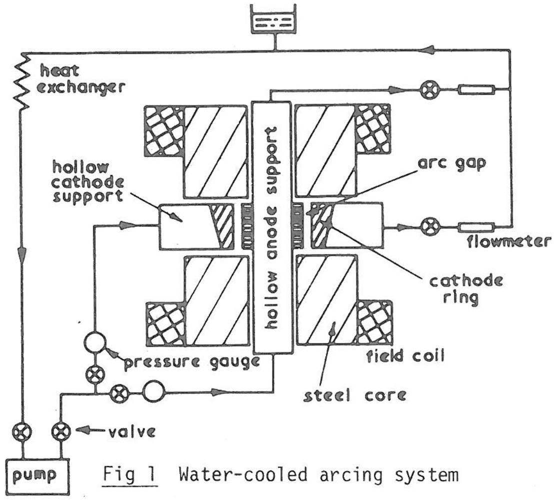

Fig 1 Water-cooled arcing system

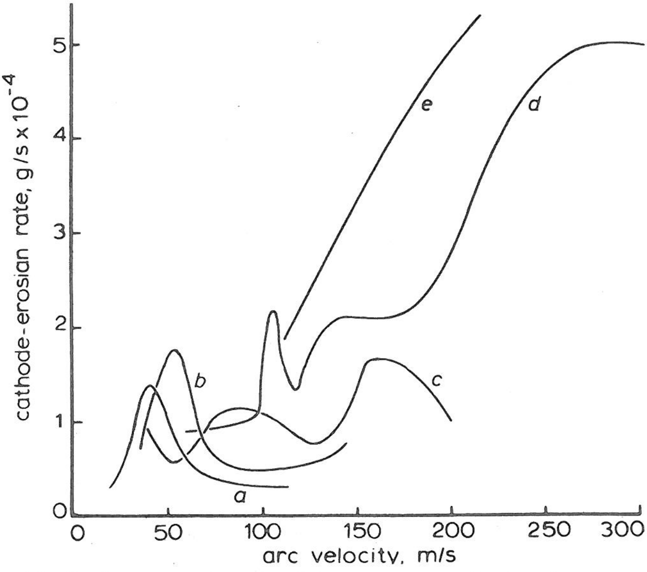

Fig 2 Erosion rate of o.f.h.c. copper cathodes for arc currents and durations of (a) 45A, 420s: (b) 100A, 420s: (c) 220A, 120s: (d) 405A, 100s: (e) 800A, 30s

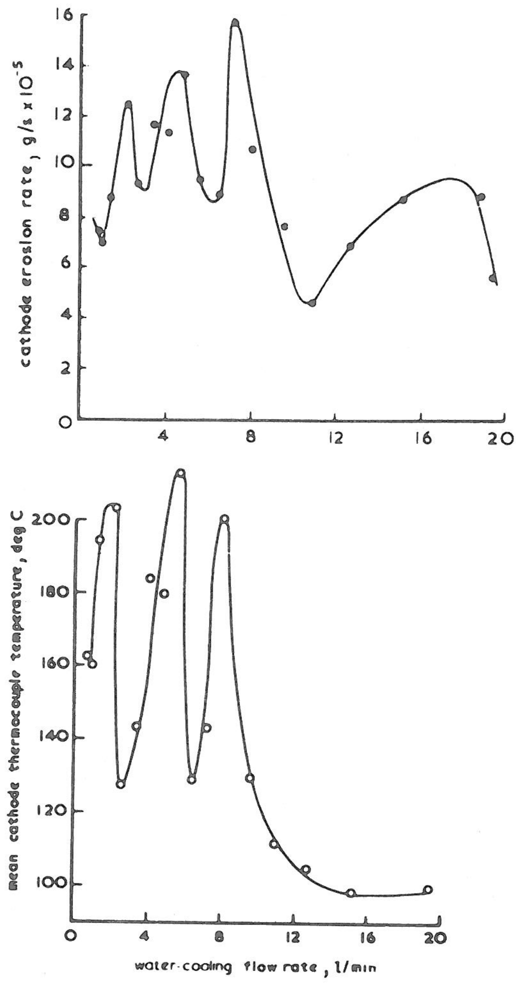

Fig 3 Erosion rate and mean temperature of o.f.h.c. copper cathode as a function of water flow rate for 48 ± 3 m/s and 100A