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TECHNICAL NOTE

Electrochemical grinding of a stainless steel felt

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1. Introduction

One of the problems which has hampered the use of metal felts has been the difficulty experienced in machining the felt to its final configuration. Such felts may be prepared by sintering a mass of metal-plated carbon fibres in moist hydrogen [1, 2], to give a matrix which is strong but very pliable. This product cannot be machined by conventional methods without undergoing considerable distortion of its matrix. It was hoped that it would prove practicable to machine this material by an electrochemistry-based process, such as electrochemical machining (ECM) [3], which should allow metal removal without placing stress on the workpiece.

ECM is a process whereby the metal workpiece from which material is to be removed is attached to the positive pole of a low-voltage d.c. power supply, and the tool, which has a shape which matches the desired final shape of the workpiece, is attached to the negative pole. A fixed gap (usually in the range 0·1–1 mm) is set between the electrodes, and electrolyte is forced through this gap, typically at speeds of 10–30 ms^{-1}. Because of its dependence on this fixed-cell configuration, however, ECM is effectively ruled out for use in machining a metal felt, since it is difficult to ensure rigidity if the workpiece is not itself rigid.

Electrochemical grinding (ECG), on the other hand, does not require such a special rigid tool-workpiece configuration, and so should lend itself to purposes such as machining of a metal felt. In ECG, metal is removed by a combination of electrolytic dissolution and abrasive action. The grinding wheel, which must be capable of conducting electricity, is made the cathode of the cell, and the workpiece is made the anode, as in ECM. The size of the gap between the electrodes is set and maintained by a combination of the size and type of abrasive particles on the wheel and the pressure of the wheel against the workpiece [4]. When electrolyte is forced into this gap, current flows through the electrolytic cell which is established and electrolytic dissolution of the workpiece occurs. The abrasive particles must be non-conducting, to diminish the danger of short-circuiting the cell; diamonds have traditionally been used as the abrasive particles [5], though other types of abrasive have been tried [6, 7].

It is possible, by careful selection of the machining conditions, to have the ECG process occur with >95% of metal removal by electrolytic dissolution. In such conditions, the role of the abrasive particles is chiefly the removal of passivating oxide layers from the metal surface. The balance between mechanical and electrolytic metal removal is affected by many variables, the chief ones being,

(1) the applied potential [6], which affects the overpotential at the anode and thus affects the current density and rate of metal removal;

(2) the rate of advance of the wheel towards the workpiece (or the pressure of the wheel on the workpiece) [7]; and

(3) the composition of the electrolyte. The phenomenon of passivation due to oxide layer formation at a metal surface is well-established, and quite different rates of metal dissolution are found during ECM in different electrolytes, depending on the degree of passivation produced on the metal surface [8]. While ECG involves constant removal of oxide layers as they form, there is still a marked effect on metal dissolution rates in different electrolytes under otherwise identical conditions [9].

It is an obvious corollary of the previous paragraph that, if the conditions are such that >95% metal removal is by electrolytic dissolution, there will be little frictional force exerted by the wheel on the workpiece. Cole [10] has examined this effect and found that the coefficient of friction, *f*, was less than 0·1 in his experiments. In view of this result, ECG might be expected to be highly suitable for use as a method of machining metal felt specimens, since it should allow metal removal with neither macroscopic nor microscopic distortion of the fibrous matrix.

The validity of these ideas was examined by performing some ECG experiments using an austenitic stainless steel felt as the workpiece material.

2. Experimental

The study was performed on an Abwood Contelyte SG 4 HE grinder. Electrolyte delivery on this unit is to the centre of the grinding wheel, from whence it is distributed across the face of the wheel by centrifugal action. The cup wheel used had a diamond grit (mesh size 100, diamond density 0·66 g cm^{-3}). The wheel speed was 31 ms^{-1} at its perimeter.

The stainless steel felt (supplied by GEC Marconi Electronics Ltd Mechanical Engineering Laboratory) was cut by guillotine into specimens (25 x 25 x 1 mm^3), and these were clamped, unsupported, so that the specimen plane was perpendicular to the plane of the grinding wheel, and the clamp was 7 mm below the plane of the ground surface. The workpiece was advanced towards the wheel in steps of 2·5 μm, using the automatic hydraulic step built into the grinder. The rate of stepping could be controlled. The workpiece was moved continually past the grinding surface of the wheel during the experiment, in a direction perpendicular to the motion of the wheel while it was in the electrolytic cell.

The criteria for success/failure of the experiments were selected to be: the finished product should have edges at which the matrix is in the same condition as on the face of the specimen, and there should be sharp, right-angled corners and no macroscopic bending of the specimen.

The two electrolytes used were (1) 1 M $NaNO_3$ + 0·5 M $NaNO_2$, which is similar to, but simpler than, those used in industrial ECG [4], and might be expected to cause passive film formation on the stainless steel felt [11]; and (2) 2 M KBr + 1 M NaCl. This electrolyte was used to gauge the effect of using an electrolyte which was expected to be considerably less passivating, due to halide ion attack on any passive layers formed [11].

Samples of the austenitic steel in solid sheet form were available, and these were used for preliminary tests of the system in place of the felt specimens.

3. Results and discussion

The preliminary tests using the solid specimens were used to determine the optimum settings of cell voltage and rate of workpiece advance when each of the electrolytes was being used. Settings of 8 V and 0·11 mm min^{-1} were selected for use with the Br^-/Cl^- electrolyte, and 9·5 V and 0·10 mm min^{-1} for use with the NO_3^-/NO_2^- electrolyte, after examination of the machined surfaces for mechanical grinding marks, and after ensuring that there was no sparking during the machining (since spark discharge damages the surfaces of both the wheel and the workpiece [4]). Because of the nature of the grinding machine used, it is possible to quote only an overall voltage which is applied to the cell, rather than an exact anode potential; however, other measurements during experiments using this machine suggest that the potential of a mild steel electrode during ECG in the same NO_3^-/NO_2^- electrolyte is approximately 1·2 V(SCE) when the applied cell voltage is 9 V, and there is likely to be little difference here.

The initial experiments using the stainless steel felt as the workpiece showed that, at these settings, there was macroscopic bending of the specimen because of the lateral pressure which was exerted upon it. It was discussed earlier how such lateral forces are due to the frictional force between the wheel and the workpiece. It was also discussed how, in a particular electrolyte, the two variables having the greatest effect on this force are (1) the applied cell voltage and (2) the rate of advance of the wheel towards the workpiece. Cole [10] has already shown how the frictional force may be reduced by raising the cell voltage which is applied, and so raising the current density. The experiments were therefore repeated, using an applied cell voltage of 10 V, and retaining the same advance rates. In the Br^-/Cl^- electrolyte, this virtually eliminated bending of the specimen, but the problem was only slightly reduced in the NO_3^-/NO_2^- electrolyte.

There are good reasons, from the points of view of lessening corrosive attack on equipment and 'stray cutting' of the workpiece, for using passivating electrolytes in electrochemically-assisted metalworking methods [11]. It was therefore investigated whether a reduction in advance rate (to 0·08 mm min^{-1}) would render the results obtained in the NO_3^-/NO_2^- electrolyte more acceptable. The effect was found to be beneficial, but the problem of bending of the specimen was still not completely removed.

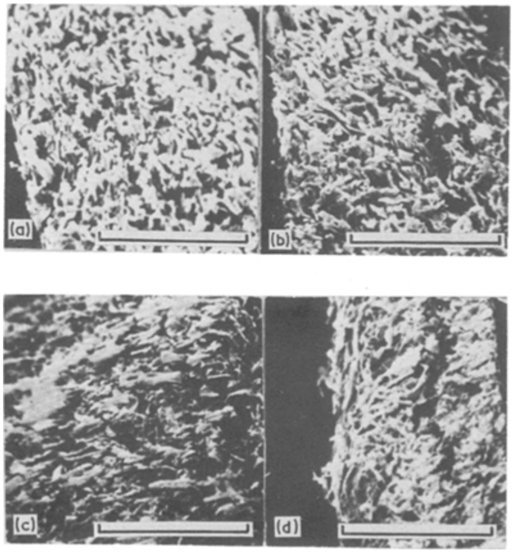

Fig. 1. Scanning electron micrographs of edges of a stainless steel felt metal which have been trimmed by different methods. (a) ECG, using 2 M KBr + 1 M NaCl as electrolyte. Advance rate 0·11 mm min^{-1}, cell potential 10 V; (b) ECG, using 1 M $NaNO_3$ + 0·5 M $NaNO_2$ as electrolyte. Advance rate 0·08 mm min^{-1}, cell potential 9·5 V; (c) conventional grinding; (d) guillotining. Bar represents 1 mm.

Fig. 1 shows electron micrographs of specimens whose edges have been machined by different methods. It is clear that there must still be some frictional force exerted by the wheel during ECG using NO_3^-/NO_2^- as electrolyte, since there is less 'smudging' of the metal fibres in Fig. 1a (Br^-/Cl^-) than in (b) (NO_3^-/NO_2^-). It will be noted, however, that this 'smudging' effect is far less marked on the specimens prepared by ECG than it is on the specimens whose edges have been ground by conventional methods (c) or cut by guillotine (d). It would appear from these results that ECG, as a general method, is more successful for cutting stainless steel felt to leave a virtually homogeneous matrix than are conventional methods.

This experimental programme has shown that conditions can be found which will allow the machining of a metal felt specimen while producing no distortion of the metal matrix, either microscopically at the machined surface or macroscopically by bending the specimen. It is not claimed that these conditions are ideal, or that the rates of machining under these conditions are sufficiently high for transfer directly to industrial use. The optimum electrolyte for use in an industrial application of the ideas presented here would undoubtedly be less corrosive than the Br^-/Cl^- electrolyte used in this study. It would appear, however, that a highly passivating electrolyte, such as the NO_3^-/NO_2^- electrolyte used here, is too passivating for use in these applications.

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