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Some investigations into the anode profile in the transition zone in an electrochemical hole sinking operation

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An empirical relationship has been suggested by some researchers to evaluate the overcut, a_o, in the transition zone. But the detailed study of this relationship has revealed that it overestimates the value of a_o for machining under large equilibrium gap conditions. In this paper, the authors give a simpler equation, based on regression analysis, for the estimation of overcut in the transition zone. Further, a_o has also been found to be a function of Y_e, f, D, r_c and V.

Nomenclature

a_o	overcut in transition zone
b_b	bare length of the electrode
D	tool diameter
E	electrochemical equivalent
E_V	effective voltage
F	Faraday's constant
f	feed rate
J	current density
K	electrolyte electrical conductivity
n_1	exponent
r_c	tool corner radius
R_{c1}, R_{c2}	constants
V	electrolyte flow velocity
Y	interelectrode gap
η	machining efficiency
ρ	density
θ	angle between feed direction and normal to the tool surface
ϕ	a function

Subscripts

e	equilibrium
m	work material
o	initial condition or inlet
t	condition after time t

1. Introduction

The analytical determination of the anode (work) profile, or alternatively the cathode (tool) profile in electrochemical machining models remains a real problem. The anode profile is normally divided into four distinct regions, namely, the stagnation, front, transition and side regions. Bare tools give a quasi-conical shape in the side region and tapered in the front region. But coated bit type tools [1] have been designed and developed to solve this problem. Such tools generate straight sided walls. Further, it is also now possible to accurately predict [2] the anode profile in the front and side regions for both zero and finite feed rates, by using Equation 1,

$$Y = Y_o + (C' - f)\,\Delta t \tag{1}$$

where $C' = \eta JE/(F\rho_m)$ and $J = E_V K/Y$. But no such theoretical equations exist for the evaluation of anode profiles in the transient [3–5] and stagnation regions [6–8]. However, for the evaluation of overcut in the transient region, a few empirical equations based on experimental data have been suggested. Equation 2 was suggested by König and Degenhardt [4] and has been tested by the authors (Fig. 1). It was found to overestimate the values of a_o, especially when the equilibrium gap

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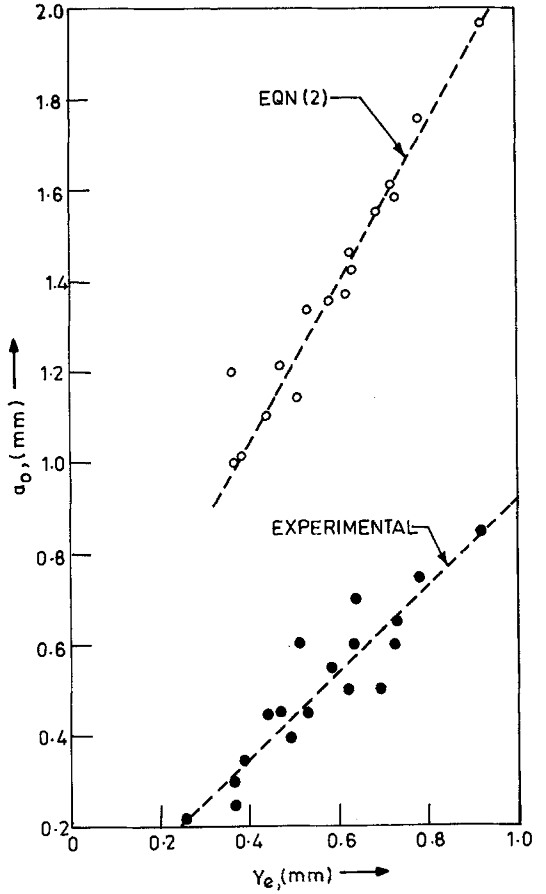

Fig. 1. Comparison of analytical results obtained using Equation 2 with experimental data.

was large and machining was carried out at high feed rates

$$a_o = 2Y_e + 0.1[6.283\ (r_c - 1)]^{0.5} \qquad (2)$$

for $b_b > 1$ mm and $1 < r_c < 5$ mm.

The authors therefore suggest a simpler equation for the prediction of the anode profile in the transition region based on regression analysis. In a few cases, a low value of the correlation coefficient was obtained; hence a comprehensive equation based on dimensional analysis has also been developed.

2. Experimental procedure

Electrochemical hole sinking experiments were conducted using brass as the cathode, and either cast or forged low alloy steel (composition given in Table 1) as the anode material. An aqueous NaCl solution was used as the electrolyte. The experiments were conducted using an electrochemical machine as shown in Fig. 2, which was designed and developed [1] in the Machine Tool Laboratory of the University of Roorkee. A replica of the hole produced was prepared using plaster of Paris and it was examined under the tool-maker's microscope to calculate overcut using Equation 3.

$$\text{Overcut} = (\text{Hole diameter} - \text{Tool diameter})/2 \qquad (3)$$

Table 1. The composition of cast low alloy steel and forged low alloy steel

Element	*Cast low alloy steel*	*Forged low alloy steel*
C	0.234	0.379
S	0.011	0.017
P	0.014	0.018
Si	0.500	0.280
Mn	1.44	0.800
Ni	0.095	–
Cr	0.060	1.020
Mo	0.073	0.278
Cu	0.063	–
Al	0.055	–
V	–	–
Other impurities	–	–

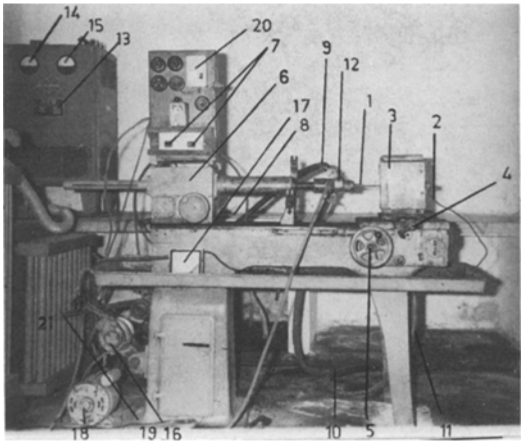

Fig. 2. Electrochemical machining apparatus. 1. Tool. 2. Workpiece. 3. Plastic box. 4. Wheel for transverse movement. 5. Wheel for axial movement. 6. Feed gear box. 7. Feed direction change knobs. 8. Feed selector. 9. Electrolyte supply pipe. 10. Overflow pipe. 11. Outflow pipe. 12. Cable for connecting tool with power terminal. 13. Rectifier unit. 14. Ammeter. 15. Voltmeter. 16. Cone pulley. 17. Fine range voltmeter. 18. Electric motor to drive feed mechanism. 19. Variac. 20. Electric connection board. 21. Main transformer.

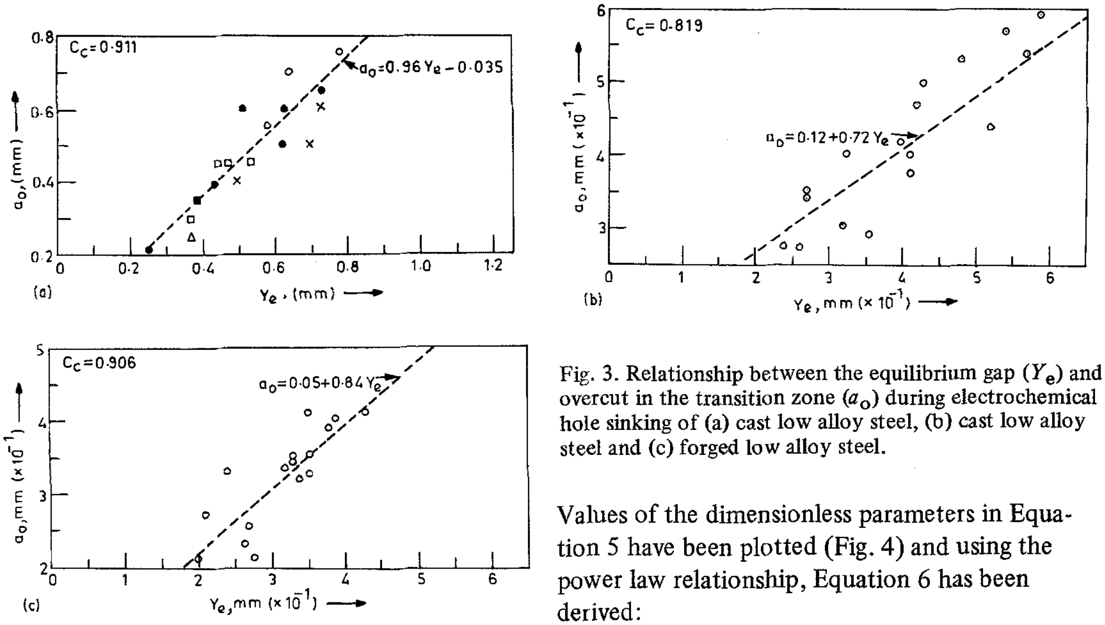

Fig. 3. Relationship between the equilibrium gap (Y_e) and overcut in the transition zone (a_o) during electrochemical hole sinking of (a) cast low alloy steel, (b) cast low alloy steel and (c) forged low alloy steel.

3. Analysis

It was found that there is an approximately linear relationship (Equation 4 and Fig. 3) between a_o and Y_e.

$$a_o = R_{c1} + Y_e R_{c2} \tag{4}$$

where $Y_e = E_V KE/(f \rho_m \cos\theta)$. Equation 4 can be used to evaluate overcut, a_o, provided the constants R_{c1} and R_{c2} are known in advance for the specified machining conditions and work materials. Coefficients R_{c1} and R_{c2} can be evaluated from experimental data in Fig. 3, however, they are different for different materials. The slope of best-fit line is almost the same for the same electrolyte, tool and work material combination, but different for two different materials, i.e. forged steel and cast steel (Fig. 3). This may be attributed to the difference in composition.

However, Equation 4 does not directly explain the effects of electrolyte flow velocity and void fraction. Hence, to account for the effect of electrolyte flow velocity, with a view to any possible further improvement in correlation coefficient, C_c dimensional analysis [1] (using a_o, Y_e, f, D, r_c and V) was carried out. The following relationship was obtained

$$\left(\frac{a_o}{r_c}\right) = \phi\,(Y_e f/D\,V). \tag{5}$$

Values of the dimensionless parameters in Equation 5 have been plotted (Fig. 4) and using the power law relationship, Equation 6 has been derived:

$$(a_o/r_c) = C_d\,(Y_e f/D\,V)^{n_1}. \tag{6}$$

The value of the correlation coefficient, in this case, is higher than that in Equation 4, and this equation is closely obeyed by experimental data (Fig. 4). However, a few deviations have been

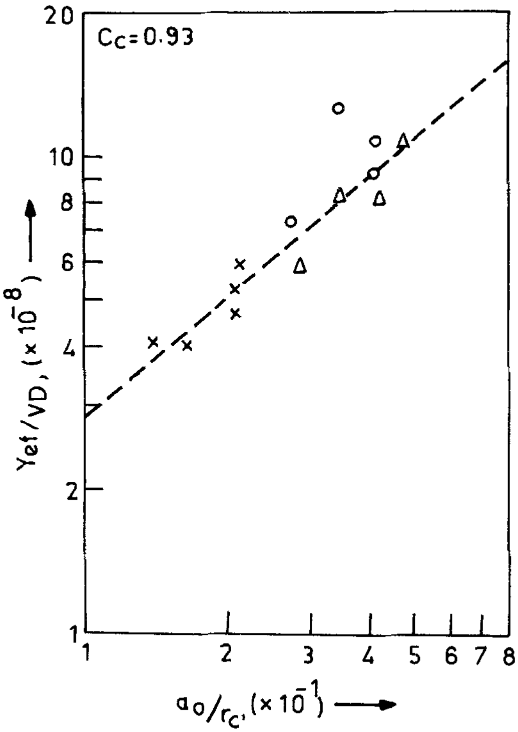

Fig. 4. Relationship between (a_o/r_c) and ($Y_e f/VD$) for cast low alloy steel with a bit type tool.

observed that may be attributed to experimental error. This simply means that if the values of C_d and n_1 are known for a particular combination of tool material, work material and electrolyte, then for the given machining conditions, the overcut in the transition zone can be predicted accurately.

4. Conclusions

It is concluded that Equation 4 gives a good estimation of overcut in the transition zone provided the values of R_{c1} and R_{c2} are known. Further, the overcut in the transition zone during electrochemical hole sinking can be predicted quite accurately by the use of the dimensional analysis Equation 6. Overcut in the transition zone is found to be a function of Y_e, f, D, V and r_c.

References

[1] V. K. Jain, PhD thesis, University of Roorkee (1980).
[2] V. K. Jain and P. C. Pandey, *Precision Engineering*, **2** (1980) 195.
[3] R. Ippolito and G. Fassolio, *Int. J. Mach. Tool Des. Res.* **16** (1976) 129.
[4] W. König and H. Degenhardt, 'Principles of Electrochemical Machining', (edited by C. L. Faust) Electrochemical Society, New Jersey (1971) pp. 68–83.
[5] W. König and H. J. Humb, *Annals CIRP* **25** (1977) 83.
[6] C. N. Larsson and E. M. Baxter, *Proc. 18th Int. MTDR Conf.* McMillan Press, London (1977) pp. 499–505.
[7] C. N. Larsson and E. M. Baxter, *Proc. IEE Conf. on Electrical Methods of Machining, Forming and Coating*, The Institute of Electrical Engineers, London (1975) pp. 161–8.
[8] C. N. Larsson and K. Muzaffaruddin, *Proc. 19th Int. MTDR Conf.* (1978) pp. 533–40.