ME 338
Manufacturing Processes II
HW#4

Instructor: Ramesh Singh
Assigned Date: Oct 26, 2018
Due Date: November 7, 2018

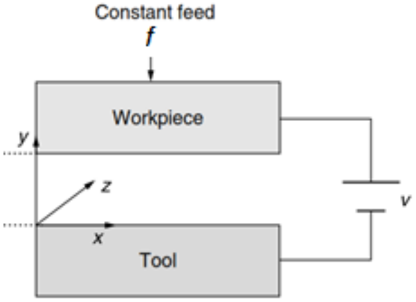
1. In Electro-chemical machining (ECM), the material removal rate is governed by Faraday's laws. For a machining of SS-316 using ECM process, calculate the material removal rate (m^3/min) for a current of 500A and 100% current efficiency. The Faraday's constant (F) is 96500As.

Composition of SS-316L alloy

ELEMENT	%	VALENCY	ATOMIC MASS (g/mole)	DENSITY (g/cm^3)
Iron (Fe)	68.2	2	55.85	7.86
Chromium (Cr)	17.2	2	51.99	7.19
Nickel (Ni)	10.9	2	58.71	8.90
Molybdenum (Mo)	2.1	3	95.94	10.28
Manganese (Mn)	1.6	2	54.94	7.43

If the constant gap voltage (V) is applied and the steady state is allowed to establish, how different alloy constituents will affect the surface roughness of the machined surface? Further, using the steady state relations for feed rate, indicate whether high or low value of feed rate will yield better surface finish? Plot approximate representative curves (no calculations required) between gap (y) and feed rate (f) to justify your conclusion.

Useful equations:



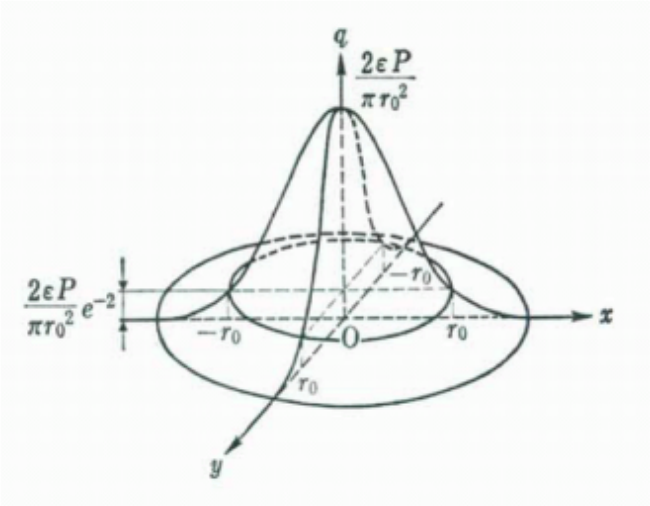
- Volume of material removed (cm^3) = CIt
- Electrochemical constant, $C = \frac{A}{ZF\rho}$

At the feed rate f (cm/s), in the direction of decreasing y, the workpiece rate of change of position dy/dt can be written as:

$$\frac{dy}{dt} = \frac{CVk}{y} - f$$

where,
I = current (A); t =time (s); A = atomic mass; Z = number of valence electrons;
F = Faraday's constant (As); ρ = density of work material (g/cm^3);
k = electrolyte conductivity ($\Omega^{-1}cm^{-1}$)

2. The lasers can be modeled as moving heat sources and they have different spatial modes such as Gaussian distribution (shown in Fig. 1) and uniformly distributed on a rectangle or a circle. The solutions could be found by integrating the transient moving point solution over the limits.



Gaussian distribution

The solution for moving point heat source in moving and fixed coordinates are given by: Eq. (1) and Eq. (2), respectively:

$$dT'(x,y,z,t') = \frac{2\delta q}{\rho C(4\pi a(t-t'))^{\frac{3}{2}}} \exp[-\frac{(X-x')^2+(Y-y')^2+(Z-z')^2}{4a(t-t')}] \qquad (1)$$

$$dT'(x,y,z,t') = \frac{2\delta q}{\rho C(4\pi a(t-t'))^{\frac{3}{2}}} \exp[-\frac{(x-vt'-x')^2+(y-y')^2+(z-z')^2}{4a(t-t')}] \qquad (2)$$

where, δq = heat (x', y', z'), r = beam radius, k = thermal conductivity, a = k/ρc = diffusivity, ρ = density, c = specific heat capacity. x-y-z are fixed co- ordinates tied to the center of the moving heat source.
Find the solutions for:

a. Gaussian moving disk heat source
Hint:

$$\mathrm{dT}'(\mathrm{t}') = \int_{-\infty}^{\infty}\mathrm{dx}'\int_{-\infty}^{\infty}\mathrm{dy}'\,\frac{4*P}{\pi*r^2}*\mathrm{Exp}\left[-\frac{2(x'^2+y'^2)}{r^2}\right]$$

$$*\frac{\mathrm{dt}'}{\rho\mathrm{c}\big(4\pi\mathrm{a}(t-t')\big)^{\frac{3}{2}}}\mathrm{Exp}\left[-\frac{(X-x')^2+(Y-y')^2+(Z-z')^2}{4*a*(t-t')}\right]$$

b. Derive the following solution for Uniform moving rectangular heat source

$$T - T_0 = \frac{2P}{8(4bl)\rho C\sqrt{\pi a}} \int_0^t \frac{dt'}{\sqrt{(t-t')}} \exp[-\frac{z^2}{4a(t-t')}] \times$$

$$[erf(\frac{x+l+vt'}{\sqrt{4a(t-t')}}) - erf(\frac{x-l+vt'}{\sqrt{4a(t-t')}})][erf(\frac{y+b}{\sqrt{4a(t-t')}}) - erf(\frac{y-b}{\sqrt{4a(t-t')}})]$$

where rectangular heat source dimensions varies from $-l < x < l$ and $-b < y < b$ Other parameters are same as above. (Ref. "Conduction of heat in solids" by Carslaw & Jaeger, page no.270)

c. With the help of above two cases, derive the solution for uniform moving circular heat source for a given depth or z:

Note that in case of Gaussian moving circular heat source, the limits vary from $-\infty\ to\ \infty$ but values die down at certain distance from center. Consequently, in case of circular heat source put appropriate limits.

(**NOTE: Numerical integration may be required for solving the final equation. Extra credits will be awarded for reaching the correct solution. Feel free to use Mathematica, Maple, Matlab or programming environment of your choice**)

3. Do a literature review to find the difference between the process and circuitry of macro and micro-EDM. List out the process capabilities and the hardware differences between them.

4. We need to cut the half-cylindrical block (shown in black, Fig. 2) from solid Tungsten block by Wire EDM. The discharge current varies with respect to time and shown in Figure 1 (sinusoid wave form). The diameter of EDM wire (d_w) is 100 µm, the inter-electrode gap (s) is 0.02 mm. Peak current is 10 A, Duty cycle is 0.5. Tungsten properties: density: 19290 kg/m3, specific heat 138 J/Kg.K, melting point 3410°C, thermal conductivity 166 W/m.K. Calculate the time taken in cutting this block? Volumetric material removal rate (MRR) in EDM (mm^3/s) in EDM is given by: MRR = $[(664*I_{avg})/(\text{Melting point})^{1.23}]$. Units of I_{avg} is in amps, and melting point is in °C.

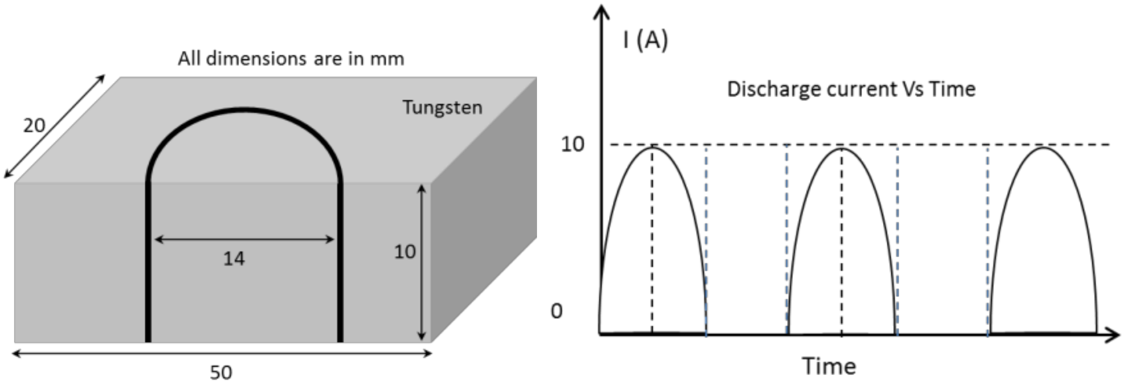


Fig. 2. Block (left), Sinusoid waveform of discharge current Vs time (right)

List the three main properties which enhance the electrical discharge machinability. Based on that suggest the properties of good EDM tool material.

5. Compare the capabilities of electron beam machining and focused ion beam machining. List the comparative advantages and disadvantages.