Nontraditional Manufacturing Processes
MF30604

Assignment -1 **Total Marks 65**

Due by 7th February 2018

(Please put in Locker no. 11. After the Due date Assignment will not be accepted)
(You may make suitable assumptions giving proper justification and if there is any data missing, you may assume a suitable value)

1. State whether the following statements are true or false. Justify your answer in brief.
Marks: 20

i. Electron-beam machining is a thermal process.
ii. Electron beam energy is absorbed at the top surface of workpiece.
iii. Electron beam machining is normally done in vacuum.
iv. Electron beam can be focused down to its wavelength range.
v. The penetration depth of e-beam in a material gets doubled with the doubling of the accelerating voltage.
vi. Penetration depth of e-beam depends upon the thermal conductivity of material.
vii. Electron beam is generated by electric field emission in high power e-beam machine.
viii. What is the main difference in the material removal mechanisms in E-beam and Ion- beam machining/
ix. How is ion beam produced?
x. Among E-beam and Ion-beam which can produce smaller features and why?

2. Explain why a hole in a 5 μm tungsten thin foil can't be done with an e-beam accelerated at 100 kV but can be done when acceleration voltage is reduced to 50 kV. The density of tungsten is 19300 kg/m^3. [3]

3. The specific power of electron beam machining (power required to remove one mm^3 material per minute) for tungsten is 12W/mm^3/min. We want to cut a 0.5 mm thick tungsten sheet with an e-beam at 12m/min speed. Though the focused e-beam diameter on the workpiece is 0.1mm, the actual spot size is mainly governed by the heat conduction in the workpiece. What is the e-beam power required to cut the sheet and what would be the kerf-width? You may assume the thermal diffusivity of tungsten as $6x10^{-5}$ m^2/s. **[5]**

4. A micro-hole is to be drilled in 500 μm thick tungsten sheet with an e-beam focused to 100 μm diameter spot at 10 kW power on the surface of the sheet.
Suggest the mode of e-beam drilling (pulsed mode or continuous mode) for producing holes with negligible heat affected zone (HAZ) at the peripheral edges of hole. What should be the e-beam pulse on-time to get HAZ –free hole drilled, the focused e-beam diameter at the work-piece surface and what will be the total drilling time?
The thermo-physical properties of tungsten are given as the following:
Specific power for e-beam machining of tungsten = 12 W/mm^3 /min, Density = 19300 kg m^{-3},
Specific heat = 140J kg^{-1} K^{-1}, Thermal conductivity =164 W $m^{-1}K^{-1}$ **[10]**

5. We want to cut a through slit of 50 μm width in a 1 mm thick Ti sheet with an e-beam at 5 kW. What should be the e-beam focus diameter at the work-piece surface and processing

speed? About 65% material is removed by vaporization and remaining 35% through melt ejection during drilling process.
The thermo-physical properties of titanium are given as the following:

Density = 4510 kg m^{-3}, Latent heat of fusion=437 kJ kg^{-1}, Latent heat of vaporization =9000 kJ kg^{-1}, Specific heat = 519J kg^{-1} K^{-1}, Melting temperature =1668°C, Boiling temperature = 3260°C, Thermal conductivity =19 W $m^{-1}K^{-1}$, E-beam power coupling efficiency, $\eta = 0.1$.
You may assume constant properties over the whole temperature range. **[8]**

6. We want to perform 25 mm deep keyhole butt welding in 25 mm thick Aluminum plates with electron beam at 50 kW power. The e-beam focus diameter is 0.5mm. What will be the welding speed and weld-bead width?
The thermo-physical properties of aluminum are given as the following:

Density = 2700 kg m^{-3}, Latent heat of fusion=397 kJ kg^{-1}, Latent heat of vaporization =9492 kJ kg^{-1}, Specific heat = 900J kg^{-1} K^{-1}, Melting temperature =660°C, Boiling temperature = 2450°C, Thermal conductivity =226 W $m^{-1}K^{-1}$
You may assume constant properties over the whole temperature range and negligible amount of vaporization. . **[7]**

7. The sputtering yield in ion beam machining of a material at 10^0 and 85^0 angle of incident is 2 and 10 respectively. If we want to maintain a constant sputtering rate at both angles of incidence, by what factor the ion current should be changed when the angle of incidence is increased from 10^0 to 85^0? **Marks: 02**

8 . If the Sputtering yield S varies proportional to $\text{Sin}^2\theta$, where θ is the angle of incident then at what angle of incident the sputtering rate will be maximum? **Marks: 03**

9. What should be ion current density to process silicon at 10nm/s sputtering rate at 10^0 angle of incident at which the sputtering yield is (say) 0.5?
Silicon atomic weight = 28g and density = 2.33 g/cm^3. **Marks: 03**

10. Full penetration bead-on-plate welding is to be done in a 6mm thick steel plate by plasma arc machine. The machine operating parameters are: plasma arc current = 150A and plasma arc voltage = 50V.
The weld width is 4 mm. Assuming that 90% plasma arc power is transferred to the workpiece and 50% of it is lost by heat conduction in the workpiece **estimate the maximum welding speed.**
The thermo-physical properties of steel are:
Density =8000kg/m^3, Specific heat =500J/kg ^{0}C, Melting temperature = 1500^0C, Latent heat of fusion =300kJ/kg. You may neglect the initial ambient temperature. **Marks: 04**

For the above Exercises (Sr. no. 5 & 6) you may use the following Energy Balance Eq.:

If electron-beam pulse on-time, τ or in case of continuous wave e-beam processing e-beam diameter, d_b and scan speed, v is given, first calculated the thermal diffusion length, d_{dif} and compare with the e-beam diameter, d_b. If this $d_{dif} > d_b$, the hole diameter in case of drilling or kerf-width, w in case of cutting will be equal to d_{dif}. If

$d_{dif} < d_b$, the hole diameter in case of drilling or kerf-width in case of cutting will be equal to d_b.

Energy balance assuming the kerf width, w is govern by thermal Diffusion length $(d_{dif} = 2\sqrt{\kappa\tau})$ as the E-beam spot size, d_b is small, less than d_{dif}

$$\eta P = w.t.v.\ \rho.\{C_p.\ \Delta T_b + L_f + m'.L_v\} = w.t.v.\ \rho.C_p.\ \Delta T^*$$

$$\Delta T^* = \Delta T_b + (L_f + m'.L_v)/C_p$$

w = Kerf width $\approx$Thermal diffusion length= $2\sqrt{\kappa.\tau} = 2\sqrt{\kappa.d_b/v} > d_b$

$$\Delta T^* = \eta\{P / 2t(k.d_b.v.\rho.C_p)^{1/2}\}$$

where

P = E-beam power in W, η= E-beam power coupling efficiency ~0.1

t= depth of penetration in cm up to which rise in temperature is ΔT_b

k= Thermal conductivity of material

d_b= Diameter of e-beam focused spot, v= Processing speed

ρ=Material density, C_p = Specific heart

ΔT_b= Boiling temperature, L_f= Latent heat of fusion,

m'= Fraction of material evaporated, L_v = Latent heat vaporization.