Nontraditional Manufacturing Processes: MF30604

Assignment -3 **Total Marks: 65**
Date of Assignment: March 25, 2018 **Date of Submission: April 02, 2018**

State whether the following statements are true or false. Support your answer in a few sentences. (2x10-20)

1.
   i. The material removal mechanism in Abrasive jet machining is thermal.
   ii. Material removal processes in USM and AWJM are different.
   iii. In Abrasive Jet Machining process the MRR increases monotonically with the increase of mass flow rate of abrasive at a constant carrier gas pressure.
   iv. Material removal rate of ductile and brittle materials by AJM process is usually the same for all other process parameters and material properties being the same.
   v. In WJM the water pressure is proportional to the diameter of the water piston of the intensifier.
   vi. In WJM a double acting intensifier is used to double the water pressure.
   vii. In WJM an orifice made of copper is used due to its high thermal conductivity.
   viii. In AWJ machining process the MRR is maximum when abrasive mass flow rate is higher than water flow rate.
   ix. USM is mainly used to machine ductile metals.
   x. In USM a horn is used between the transducer and tool for vibration isolation.

2. Estimate the material removal rate in AJM of a brittle material with flow strength of 4 GPa. The abrasive flow rate is 5 gm/min, jet velocity is 250 m/s and density of the abrasive is 4 gm/cc. (3)

3. Material removal rate of a ceramic material in AJM is 15 mm^3/min. Calculate the material removal per impact as well as indentation radius if mass flow rate of abrasive is 2 gm/min, density is 3 gm/cc and grit size is 50 μm. (4)

4. Glass is being machined by USM at a MRR of 10 mm^3/min by Al_2O_3 abrasive grits having a grit diameter of 50 μm. If 100 μm grits were used, what would be the MRR? (4)

5. In the problem no.4 if the operating frequency is increased from initial setting of 20 kHz to 25 kHz., what will be the new MRR. (3)

6. In the problem no. 4, the feed force is increased by 50% along with a reduction in concentration of abrasive in slurry by 40%. What would be the effect on MRR? (2)

7. In water jet machine determine the water jet velocity and mass flow rate of water , when the water pressure is 4000 bar, being issued from an orifice of diameter 0.5 mm. The orifice coefficient is 0.9. (3)

8. In abrasive water jet machine having parameters as in question no. 7, if the mass flow rate of abrasive is 1 kg/min, determine the abrasive water jet velocity assuming no loss during mixing process. (3)

9. Determine depth of penetration, if a steel plate is machined by the AWJM of question 8 at a traverse speed of 150 mm/min with an insert diameter of 1 mm. The specific energy of steel is 15 J/mm^3. (3)

10. A workpiece has a 10µm thick ceramic coating on its surface. The strength of coating is 5Gpa. This coating is to be removed by an Abrasive Jet of grit diameter 40µm and grit density 5g/cc. What should be the velocity of the AJ to remove the total thickness of the coating in a single impact of an abrasive grit? Estimate the AJ mass flow rate to clean up 10cmx10cm area in 5 minute machining time. (5)

11. Material removal rate of a ductile material in AJM is $30mm^3/min$. Calculate the material removal per impact as well as the indentation radius if the mass flow rate of abrasive is 6g/min, density is 5g/cc and the grit diameter is 40µm. The strength of the material is 2GPa. Estimate the AJ velocity also. (5)

12. You are using one USM for die sinking upto a depth of 3 mm as per customer's order, using abrasive 'A' of list. However, the customer changes the order so that the new depth is 5 mm but he wants it to be completed in the same time. If you can only use the abrasives in the list, which abrasive would be the most appropriate? Show calculations for different stages of selection. The work piece hardness is 1200 kgf/mm^2. Assume μ to be same for all abrasives. Given, c = volume concentration of abrasives in water slurry (v/v), A = area of tool, F = static force, a_0 = amplitude, d_g = average abrasive grit dia, mm, σ_w = flow stress of work piece, λ = ratio of hardness of work piece to that of USM tool material (not abrasive) and f = frequency. Use the following relation. Assume any data not supplied.

[5]

$$MRR \quad \alpha \quad \frac{c^{1/4} A^{1/4} F^{3/4} a_o^{\;3/4} d_g f}{\sigma_w^{\;3/4} (1+\lambda)^{3/4}} \mu^{3/4}$$

Sl No	Abrasive material	ρ g/cc	Hardness, kgf/mm^2	Average grit dia, µm	c
1	Abrasive 'A'	3	2500	50	0.60
2	Abrasive 'B'	4	2800	60	0.75
3	Abrasive 'C'	5	3000	85	0.56
4	Abrasive 'D'	6	2700	100	0.56

13. In an abrasive water jet machine, derive the expression for the depth of blind groove cut by AWJM (given below, where the symbols carry their usual meaning).

$$h_t = \xi c_d \times \frac{\Pi}{4} d_o^{\;2} R \left(\frac{\eta}{1+R} \right)^2 \frac{p_w^{3/2}}{u_{job} d_i v_f} \sqrt{\frac{2}{\rho_w}}$$

While cutting such a blind groove with mixing ratio R = 0.65, due to overheating of control circuit, the cutting velocity of the table comes down by 10 % while the abrasive mass flow rate and water mass flow rate get reduced by 10 % and 8 % respectively. If the groove depth changes, the job will be rejected. Find out whether the job gets rejected. **[5]**

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State whether the following statements are true or false. Support your answer in a few sentences. (2x10-20)

1.

i. The material removal mechanism in Abrasive jet machining is thermal.

False. It is mechanical

ii. Material removal processes in USM and AWJM are different.

True, both processes are mechanical

iii. In Abrasive Jet Machining process the MRR increases monotonically with the increase of mass flow rate of abrasive at a constant carrier gas pressure.

False, after an initial increase it tends to saturate and fall.

iv. Material removal rate of ductile and brittle materials by AJM process is usually the same for all other process parameters and material properties being the same.

False, in case of brittle material MRR is relatively more, as hemispherical volume is removed.

v. In WJM the water pressure is proportional to the diameter of the water piston of the intensifier.

False, it is inversely proportional to the piston diameter

vi. In WJM a double acting intensifier is used to double the water pressure.

False, it is used to minimize pressure fluctuations.

vii. In WJM ~~an~~ orifice made of copper is used due to its high thermal conductivity.

False, orifice made of Sapphire is used.

viii. In AWJ machining process the MRR is maximum when abrasive mass flow rate is higher than water flow rate.

False, it is theoretical maximum when abrasive and water flow rates are equal.

ix. USM is mainly used to machine ductile metals.

False, it is mainly used for machining brittle materials

x. In USM a horn is used between the transducer and tool for vibration isolation.

False, it is used to amplify the mechanical vibration amplitude.

2. Estimate the material removal rate in AJM of a brittle material with flow strength of 4 GPa. The abrasive flow rate is 5 gm/min, jet velocity is 250 m/s and density of the abrasive is 4 gm/cc. (3)

For brittle materials

$$MRR = \dot{M}_a V^{3/2} / \rho^{1/4} \cdot H^{3/4} \qquad H \approx 3 \text{ Flow strength} \approx 12 GPa$$

$$MRR = \frac{(5\times10^{-3}/60) \times 250^{3/2}}{(4000)^{1/4} \times (12\times10^{9})^{3/4}} =$$

3. Material removal rate of a ceramic material in AJM is 15 mm^3/min. Calculate the material removal per impact as well as indentation radius if mass flow rate of abrasive is 2 gm/min, density is 3 gm/cc and grit size is 50 µm. (4)

$$MRR \text{ per impact} = \frac{MRR}{N} = \frac{MRR \times \pi d^3 \rho}{6 \dot{M}_a} = \frac{(15\times10^{-9}/60)\times3.14\times(50\times10^{-6})^3\, 3000}{6\times 2\times10^{-3}/60}$$

$$\approx \underline{1.47\times10^{-6}}\ mm^3/\text{impact}$$

In brittle material $MRR = 2/3\pi N (d\delta)^{3/2} \Rightarrow \delta = \underline{\underline{1.58 \mu m}}$

4. Glass is being machined by USM at a MRR of 10 mm^3/min by Al_2O_3 abrasive grits having a grit diameter of 50 µm. If 100 µm grits were used, what would be the MRR? (4)

$$MRR \propto d_g \Rightarrow MRR_{100} = \frac{MRR_{50}}{50}\times100 = 20\ mm^3/min.$$

5. In the problem no.4 if the operating frequency is increased from initial setting of 20 kHz to 25 kHz., what will be the new MRR. (3)

MRR in USM $\propto f$ $\Rightarrow MRR_{25} = \frac{MRR_{20}}{20} \times 25$

$= 12.5\ mm^3/min.$

6. In the problem no. 4, the feed force is increased by 50% along with a reduction in concentration of abrasive in slurry by 40%. What would be the effect on MRR? (2)

MRR in USM $\propto C^{1/4} F^{3/4}$

Change in C & F $\Rightarrow 0.6^{1/4}\ 1.5^{3/4} = 1.193.$

Percentage increase $\Rightarrow (1.193 - 1) \times 100 = 19.3\%.$

7. In water jet machine determine the water jet velocity and mass flow rate of water , when the water pressure is 4000 bar, being issued from an orifice of diameter 0.5 mm. The orifice coefficient is 0.9. (3)

$$V_\omega = C_d \left(\frac{2 P_\omega}{\rho_\omega}\right)^{1/2} = 0.9 \left(\frac{2 \times 4000 \times 10^5}{1000}\right)^{1/2} \approx 805\ m/s.$$

$$\dot{m}_\omega = \frac{\pi}{4} d_o^2\ \rho_\omega\ V_\omega \approx 0.16\ kg/s \approx 9.6\ Kg/min.$$

8. In abrasive water jet machine having parameters as in question no. 7, if the mass flow rate of abrasive is 1 kg/min, determine the abrasive water jet velocity assuming no loss during mixing process. (3)

$$\dot{m}_\omega V_\omega = \dot{m}_a V_{a\omega} + \dot{m}_\omega V_{a\omega}$$

$$V_{a\omega} = \frac{\dot{m}_\omega V_\omega}{\dot{m}_a + \dot{m}_\omega} = \frac{9.6 \times 805}{1 + 9.6} \approx 729\ m/s.$$

9. Determine depth of penetration, if a steel plate is machined by the AWJM of question 8 at a traverse speed of 150 mm/min with an insert diameter of 1 mm. The specific energy of steel is 15 J/mm^3. (3)

$$V_t = \frac{\pi}{4}\left\{\frac{\eta R P_w^{3/2} C_d^3 d_o^2}{U_a d_i h_t (1+R)^2}\left(\frac{2}{\rho_w}\right)^{1/2}\right\}$$

$\eta = 1$, $C_d = 0.9$, $V_t = 150$ mm/min, $R = \dot{m}_a/\dot{m}_w = \frac{1}{9.6} = 0.1$.

From this $h_t \approx 112.8$ mm

10. A workpiece has a 10μm thick ceramic coating on its surface. The strength of coating is 5Gpa. This coating is to be removed by an Abrasive Jet of grit diameter 40μm and grit density 5g/cc. What should be the velocity of the AJ to remove the total thickness of the coating in a single impact of an abrasive grit? Estimate the AJ mass flow rate to clean up 10cmx10cm area in 5 minute machining time. (5)

In ceramic coating, depth of coating removed $\approx r = (d_g\delta)^{1/2} = 10\,\mu m$

$\therefore \delta = (10\times10^{-6})^2/40\times10^{-6} = 2.5\times10^{-6}$ m.

Required MRR $= \frac{10\times10\times10\times10^{-4}}{5\times60}\frac{cm^3}{s} \simeq 3.3\times10^{-10}\ m^3/s$.

$V = \frac{\delta}{d}\left(\frac{6H}{\rho}\right)^{1/2} = \frac{2.5\times10^{-6}}{40\times10^{-6}}\left\{\frac{6\times3\times5\times10^{9}}{5000}\right\}^{1/2} = 265.2$ m/s.

$MRR = \dot{M}_a V^{3/2}/\rho^{1/4}H^{3/4} \Rightarrow \dot{M}_a = 74\times10^{-5}$ kg/s $= 44.4$ g/min.

11. Material removal rate of a ductile material in AJM is 30mm^3/min. Calculate the material removal per impact as well as the indentation radius if the mass flow rate of abrasive is 6g/min, density is 5g/cc and the grit diameter is 40μm. The strength of the material is 2GPa. Estimate the AJ velocity also. (5)

In ductile materials, $MRR = 0.5\,\dot{M}_a V^2/H$ $H_v \approx 3\sigma = 6$ GPa

$\Rightarrow V = \left(\frac{MRR\cdot H}{0.5\dot{M}_a}\right)^{1/2} = \left(\frac{30\times10^{-9}}{\cancel{60}}\times\frac{\cancel{6}\times10^{9}}{0.5\times\cancel{6}\times10^{-3}}\times\cancel{60}\right)^{1/2} \simeq \underline{245\ m/s}$.

MRR per impact $= MRR/N = \frac{MRR\ \pi d^3\rho}{6\dot{M}_a} = \underline{8.4\times10^{-7}}\ mm^3/\text{impact}$

$\Gamma = \pi\delta^2 d/2 = 8.4\times10^{-7}\ mm^3 \Rightarrow \delta = \left(\frac{2\times8.4\times10^{-7}}{\pi\times0.04}\right)^{1/2} = 36.5\times10^{-4}\ mm = \underline{3.65\ \mu m}$

12. You are using one USM for die sinking upto a depth of 3 mm as per customer's order, using abrasive 'A' of list. However, the customer changes the order so that the new depth is 5 mm but he wants it to be completed in the same time. If you can only use the abrasives in the list, which abrasive would be the most appropriate? Show calculations for different stages of selection. The work piece hardness is 1200

kgf/mm^2. Assume μ to be same for all abrasives. Given, c = volume concentration of abrasives in water slurry (v/v), A = area of tool, F = static force, a_0 = amplitude, d_g = average abrasive grit dia, mm, σ_w = flow stress of work piece, λ = ratio of hardness of work piece to that of USM tool material (not abrasive) and f = frequency. Use the following relation. Assume any data not supplied.

[5]

$$MRR \;\alpha\; \frac{c^{1/4}A^{1/4}F^{3/4}a_o^{\;3/4}d_g f}{\sigma_W^{\;3/4}(1+\lambda)^{3/4}}\mu^{3/4}$$

Sl No	Abrasive material	ρ g/cc	Hardness, kgf/mm^2	Average grit dia, µm	c
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Revised $MRR_x = 5/3\, MRR_A$ to maintain the same maching time

$A, F, \lambda, \sigma_w, F, a$ & μ are unaltered $\therefore MRR \propto c^{1/4} d_g$

$MRR_A \propto 0.6^{1/4} \times 50 = 44.$ $\quad MRR_x \propto \frac{5}{3} \times 44 = 73.35$

Abrasive B $\rightarrow c^{1/4} \cdot d_g = 55.84$

Abrasive C $\rightarrow$ $= 73.53$ ✓ $\quad$ Abrasive 'C'.

Abrasive D $\rightarrow$ $= 86.5$

13. In an abrasive water jet machine, derive the expression for the depth of blind groove cut by AWJM (given below, where the symbols carry their usual meaning).

$$h_t = \xi c_d \times \frac{\Pi}{4} d_o^{\,2} R \left(\frac{\eta}{1+R}\right)^2 \frac{p_w^{3/2}}{u_{job} d_f v_f} \sqrt{\frac{2}{\rho_w}}$$

While cutting such a blind groove with mixing ratio R = 0.65, due to overheating of control circuit, the cutting velocity of the table comes down by 10 % while the abrasive mass flow rate and water mass flow rate get reduced by 10 % and 8 % respectively. If the groove depth changes, the job will be rejected. Find out whether the job gets rejected. **[5]**

$$h_t \propto \frac{R}{(1-R)^2 V_t} = \frac{5.31}{V_t} \qquad R = \dot{m}_a / \dot{m}_w$$

With Charged Conditions $V_{mod} = 0.9\, V_t$, $R_{mod} = \frac{0.9\dot{m}_a}{0.92\dot{m}_w} = 0.978 R = 0.978 \times 0.65 = 0.639$

$$h_t|_{mod} \propto \frac{0.639}{(1-0.639)^2 \times 0.9 V_t} = 5.45/V_t \approx h_t$$

Only Marginally Changed.