Name: ______________________ ID: _______________________

ME 363
EXAMINATION NO. 1
Solution

FALL 2023

Problem	Point value	Score
1	15	______
2	15	______
3	15	______
4	15	______
5	40	______
6	30	______
		______
		______
total = 100		______

INSTRUCTION: This is a closed book exam. You have two hours to complete the exam.
You are not allowed to use a computer or cell phone during the exam.

1. The diameters of some shafts and holes to be assembled were measured and the results are given in the table below.

	1	2	3	4	5	6	7	8	9	10	average	std
Shaft	9.86	9.94	9.91	9.92	9.79	9.89	9.91	9.86	10.01	9.93	9.902	0.058
Hole	10.01	10.11	10.04	10.12	10.05	10.06	10.11	10.07	10.06	10.08	10.071	0.035

Unit: mm

(a) Express the dimensional tolerance of the shafts and holes using the bilateral and unilateral notations. For the unilateral notation, use 0 as the lower tolerance limit for the holes and 0 as the upper tolerance limit for the shafts. (Hint: they must represent the same ranges)

Bilateral

shafts: 9.902±0.174,
holes: 10.071±0.105,

Unilateral

shafts: $10.076^{0}_{-0.348}$,
holes: $9.966^{+0.315}_{0}$,

(b) For the manufacturing process making the shafts, assuming USL = 10.00 and LSL = 9.80, determine the process capability C_p and C_{pk}.

$$C_{pk} = \frac{10.2-9.7}{6\times0.058} = 1.44$$

$$C_{pk} = \frac{\min(|10.2-9.902|,|9.7-9.902|)}{3\times0.058} = \frac{\min(0.298,0.202)}{3\times0.058} = 1.16$$

(c) This problem is related to surface roughness. The surface roughness was measured on a milled piece in the feed direction with the following values. Calculate the arithmetic surface roughness R_a and R_q values. (unit in micron)

1	2	3	4	5	6	7	8	9	10	11	12	average	STD
-0.23	0.42	1.22	-0.5	-0.95	-0.11	1.11	-0.55	-0.95	-0.11	1.42	0.22	0.08	0.82

$$R_a = \frac{\sum |y_i - \bar{y}|}{N} = \frac{0.31 + 0.34 + 1.14 + 0.58 + 1.03 + 0.19 + 1.03 + 0.63 + 1.03 + 0.19 + 1.34 + 0.14}{12}$$

$$= \frac{7.955}{12} = 0.663$$

$$R_q = \sqrt{\frac{\sum (y_i - \bar{y})^2}{N}} = \sqrt{\frac{0.31^2 + 0.34^2 + 1.14^2 + 0.58^2 + 1.03^2 + 0.19^2 + 1.03^2 + 0.63^2 + 1.03^2 + 0.19^2 + 1.34^2 + 0.14^2}{12}}$$

$$= \sqrt{\frac{7.315}{12}} = 0.781$$

2. The ultimate tensile strength for a metal specimen in the cylindrical shape is 500 MPa (in terms of true stress), and necking occurs at a true strain of ε = 0.23 during the tensile test of the specimen. The material strain hardening index is n = 0.23. The cylindrical sample initial diameter is 15 mm and initial length is 40 mm.

(a) Determine the material strength coefficient K = ?

$$\mathrm{K}\varepsilon^{n} = 500\,\mathrm{MPa}$$
$$\mathrm{K}0.23^{0.23} = 500\,\mathrm{MPa}$$
$$K = 701\,MPa$$

(b) During the tensile test of the specimen, what is the force (in the unit of Newton) required to make the specimen reach the necking point?

$$F = \sigma \cdot A = \sigma \cdot A_0 e^{-\varepsilon}$$
$$\sigma = 500\,\mathrm{MPa}$$
$$A_0 = \frac{\pi}{4} d_0^2 - 1765.7 \times 10^{-1}\; m^2$$
$$\varepsilon = 0.23$$
$$\Rightarrow F = 70.2\; kN$$

(c) What are the engineering stress and strain of the specimen when it reaches the necking point?

$$\sigma_e = \sigma_t \cdot A_0 e^{-\varepsilon_t} = 397.3\, MPa$$
$$\varepsilon_e = e^{\varepsilon_t} - 1 = 0.256$$

(d) What is the energy per unit volume of material that needs to be supplied to make the specimen material reach **<u>the necking point</u>** (Hint: this is <u>not</u> asking for toughness).

$$\int_0^{0.23} K\varepsilon^n d\varepsilon = 9.35 \times 10^7\; J/m^3$$

3. An orthogonal machining process has the following parameters: the cutting velocity V = 2.1 m/s, t_0=0.15 mm, chip thickness t_c=0.19 mm, width of cut w_0 = 7 mm, the thrust force F_t is 20% of the main cutting force F_c (i.e., $F_t = 0.2\,F_c$) and the rake angle is 11^o. The workpiece material specific cutting energy is 1.5×10^9 J/m^3.

(a) Determine the main cutting force F_c and the thrust force F_t.

$$F_c = U \bullet w \bullet t_0 = 1575\ N$$
$$F_t = 0.2F_c = 315\ N$$

(b) Please determine the material removal rate (in the unit of m^3/s)

$$MRR = Vwt_0 = 2.1\times10^6 \times 7 \times 0.15 = 2.2\times10^6\ mm^3/s$$

(c) Determine the chip velocity (in the unit of m/s)

$$V \cdot t_0 = V_{chip} \cdot t_c \Rightarrow V_{chip} = 1.66\ m/s$$

(d) Determine the average shear stress and normal stress in the shear plane.

$$r = \frac{t_0}{t_c} = 0.7895$$
$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha} \Rightarrow \phi = 42.4$$
$$F_s = F_c\cos\phi - F_t\sin\phi = 950.7\ \text{N}$$
$$F_N = F_c\sin\phi + F_t\cos\phi = 1294.6\ \text{N}$$
$$\text{A} = \frac{w_0 t_0}{\sin\phi} = 1.56\times10^{-6} m^2$$
$$\sigma_s = F_s/A = 611\ MPa$$
$$\sigma_N = F_N/A = 832\ MPa$$

4. A tool life experiment of a turning process was carried out with a cutting tool and the following machining conditions. The tool life equation was established.

feed: 0.025 in/rev
depth of cut: 0.015 in
workpiece diameter: 2 in
length of the cut: 10 in
C_o*: operating cost per unit time ($120/hour)*
T_c*: time to change the tool (120 seconds)*
C_t*: initial cost of the tool ($15 for each cutting tool edge)*

(a) Tool life was determined to be 60 min and 10 min for the cutting speed of 350 fpm and 500 fpm, respectively. Determine the Taylor tool life equation parameters. VT^n=C, where V and T are in the unit of *fpm* and minutes, respectively.

Taylor's tool life equation, $\mathrm{VT}^{\mathrm{n}} = C$

$$350 \times 60^{\mathrm{n}} = \mathrm{C}$$

$$500 \times 10^{\mathrm{n}} = \mathrm{C}$$

$$6^n = 1.43 \Rightarrow n = 0.2$$

$$C = 350 \times 60^{0.2} = 793.8$$

(b) Calculate the optimal cutting speed for this operation to yield the minimum machining cost per part. (Hint: pay attention to the units).

$$T_{\min} = \left(\frac{1}{n} \text{-} 1\right)\left(\frac{C_t + T_c C_o}{C_o}\right) = \left(\frac{1}{0.2} \text{-} 1\right)\left(\frac{15 + 2 \times 2}{2}\right)$$

$$= 11.4 \ \text{min}$$

$$V_{\min} = \frac{C}{T_{\min}{}^{n}} = \frac{793.8}{11.4^{0.2}} = 487.9 \ fpm$$

(c) Calculate the estimated power consumption for this material if the specific cutting energy for this material is known to be 0.6 hp/in^3/min?

$$HP = HP_s \times MRR$$

$$= 0.6 \times 0.025 \times 0.015 \times 487.9 \times 12$$

$$= 1.38 \ hp$$

(d) Calculate the cost per part at the optimal cutting speed calculated in part (b), assuming that the loading and unloading time per part is 120 seconds in total. (Hint: the operating cost for the time spent on the part loading and unloading is the handling cost C_4).

$$CT = \frac{L}{f_m} = \frac{L}{f_r N} = \frac{L\pi D}{f_r 12V} = \frac{10 \times \pi \times 2}{0.025 \times 12 \times 383.5} = 0.55\ min$$

$$C = CT \cdot \left(C_0 + \frac{C_t + C_0 T_c}{T}\right) + \$2 \times 2$$

$$= 0.55 \times \left(2 + \frac{15 + 2 \times 2}{38}\right) + \$2 \times 2$$

= 1.1+0.22+0.06+4

$$= 1.375 + 4 = \$5.375$$

5. Multiple Choice Problems. Select the right answer to the question. There is only one answer for each question. (40 pts)

A. Which of the following mechanical properties of a medium carbon steel typically increases with the temperature:

(a) Ultimate tensile strength (b) Fatigue life

(c) True strain right before fracture (d) Hardness

B. Metal A has a higher yield strength but smaller elastic modulus (Young's modulus) than Metal B. Both Metal A and B are linear elastic material up to their yield points. Which of the following statements is definitely correct for Metal A and B specimens during tensile tests:

(a) Metal A has a larger strain at the yield point than Metal B.

(b) Metal A has a smaller hardness than Metal B

(c) Metal A has a smaller resilience than Metal B

(d) Metal A has a shorter fatigue life than B.

C. For a turning process on a given workpiece using a given cutting tool, if the cutting speed V is increased, the feed per round (f_r) is increased and the cutting depth remains the same, then which of the following statements is correct:

(a) The material removal rate decreases.

(b) The spindle speed N increases

(c) The main cutting force decreases

(d) The cutting power remains the same

D. Which of the following statements about cutting tools is correct:

(a) A tungsten carbide cutting tool has no metallic component.

(b) To produce coated tungsten carbide cutting tools, people can use either physical vapor deposition or chemical vapor deposition.

(c) A polycrystalline diamond cutting tool can be suitably used to cut low carbon steel.

(d) A Sialon cutting tool can be suitably used to cut steels.

E. Which of the following typically increases the fatigue strength of a metal workpiece

(a) A higher environmental temperature

(b) A smoother surface

(c) Tensile surface residual stresses and compressive residual stresses in the workpiece's inner region

(d) A larger number of cracks

F. Which one of the following gage blocks represents the grade with the **highest** accuracy?

(a) 0.5 (b) 1

(c) 2 (d) 3

G. Choose an incorrect statement:

(a) Job shop is a general purpose manufacturing operation like student machine shop.
(b) Flow shop is like a chemical plant.
(c) Cell shop may consist~~s~~ of various programmable CNC machines that can be used for machining of various parts
(d) Project shop represents operations such as construction of a bridge.

H. Which one of the following workpiece properties is NOT a critical factor to machinability?

(a) Microstructure and the resulting hardness (b) Chemistry

(c) Fatigue strength (d) Compatibility with cutting tool material

I. Choose an incorrect statement related to milling.

(a) In upmilling, chip thickness changes from thin to thick.

(b) Higher clamping force is needed in upmilling than in downmilling

(c) Downmilling is more likely to induce chatter than upmilling

(d) Downmilling is also called climb milling.

J. Which one of the following hardness tester is used to determine the hardness based on the indentation penetration depth?

(a) Brinell (b) Rockwell

(c) Vickers (d) Knoop

K. Which one of the followings is NOT the benefit of high speed machining?

(a) Easy chip removal (b) Improved surface finish

(c) Higher cutting force (d) Lower thermal distortion

L. Select an incorrect statement related to CNC

(a) Tool geometry is defined by T word.

(b) During the execution of G01, the velocity is controlled by F word

(c) B axis is the rotational axis defined with respect to Y axis

(d) G06 is used to execute a previously defined spline

M. Which of the following is NOT an advantage of CNC:

(a) High productivity (b) Reduced operator skill required

(c) Lower equipment cost (d) Reduced lead time