MIT 2.008 Design and Manufacturing II

Spring 2023

March 22, 2023

- Closed Book
- All work for CREDIT must be completed in this quiz document
- You are allowed one double-sided, handwritten 8.5” x 11” notes sheet
- Calculators are allowed

Name: _____

Problem 1		Out of 15 points
Problem 2		Out of 20 points
Problem 3		Out of 25 points
Problem 4		Out of 20 points
Problem 5		Out of 20 points
Total		**100 points**

Problem 1

Circle or write in the correct answer(s). (**1 pt each)**

a) Injection molding, when starting from pellets, begins with a (**filling / plasticizing**) step where the pellets are fed into a screw-type extruder via a hopper.

b) In injection molding, deformation due to warpage can be reduced by reducing the cooling time and lowering the ejection speed. **True / False**

c) Injection-molded uniform part thickness helps the plastic cool evenly and avoid residual stresses. **True / False**

d) Improving the surface finish on an injection mold can help decrease flash defects. **True / False**

e) In thermoforming, it is a general rule of thumb that the area of the plastic sheet that touches the mold (**first / last**) will be the thinnest.

f) Increasing the draw ratio in thermoforming is likely to reduce tearing defects. **True / False**

g) (**Heating / Cooling**) is usually the rate-limiting step in thermoforming since it is limited by the rate of convective and radiative heat transfer.

h) You are turning a part on a lathe with a constant surface speed, feed, and depth of cut. If you step down to a new diameter that is half of the original diameter, the cutting force (**decreases / stays the same / increases**).

i) In machining, it's possible to have zero thrust force. **True / False**

j) The angle between the plane of a cut and the surface of a workpiece in machining is known as the (**rake angle / shear angle**).

k) In machining, you want to avoid changing feed and surface speed in tandem with each other to make sure you are optimizing your process. **True / False**

l) The insertion force for press fit is linear with insertion depth. **True / False**

m) With regards to process control, it is possible to be in control but fail to meet specification requirements. **True / False**

n) When Cp > Cpk, it indicates that the average is centered on the target value. **True / False**

o) Your tolerances always have to be +/- 3 standard deviations. **True / False**

Problem 2 - Injection Molding

Let's analyze the following parts:

Figure 1. *Pawn chess piece.*

Figure 2. *Bottle cap.*

a) Sketch cross sections of the molds used to make **both** these parts, **identifying and labeling** all critical features of the part and components of the mold. **(10 pts)**

You are hired as a consultant by a company that manufactures jewel CD cases. In particular, they are having trouble with the black piece that holds the CD (**Figure 3**). The processing conditions and material properties are listed in the table below.

Injection temperature (T)	260 °C
Injection pressure (P_i)	3000 psi
Hold pressure (P_h)	5000 psi
Cooling time (t_c)	10 s
Material	Polystyrene
Thermal diffusivity (α)	5.9 x 10^{-4} cm^2/s
Coefficient of thermal expansion (a)	8 x 10^{-5} 1/K

Figure 3. *CD case.*

b) If the company is making **four** of these parts per mold, how much clamp force needs to be applied by the injection molding machine? **(4 pts)**

c) The company is having problems with case breaking in the locations shown in **Figure 4**. Why are the cases breaking here? It may be helpful to use a sketch to show your reasoning. **(3 pts)**

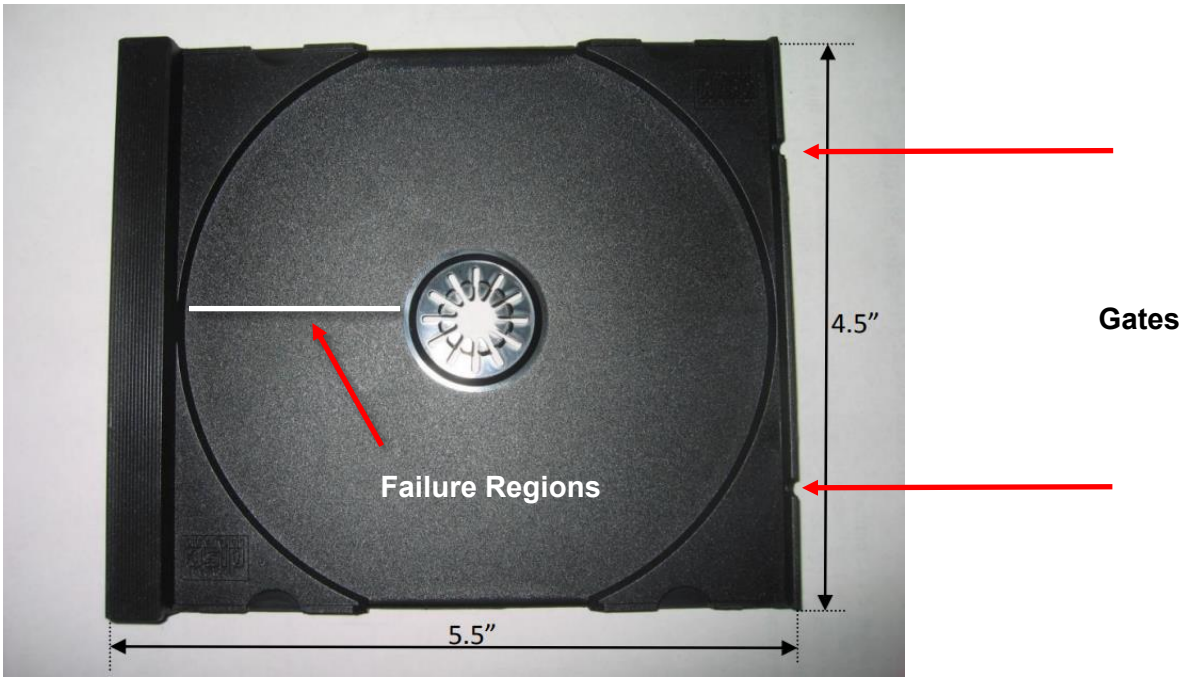


Figure 4. *CD case failure regions.*

d) What changes would you recommend to alleviate this issue? **(3 pts)**

Problem 3 - Cutting

The iPhone 6 housing (shown below) is to be machined from an aluminum (6000 series) block.

Figure 5. *iPhone 6 aluminum housing.*

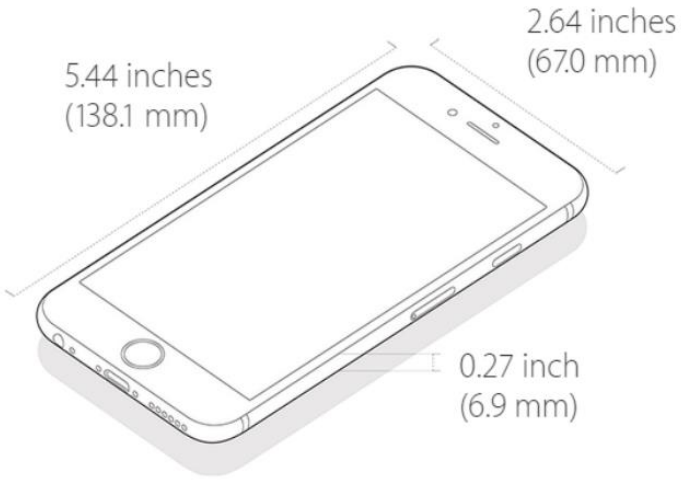


Figure 6. *iPhone 6 dimensions.*

a) If **half** of the workpiece volume is removed by machining using one 0.25-in-diameter, 4-flute (teeth) end-mill, estimate the machining time. Refer to the table below for machining parameters. **(15 pts)**

	Specific energy (hp-min/in^3)	Feed (in/tooth)	Cutting speed (ft/min)	Depth of cut (in)
Aluminum	0.30	0.002	150	0.05

b) To optimize surface finish, the manufacturers decide to change end mills for the final 20% of the machining process. Revise your estimate assuming that 80% of the machining is done using the tool in part (a) and the remaining 20% is done using a 1/16-in-diameter, 2-flute tool with the same machining parameters. **(10 pts)**

Problem 4 – Assembly & Joining

Shrink fits (analogous to press fits) take advantage of thermal expansion to hold two components together without additional fixturing or adhesives. Consider a 5 mm thick aluminum ring of inner radius (r_i) 4 cm that was shrunk to fit into an aluminum outer ring with outer radius (r_o) 10 cm. The interface (R) between them is thus 4.5 cm from the center. Their depths (into the page) are equal to 1.5 cm. The static friction coefficient between them is 0.7. Use E = 70 GPa and $\alpha = 20 * 10^{-6}$ 1/K.

The process of assembling them together was:

- Heat the outer ring to 200°C above the ambient until the inner radius of the outer ring could smoothly fit over the inner ring.
- Allow assembly to cool to ambient.

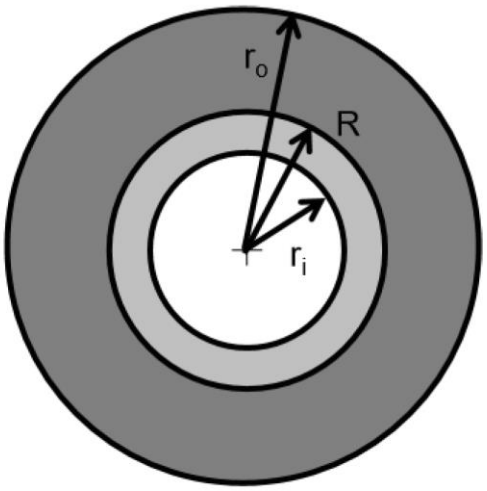


Figure 7. *Joining of two aluminum rings.*

a) What is the force required to separate the two rings after they have reached thermal equilibrium with the ambient? **(5 pts)**

b) If the coefficient of kinetic friction is 0.55, what is the work required to complete the separation? (Press fit equations can apply here). **(5 pts)**

c) If the thickness of the inner ring is doubled and the interface radius unchanged, **calculate** what happens to the force you calculated in part (a) and the work needed to separate the assembly you calculated in part(b)? **(5 pts)**

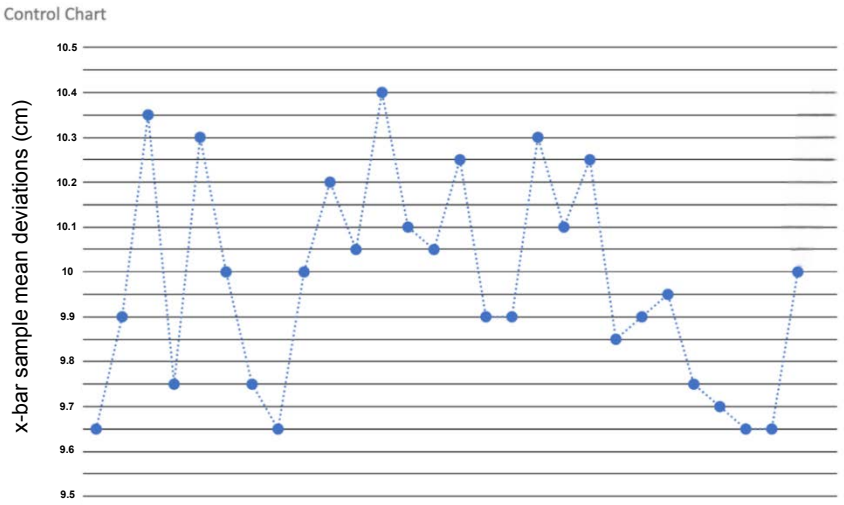
d) What about when the outer ring doubles its thickness, keeping the original inner ring thickness and interface radius the same? Please **calculate** and **explain** what happens to the force you calculated in part (a) and the work needed to separate the assembly you calculated in part(b)? **(5 pts)**

Problem 5 - Variation / Quality Control

We are tasked with improving a steel plate process to produce defect-free parts as quickly as possible. The target plate thickness is 100 cm with a USL of 103 cm and a LSL of 97 cm. Previous testing has shown that the process has a $C_p = 0.80$ and $C_{pk} = 0.20$.

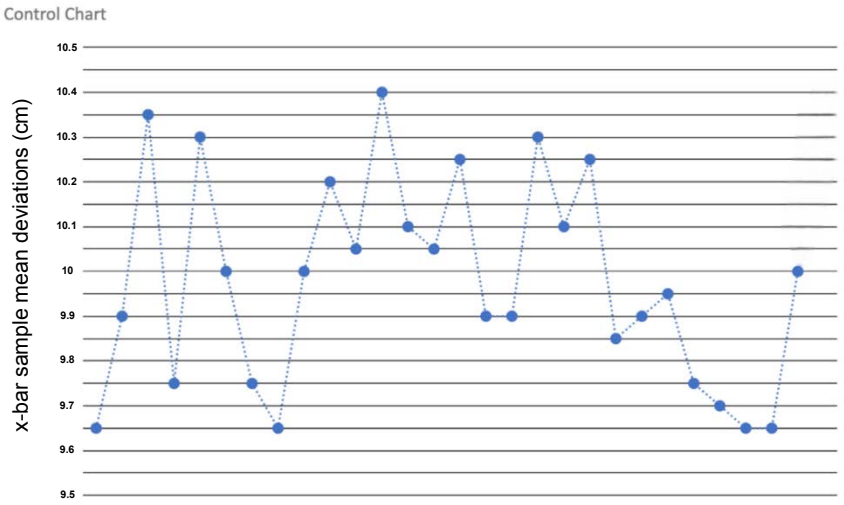
a) Calculate the current mean (μ) and standard deviation (σ)? What is the percentage of NON-conforming parts? **Appendix I** provides z-score tables. **(5 pts)**

Now, let's focus on quality control for the mean sample shown below. A distribution of 30 **sample means** is monitored to ensure whether the process is in control. Each sample mean is comprised of 16 **samples**. The grand mean, which is the average of the sample means, is 10. The mean sample standard deviation is 1.5.



b) Calculate the UCL ($3\bar{\sigma}$) and LCL ($-3\bar{\sigma}$). **(4 pts)**

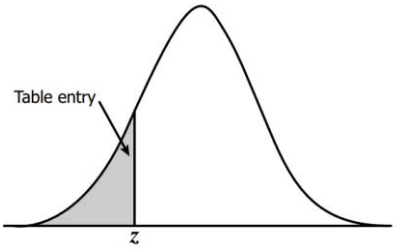
c) Plot on the graph the following components: UCL, LCL, and $\bar{\bar{x}}$. **(6 pts)**



d) Is the process in control? Please explain in detail, draw any other items on the graph needed and quote specific references if used. (**5 pts)**

Appendix I: Z-score Table

$$z = \frac{x - \mu}{\sigma}$$



z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
–3.4	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
–3.3	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
–3.2	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
–3.1	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
–3.0	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
–2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
–2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
–2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
–2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
–2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
–2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
–2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
–2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
–2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
–2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
–1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
–1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
–1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
–1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
–1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
–1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
–1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
–1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
–1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
–1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
–0.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
–0.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
–0.7	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
–0.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
–0.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
–0.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
–0.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
–0.2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
–0.1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
–0.0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

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