Massachusetts Institute of Technology
2.008: Design and Manufacturing II

Problem Set 4 Solutions

Problem 4-1. Welding Speed

(a) Plot welding speed as a function of weld pool depth for depths s = 1mm to 25mm at two preheat temperatures, T_p = 70F and T_p = 700F. Plot the two curves on the same graph [consider using a spreadsheet to do this]. Show any formulas that you derive.

In order to graph the weld-pool depth versus the welding velocity, V, we use the following relationship

$$V_w \geq \frac{d}{t_m} = \frac{.8\alpha J}{s^2}$$

Choosing 1020 steel as the material and a weld tip with diameter 2mm, the constants are $\alpha = 14.1\ mm^2/s$ *and* $J_i = .448\frac{T_m - T_i}{h_{fs}}$. *First we change the Fahrenheit temperatures to Celcius:* $70°\ F = 21.2°\ C$ *and* $700°\ F = 371.1°\ C$. *Then* $J_1 = (.448)\frac{1500-21.2}{247} = 2.682$ *and* $J_2 = (.448)\frac{1500-371.1}{247} = 2.047$.

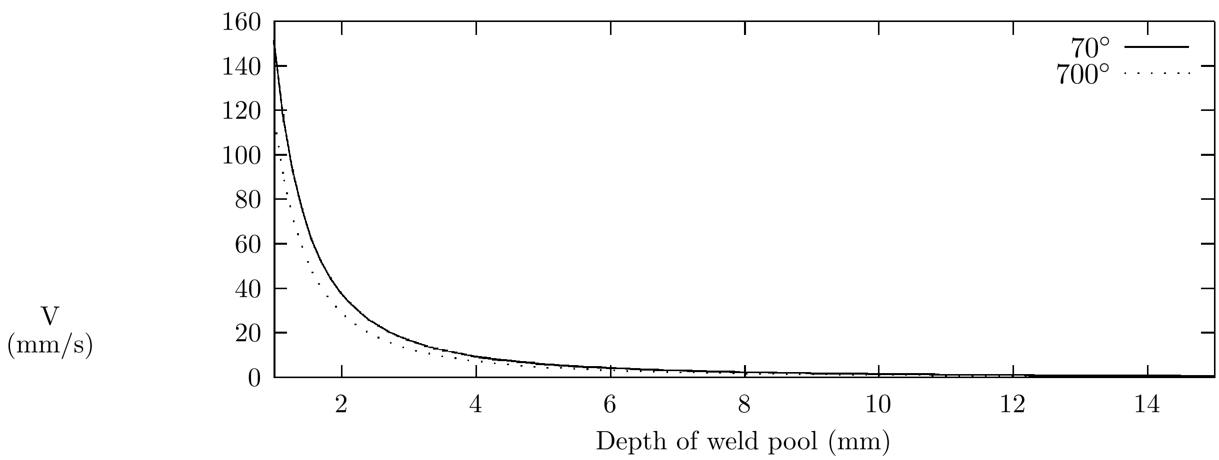

Figure 1: Welding pool depth vs Weld Velocity

(b) Explain what the point of this exercise is, ie., how does this shape how you design a part and the process that you use to make the part when welding is involved.

At pool depths less than 4mm, interaction speed is quite sensitive to the pool depth. Therefore, welding thin sheets will require attention to process. This equation is used as one lower bound on the welding speed. Heat interaction is another consideration.

Problem 4-2. Cutting model

(a) Estimate the rate of production for the part in Figure 1 using the parameters from the following table. You may assume the part enters the cutting process as a rod that is 2.3 inches long at a radius of 1 inch. Plot the amount of power (in hp) required during the turning of this part.

w	Width of Cut	0.100 in
f	Feed Rate	0.020 in/rev
α	Rake angle	10 deg
ω	Spindle speed	400 rev/min
μ_f	Friction specific Energy	0.10 hp/min/in^3
μ_s	Shear specific Energy	0.40 hp/min/in^3
C	Taylor tool constant	350
n	Taylor tool exponent	0.45
t_c	Cost per tool	$20

Four passes will be required, since each pass removes 0.100 *radially. Since each pass is two inches long, each pass requires* $2/.020 = 100$ *revolutions of the lathe, and at* 400*rev/min, each pass therefore requires 15 seconds.*

The part therefore requires 1 minute, so the rate of production is 1*/min.*

Power is equal to specific cutting energy times the material removal rate. In order to estimate the energy lost to other factors, I am multiplying the specific energies by a factor of 1.05. Therefore, we have

Pass	*r (in)*	*MRR (in^3/m)*	*Power (Hp)*
1	*1*	$800\pi(0.02)(.1) = 5.02$	$(0.4 + 0.1)(1.05)(5.02) = 2.64$
2	*0.9*	$720\pi(0.02)(.1) = 4.52$	$(0.4 + 0.1)(1.05)(4.52) = 2.37$
3	*0.8*	$640\pi(0.02)(.1) = 4.01$	$(0.4 + 0.1)(1.05)(4.01) = 2.11$
4	*0.7*	$560\pi(0.02)(.1) = 3.51$	$(0.4 + 0.1)(1.05)(3.51) = 1.84$

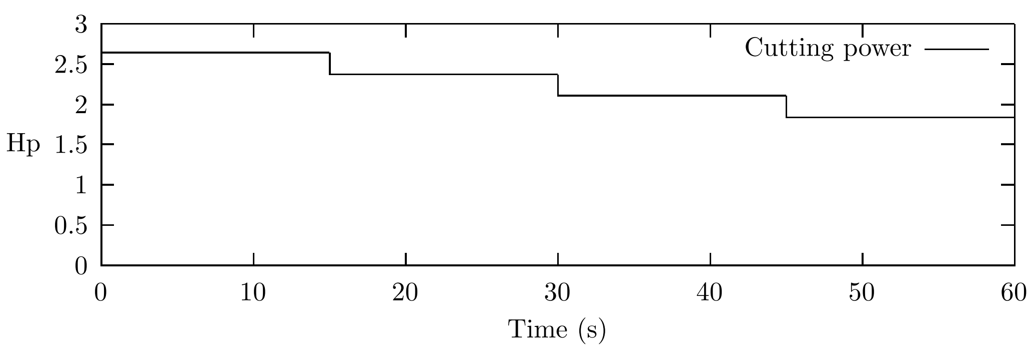

Figure 2: Power vs time for the part.

(b) What is the tooling cost per part as a function of ω? [Note, the velocity changes during the two passes]. Use a spreadsheet to plot the tool cost vs V_c for values from 350 rev/min to 450 rev/min.

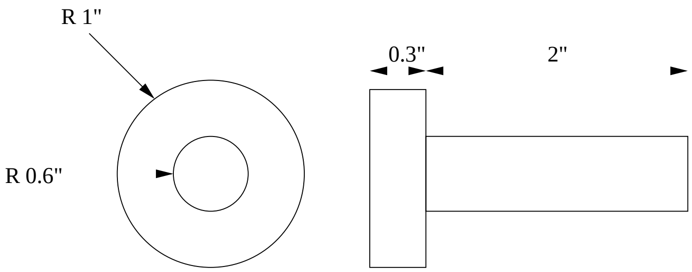

Figure 3: Turned Flange

The way that this problem is currently stated makes it really quite difficult. The Taylor equation gives tool life for a specific speed. However, by fixing ω*, the speed changes throughout the turning process, and so the rate of wear changes. One compromise (approximation) might be to take the geometric mean of the different speeds. The geometric mean of the radii are* $\sqrt{(1)(.9)(.8)(.7)}^4 = 0.8425$*, therefore, the corresponding speed would be* $2\pi * 0.8425 * \omega$*. As* ω *varies from* 350 *to* 450 *rev/minute, the tool life is computed by* $t_{life} = (\frac{C}{v})^{1/n}$ *and this is shown below:*

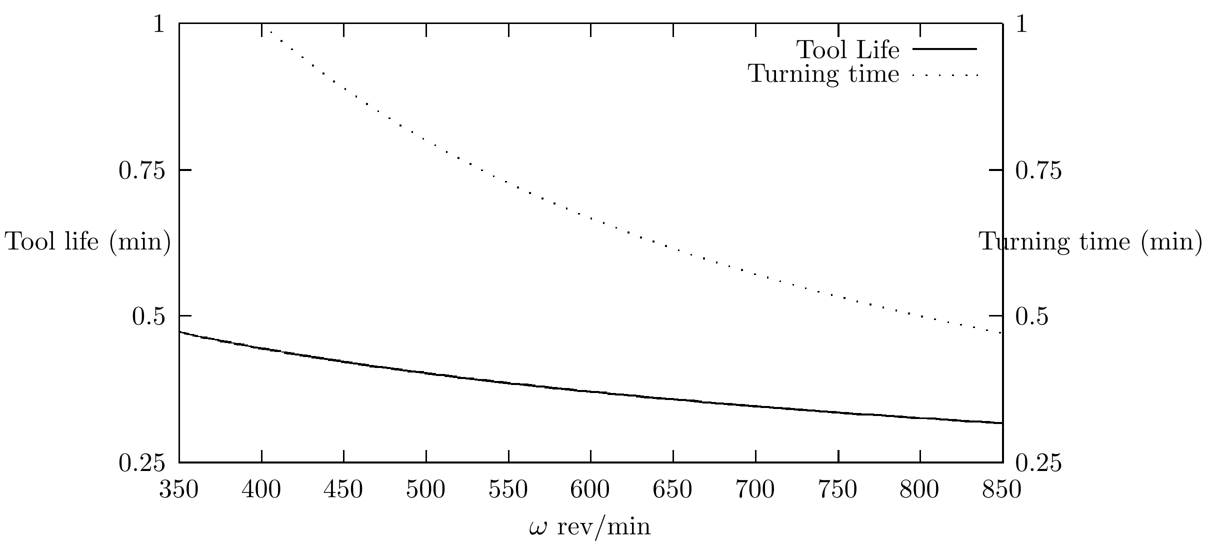

Figure 4: Tool life.

Recall from above that each part requires approximately 400 revolutions to produce. Therefore, at each speed, the part takes $t_{make} = 400/\omega$ *minutes to produce. The number of tools needed per part is therefore* t_{make}/t_{life} *and since each tool costs* 20 *dollars, the tooling cost is simply that figure times twenty. The tooling cost is plotted below:*

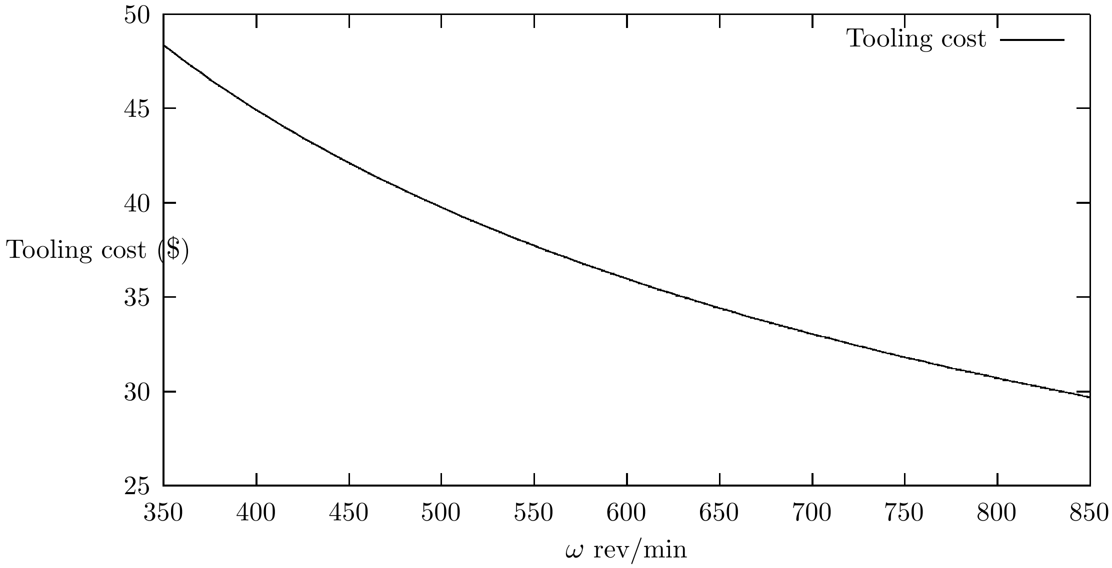

Figure 5: Tooling cost! Expensive part!

Since this computation does not take into consideration the cost of changing tools, it appears that running faster is cheaper since the amount of time saved in making the part by using a higher spindle speed overwhelms the extra cost of reducing tool life– the tool constants are such that the tool life degrades very slowly.