JASON MEYER
MECHANICAL ENGINEER /// DANTE SOLUTIONS

A furnace heating investigation with HTP Sim

Testing the rule of thumb on furnace heating times

INTRODUCTION

For generations, heat treaters have used a simple rule of thumb to estimate how long a part needs to soak in a furnace before it reaches temperature: Heating a cold part placed in a hot furnace takes about one hour per inch of section thickness to reach temperature.

Like most good rules of thumb, it survives because it is easy to remember, easy to apply on the shop floor, and, historically, safe. A planner can design a furnace cycle from a print in seconds, without a heat transfer background or access to simulation software, and the number has enough built-in margin that it rarely leads to an underheated part. However, this factor of safety could be too conservative.

Overheated parts have an additional concern for excessive grain growth if the temperature is too high or if the heating time is too long. As furnace and cycle times become more important for throughput, it is worth asking whether an hour per inch is leaving time, and money, on the table.

To find out how much margin is really built into the number, a modeling investigation was performed using HTP Sim to test the validity of the rule of thumb for furnace heating times.

CASE STUDY

This investigation uses a simplified, 1D profile, representation of a sufficiently long cylinder bar geometry, where end-cooling effects are considered insignificant. The material of the bar was 4140 steel in the annealed condition. Convection was applied at the surface using a general heat transfer coefficient, derived from furnace trials and thermocouple data, of 50 W/(m^2·K) at 20°C, increasing linearly to 120 W/(m^2·K) at 1,000°C. This value is interpolated, and applied, based on the instantaneous surface temperature during heating. Cylinders ranging from one inch up to 12 inches in section thickness were modeled to see how time to temperature scales with size.

Two heating schedules were compared. The first, a straight heating profile, brought each cylinder directly from room temperature to an 850°C soak. The second, a stepped heating schedule, held the part at an intermediate 700°C step before ramping to the same 850°C soak, a practice commonly used to limit distortion by reducing thermal gradients before the austenite transformation. For the stepped models, total heating time was calculated as the time to first reach 700°C plus the additional time to reach the 850°C soak temperature, both within 10°C.

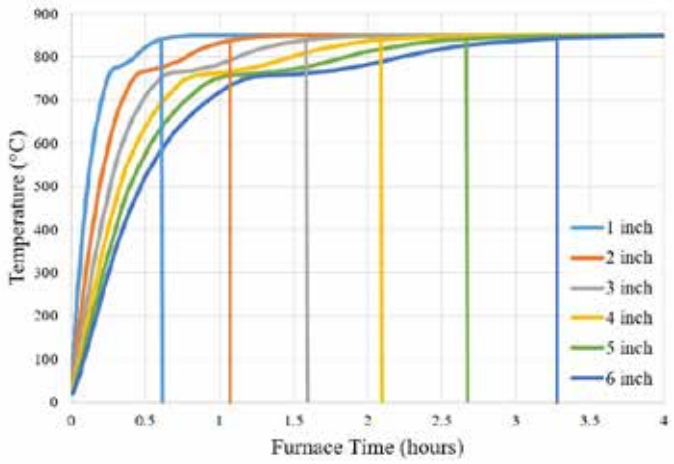

Figure 1: Simulated Time-Temperature histories for cylinders ranging from one inch to 6 inches with a straight-heating profile.

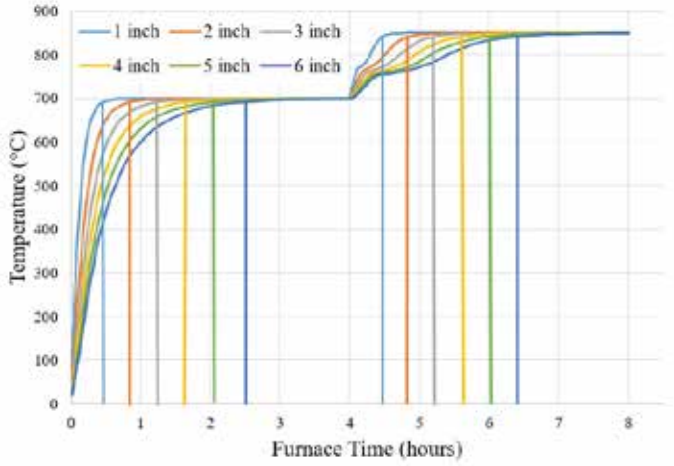

Figure 2: Simulated Time-Temperature histories for cylinders ranging from one inch to 6 inches with a stepped-heating profile.

Section Thickness	1 inch	2 inch	3 inch	4 inch	5 inch	6 inch	12 inch
Straight Heating (hr)	0.643	1.149	1.669	2.213	2.711	3.336	7.041
Stepped Heating (hr)	0.926	1.659	2.424	3.222	3.898	4.916	10.037
Difference (%)	36.1	36.3	36.9	37.1	35.9	38.3	35.1

Table 1: Simulated straight and stepped heating times, in seconds, by section thickness, with the percent time increase of the preheat step.

RESULTS

Figures 1 and 2 show the time-temperature histories of a point in the core of the cylinder for section thickness ranging from one to 6 inches, and vertical lines showing the minimum time to reach within 10°C of the target temperature. The histories show a steady ramp in temperature as the parts heat up, with a slight dip in temperature when the endothermic transformation to austenite occurs. On average, the straight heating profile added about 0.6 hours, about 35 minutes, per

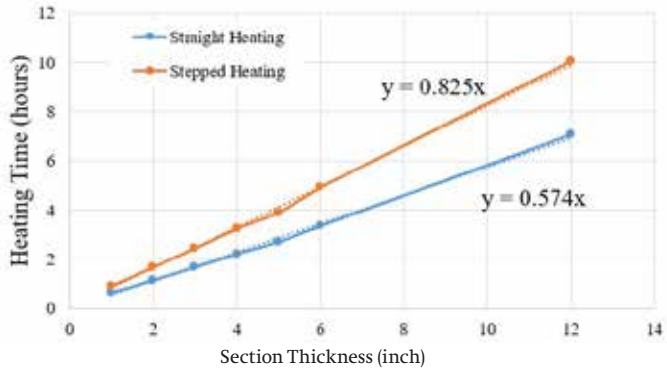

Figure 3: Simulated heating times vs. section thickness for cylinders ranging from one inch to 12 inches for both the straight and stepped heating profiles.

inch of section thickness, while the cumulative time for the stepped-heating models added about 0.8 hours, about 50 minutes, per inch of section thickness. The results of both models hint at a linear relationship for heating times vs. section thickness. To further validate this linearity, a model with a 12-inch section thickness was executed and a heating time vs. section thickness plot was generated, shown in Figure 3. Trendlines show a linear relationship, with the fit equation displayed on the plot for each condition.

Table 1 shows the simulated heating times for the straight heating and stepped heating profiles by section thickness, and the percent difference between the two models. Overall, the preheating step increased heating time compared to the straight-heating profile, with an overall increase of 35 percent to 38 percent, regardless of section thickness. Comparing these values to the rule of thumb of one hour per inch, the simulated straight heating time is only roughly 60 percent of that figure, and the stepped heating time is about 83 percent of the rule of thumb time.

CONCLUSIONS

The modeling shows that the one-hour-per-inch rule of thumb is conservative for cylindrical sections heated by convection under the heat-transfer profile shown, for both straight and stepped heating schedules. It's also worth noting that the geometry used in this investigation is itself conservative, since a 1D centerline model does not capture the additional heat transfer that would occur through the end faces of a real, finite-length cylinder. A physical part would therefore be expected to reach temperature somewhat faster than predicted here, which means the true margin built into the rule of thumb is likely even greater than these results suggest.

No reason to get heated, none of this makes the rule of thumb wrong. As a quick, geometric estimate it remains a reasonable starting point, particularly for parts with a low surface-area-to-volume ratio. For shops looking to tighten cycle times, better use furnace capacity, or avoid unnecessary grain growth, process modeling offers a way to right-size heating times to the actual part and furnace conditions rather than defaulting to a decades-old rule of thumb built for a very different set of assumptions.

ABOUT THE AUTHOR

Jason Meyer joined DANTE Solutions full time in May 2021 after receiving his Master's degree in mechanical engineering from Cleveland State University. His main responsibilities include marketing efforts, project work, and support and training services for the DANTE software package and the DANTE utility tools. Contact him at jason.meyer@dante-solutions.com.