



Physics

Basic Thermodynamics

Steel Manufacturing

Stem Labs

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Objectives

In this simulation students will be able to understand basic thermodynamics calculations and their application to the production of steel alloys.

Academic Content

- Heat Transfer
- Latent Heat of Fusion
- Latent heat of Vaporization
- Dilatation of Metals

Introduction

Steel manufacturing involves a wide range of engineering and scientific disciplines. To manufacture a specific steel alloy with special properties engineers and scientist must carefully design the right manufacturing process. This process must include the right casting temperatures, the cooling and shaping process, and the chemical composition of the alloy.

One of the most common steel products manufactured by steel companies are steel rolls which are made by flattening a steel plate into the right thickness and then rolling it. **Fig1**

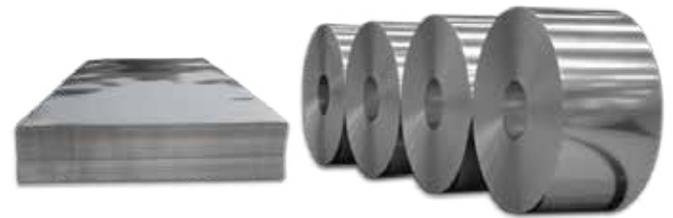


Fig 1 4 Steel Rolls. This steel product is made by flattening and shaping a large steel plate in several shaping stations.



Fig 2 PNX Labs Steel Shaping Rolls. To manufacture the steel alloy into the right shape companies make use of powerful machinery to apply hundreds of tons of pressure to the metal while it is at high temperatures.

The Process

Depending on the shape and properties of the final product engineers design different production processes. For simple products which require a simple formation process like steel rolls the process is usually the following:

- 1.- Pre-heating (usually at 900 -1,200 C)
- 2.- Cleaning.
- 3.- Shaping
- 4.- Cooling and cleaning
- 5.- Rolling

The Science

Heating the Alloy: The process usually starts by heating the prepared alloy plates in electric or gas furnaces. The amount of heat in KJ or MJ that has to be applied to the furnace depends on the chemical composition of the alloy. For calculating the amount of heat to be applied per Kg or Ton of a specific element in the alloy's composition we make use of the following equation **(1)**:

$$(1) E = (m)(T_f - T_i)(C_p) + (m)(L_f)$$

Where **(m)** is the mass of the element, **(C_p)** is the heat capacity, **(T_f and T_i)** are the final and initial temperatures, and **(L_f)** is the latent heat of fusion.

Latent Heat of Fusion: The latent heat of fusion is the amount of energy per unit of mass that must be applied to a substance to change its state from solid to liquid at a constant temperature and pressure. Note that if we want to heat a substance to a temperature below the melting point we don't need to include the latent heat of fusion and therefore the energy required is:

$$(2) E = (m)(T_f - T_i)(C_p)$$

Latent Heat of Vaporization: The latent heat of vaporization is the amount of energy per unit of mass that must be applied to a substance to change its current state to a gas at a constant temperature and pressure. Note that if we want to heat a substance to a temperature below this point we don't need to include the latent heat of vaporization **(3)**.

$$(3) E = (m)(T_f - T_i) + (m)(H_v)$$

Where **(m)** is the mass of the substance, **(T_f and T_i)** are the final and initial temperatures, and **(H_v)** is the latent heat of vaporization.

Cooling the Alloy: At several stages of the manufacturing process, the alloy must be cooled by using water. Note that the energy required to heat substance is the same energy required to cool it in an ideal state.

Heat Transfer: When cooling the alloy, energy is transferred to the cooling water. The amount of water required to cool the alloy will depend on the amount of energy that has to be absorbed from the alloy, the initial temperature of the water. Note that the water can only absorb heat until it reaches evaporation therefore only a fixed ΔT can be used.

Thermal Expansion: When the alloy is heated in the furnace, thermal expansion occurs which is the property of a substance to change its shape in response to a change in temperature. As the alloy is cooled its volume decreases. This process can be modeled with the following equation (4):

$$(4) L = L_i (1 + \Delta T(\alpha))$$

Where (**L_i**) is the initial length of the material, (**ΔT**) is the change in temperature, and (**α**) the coefficient of thermal expansion.

Special Considerations

For the purpose of this simulation we will consider a **Heat Transfer Efficiency of 100%**. The **initial water temperature is 0 C** and the **initial alloy temperature is 40 C**.

In a real case scenario efficiencies are lower due to ambient conditions and several physical phenomena. Nevertheless all the equations mentioned above form the basis of all the industrial control techniques employed to achieve the highest efficiency possible.

Properties Table

	Lf KJ/Kg	Tm C	Cp(KJ/kg*K)	Density (Ton/m ³)	α (m*K)
Carbon	57.59	3555	0.71	2.3	$7 \cdot 10^{-6}$
Chromium	331	1907	0.449	7.9	$5 \cdot 10^{-6}$
Iron	272	1538	0.45	7.7	$1 \cdot 10^{-6}$
Manganese	268	1246	0.479	7.3	$2.2 \cdot 10^{-5}$
Molybdenum	289	2623	0.277	10.2	$5 \cdot 10^{-6}$
Nickel	297	1455	0.5	8.9	$13 \cdot 10^{-6}$
Phosphorus	21.1	44	0.769	1.83	$1 \cdot 10^{-6}$
Silicon	1926	1414	0.711	2.8	$3 \cdot 10^{-6}$
Sulfur	53.96	115	0.73	1.96	$1 \cdot 10^{-6}$

*Tm = Melting Temperature

* Heat Capacity of Water 4.20 KJ/(Kg *K)

* Latent Heat of Vaporization of Water 2260 KJ/Kg

Operation

The operation of this steel manufacturing facility illustrates a very simple process. Students will be required to make several calculations in order to input the physical variables of the process and simulate the production of the desired alloy. Instructions are described in the following pages.



Fig 3 This is the control room for the steel manufacturing, here students will input all the operation parameters to simulate the production of a specified alloy appointed by the professor. At the bottom of the stairs there is a blue circle which will teleport the student to the control room.

Fig 4. Inside the control room, you will find the control stations which is where students will input the process variables. The control station has 4 screens which illustrate:

1. The materials input and heat of the furnace
2. The cooling parameters
3. The length specifications
4. Process warnings and errors.



Fig 5 This is the materials and furnace control station. Here is where students will input in increments of 100kg the amount of KG of each element to be added to form the alloy. Students will then specify the temperature the material must reach in order to be ready to enter the production process. By considering the heat capacity and the latent heat of fusion of the elements in the alloy, students will be required to calculate the amount of energy to be added to the furnace to reach the desired temperature. Once the input parameters are ready, press the red button and move to the next station.



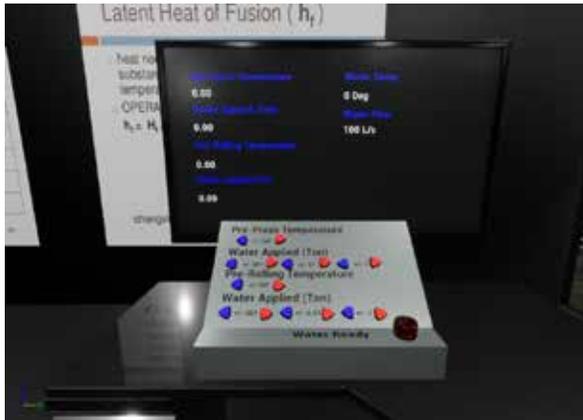


Fig 6 This is the cooling station. In this station students will specify the pre-press and pre-rolling temperatures of the alloy. Based on those temperatures, the latent heat of evaporation of water and the thermal properties of the alloy, students will have to calculate the amount of water to cool down the material to the specified temperatures. Once the cooling parameters have been specified, press the red button and move to the next station.

Fig 7 In the final control station, students will select the desired length of the material once it reaches a temperature of 40 deg C. By considering coefficient of dilatation for the elements in the alloy, students will have to calculate the initial length of the material when its on the furnace to obtain the final length specified. The computer will calculate the length of the material at various stages and will also output the current station of the process. Once the length parameters have been specified, press the red button and move to the next station.

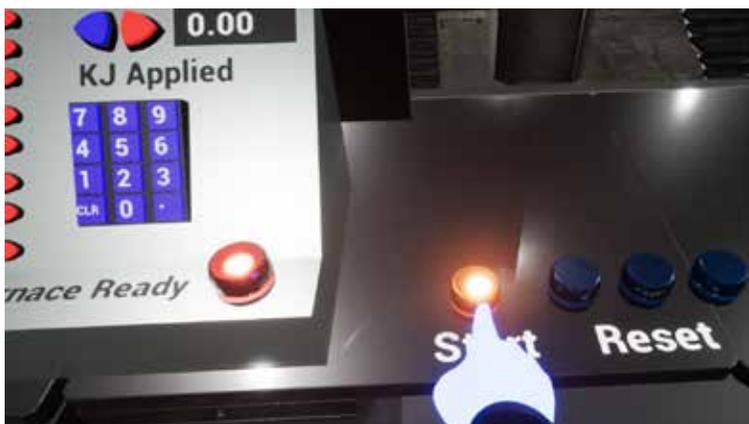
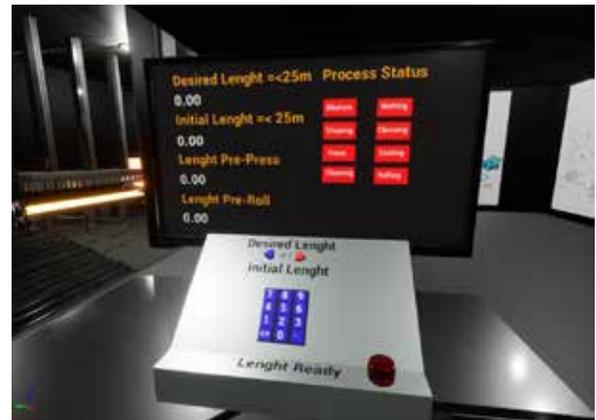


Fig 8 Once all the parameters of the process have been selected and all the Ready buttons have been turned on, we can press the Start button. Walk outside of the control room to visualize each step of the process until the alloy material has been rolled. The computer will let you know at the end of the simulation if the production process was successful, if not return to the control room and check the process error screen to correct your calculations. Before correcting the calculations and selecting the new parameters, press the 3 blue reset buttons to reset the simulation and then input all the parameters again.

Controllers



A or X

- Hold To Select Teleport Destination
- Release to teleport

Grip L or R

- Point Index Finger



Tip: While Holding A or X to select teleport destination, rotate your forearm to change the orientation of view when teleporting.



Fig 10 When pressing buttons and switches, hold Grip L or R depending on which hand you will use and then press the button with the index finger. You will hear a click which means that the button was pressed successfully.

Fig 9 When teleporting hold A or B to select the destination and then rotate your forearm to change the orientation view when teleporting.

