Rolling Manufacturing Process: Simulation and Cost Analysis

Juan Martínez Alvez
Advisor: Dr. Jeannette Santos
Department of General Engineering
University of Puerto Rico-Mayaguez Campus

Abstract

Hot and cold rolling are methods for fabricating long metal sheets and plates. This work presents a rolling simulation developed in Visual Basic. The simulation allows the user to supply some basic information, to change five parameters, and finding out how many passes i.e. how many times does the plate go through the roll, have to be used for a particular situation. The power consumption of the process is also calculated. This is the first version and the model was kept as simple as possible. However, this simulation can be used for cost analysis, process planing and for the purpose of teaching simple situations.

1. Introduction

The hot and cold rolling is an important manufacturing process used in the metallurgical industry. The flat rolling process, Figure 1, reduces the thickness of a uniform cross section area of a plate or a sheet. A simulation was developed in Visual Basic 5 and allows an interactive environment with the user. Cost analysis and process parameters such as temp and roll diameter size are studied.

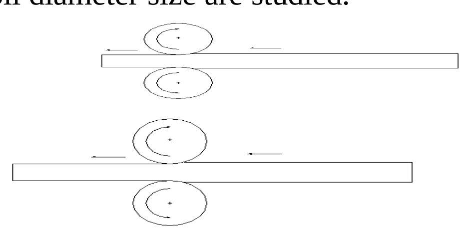

Figure 1 Rolling Manufacturing Process

The user gives conditions such as initial and final thickness, shown in Figure 2. Several parameters such the material, temperature, roll diameter, roll velocity, and how the process is performed with constant draft or constant reduction can be changed in the simulation. The selection is restricted by the options presented in it. The results are shown as the power consumption and the number of passes needed for the particular situation. Figure 2 shows a simulation run.

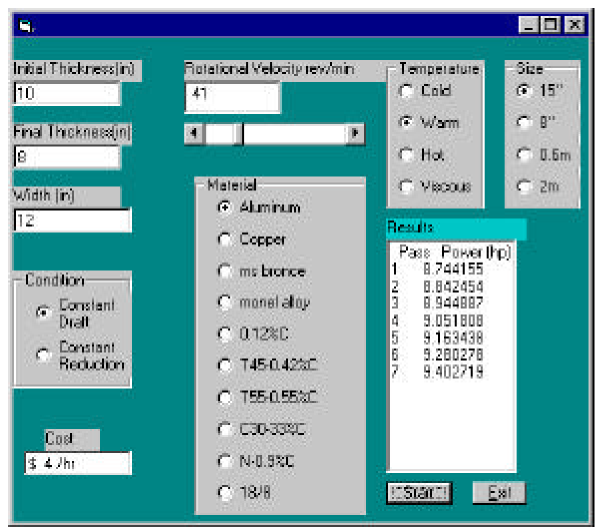

Figure 2 A Run of the Rolling Simulation

This is a fast and easy way to know about the behavior of the process and making decisions from its results. The simulation predicts the company energy expenses, the economic viability and the number of rolls used. Determining the number of passes, the production plant can be designed because the number of passes is equal to the roll in series.

The limitations of the simulation are

1. Only four roll sizes can be used.

2. Only a small number of different materials can be specified.
3. The temperature does not take in consideration the recrystallization temperature of the material.

Most of these limitations are due to the lack of information about the value of certain parameters. As for many other simulations, the principal limitation is the unknown relationship among the variables that fully describe the system under study.

In section 2 the available options in the simulation are presented. In section 3 the equations used for the simulation are given, a detailed explanation of them can be found elsewhere (1, 3).

2. Available Options in the Simulation

2.1 Calculations Option

The simulation has two options in the way the calculations can be performed. The number of passes, n, will be the number of times the material or plate needs to go through the roll to obtain the final thickness. The plate will have an initial thickness of t_0 and a final thickness of t_f.

- Draft is defined as the thickness variations in a difference expression:
  $$d = t_0 - t_f$$
- Reduction is one way to express the thickness variation, but as a ratio:

$$r = \frac{d}{t_0}$$

The two ways to perform the calculations are using constant reduction or constant draft. Both affect the number of passes, n, as shown below.

<u>The Constant Reduction</u>

The general definition that has been given for reduction for any of the step (n) is:

$$r_n = \frac{d_n}{t_{n-1}} = \frac{t_{n-1} - t_n}{t_{n-1}}$$

Where: $r = r_1 = r_2 = \cdots = r_n$

The mathematical iteration to obtain a specific thickness for any step is:

$$t_1 = t_0\,(1 - r)$$

$$t_2 = t_1\,(1 - r) = t_0\,(1 - r)^2$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$t_n = t_{n-1}(1 - r) = t_0 (1 - r)^n$$

The number of steps to obtain the final thickness at constant reduction is:

$$n = \frac{\ln\left(\dfrac{t_n}{t_0}\right)}{\ln\left(1 - r\right)}$$

To obtain the minimum possible steps let
$r = r_{max}$, r_{max} is defined in section 3.

Moreover, the draft in each step is expressed as:

$$d_n = t_{n-1} - t_{n-1}\left(\frac{t_n}{t_0}\right)^{1/n}$$

<u>The Constant Draft</u>

Using the definition of draft

$$d_n = t_{n-1} - t_n$$

For constant draft:

$$d = d_0 = d_1 = d_2 = \cdots = d_n$$

$$r_0\,t_0 = r_1\,t_1 = r_2\,t_2 = \cdots = r_n\,t_n$$

$$t_0 - t_1 = t_1 - t_2 = t_2 - t_3 = \cdots = t_{n-1} - t_n$$

$$\therefore$$

$$d = t_0 - t_1 = t_0 - \frac{r_0}{r_1} t_0$$

$$= t_0\left(1 - \frac{r_0}{{}_1}\right) = t_1\left(1 - \frac{r_1}{{}_2}\right) = \cdots = t_{n-1}\left(1 - \frac{r_{n-1}}{r_n}\right)$$

The above can be expressed as

$$r_0\,r_1 = r_1 - r_0$$

$$r_1\,r_2 = r_2 - r_1$$

$$\vdots \qquad \vdots$$

$$r_{n-1}\,r_n = r_n - r_{n-1}$$

If ($r_0 r_1 = r_1 - r_0$) then $\quad r_1 = \frac{r_0}{1-r_0}$

If ($r_1 r_2 = r_2 - r_1$) then $\; r_2 = \frac{r_1}{1-r_1} = \frac{r_0}{1-2r_0}$

$$\vdots \qquad\qquad \vdots \qquad\quad \vdots$$

$$r_{n-1} r_n = r_n - r_{n-1} \qquad r_n = \frac{r_{n-1}}{1-r_{n-1}} = \frac{r_0}{1-n r_0}$$

The expression for n at constant draft is:

$$n = \frac{r_n - r_0}{r_0 r_n} = \frac{\left(\frac{t_0}{t_n} - 1\right)}{r_0 \left(\frac{t_0}{t_n}\right)} = \frac{t_0 - t_n}{r_0 t_0} = \frac{t_0 - t_n}{d}$$

To obtain the minimum possible steps let $d = d_{max}$, d_{max} is defined in section 3.

Both expressions for n are used in the simulation, giving the options to the user.

2.2 Materials Option[1]

In order to implement the simulation several materials constants were needed such as the average flow stress constants K and m as presented in Table 1. The description for these constants and the equations used can be found elsewhere (1,3).

Table 1 Material constants

Material	K	m
Aluminum	19.1	0.38
Cu	64.5	0.55
Ms (brass)	116	0.76
Monel alloy	152.4	0.52
0.12% C	66	0.248
T45-0.42%C	115.7	0.22
T55-0.55%C	167.5	0.325
C30-.33%C	103.8	0.255
N-0.9%C	148	0.27
18/8	219.5	0.87

[1] K,m are the average flow stress constants (MPa)

2.3 Temperatures Option

The friction coefficient (μ) is function of the working temperature, the material, and the lubrication.

$$\mu = f(\text{Temp, Material, lubrication})$$

For this simulation it is assumed that temperature is the only factor that affect the friction coefficient. Using the following data

- Cold: $\mu = 0.1$

T_{cold} is below the recrystallization temperature of the material.

- Warm: $\mu = 0.2$

T_{warm} is about the recrystallization temperature of the material

- Hot: $\mu = 0.4$

T_{hot} is above the recrystallization temperature of the material.

- Sticking: $\mu = 0.7$

2.4 Diameters Option

Four different roll diameters are given as options.

- $d_1 = 15$ in
- $d_2 = 8$ in
- $d_3 = 0.6$ m
- $d_4 = 2.0$ m

3 Equations used during the implementation of the Rolling Simulation

3.1 Parameters

Before any calculation the following expressions are used to find out the maximum draft or reduction that can be performed on the material for a given roll size and temperature.

- The maximum possible draft.

$$d_{max} = m^2 \cdot R$$

where:

R is the roll radius

- The maximum possible reduction. $r_{max\,n} = \frac{d_{max}}{t_{n-1}}$

3.2 Common formulas (different interpretation)

- Contact Length $L_n = \sqrt{(R \cdot (t_{n-1} - t_n))}$
- True strain: $e_n = \ln \frac{t_{n-1}}{t_n}$
- Average flow stress $Y_{fn} = \frac{K \cdot e_n^m}{1+m}$

  where:

  k ≠ m

  when k = m the material form necking
- Rolling force: $F_{total} = w \cdot \sum_{i=1}^{n} (L_i \cdot Y_{f\,i}) = w \cdot \sum_{i=1}^{n} (L_i \cdot \frac{K \cdot e_i^m}{1+m})$

  where:

  w is the width of the plate or sheet
- Rolling power

  $$P_{total} = 2p \; N_{\substack{rotation \\ speed}} \cdot F_{total} \cdot \sum_{i=1}^{n} L_i$$

  where:

  N is the roll rotational speed
- Process cost

  $$\mathrm{Cost} = \mathrm{P}_{\mathrm{total}} \cdot \frac{\$}{kW} \left(or \cdot \frac{\$}{hp} \right)$$

4. Conclusion

A basic simulation of a rolling process has been developed. Providing a user friendly interactive environment with several options. Allowing the user to know the process and the effect of several variables on the results. The simulation can be used for cost analysis, process planing and for teaching simple situations of the flat rolling process.

5. Recommendations

Further improvements can be done to the simulation and here are some of them

- To add more options for roll diameters and materials. An alternative is that the user could input the roll diameter and/or the properties of any given material.
- Validation of the simulation by comparison of the simulation results with the results of an actual industry.
- Finding out an expression for the friction coefficient in terms of temperature, materials, and lubrication. Or at least a better relation for recrystallization temperature. The one used does not used the recrystallization temperature of the material.

6. References

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