Simulation of Symmetric and Asymmetric Shape Rolling Processes

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Abstract*— Steel is still a dominant structural material in use today and will be in the foreseeable future. It is estimated that the rolling process is used in 80-90% of the steel production worldwide. However, there are currently no off-line tools commercially available to predict a priori the microstructure and hence, the mechanical and geometric properties, of a rolled product after the steel has been subjected to the series of operations necessary for obtaining the desired shape. Consequently, attempts to correlate the rolling characteristics with mechanical properties and microstructure in the finished product have been predominantly empirical in nature. These empirical models may at best be valid under conditions that were used to generate the data, i.e. specific mill conditions and/or type of steel, but do not provide a detailed description of parameters throughout the product. Rod and bar customers today are demanding tighter specifications for tolerances on geometric, mechanical and microstructure properties to satisfy the requirements of the products they manufacture. This presents a problem for many rolling mill operators, who are accustomed to meeting stringent requirements on geometric and mechanical properties but not microstructural parameters. In order to determine precise mechanical equipment and processing necessary for optimizing the microstructure, more sophisticated computer models of deformation and microstructure evolution are needed. The coupling of the rolling process simulation with both deformation and microstructure evolution is a capability that is missing in the steel industry - as cited by a Steel Roundtable held in 1998 by the American Iron and Steel Institute (AISI). The goal of this project is to develop an off-line finite element model of hot rolling process to simulate mechanical deformation of rod and bar rolling that can be used by mill engineers in the steel industry and compare the results with experimental data and various empirical models.

Keywords*— *Rolling, Steel, Microstructure, simulate.

I. INTRODUCTION

Product development testing can be carried out off-line via simulations yielding a major reduction in the product development cycle time and expensive on-line testing. Off-line testing can also be carried out even though full-scale facilities do not exist. As basic research, it will provide opportunities for the refinement and validation of current process models of hot rolling steel. The models facilitate us to use advanced technology currently unavailable to companies and also provide opportunities for professional development in a field where little is currently offered. The results of the work will also have future expansion possibilities, including the extension of the capabilities to on-line models to aid in process setup and control in the rolling mill. This work will have a broad impact on the steel industry by providing state-of-practice technology to carry out process and product development that will lead to more competitive products in national and overseas markets.

II. EXPERIMENTAL

The two researche and development objectives consist of the following:

- Thermo-mechanical Deformation Model. Using the commercial finite element code
DEFORM™-3D a three-dimensional thermo-mechanical deformation model is developed to model the multi-stand finishing rolling process under high temperature and high-speed conditions.
- Verification and Validation. Results of the three-dimensional finite element thermo mechanical deformation model are compared to results from the state-of-the-art empirical model and experimental results for a few baseline cases.

Theoretical and empirical rolling models are a valuable alternative in validating full-scale mill testing and verifying the finite element-rolling model. Theoretical and empirical models to predict geometric and deformation parameters are well established for strip and plate rolling, however, forming conditions in rod and bar rolling is three dimensional and the former is two-dimensional. In this chapter the state-of-the-art of theoretical and empirical models for rod and bar roundoval-round rolling will be discussed. The major advantage of these models is their simplicity and fast computational time to obtain a solution. Furthermore, these models are fairly accurate in calculating certain parameters of the rod/bar rolling process and the rolled products. However, these models do not provide detailed information about how a parameter varies throughout the rod/bar length and cross section and in that sense can only yield limited global information. These geometric and deformation models include spread and side free surface, section profile (cross-sectional area), mean effective plastic strain and strain rate, and roll force and torque (power).

1.1 Spread

Spread is defined as the dimension of the deformed stock after rolling in the direction normal to the direction of rolling (perpendicular to paper) as shown in figure. In other words, it measures the increase of width of the stock due to rolling deformation. The side free surface is defined as the region of the stock surface that does not come in to contact with the rolls during the rolling process as signified by the thick line in figure 1.

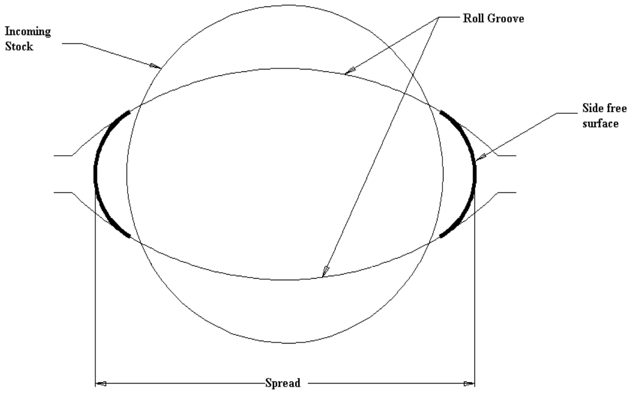


Fig 1.1

1.2 Mean Effective Plastic Strain

The mean effective plastic strain at a rolling stand is defined as the maximum average effective (equivalent) plastic strain of the stock at a given stand during the rod/bar rolling process. Calculation of mean effective plastic strain is extremely important for predicting and controlling the mechanical properties of the rod/bar after rolling because all mathematical models of microstructure evolution requires thermomechanical variables such as mean effective plastic strain, mean effective plastic strain rate and temperature at each rolling stands. Temperature evolution due the mechanical energy converted to heat during the deformation process is also dependent on mean effective plastic strain and mean effective plastic strain rate. Furthermore, mean effective plastic strain rate is in turn a function of mean effective strain and the process time. All of this suggests that the capability of predicting mean plastic strain is essential for controlling the mechanical properties and microstructure of the output rod/bar.

1.3 Roll Force

Calculation of roll force is important because calculation of torque and power in a rolling mill is based on calculation of roll force. Accurate prediction of roll force for grooved rolling is considerably more difficult than predicting the geometry of the stock. There are essentially three problems, present during flat rolling as well but somewhat easy to handle. They are

1) Material’s resistance to deformation, as a function of strain, strain rate and temperature.

2) The ability to calculate the distributions of the strains, strain rates, stress and temperature in the deformation zone.

3) The conditions at the roll metal interface, i.e., the coefficients of friction and heat transfers.

1.4 Strain Rate

The strain rate in rod and bar rolling changes at various stages of deformation. The strain rate is maximum at the entrance to the roll and decreases along the roll bite, finally becoming zero at the outlet. For this reason, it is necessary to introduce an “average” strain rate for a given pass. The average strain rate can be defined as the strain over a time interval.

1.5 Flow Stress

Most of the empirical constitutive equations are based on the thermodynamical concept that flow stress of a material depends on present values and past history of observable variables such as strain, strain rate and temperature.

III. EXPERIMENTAL PROCEDURE

The motivation to work with the simulation tool DEFORM™ is the need to more efficient manufacturing processes and the competitive advantage that you can give to your company by enabling it to:

- Reduce production costs by minimizing manufacturing defects and eliminate potential operating problems with products
- Shorten the time required to bring products to market
- Reduce the costs for tooling
- Eliminate expensive and time-consuming prototype development
- Increase production rates
- Reduce material waste
- Technology development through a greater understanding of the detailed metal flow and thermal characteristics of your processes
- Improve the quality of products and manufacturing processes.

The general approach is to define the geometry and material of the initial workpiece in DEFORM, then sequentially simulate each process that is to be applied to the workpiece.
The recommended sequence for designing a manufacturing process using DEFORM

1. Define your proposed process
2. Final forged part geometry
a. Material
b. Tool progressions
c. Starting workpiece/billet geometry
3. Processing temperatures, reheats, etc.
4. Gather required data
a. Material data

b. Processing condition data
5. Using the DEFORM pre-processor, input the problem definition for the first operation
6. Submit the data for simulation
7. Using the DEFORM post-processor, review the results
8. Repeat the preprocess-simulate-review sequence for each operation in the process
9. If the results are unacceptable, use your engineering experience and judgment to modify the process and repeat the simulation sequence.

3.1. Proposed flowchart for FEM Rolling Model

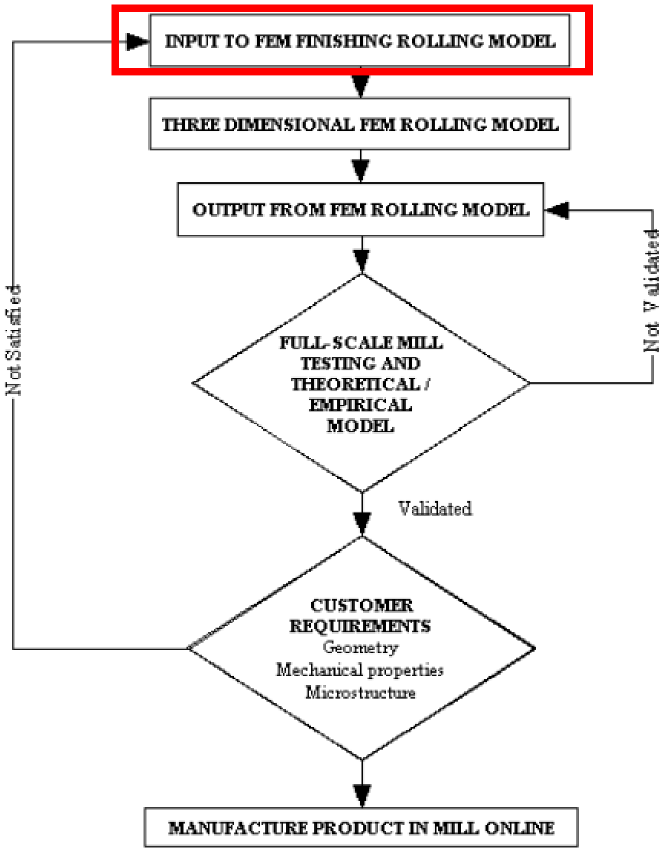


Fig. 3.1

3.1.1 Preprocessing Stage

Finishing Rolling Stands	Incoming Stock
Pass Sequence	Translational Speed
Stand Spacing	Section Profile
Roll Material	Section Length
Roll Diameters	Material
Roll Gaps	Chemical Composition
Roll Grove Geometries	Austenite Grain Size
No-twist Rolling	Temperature
Roll Temperature	Stress-strain-Strain Rate Data
Rotational Speed of Rolls	

Table 3.1.1

3.1.2 Processing or Simulating or Solving Stage

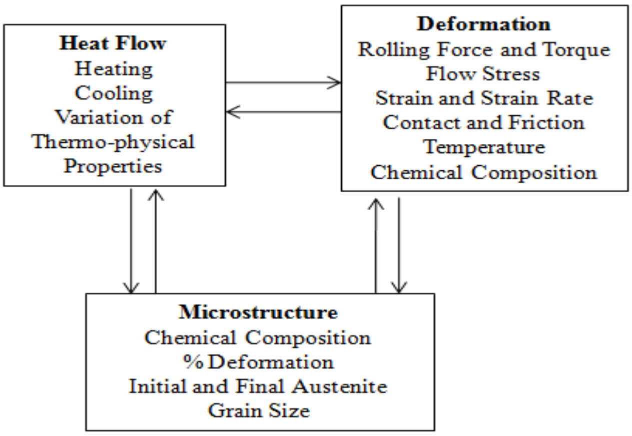


Fig. 3.1.2

3.1.3 Output from FEM Rolling model

Geometry	Mechanical Properties	Microstructure
Section Profile Roundness Tolerance	Force Strain and Strain Rate % Reduction in Area Damage	Grain Size Distribution

3.2. Asymmetric Rolling Process

ASR is associated with a shear deformation in addition to the deformation in plane strain compression during symmetric rolling (SR). In ASR the shear strain results from a difference in velocity between the bottom and top surfaces of the sheet, leading to shear strain in the whole thickness of the sheet in one pass.

The mechanism of texture evolution, occurrence of dynamic recrystallization or ideal position, and their persistence characteristics are not yet well understood. The analysis of these characteristics is helpful in understanding the texture evolution differences between ASR and SR and could help proposing appropriate asymmetric rolling strategies in order to change the final texture and thus modify the mechanical properties of rolled sheets.

In the present investigation asymmetric rolling of Aluminum was carried at different temperatures and the evolution of texture has been studied and compared with conventional (symmetric) rolling under at same temperature and strain rate.

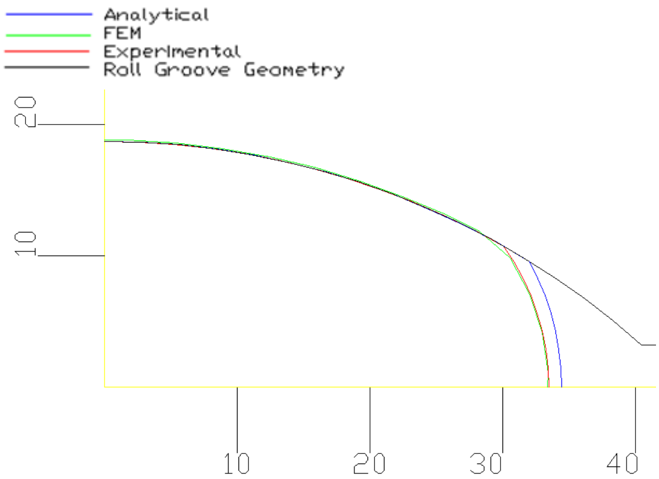
In the ASR process the circumferential velocities of the upper and lower rollers are different, so shear deformation is applied throughout the thickness of the sheet.

Different circumferential velocities can be achieved by three ways:

(i) Rollers with different radii
(ii) Rollers with different angular velocities
(iii) Different lubrication conditions between the sheet and each of the two rollers.

IV. RESULTS AND DISCUSSION

4.1. Calibration and Validation of DEFORM™-3D to carry out Shape Rolling Simulations on it.



	Theoretical	FEM	Experimental
Spread (mm)	68.87	66.71	66.979
(% Error)	-2.746%	+0.403%	--
Cross Sectional Area (mm)	2084.9094	2047.7851	2043.11
(% Error)	-2.005%	-0.228%	--
Rs (mm)	20.30	18.68	18.5
(% Error)	-8.867%	-0.9636%	--

- The software was validated successfully for the calculation of parameters such as Spread, Cross – Sectional area, Roll Force, Strain, Strain Rate and Perimeter of a profile.

- Multi Stand Shape Rolling process was successfully executed, parameters involved were calculated, noted and tabulated.

	ASTM Requirements	**Republic Mill Testing**	**Obtained FEM Values**
Roundness (mm)	0.08	0.06	0.1227
Tolerance (mm)	+/- 0.08	+/- 0.07	+0.0832 -0.0395

4.2 Microstructural behavior of the workpiece with both Symmetric and Asymmetric Rolling processes was studied.

- In general, the workpiece bends towards the surface with lower plastic strain. The plastic strain depends upon the initial thickness.
- The grain size increased with higher rolling temperature for both cases.
- By studying the graphs, it can be confirmed that the difference between the size of bigger and smaller grains reduce in case of ASR. Thus supporting in the microstructure and grain evolution.
- The size of grains is almost equal and diversities are reduced in case of ASR.

		Microstructure size (in μm)	
		SR	**ASR**
At 20°C	Till angle of bite	3.48715	3.65524
	After travelling a distance	3.48778	Neglected
At 250°C	Till angle of bite	3.50455	3.88406
	After travelling a distance	3.31288	5.73849
At 350°C	Till angle of bite	3.49446	3.86827
	After travelling a distance	8.63827	10.6186

4.3 Future Work

- Asymmetric Rolling process is to be studied in a better way and research is still being carried out in this field.
- Roll Force values during Asymmetric Rolling process are to be validated with the Shop Floor results.

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