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Applications of Modeling in Rolling Processes

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Abstract—*Rolling is one of the most important forming processes and roughly 80-90% of steel are produced using rolling. In rolling numerous process parameters can influence the final dimension e.g. draft, roll diameter, rolling speed, temperature, material property and mill elasticity. In structural rolling roll pass design is one the most important parameter which decides the final shape of the product.*

Development of any new profile is difficult as industrial trials are expensive and stoppage in production leads to lower mill utilisation thereby increasing cost of production. Simulation and modeling gives insight of the rolling that can be used for optimization of process. Modification in roll pass, drafting schedule and its effect on final dimension, mill load can be obtained which results in saving in time and investment prior to actual production process. Modeling can also provide information that is not available on the shop floor.

In the present paper, several examples of process modelling applications on different types of rolling process are discussed. It was found from the simulation results that Process modelling can be an effective tool to improve process design, such as modification of rolling defect, reduction in mill load, stress on the rolls and dimensional change during the rolling process.

Keywords*: Rolling simulation, process modelling, optimisation, finite elements.*

1. INTRODUCTION

The concept of Finite Elements (FE) was originally introduced in the 1950's as a method of structural analysis for the aircraft industry [1]. Since then, it has evolved and its wide application covering various classes of metal forming problems such as rolling, forging and allied processes. The FE technique can be used to simulate the metal forming before performing actual experiments, which can reduce the cost and development time for the process design.

Recently most of the products in world are designed using sophisticated computer generated models and finite element analysis (FEA). Conventional design consists of designing the process for various parameters and optimizing these parameters to develop an optimized process. This design procedure is based on the assumption that the design parameters remain constant throughout the process. There are different approaches that designers use to build an acceptable design: (i) experience-based and (ii) deterministic-based.

Experience-based design has been in use for many years. In this process the designer utilizes the experience and knowledge acquired from many years of work in the rolling field to develop a new design. This is a good method to solve problems in existing designs. Since experience-based design requires construction of the dies for every design conceived, it is not a cost-effective method for developing a new design.

Deterministic-based design is a method which was developed to integrate the experience-based design and numerical design processes. This design method involves sophisticated computer-generated models and finite element analysis and is based on sound physical models that are mathematical approximations to represent various process parameters, such as material properties, deformation, phase transformation, roll pass geometry etc.

Extensive work has been done utilizing the above-mentioned methods toward reduction of material waste, roll pass design, die design, energy conservation, lubricant design and heat treatment to improve the quality of the rolled and forged products.

The objective of simulation and modeling is to provide a model which not only generates simulation results, but does so in a way which would be appropriate for use for the Industry. Simulation and modeling can result in saving in time and investment prior to actual production process. Simulation also provides insight into a potential process that can influence the design before problems occur. Modeling can also provide information that is not available on the shop floor.

The aim of FE application to metal forming problems is to predict physical quantities such as stress, strain, velocity, and temperature throughout the deformed solid. This implies that the physical quantities are required at infinite number of points, which defines a problem with infinitely many degrees of freedom. The FE method is based on the idea of discretisation where the deformation zone is divided into a finite number of sub-zones called elements. The elements are connected together at the corners and at selected points at the edges called nodes. For each element, the individual relationship between the applied nodal forces and the resulting nodal variables such as velocity and temperature are calculated and the element stiffness obtained.

2. NECESSITY FOR OFF-LINE ROLLING SIMULATIONS

Steel is a main structural material in use in world today and will be in future also. The tendency towards producing steel in a consistent manner - the finished products with specifically controlled micro-structural and mechanical properties within narrow limits has distinctly intensified while the quality and dimension range have significantly increased in recent years. Furthermore, mill customers, e.g., automotive manufacturers who use the rod and bar stock to produce fasteners, valve springs and other parts, demand even narrower finished-product tolerances. For SAIL to be globally competitive in cost and quality, it must be a leader in innovation and technology.

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 in the world to predict the microstructure and hence, the mechanical and geometric properties, of a long 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. Furthermore, the rolling trials required for empirical studies are very expensive and a process model that can correlate the rolling characteristics with the microstructural parameters could be very beneficial.

Developed off-line software tool intended to significantly improve the process and product development of rolled steel bars and rods. The prediction accuracy of current deformation models (for rolling, extrusion, etc.) on quantitative microstructure-property relationships is limited and is a barrier to major advances in rolling process technology.

3. APPLICATION OF FE METHOD IN ROLLING

The fundamentals of the rigid-viscoplastic FE method and the mathematical formulation are well established. Several authors ([2], [3], [4], [5], [6]) have applied the FE method to determine more detailed information of material flow for shape rolling in the analysis process. Hacquin *et al.* [10] presented a coupled model of thermo-elastoviscoplastic strip deformation and thermo-elastic roll deformation. The model was used to predict profile defects, strain, and stress maps, including residual stresses in hot and cold rolled strips. In rod rolling 3D finite element was used to determine strain distribution for prediction of microstructural material evolution ([7], [8], [9]). Several authors ([10], [11], [12], [13], [14]) have used FE to determine the thickness accuracy of the strip products. These studies calculated the required rolling force, torque, and power in terms of other process parameters such as roll speed, thickness, and temperature. Recently, Kim and Im [15] applied a three-dimensional FE program for analyzing shape rolling processes considering heat transfer based on rigid thermo-viscoplastic approach. round–oval, oval-oval, square–oval, and square–diamond passes were simulated at different friction conditions with and without temperature effects. Three-dimensional (3D) FE based codes enable the modelling of large plastic deformation. The FE modelling technique is reported to be more accurate and it provides detailed information of plastic deformation when compared to classical rolling theories. The FE technique has a considerable advantage to the traditional mathematical approaches because it can calculate most of the parameters characterising the process (forces, stresses, velocities, displacements, temperatures etc) in a single simulation.

FE methods are capable of predicting quite accurate deformation behaviour such as roll contact stresses, rolling load, and rolling torque required for RSD. However, they can be computationally expensive and the time required for a fully converged solution limits its wider application for optimisation problems. Since various design parameters are considered simultaneously, quite often practitioners seems to be content with any solution that appears feasible in light of the computational burden.

4. RECENT MATHEMATICAL MODELING METHODS

In spite of reported model accuracy of the FE methods in metal forming problems there is still an increasing interest to use simplified mathematical formulae for predicting complex metal forming behaviours. There are various reasons why the mathematical approach is still popular in the industry. It is a simplified alternative to the complex FE formulations and it requires less computational efforts. Rudkins and Evans [16] and Lenard *et al.* [17] performed off-line calculations to aid in the finishing of mill setups. In their study they used different formulae to determine the likely rolling loads for a given reduction pattern and compared the results obtained with Finite Element calculations. They concluded that the FE results gives accurate prediction of mill loads while the Sims model [18] slightly under-predicts the values compared to that actual. Joun and Hwang [19] developed an approximate mathematical approach for predicting roll pressure and tangential stress at the roll-strip interface. The authors reported that theoretical predictions agree with FE results and experimental results. Although there was no optimisation study reported in the paper, the authors suggested that the method could be used for optimising rolling parameters.

5. EXAMPLES OF SIMULATION IN METAL WORKING

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5.1 Simulation of Wheel making

Modern railway wheels are manufactured by a multi-stage hot metal forming process consisting of upsetting, forging, punching, rolling, dishing, heat treatment and machining process. Simulation of Wheel making was carried out on the DEFORM software.

Simulation and modeling is mainly used for improvement in existing process, improvement in design of existing tools and tackles, design of new process and products, Simulation and modeling can be used for all the processes in wheel making but are most useful in the field of block reheating, upsetting, forming, rolling, dishing and heat treatment. Apart from these processes simulations can also be carried for casting of ingot for reduction in casting defects. Now a days development and optimization of new design of wheels are mostly carried out by modeling and simulation. Different steps in wheel making process are shown in Fig. .1.

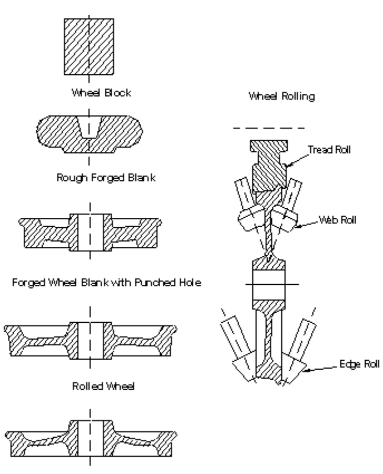


Fig. 1: Different Steps in Wheel Making

Hot forging can be subdivided as heating, forging, heat treatment and cooling process. Before start of simulation job understanding of complete process of manufacturing is of prime importance but identification of process variables are equally important.

If work piece eccentricities and die misalignments are ignored, the early stages in the process can be regarded as axisymmetric. Clearly, in this case a 2D analysis is appropriate. In such instances, run times are relatively small and the key usability issue becomes the ability of the program to run seamlessly without user intervention.

Complete process of wheel making including Upsetting, Forming and rolling was simulated. Simulated results were in close agreement with the actual plant data. This simulation can be used for design of new tools and tackles for improvement in tool life and reduction in defects generation. Simulation and modeling can result in saving in time and investment prior to actual production process. Simulation also provides insight into a potential process that can influence the design before problems occur. Modeling can provide information that is not available on the shop floor.

5.2 Development of off line model of Bar Rolling

Dimensional accuracy and mechanical quality are two major goals required to achieve in process design of bar rolling. These two objectives have been widely sought in the past decade by many researchers. Its importance has been doubled in recent years due to ever increasing competition in steel market. Particularly for improvement in mechanical quality, microstructural change during rolling must be accurately modeled because the mechanical properties are highly dependent on it. Bar and Rod customers are demanding stringent tolerances on dimensional, mechanical and microstructure properties.

Multi stand 32 mm round rolling process was simulated by using DEFORM 3D. Setup for rolling process is shown in Fig. .2. Model was validated by actual shop trials. Using this models information like temperature distribution during rolling, spread of metal, mill loads etc can be obtained at different stages of the process. This model is also useful in predicting effect of change in process variables on final dimension of the stock. This type of model reduces/eliminate costly mill trials for development of new product or process. The simulations would be used to evaluate roller groove geometries, roll gap settings, stand spacing and other parameters for design comparisons. The optimum design of groove profiles and other process parameters is a key factor for effective processing (to get proper dimensions, internal deformation and microstructure distribution) and ensuring that the required as-rolled product properties are achieved according to customer specifications.

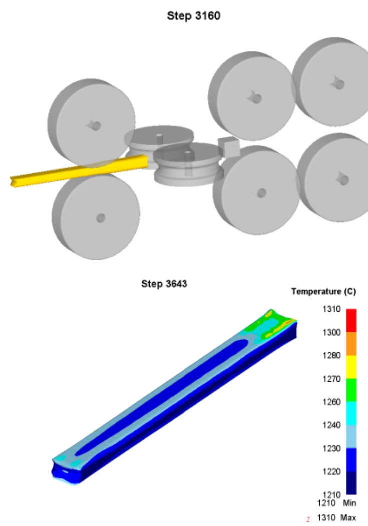


Fig. 2: Rolling Simulation of 32 mm bar rolling

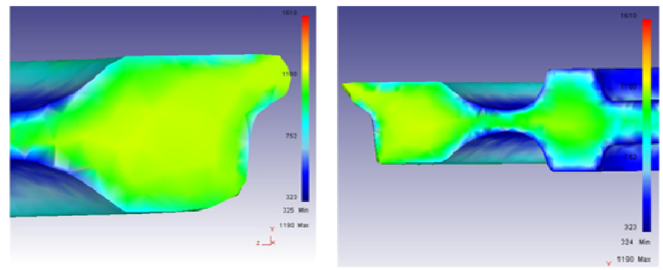
Many more processes of long product rolling are now being modeled for improvement in the process and product. Some of the literatures are showing Microstructure modeling in the field of long product rolling. Similarly modeling of slit rolling, rail wheel interactions, prediction of life cycle of rails etc is carried out for information which are difficult to get otherwise.

5.3 Block weight optimisation of S Profile Wheel

Wheel and Axle Plant, Durgapur Steel Plant produces mainly BG Coach and DLW wheels. Now “S” Profile and EMU wheels are also being produced and supplied to Indian Railways and requirement of these wheels are increasing every year. Block weight requirement of “S” Profile wheel is more than block weight of DLW wheel and only 2 wheels are made from one ingot therefore yield from ingot to wheel is less.

To improve upon yield of “S” Profile wheel from ingot, optimization of block weight was carried out through simulation, so that 3 OK wheels are obtained from one ingot. Process variables considered during for the simulation were initial temperature, weight and geometry of the block, variation in forging press controls, friction in the dies, dwell time at different stages, block positioning in the dies, scales on the block, die velocity and ambient temperature. Simulation was run using different blocks weights and upset heights. Results of modifications in process are shown in Fig. 3. Simulation results were validated at shop floor which showed close agreement with the actual process.

As per rejection pattern of S Profile wheel maximum wash out happens on the tread and Outer diameter of the finished wheels. So for properly filing up of the tread and outer diameter of the wheel upset height was reduced. Upset height was reduced and modification in die profile was carried out to get desired results. Simulation with modified process parameters was carried out to get OK wheel from less block weight.



Before Modification **After Modification**

Fig. 3: Filling of dies

With these modifications 3 OK “S” profile wheels can be made from one ingot. The simulation results for forging operation have good co-relation with the shop floor results having accuracy of more than 95%.

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