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Mini Review

Brief Overview on the Application of Finite Element Method on Flat Rolling Processes

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Abstract

The Finite Element Method (FEM) is a widely used method for the simulation of bulk forming. So far, the contribution of FEM has been significant in the field of flat rolling, making it an established and accurate approach for process simulation. This mini review highlights some of the typical applications of the FEM that have emerged throughout the years of FEM utilization.

Keywords: FEM; Rolling; Simulation

Introduction

Amongst forming, flat rolling processes consist most of the selected methods for all applied technical alloys and materials used in various applications. Flat rolling is a bulk forming process where a metal plate or strip passes through counter rotating rolls and deforms plastically to reduce its thickness. Complicated phenomena take place in the material and the mill during their interaction, which in turn have a significant influence on the quality of the final product. Many tools have been developed through the years that would help the engineers predict and, thus, control the process result. A very prominent and widely used computational tool is FEM. The FEM is a numerical technique that discretizes a complicated system into finite simpler systems (finite elements) and solves partial differential equations to approximate the solution. Considering the cost related to industrial trials, the use of FEM has gained great popularity amongst engineers. Figure 1 shows indicative results that are typically extracted when FEM is applied, such as the stress field during rolling, see Figure 1(a), and the calculated Force diagram, see Figure 1(b), which are usually also validated using industrial and/or laboratory/actual data.

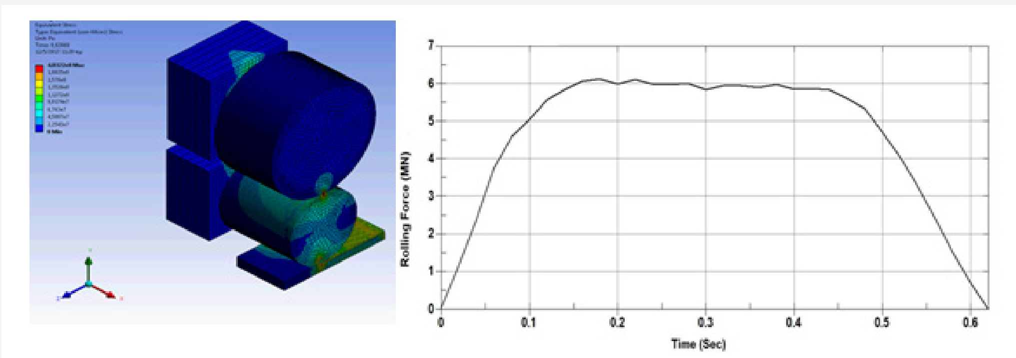

Figure 1: Stress profile in the plate during rolling (a) and Force diagram (b) calculated by FEM.

Various finite element algorithms that are predominantly based on either static implicit or dynamic explicit formulation are available as commercial packages for the simulation of forming processes. The static implicit method can be very efficient under quasi-static conditions such as in forming processes [1-3]. Large time step size and iterative solution of equations until a convergence criterion is fulfilled ensures high accuracy and time efficiency. Nevertheless, highly non-linear problems with nonlinear materials, local instabilities, frictional sliding, variable and complicated contact conditions, etc. are difficult to be managed resulting to high resource requirements and computational cost. In that case, the time-step becomes minimal with more iterations necessary for every time increment in order to achieve convergence, which in many cases is even impossible to obtain whatsoever [4-12].

The dynamic explicit method was introduced as a solution to the problems. The equation of motion is solved by inversion of mass matrix, a much simpler operation comparing to the inversion of the stiffness matrix that is required in the implicit method. The iterative scheme is superseded by very small time increment to ensure stable solution [12-14]. Time increment is only influenced by the Courant–Friedrichs–Lewy condition, which is mesh size and material property dependent, and is not affected by the complexity of the model and non-linearities [11,12,14]. Nevertheless, stability is obtained only when the maximum time increment is lower than a critical value of the smallest transition times for a dilatational wave to cross any element in the mesh. In simulation of rolling, the time increment can become so small that the time required for the solution of the problem might become unrealistic.

Comparison between the two methods for rolling simulation can be found in literature [15-17]. For plate rolling, although similar accuracy can be obtained between the two methods, the explicit method is a more efficient and stable method for 2D problems comparing to the implicit method [15]. However, more recent developments in the implicit solver for forming processes increased the efficiency of the implicit method to an extent that it became more efficient comparing to the explicit method even in 3D rolling models [16]. Nevertheless, when the 3D model becomes more complicated comprising also of elastic work rolls and support rolls, the explicit method becomes once again more efficient comparing to the implicit method [17].

Through the years, the FEM approach has become an established method for the simulation of rolling process. During rolling, high forces develop between the plate and the rolls and, moreover, temperature gradient evolves both in the plate and the rolls. Those phenomena play important role on the final product quality. In addition to the fact that most rolling plants utilize the same equipment for rolling a wide range of materials with various levels of mechanical properties, initial geometry of the plate and final specifications, force and temperature evolution are the fundamental questions that trouble the production engineers during the pass schedule design. Both parameters, including stress and strain profiles, can successfully be computed by the FEM that provides that valuable information even from the early steps [18-32].

Further utilization of the FEM enabled the simulation of various other quality characteristics. A lot of attention has drawn the shape optimization and the flatness improvement. The strip profile (crown) is correlated with the deflection of the roll stack and can be controlled by counter bending the rolls using integrated systems. Information of the crown can originate from FEM calculation and can be incorporated in the pass schedule design [33-41]. The same applies for the optimization edge profile which is significant for the reduction of edge cracks and edge material removal retaining the same equipment [16,42-43]. The crack initiation as well as other undesirable phenomena occurring during rolling such as wear and plate refusal have likewise been studied by FEM [44-46].

Temperature evolution and gradient caused by heat flux from the strip to the roll have also an effect on the process and the material quality. The work rolls temperature state has a direct impact on its instantaneous geometry and, therefore, on the products flatness. Many researchers have focused on the prediction of thermal camber and the methodology for heat extraction through cooling [47-51].

On the other hand, temperature in the material facilitates the beginning of microstructural changes. Many efforts have been made to integrate algorithms in FEM models that consider the metallurgical aspects that cause the material to soften with time via recovery and recrystallization, to harden via phase transformations or precipitation and to alter its texture and anisotropy [52-56].

Conclusion

For practical purposes, this mini report briefly reviewed the most commonly used applications of FEM analysis as emerged throughout the years regarding flat rolling. The FEM not only allowed engineers to better understand the rolling process itself, but also to accurately predict the influence of critical process conditions such as thermal and mechanical interaction, tribological conditions, material properties and related microstructural phenomena on the product's final quality. Therefore, FEM can and is nowadays used as a tool to optimize the rolling process and to reduce the production cost.

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Conflict of Interest

No conflict of interest.

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