DYNAMIC ANALYSIS OF A WORKPIECE DEFORMATION IN THE ROLL BENDING PROCESS BY FEM SIMULATION

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ABSTRACT
High strength steel is widely used in the manufacturing of parts dealing with heavy cyclic loads and corrosive environments. But to obtain accurate final shapes for this type of steel by roll bending process is not easy. And it becomes a hard-to-solve problem when the part to produce is large, thick and unrepeated. In order to analyse the dynamic deformation of the workpiece during the roll bending process, Finite Element Method (FEM)–Ansys/LS-Dyna is introduced to do this research. Various dynamic simulations based on 3D element models are performed to provide better understanding of whole deformation history and distribution of stress-strain of the workpiece during this particular process. The results from FE simulation are then compared with corresponding experiment results from an industrial roll bending machine.

Keywords: FE dynamic simulation, roll bending-process, Nonlinear FEM, Elasto-plastic

1. INTRODUCTION
Roll bending is a continuous forming process where plates, sheets, beams, pipes, and even rolled shapes and extrusions are bent to a desired curvature using forming rolls. With the advantages such as reducing the setting up time and material, lowering the cost in tooling investment and equipment and to achieve high final shape quality, over the years, the roll bending process was one of the fundamental process used in metalworking. Moreover, this process is a manufacturing method that is beginning to be taken into serious consideration by industrials for producing large, thick parts such as the thick conical shape of the crown in a Francis turbine runner.

The description of the basic principle and operation for this process can be found in Kohser (2002) and Couture P. (2004). Bouhelier (1982) gives the formulas for calculating the springback, applied forces and the essential required power. Yang (1988) constructed a simulation model for estimating deformation during the various periods of the roll-bending process. Hua et al (1994-1999) have done a considerable amount of work studying the four-rolls bending process and for understanding the bending mechanism. Based on experiments, they discuss the mechanism of roll-bending process. Analyses of pyramidal three-roll bending process bending can also be found in some publications (Yang (1988), Bassett M. B (1996), Hansen N. E. and Roggendorff S. (1979)), but none of them deals with dynamic analysis of workpiece during the process. The roll bending process on the other hand is a particular bending process where the plate may be assumed as static three points bending, but in the whole process consideration, the deformations of workpiece are dynamic and its single-bending assumption will limit understanding of the bending mechanisms. Therefore, in a more recent article Zeng J., Liu Z., and Champliaud H. (2008) or Feng Z., Champliaud H., Dao.T.M. (2009), or Feng Z., Champliaud H. (2011) developed a 3D simulation model which is based on the elastic-plastic explicit dynamic FEM under the Ansys/LS-Dyna to study the dynamic process of roll plate bending for thick plate conical tubular shape. However, the authors only discuss the deformation of workpiece in the whole process; the distribution of stress-strain leaved in the workpiece of each step of this process has not been studied yet. Hence 3D dynamic FE simulation and dynamic deformation of the workpiece by an asymmetrical roll bending machine will mainly be discussed in this paper.

2. DEFORMATIONS OF WORKPIECE
The axisymetric roll bending model that consists of three rolls of same radius r is used to shape the flat-plate thickness t into a final radius R as shown in Fig1. During the process, the lateral roll is raised up to a specific position to control the diameter of the final shape while the workpiece is fed and driven forward by two rotating bottom and top rolls. By this relationship, dimension of the final shape depends on the position of the rolls, see Eqn. (1)

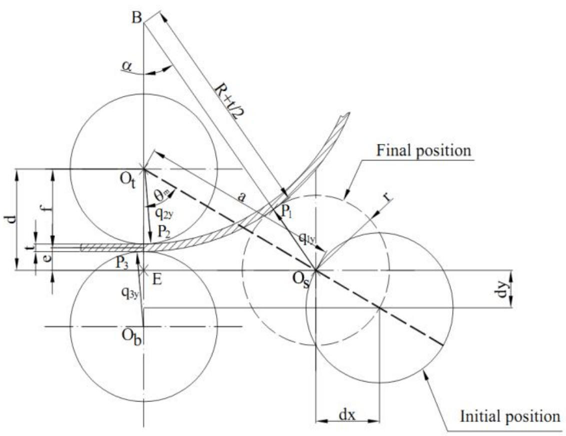


Figure 1: Geometric setup of the asymmetric roll bending process

$$R = \frac{(a^2 + f^2 - (r + t/2)^2 - 2af\cos(\theta_m))/2}{(r + t/2 + f - a\cos(\theta_m))} \quad (1)$$

As seen in Fig. 1, the workpiece can be modeled as a beam under three point bending where the plate between P_1P_3 is restricted by contacts with top roll, bottom roll and lateral roll during continuous roll bending mode. If the lateral roll is raised up to a desirable position where the applied stress in the plate is below the yield stress of material, this plate will recover its original shape when loading is removed. Otherwise, the plate will be plastically deformed. The types of these loadings are shown in Fig.2

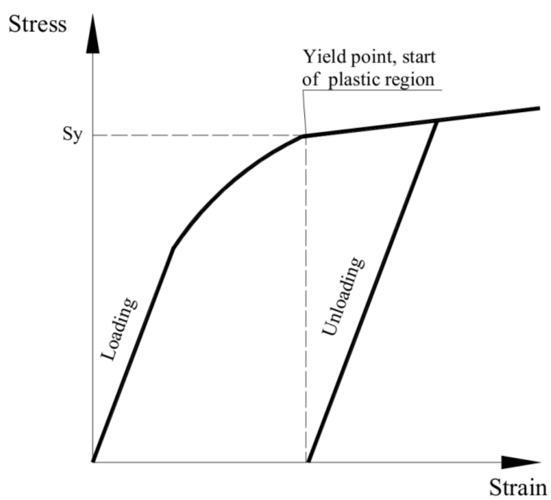


Figure 2: Types of loadings in roll bending process

3. FINITE ELEMENT MODEL AND EXPERIMENTS

In this section, a 3-dimensional numerical FE model of roll bending process described in section 2 was built in the Ansys/ LS-Dyna environment (2011). The FE model consists of four main components: three rolls, and one forming plate which are illustrated in Fig. 3

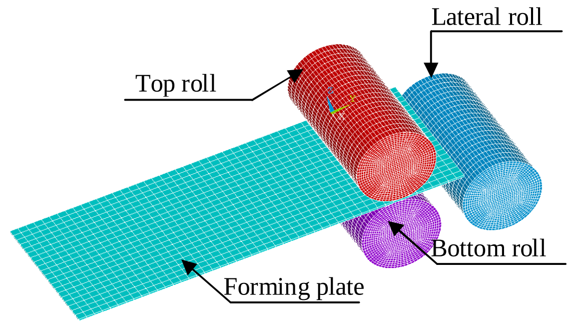


Figure 3: FEM model of roll bending process

The FE simulation involves structural computations for predicting the distribution of stress leaved in workpiece from the initial pass to the final pass of the process. Since the plate thickness is much smaller than its width and the length, this kind of structure is generally modeled with the explicit SHELL163 element of Ansys/LS-Dyna. The rolls are considered as rigid body in comparison with the elasto-plastic deformable plate.

Stainless steel is commonly selected for turbines and hydraulic accessories, so simulation is done with the stainless steel ASTM A743 grade CA-6NM by using the data provided in Zeng J. (2008). In this simulation, bilinear isotropic model (BISO), a material model of Ansys/LS-Dyna that uses two slopes to represent the behavior of material.

The interaction between components is defined by contact surface. In this roll bending process model, the surface of the roll is smaller than the surface of workpiece. Therefore, the automatic node to surface contacts were used to define interaction between rolls and plate. This kind of surface contact is efficient when a smaller surface come into contact with a larger one. There are three main contact surfaces defined between the plate and rolls for our roll bending FE model. The workpiece is driven and deformed to its final shape via these contact surfaces. Besides, two coefficients of friction include static friction and dynamic friction that must be defined for the contact model when defining the contact surface. The values of the two coefficients of friction are available in Zeng J. (2008). For loading condition, in this simulation, the top and the bottom rolls are constrained as rotation and no translation. The lateral roll is constrained as translation and no self-rotation to press the forming plate against the top roll. The plate is not typically constrained, but by the rolls through contacts in this simulation.

For measuring the stress distribution on the plate, a strain gauge, known as a device whose electrical resistance varies in proportion to the amount of strain in the device, is used to record the strain during the bending process. Attached the strain gauge directly to the plate by special glue is shown in Fig.4. Then the plate is fed into machine for bending (Fig.5). The strain gauge will record and export the strain value of plate into a strain recorder when the plate is deformed.

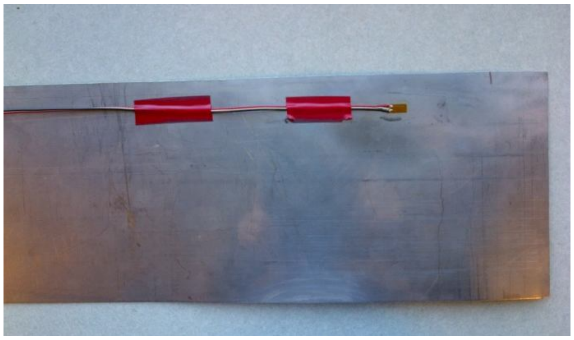


Figure 4: Gluing the strain gauge directly on the plate

From the strain ε read by "The Vishay model P3 strain recorder", the amount of applied stress σ can be computed using the following formula

$$\sigma = E\varepsilon \qquad (2)$$

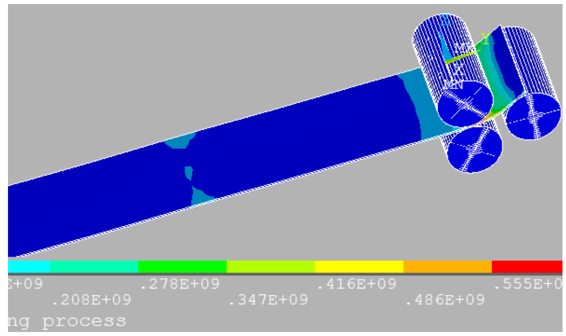
Where E is modulus of elasticity of material

Figure 5: Roll bending process experiment

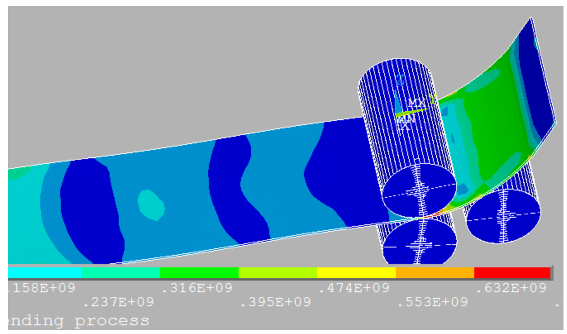
4. RESULTS AND DISCUSSION

The FE model of axissymetric roll bending machine discussed in section 3 is built in the Ansys/ LS-Dyna environment. The main geometrical data taken from the roll bending machine at École de technologie Supérieure (Canada) includes radius of rolls r=100 mm, operating action line angle of lateral rolls $\theta_m = 60^0$ The research accomplished to date on this process is preliminary, but very promising. Finite Element Method is quite successful to simulate the roll bending process.

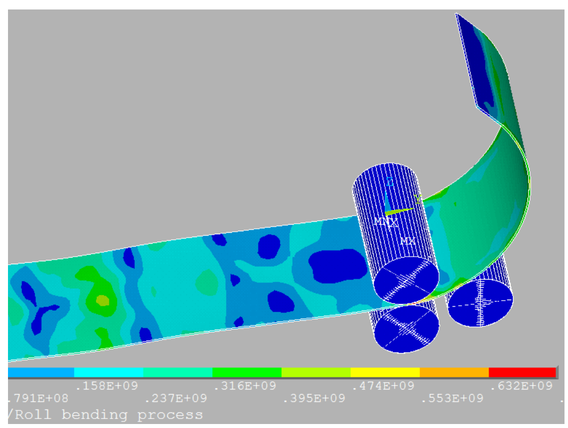
The successive shapes of the forming plate can be plotted at each step of this process as shown in Fig.6.



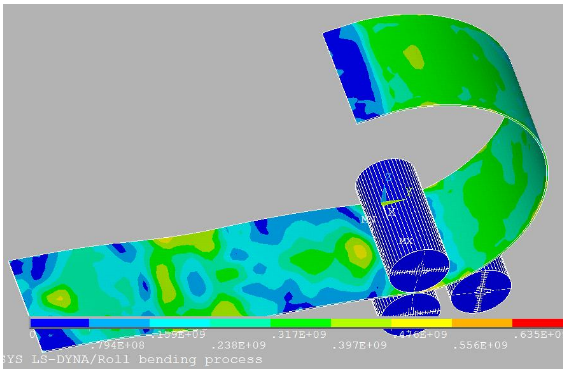
Distribution of stress at the early stage of the process



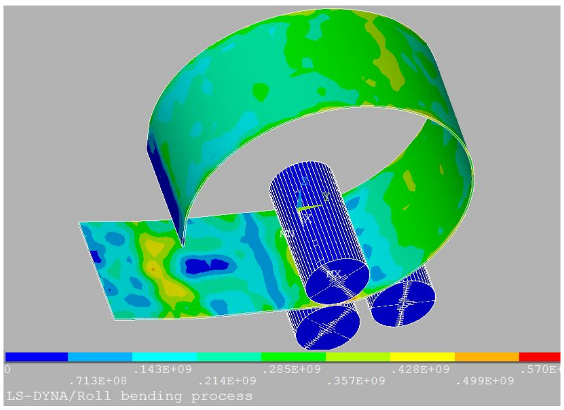
Distribution of stress at 20% of the process



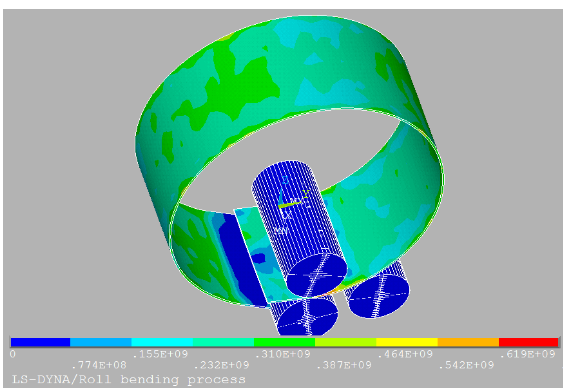
Distribution of stress at 40% of the process



Distribution of stress at 60% of the process



Distribution of stress at 80% of process



Distribution of stress when the process is completed

Figure 6: Shape of workpiece at various steps of the roll bending process

These results are interesting because it assists in establishing and shaping whole working-process in an industrial context. The bending stress results from FE simulation for above different time steps of roll bending process are compared and shown in Fig.7. In the deformation zone P_3P_1, the bending stress increases when the workpieces is fed into the upper and bottom rolls. After getting the maximum value at the contact region between the plate and the top roll, this value will reduce and get minimum value in the contact region between plate and lateral roll. However, as can be observed from Fig.7, the curve of stress distribution at the early stage of this process is different with other stages. The maximum bending stress obtained in the deformation zone at this stage is also higher than the steady bending continuous stages.

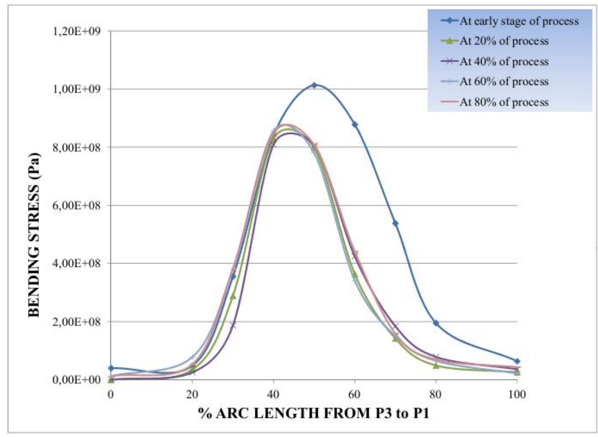


Figure 7: Stress distribution at various steps of the roll bending process

These differences may be explained by changing of contact region between the plate and rolls. The flat workpiece is firstly elastically deformed when the lateral roll is firstly raised up until reaching a desirable position, where the plastic deformation will occurs to get a desirable radius. The bending stress value is dependent on material properties and workpiece process parameters (the plate thickness, bending radius etc.). However, in the steady continuous bending stage, under condition of rotating of rolls and moving towards of workpiece, there may occur losing contact between workpiece and upper and bottom rolls and thus the constraint of the bending system becomes less rigid. The combination of these effects would affect the stress distribution leave in the workpiece.

As mentioned, there are many workpiece characteristics that affect formability of the roll bending process such as the plate thickness, the final shape radius, material properties etc. Among them, plate thickness may have the highest influence. Therefore, it is necessary to understand the influences of this parameter on the stress-strain distribution of workpiece during the roll bending process. Comparisons of FE simulation for roll bending flat plates with thickness of 1.0mm, 1.5mm, 2.0mm, 2.5mm and 3mm into 80mm of final shape radius can be seen in Fig.8. Note that in these simulations, only plate thicknesses are changed while other input material properties and workpieces parameters are identical. The curves of FE simulation results for five different plate thicknesses tend to get the maximum bending stress at the position of 40% of arc length from P_3 to P_1 in the deformation zone (getting start at P_3) as seen in Fig. 8

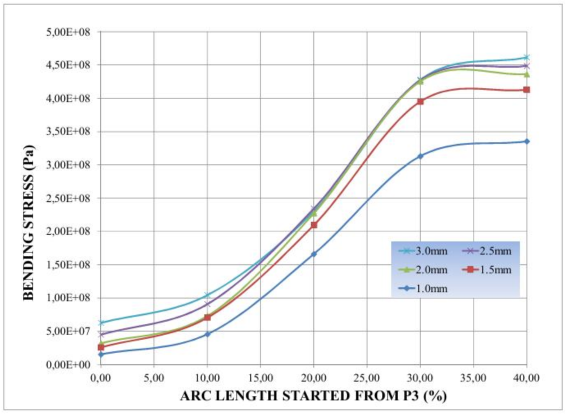


Figure 8: Stress distribution for various plate thicknesses

It can be also observed from Fig. 8 that the bending stress increases quickly when the plate thickness is over 1.0 mm. As expected, the thicker workpiece will get higher stress value. However, as summarized in Fig. 9, the bending stress increases 1.23 times, 1.30 times, 1.34 times and 1.38 times when the plate thickness go up 1.5 times, 2.0 times, 2.5 times and 3.0 times, respectively. In other words, it is a nonlinear changing of bending stress when the plate thicknesses are increased. This simulation results are not only adequately representing the bending process but also help for choosing a machine capacity depending on the plate thickness.

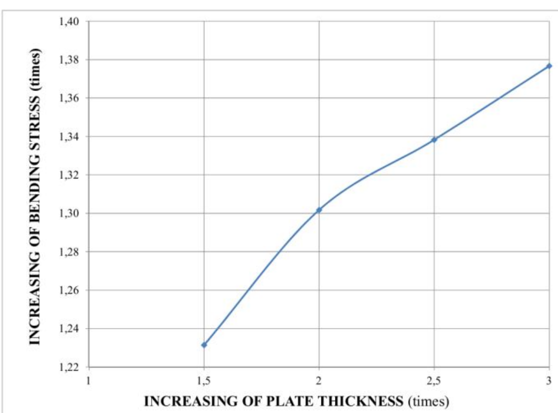


Figure 9: Nonlinear changing of bending stress

In Fig. 10 and Fig. 11, a series of simulations and experiments were performed on 1mm stainless steel with various final radius to study the effects of final radius on bending stress. While the width and thickness of workpiece always remain constants, its radius reduces by rising up the lateral roll. For experiments, all input parameters are kept the same as the input parameters of FE simulations. It can be seen the curve for two results tends to reduce, from small radius to large radius of final bending shape.

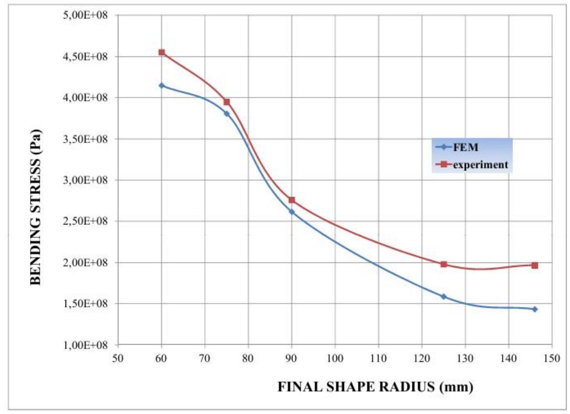


Figure 10: Stress distribution for various final shape radius.

It seems, in general, the FE results compare quite well with value from experiment results. However, the maximum bending stress between 70mm and 90 mm of final shape radius gives better results than the two ends of curves for both FE simulations and experiments. This one can be explained based on the graph of Figure 2. When the radius of final shape is too large, the plastic deformation will not occur. It is also the same problem if the radius of final shape is too small. Plastic deformation gauge cannot be read by the strain gauge for very small radius.

This work is presented in order to get a better understanding of dynamic simulation roll bending process by FEM. Establishing influences that affect formability of the roll bending process will be a part of future works.

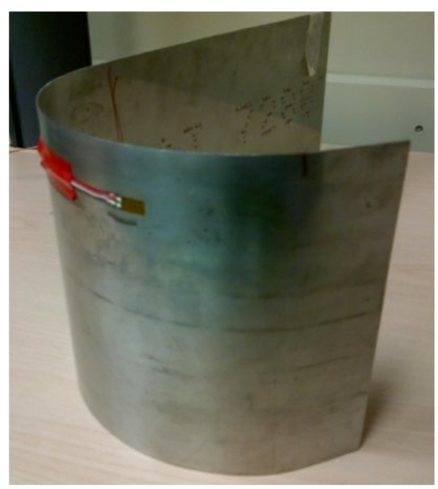


Figure 11: Workpiece after roll bending process

CONCLUSION

Based on dynamic FEM simulation and experimental results, the present work analyses the factors that influence the bending stress of plate during roll bending process. It is seen that the bending stress at the early stage of roll bending process is different with continuous bending stage. In addition, by increasing the plate thickness, the maximum bending stress leaved in the workpiece vary non-linearly. Otherwise, with bigger final shape radius, the smaller bending stress is found by both FE simulation and experiment results. It might be useful results for industry for controlling parameters and improve the quality of the final shape.

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