

An Idea for Predicting Residual Stress Field of Roll Tensioned Circular Saw Blade

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Abstract

In this paper, a concise and fast 2D model of the roll tensioning process was built using the finite element method. Elastic thermal expansion is used to simulate rolling plastic deformation. A 3D model considering contact between roller and circular saw blade was also built. Through comparison of residual stress results obtained by the 2D model, 3D model, and X-ray stress test method, the correctness and feasibility of the 2D model were proven. While accounting for the diversity of circular saw blade structure, this paper provided an idea for rapidly predicting the residual stress field of a roll-tensioned circular saw blade.

Wood cutting processes and cutting tools are the subjects of important research focus in the field of wood science and technology. During the wood sawing process, cutting temperature increases on the saw blade body, and it is impossible to add coolant lubrication. A circular plastic pit is formed on the surface of the circular saw blade by roller pressing and a residual stress field is produced in the circular saw blade after the roll tensioning process. Roll tensioning is used to counteract adverse effects of cutting heat and is important for dynamic stability of the circular saw blade.

The residual stress distribution of a roll-tensioned circular saw blade with ideal disk structure was calculated and tested (Szymani and Mote 1974, 1979). This is an analytical method, which is only suitable for circular saw blades with ideal disk structure. A finite element model of the roll tensioning process was established and proven correct by experimental verification (Nicoletti et al. 1996, Heisel et al. 2014, Merhar et al. 2017). The finite element method is a numerical method, which is suitable for circular saw blades of any structure, but it requires a lengthy calculation process. The influence of the material properties of the saw blade on the residual stress field were studied by this method (Li and Zhang 2017). In addition to the roll tensioning process, some scholars studied other tensioning methods, such as the multispot pressure tensioning and laser shock tensioning processes. Generation and regulation mechanisms of the residual stress field of the circular saw blade after multispot pressure

tensioning was analyzed (Li et al. 2015, Li and Zhang 2019a). The theoretical analysis model of the laser shock tensioning process was built based on laser shock wave theory. Laser energy, spot diameter, and impact zone distribution have a great effect on residual stress field (Li and Zhang 2018).

A 3D model of the roll tensioning process can be built using finite element software. The model can predict the residual stress field of a roll-tensioned circular saw blade; however, the calculation process takes a long time and one calculation can be applied to only one type of circular saw blade structure. When the structure of the circular saw blade is changed, a new model must be built, with a long and inevitable calculation process. These disadvantages limit the application of the 3D model for production.

In addition, circular saw blade structure shows a diversified development trend in recent years. Circular saw blades now often incorporate holes, slots and other

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structures. When circular saw blade structure is changed, the residual stress field of the circular saw blade after the roll tensioning process also changes, even if the roll tensioning process parameters have not changed. Therefore, the development of novel approaches for predicting residual stress of circular saw blades with arbitrary structure after the roll tensioning process is important for production and academic research.

A 2D model for predicting the residual stress field of a circular saw blade with arbitrary structure after the roll tensioning process was built and is discussed in this paper. This paper focuses on the process and considerations of modeling.

Materials and Methods

A 2D model of the roll tensioning process

The rolling region of a circular saw blade after the roll tensioning process consists of two parts (Schajer and Mote 1983, 1984) as shown in Figure 1: the part with radial displacement >0 , and the part with radial displacement <0 . There is a boundary line with radial displacement $=0$. A residual stress field is formed outside the rolling region as a result of the expansion effect of the region both inward and outward.

A 2D model for predicting residual stress of a circular saw blade was built using the finite element method. This model used the elastic thermal expansion process to simulate the expansion effect of the rolling region. The modeling idea referred to modeling of the laser shock tensioning process (Li and Zhang 2019b). The assumptions and constraints of the 2D model are shown as follows.

- (1) The boundary line with zero radial displacement was assumed to be in the middle of circumferential rolling region. A radial displacement constraint was applied to the boundary line, as shown in Figure 2.
- (2) A coefficient of elastic thermal expansion, 0.00001, was applied to the rolling region. Temperature T_1 was

applied to the outer elastic thermal expansion zone. Temperature T_2 was applied to the inner elastic thermal expansion zone. Width of the rolling region was L . It should be noted that T_1 and T_2 were not temperatures in the physical sense.

- (3) A Z-direction displacement constraint was applied to the center hole, as shown in Figure 2.
- (4) Geometric parameters of the circular saw blade are shown in Figure 3. Elastic modulus of the circular saw blade was set to 210 GPa. Poisson's ratio of the circular saw blade was set to 0.3.
- (5) A 2D shell element was chosen for the model. The elements in the elastic thermal expansion zone were set dense, as shown in Figure 2.

Width of the rolling region, L , was set according to practical experience or calculation result obtained by the 3D model. Temperatures T_1 and T_2 could be adjusted, and could be obtained by comparison between the residual stress field of the circular saw blade calculated by the 2D model and tested residual stress field or by the residual stress field calculated by the 3D model.

Notably, when temperature T_1 and T_2 are determined, the circular saw blade of the 2D model would not be limited to ideal circular structure. As long as the thickness, diameter, and center-hole diameter of the circular saw blade and roll-tensioning process parameters are fixed, the circular saw blade could have holes or slots.

A 3D model of the roll tensioning process

A 3D model of the roll tensioning process was also built using ABAQUS finite element software (Heisel et al. 2014), and was used to compare with the results obtained via the 2D model. Considering the symmetry of roll tensioning in the vertical direction, the 3D model of the roll tensioning process was established in half, as only a one roll and a half thickness circular saw blade was modeled, as shown in Figure 3. Yield strength of the circular saw blade was set to 780 MPa. Downward loading

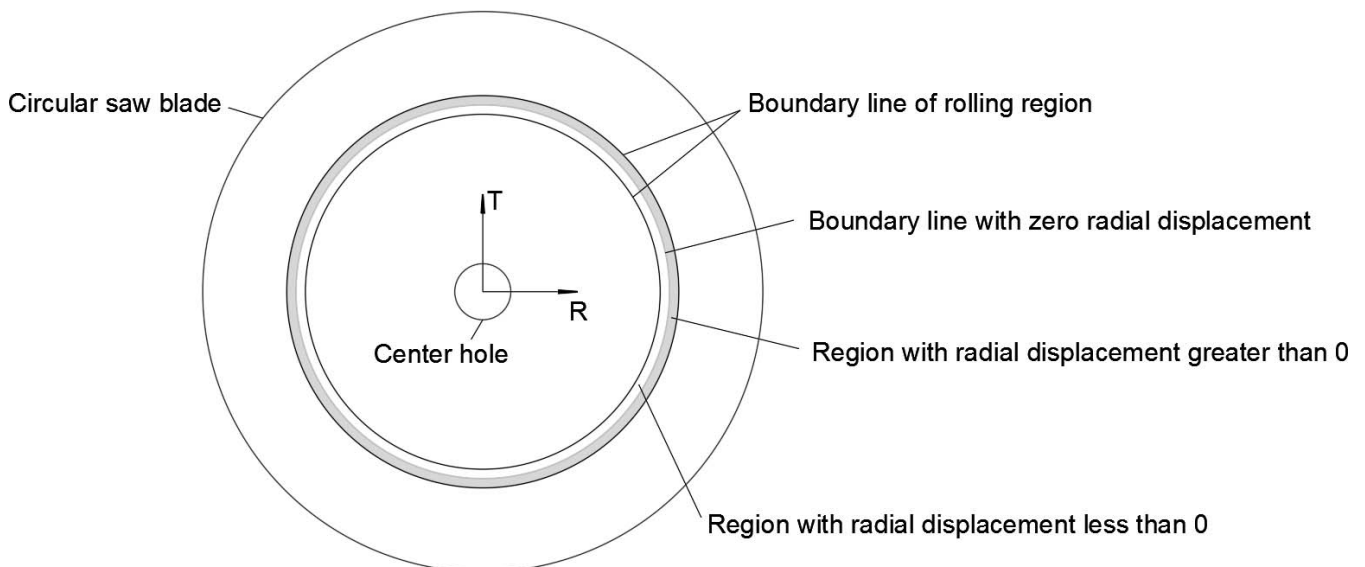


Figure 1.—Composition of the rolling region of a circular saw blade.

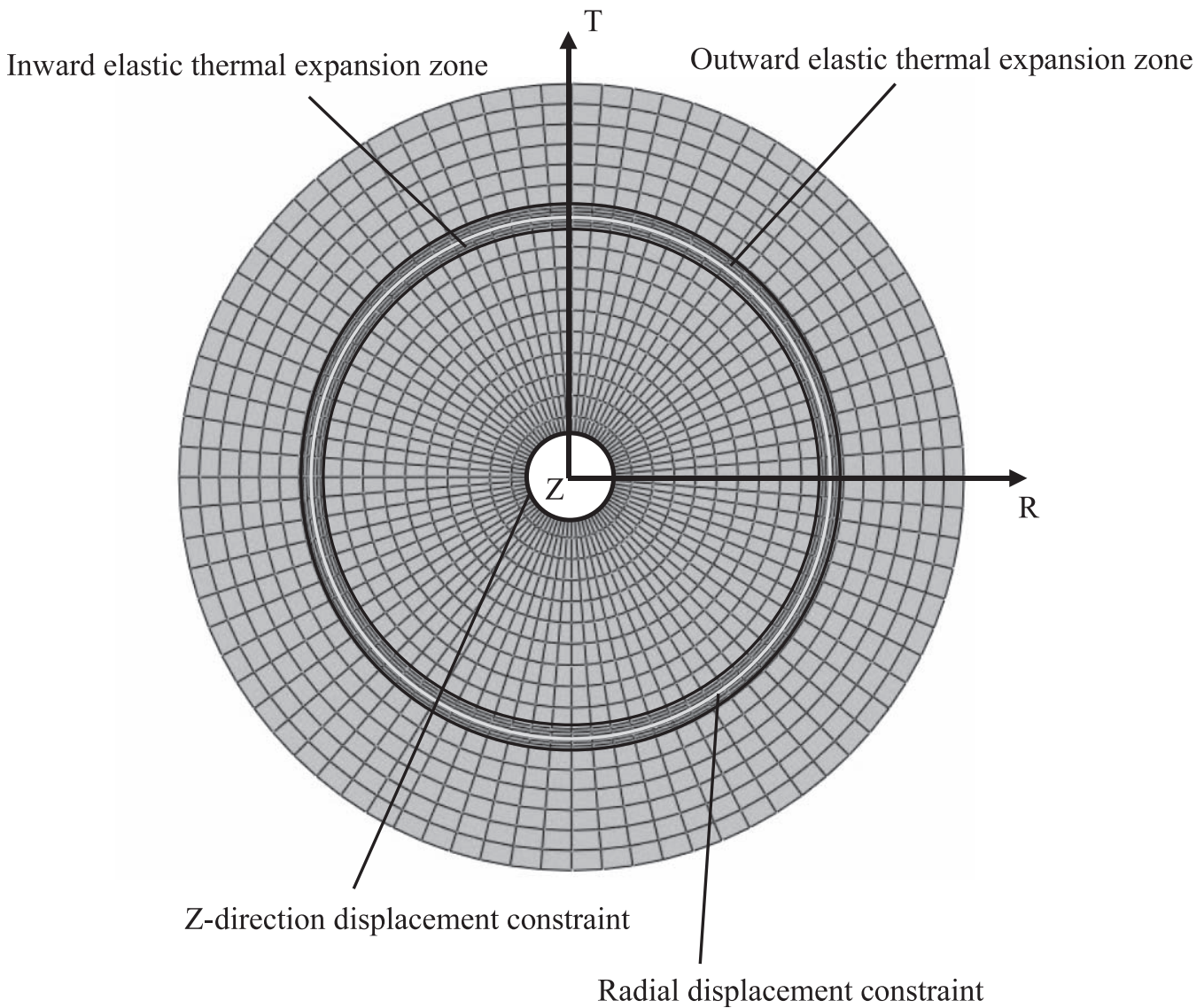


Figure 2.—2D model predicting residual stress of a circular saw blade.

force of roller was set to 10 kN, according to the situation. A 3D 8-node reduced integration element was chosen for the model. The elements in the rolling region were set dense, as shown in Figure 4.

Test method for the residual stress field of the circular saw blade

For X-ray residual stress detection, the residual strain can be obtained by measuring the displacement of diffraction line, and then the residual stress is obtained by Hooke's law. Herein, residual stress field outside the rolling region was tested by X-ray stress meter, as referred to in previous research methods and results (Umetsu et al. 1989, 1994). An X-350A type X-ray stress meter was used for the experiment. This experiment used the same inclination angle method. Radial and tangential stress of the roll-tensioned circular saw blade were the focus of this paper. The circular saw blade used in the experiment was made of #65 Mn; it was 300 mm in outer

diameter, 30 mm in inner diameter, and 2 mm in thickness (Fig. 3). Several test points were selected in the radial direction of the circular saw blade, where the radial and tangential stress of the test points were tested and recorded.

Results and Discussion

The residual stress field outside the rolling region was calculated using the 2D and 3D models in Figures 2 and 4. Temperatures T_1 and T_2 were adjusted to make the calculation results of the 2D model approximate those of the 3D model. When T_1 and T_2 were set as 550 and 130°C, respectively, the residual stress fields outside the rolling region calculated by the 2D and 3D model were very close to each other (Fig. 5).

The outer elastic thermal expansion zone is equivalent to the part with radial displacement >0 (Fig. 1). The outer edge of the circular saw blade is free and unconstrained, so the part with radial displacement >0 has wider expansion

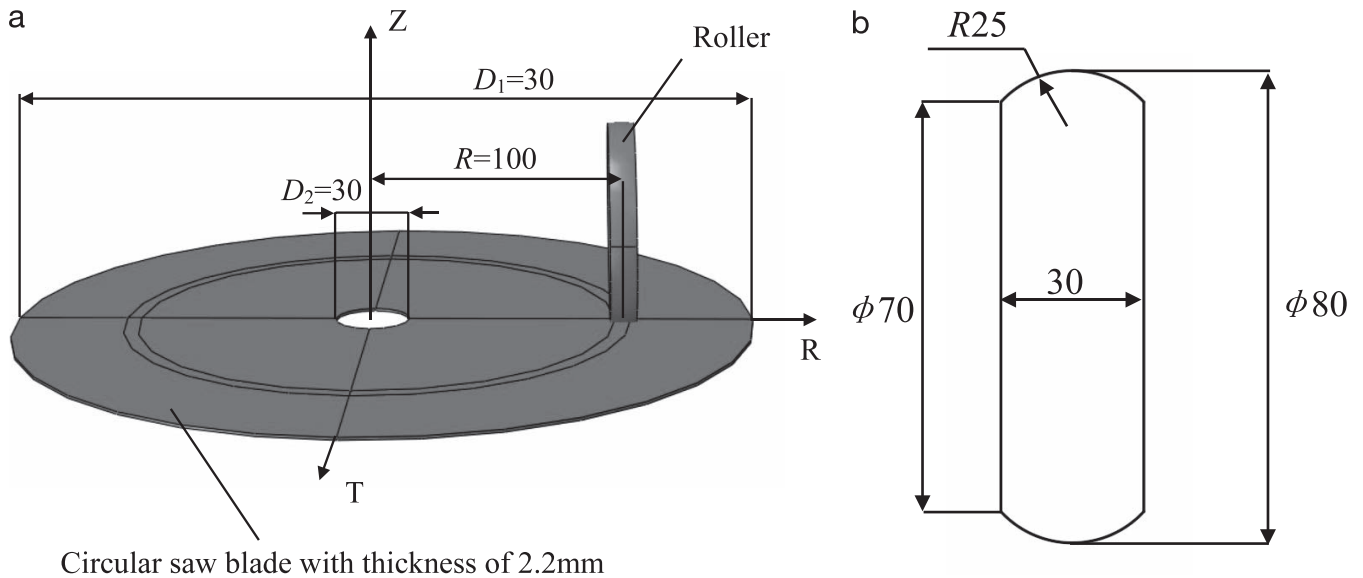


Figure 3.—3D model of the roll tensioning process. (a) Roll tensioning process. (b) Roller.

space. For the 2D model, it means that the outer elastic thermal expansion zone needs higher temperature in order to approximate the expansion space of the part with radial displacement >0 in Figure 3.

The inner elastic thermal expansion zone is equivalent to the part with radial displacement <0 (Fig. 1). The inner edge of the circular saw blade is constrained, so the part with radial displacement <0 has less space of radial contraction. For the 2D model, it means that the inner elastic thermal expansion zone needs lower temperature in order to approximate the radial contraction space of the part with radial displacement <0 in Figure 3.

For the 2D and 3D models, the stress field inside the rolling region showed some differences, for several reasons

(Fig. 5). First, the element types of the 2D and 3D models are different. Second, solution errors of the 2D and 3D models are different. Third, boundary conditions of the central hole of the 2D and 3D models are different. From the overall trend, the theoretical calculation results of radial and tangential stress obtained by the 2D and 3D models showed the same distribution trend as that tested by X-ray stress meter, which proved the correctness and feasibility of both theoretical models.

When dealing with structural change of a circular saw blade, if the roll-tensioning process parameters and thickness of the circular saw blade were kept the same, temperatures T_1 and T_2 could be obtained by the 2D and 3D models of the ideal circular saw blade shown in Figures 2

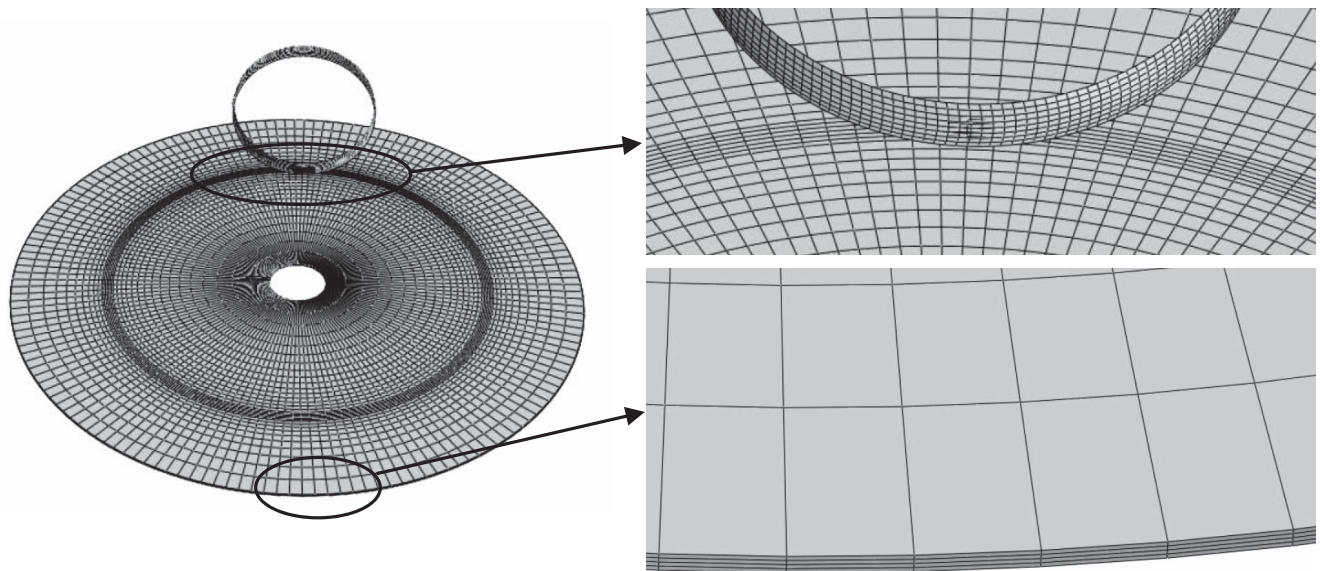


Figure 4.—Meshing of the 3D model.

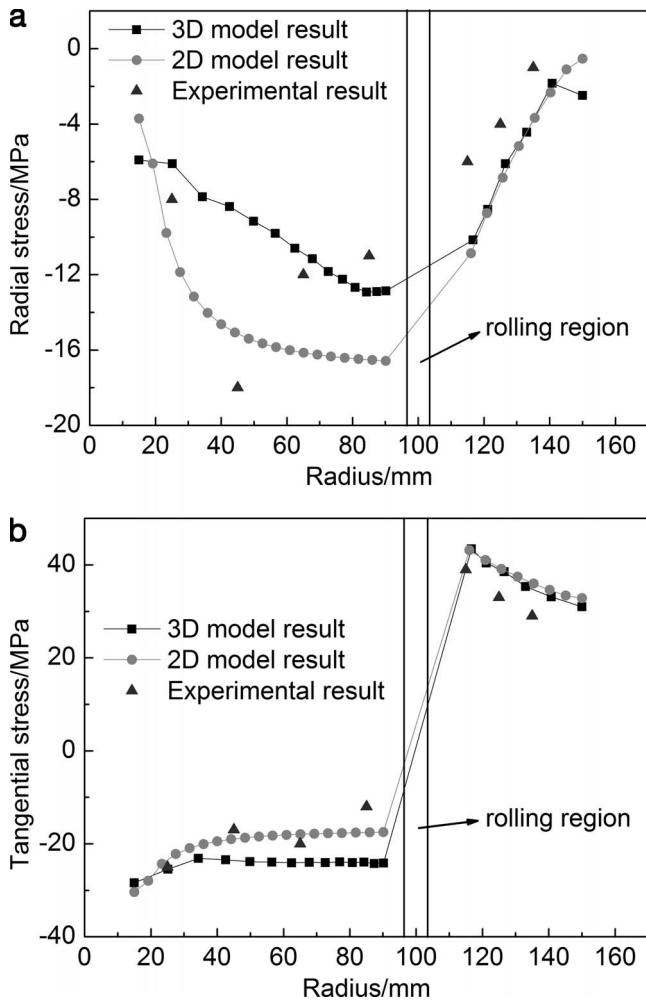


Figure 5.—Residual stress field of a circular saw blade obtained by theoretical and experimental means. (a) Radial stress distribution. (b) Tangential stress distribution.

and 4. That is to say, if the structure of a circular saw blade is changed, one only need to rebuild a 2D model of the circular saw blade, and let it bear the temperature load T_1 and T_2 . The residual stress field outside the rolling region would be correspondingly obtained by the 2D model, with no need to account for the complex contact operation between the roller and circular saw blade as in the 3D model.

As shown in Figure 6, a circular saw blade with eight holes had the same outer diameter, center diameter, and thickness as that blade in Figure 3. The same roll-tensioning process parameters were applied to this circular saw blade. Therefore, T_1 and T_2 were also set at 550 and 130°C, respectively. The residual stress field outside the rolling region was calculated by the 2D model. In order to verify the correctness of the modeling idea in this paper, the 3D model of the circular saw blade shown in Figure 6 was also built. The calculation results of the 2D and 3D models were compared as shown in Figures 7 and 8. Whether using the 2D or 3D model, the distribution of residual stress in paths 1 and 2 all showed the same trend.

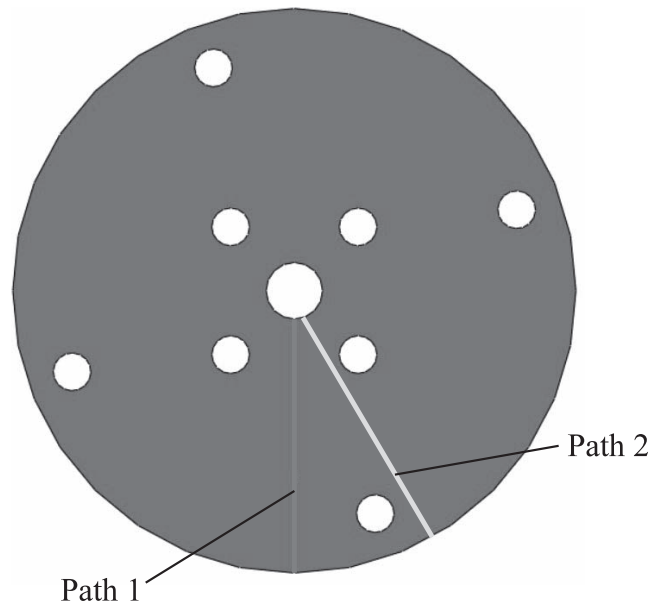


Figure 6.—An example of a circular saw blade with new structure.

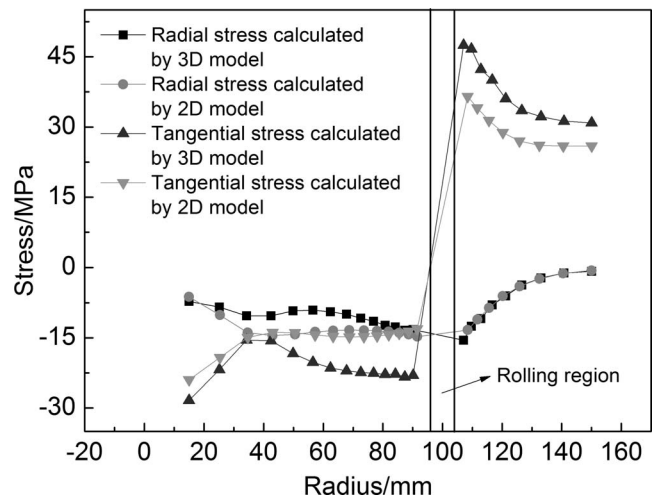


Figure 7.—Residual stress in Path 1.

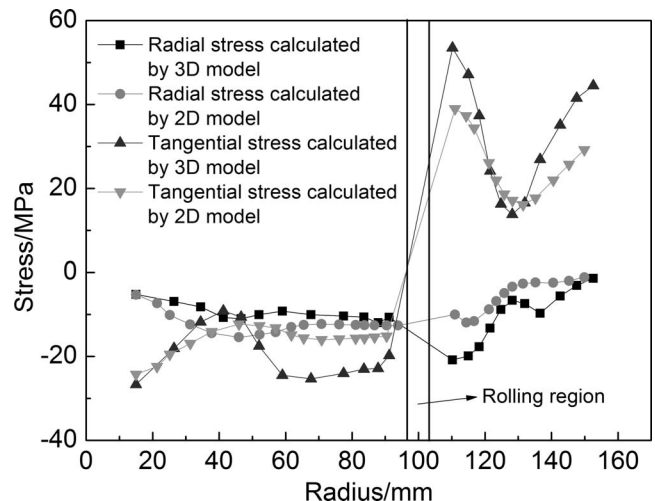


Figure 8.—Residual stress in Path 2.

Conclusion

- (1) In this paper, a concise and fast 2D model of the roll tensioning process was built using the finite element method. The model used elastic thermal expansion to simulate plastic deformation of the rolling region. The 2D model does not require accounting for the complex contact operation between roller and circular saw blade. The model can adapt to changes of circular saw blade structure and reduce the amount of calculation.
- (2) The correctness and feasibility of the 2D model were proven by a traditional 3D model of the roll tensioning process and the X-ray stress test method.

Acknowledgments

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