Effect of Yield Strength of a Circular Saw Blade on the Multi-spot Pressure Tensioning Process

Bo Li,* Zhankuan Zhang, Weiguang Li, and Xiaorui Peng

In this study, a numerical model of the tangential tensioning stress distribution of a circular saw blade tensioned by multi-spot pressure was established using theoretical analysis, and the tangential tensioning stress distribution of the circular saw blade calculated by the model was shown to be true and reliable. The effect of yield strength of the circular saw blade on the distribution of tangential tensioning stress was studied using the numerical model. The research achievements showed that a circular saw blade made with high-strength or ultra-high-strength steel yielded a better tensioning effect during the multi-spot pressure tensioning process, which could promote the application of a circular saw blade made by high-strength or ultra-high-strength steel.

Keywords: Circular saw blade; Multi-spot pressure tensioning; Finite element method; High-strength steel

*Contact information: Research Institute of Wood Industry, Chinese Academy of Forestry, Beijing 100091, China; *Corresponding author: libohongxing@sina.com*

INTRODUCTION

Because of increased environmental awareness, wood processing enterprises are increasingly requiring highly-effective, sustainable wood use. In the field of wood processing, the circular saw blade is an important tool. Its cutting precision and material-saving ability are the most important features for wood processing enterprises. At present, the circular saw blade is becoming thinner and thinner in order to reduce kerf loss. However, when a circular saw blade is cutting a work piece, tangential and radial tensile stresses are produced because of the centrifugal force generated by the high rotational speed of the blade.

Thermal stress is also produced, because the temperature at the edge of the blade is higher than in other regions. These two stresses cause high tangential compressive stress on the edge of the circular saw blade, causing a buckling deformation that reduces cutting precision, increases kerf loss, and shortens the saw's life (Li *et al.* 2015). The above-mentioned phenomena can easily occur in the case of a thin circular saw blade. Therefore, the application of the thin circular saw blade has both advantages and disadvantages.

The multi-spot pressure tensioning process is one kind of tensioning method that is applied in order to avoid the above-mentioned phenomenon. The tangential tensile tensioning stress field is produced during the tensioning process in order to compensate for the tangential compressive stress, which improves the stability and quality of the circular saw blade. However, the thin circular saw blade requires tangential tensioning stress with more reasonable distribution to maintain stability, mainly in the range of higher maximum difference of tangential tensioning stress.

The high strengthening of metallic materials is one of the feasible technology tactics and strategies for resources and energy-saving, as well as emission reduction. The wide application of high-strength or ultra-high-strength steel is being vigorously promoted at home and abroad, which impels the basic theory research and the application technology development of high-strength or ultra-high-strength steel manufacturing to become an international frontier and hot spot. High residual stress is admittedly produced onto high-strength or ultra-high-strength steel in the course of plastic deformation. Tensioning stress is essentially residual stress. Therefore, a thin circular saw blade made from high-strength or ultra-high-strength steel may be more suitable for obtaining high values of tangential tensioning stress and more reasonable distributions during the multi-spot pressure tensioning process. There has been no related theoretical research about this.

At present, studies about the tensioning processes of circular saw blades have mainly focused on the effect of tensioning on the dynamic stability of the blades (Szymani and Mote 1974; Carlin *et al.* 1975; Schajer and Mote 1983; Schajer and Mote 1984; Schajer and Kishimoto 1996; Stakhiev 2004; Ishihara *et al.* 2010; Cristóvão *et al.* 2012; Ishihara *et al.* 2012). The generation of tensioning stress during tensioning processes has been studied by a few researchers. A theoretical model of the roll tensioning process was established by Szymani and Mote (1979). A model of the roll tensioning process was established by Nicoletti based on the finite element method, and the tensioning stresses were determined (Nicoletti *et al.* 1996). An FEM simulation model for the roll tensioning of circular saw blades, which allowed for the investigation of various roll tensioning parameters, was developed by Heisel *et al.* (2014). A mathematical model of tangential tensioning stress in the edge of a circular saw blade tensioned by multi-spot pressure was established for the quality control of circular saw blades by Li *et al.* (2015). However, to date, for circular saw blades made from high-strength or ultra-high-strength steel, there has been little theoretical research about the generation of tangential tensioning stress during the multi-spot pressure tensioning process.

Yield strength is the main performance parameter for high-strength or ultra-high-strength steel. In this paper, the effect of yield strength of the circular saw blade on the generation of tangential tensioning stress was analyzed. The tensioning effect of the multi-spot pressure tensioning process was evaluated by the tangential tensioning stress distribution. The results of this research can be used to promote the application of circular saw blades made from high-strength or ultra-high-strength steel.

EXPERIMENTAL

Materials

The parameters of the circular saw blade are shown below (Li *et al.* 2015). The material was 65 Mn; the hardness was HRC42; the diameter was 356 mm; the thickness was 2.2 mm; and the diameter of the hole was 30 mm. The yield strength of the circular saw blade was 430 MPa. Its elastic modulus and Poisson ratio were 210 GPa and 0.3, respectively. The parameters of the spherical pressure head are shown below. Its hardness was HRC60; its radius was 70 mm; and the loading force was 100.0 kN. The distribution of spots is shown in Fig. 1.

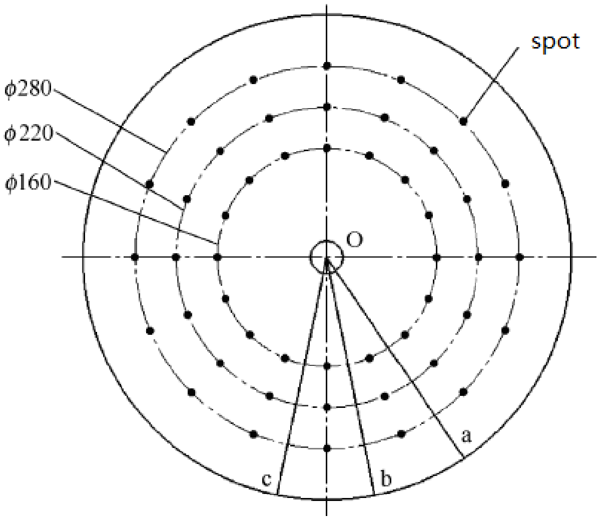

Fig. 1. Distribution of spots on the circular saw blade

Methods

Tangential tensioning stress measurement

As shown in Fig. 1, Line a, Line b, and Line c were inserted into a specified radial path of the circular saw blade. There were 14 points on each line. Each point was numbered from 1 to 14 from the inside to the outside, respectively. Among them, the distance between the first point and the center of the circular saw blade was 38 mm. The distance between each point was 10 mm. In order to improve the test precision, the tangential tensioning stress of each point was tested twice by an X-ray stress meter, as shown in Fig. 2 (Umetsu 1989; Umetsu *et al.* 1994). The average value of the test results of the points with the same number was the final tangential tensioning stress value.

Fig. 2. X-ray stress meter

Mechanical model of the multi-spot pressure tensioning process

The mechanical model of the multi-spot pressure tensioning process was built with reference to Li *et al.* (2015). The multi-spot pressure tensioning process was assumed to include two mechanical processes: the one-spot pressure process; and the process of elastic deformation of a disk with many through-holes subjected to uniform, radial compressive stress. The radius (*m*) of the axial through-hole was the same as the radius of the local plastic deformation region. The uniform radial compressive stress (q_a) applied to the inner wall of the through-hole was equal to the average radial compressive stress at the boundary of the local plastic deformation region, as shown in Fig. 3. The two mechanical processes were built *via* the finite element method (FEM), as shown in Figs. 4 and 5, considering the axial symmetry of the first process and the symmetry of the second process.

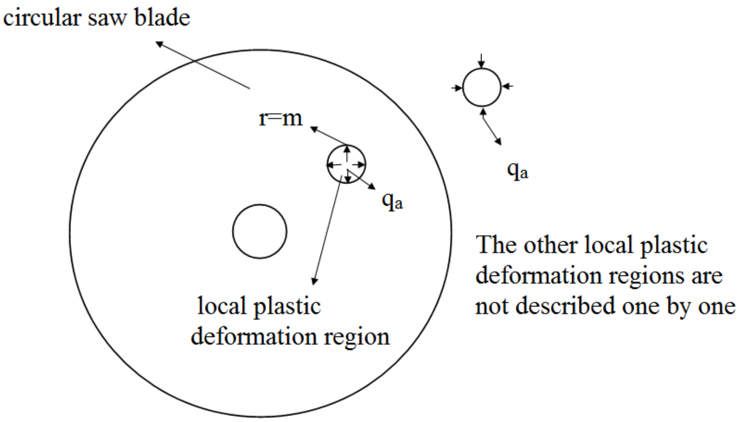

Fig. 3. Mechanical model of the multi-spot pressure tensioning process of circular saw blades

Fig. 4. Schematic diagram of the geometric model of the one-spot pressure process

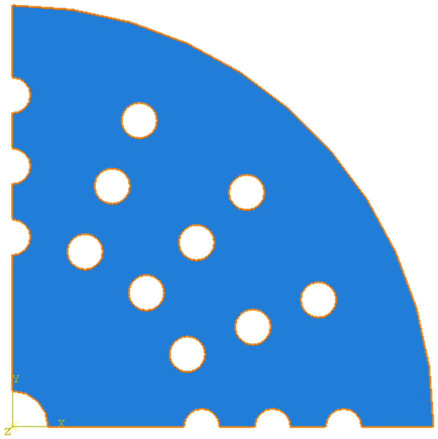

Fig. 5. Schematic diagram of the geometric model of the elastic deformation process of a disk

RESULTS AND DISCUSSION

The contrast between the tangential tensioning stress of the circular saw blade calculated by the simulation model and the measured results in the specified radial path of the circular saw blade are shown in Fig. 6. As shown in Fig. 6, the tangential tensioning stress distribution of the circular saw blade calculated by the simulation model and the measured results in the specified radial path of the circular saw blade followed the same trend, and the values were similar in most regions, which demonstrated that the tangential tensioning stress of the circular saw blade calculated by the model in this paper was true and reliable.

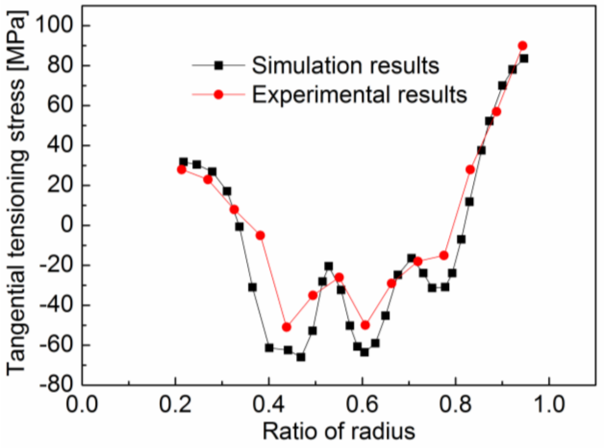

Fig. 6. Contrast between the simulation and the measured results

The loading forces of (*F)* were: 40, 60, 80, 100, 120, and 140 kN. The yield strengths of the circular saw blade were: 300, 600, 900, and 1200 MPa. The metallic material of the circular saw blade was assumed to be linear hardening. Its strain hardening rate was 500 MPa.

The radius (*m*) of the plastic zone and radial compressive stress (q_a) were the main factors that determined the distribution of tensioning stress of the circular saw blade (Li *et al*. 2015). The effects of yield strength of the circular saw blade on them were analyzed by the numerical model, as shown below.

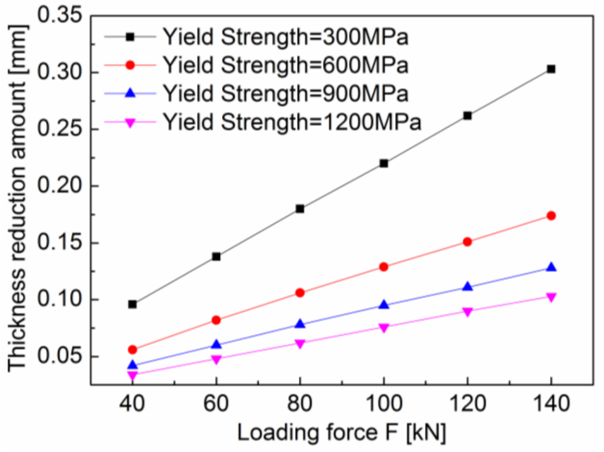

Fig. 7. Variation of thickness reduction amount with loading force in different yield strengths

As shown in Figs. 7 and 8, the thickness reduction amount of blade and radius (*m*) of the plastic zone were increased with a loading force of (*F)* when the circular saw blade was in any yield strength because the increase of loading force promoted the local plastic deformation. The thickness reduction amount of blade and radius (*m*) of the plastic zone were decreased with yield strength when the circular saw blade was in any loading force of (*F)* because the increase of yield strength increased the metal deformation resistance and restrained the local plastic deformation.

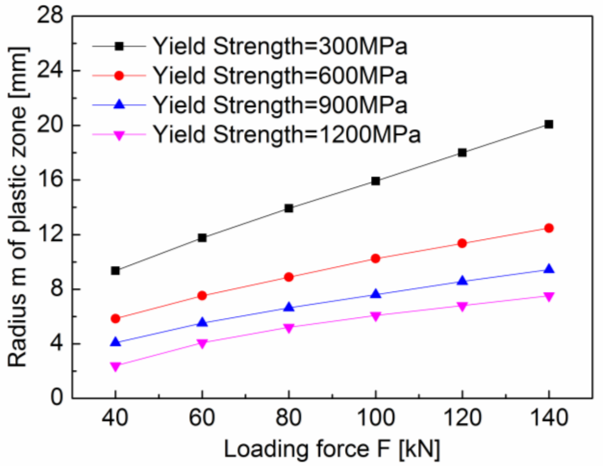

Fig. 8. Variation of radius (*m*) of the plastic zone with loading force in different yield strengths

As shown in Fig. 9, the radial compressive stress (q_a) was almost unchanged with loading force *F* when the circular saw blade was in any yield strength because the metal in the junction between the elastic and plastic deformation zones had the same stress state.

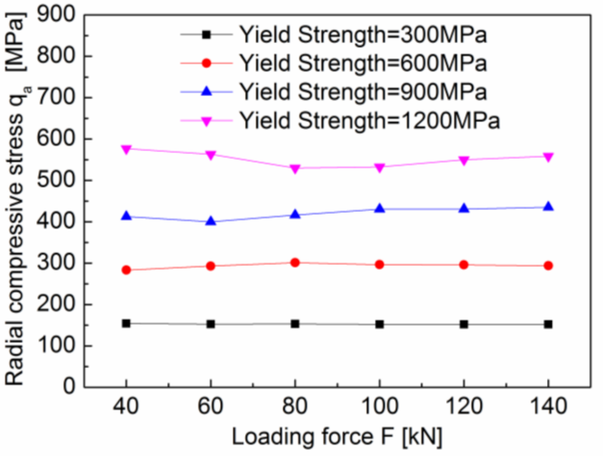

Fig. 9. Variation of radial compressive stress (q_a) with a loading force in different yield strengths

The radial compressive stress (q_a) was increased with the yield strength of the circular saw blade. When the yield strength of the circular saw blade was 300 MPa, the radial compressive stress (q_a) was approximately 152 MPa. When the yield strength of the circular saw blade was 600 MPa, the radial compressive stress (q_a) was approximately 296 MPa. When the yield strength of the circular saw blade was 900 MPa, the radial compressive stress (q_a) was approximately 420 MPa. When the yield strength of the circular saw blade was 1200 MPa, the radial compressive stress (q_a) was approximately 550 MPa.

The distribution of tangential tensioning stress of the circular saw blade is shown in Fig. 6. The maximum tangential tensioning stress was on the edge of the circular saw blade. The minimum tangential tensioning stress was in the middle of the circular saw blade. The maximum difference of tangential tensioning stress was the difference between the maximum and minimum tangential tensioning stress, which represents the tensioning effects of the multi-spot pressure tensioning process. The maximum tangential tensioning stress, minimum tangential tensioning stress, and maximum difference of tangential tensioning stress were three important indicators that described the distribution of tangential tensioning stress. The greater maximum difference of tangential tensioning stress meant that the circular saw blade could maintain stability during large temperature differences when it was at work. Therefore, the effects of yield strength on the maximum tangential tensioning stress, minimum tangential tensioning stress, and maximum difference of tangential tensioning stress were analyzed by the numerical model, as shown below.

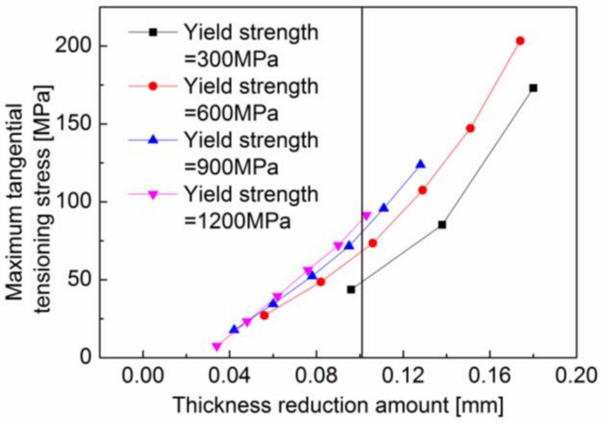

Fig. 10. Variation of maximum tangential tensioning stress with thickness reduction amount in different yield strengths

When the thickness reduction amount of blade exceeded 0.1 mm, it meant that excessive deformation was produced on the circular saw blade. The indentations of the circular saw blade could be easily seen, which is not good for manufacturing. To obtain tangential tensioning stress with better distribution, excessive deformation is produced onto the thin circular saw blade made by steel with a lower yield strength during the multi-spot pressure tensioning process. This is unfavorable for the circular saw blade made by steel with lower yield strength. In summary, tangential tensioning stress with better distribution and moderate plastic deformation are needed for the circular saw blade during the multi-spot pressure tensioning process.

As shown in Fig. 10, the maximum tangential tensioning stress of the circular saw blade was increased with the thickness reduction amount of blade when the circular saw blade was in any yield strength because the increase in reduction amount made the radius (*m*) of the plastic zone increase. When the thickness reduction amount of blade was less than 0.1 mm, the change range of maximum tangential tensioning stress was different when the circular saw blade was in a different yield strength. The simulation results showed that the maximum tangential tensioning stress could change in a larger range when the yield strength of the circular saw blade was changed. When the thickness reduction amount of blade was less than 0.1 mm and a moderate plastic deformation was produced, the circular saw blade with a higher yield strength could achieve a higher maximum tangential tensioning stress.

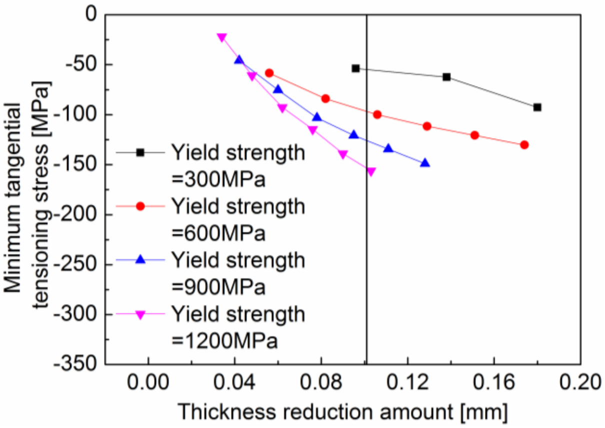

Fig. 11. Variation of minimum tangential tensioning stress with thickness reduction amount in different yield strengths

As shown in Fig. 11, the maximum tangential tensioning stress of the circular saw blade was decreased with the thickness reduction amount of blade when the circular saw blade was in any yield strength. The simulation results showed that the minimum tangential tensioning stress could change in a larger range when the yield strength of the circular saw blade was changed. When the thickness reduction amount of blade was less than 0.1 mm and a moderate plastic deformation was produced, the circular saw blade with a higher yield strength could achieve a lower minimum tangential tensioning stress.

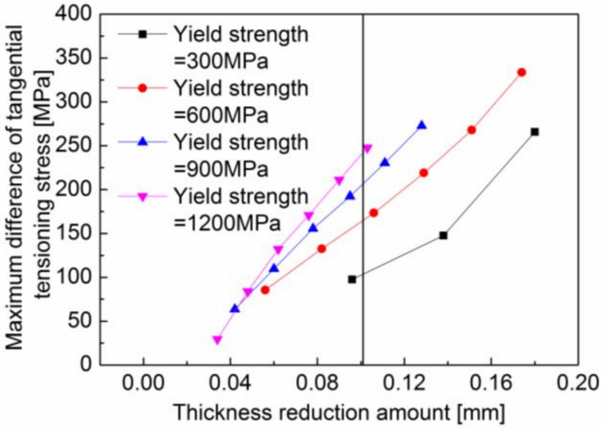

Fig. 12. Variation of the maximum difference of tangential tensioning stress with thickness reduction amount in different yield strengths

As shown in Fig. 12, when the thickness reduction amount of blade was less than 0.1 mm, the change range of the maximum difference of tangential tensioning stress was different when the circular saw blade was in different yield strengths. The simulation results showed that the maximum difference of tangential tensioning stress could change in a larger range when the yield strength of the circular saw blade was increased. When the thickness reduction amount of blade was less than 0.1 mm and a moderate plastic deformation was produced, the circular saw blade with a higher yield strength could achieve a higher maximum difference of tangential tensioning stress. This showed that the circular saw blade with higher yield strength could achieve better tangential tensioning stress distribution with a moderate plastic deformation. It was demonstrated that a circular saw blade made with high-strength or ultra-high-strength steel was more suitable for achieving better tangential tensioning stress distribution with moderate plastic deformation during the multi-spot pressure tensioning process, theoretically.

CONCLUSIONS

1. In this study, a numerical model for the tangential tensioning stress of a circular saw blade tensioned by multi-spot pressure was established by theoretical analysis and calculation. The model accurately predicted the tangential tensioning stress distribution of the blade, which was proved to be true and reliable by experimental data. The effect of yield strength of the circular saw blade on the distribution of tangential tensioning stress was studied by the numerical model. The effect of the circular saw blade made from high-strength or ultra-high-strength steel on the tensioning effect of the multi-spot pressure tensioning process was studied, theoretically.
2. The simulation results showed that the circular saw blade with higher yield strength could achieve better tangential tensioning stress distribution with a moderate plastic deformation, and the circular saw blade made from high-strength or ultra-high-strength steel was more suitable for achieving a better tensioning effect during the multi-spot pressure tensioning process.

ACKNOWLEDGMENTS

We gratefully acknowledge the financial support of the National Natural Science Foundation of China (No. 31270605) and the Agricultural Science Technology Achievement Transformation Fund of China (No. 2013G B24320607).

REFERENCES CITED

Carlin, F., Appl, F. C., and Bridwell, H. C. (1975). “Effects of tensioning on buckling and vibration of circular saw blades,” *Journal of Engineering for Industry* 97(1), 37-48. DOI: 10.1115/1.3438574

Cristóvão, L., Ekevad, M., and Grönlund, A. (2012). “Natural frequencies of roll-tensioned circular saw blades: Effects of roller loads, number of grooves, and groove positions,” *BioResources* 7(2), 2209-2219. DOI: 10.15376/biores.7.2.2209-2219

Heisel, U., Stehle, T., and Ghassem, H. (2014). “A simulation model for analysis of roll tensioning of circular saw blade,” *Advanced Materials Research* 1018(2014), 57-66. DOI: 10.4028/www.scientific.net/AMR.1018.57

Ishihara, M., Noda, N., and Ootao, Y. (2010). "Analysis of dynamic characteristics of rotating circular saw subjected to thermal loading and tensioning," *Journal of Thermal Stresses* 33(5), 501-517. DOI: 10.1080/01495731003659208

Ishihara, M., Murakami, H., and Ootao, Y. (2012). "Genetic algorithm optimization for tensioning in a rotating circular saw under a thermal load," *Journal of Thermal Stresses* 35(12), 1057-1075. DOI: 10.1080/01495739.2012.720452

Li, B., Zhang, Z. K., Li, W. G., and Peng, X. R. (2015). "Model for tangential tensioning stress in the edge of circular saw blades tensioned by multi-spot pressure," *BioResources* 10(2), 3798-3810. DOI: 10.15376/biores.10.2.3798-3810

Nicoletti, N., Fendeleur, D., Nilly, L., and Renner, M. (1996). "Using finite elements to model circular saw roll tensioning," *Holzals Roh-und Werkstoff* 54(2), 99-104. DOI: 10.1007/s001070050146

Schajer, G. S., and Kishimoto, K. J. (1996). "High-speed circular sawing using temporary tensioning," *Holz als Roh-und Werkstoff* 54(6), 361-367. DOI: 10.1007/s001070050202

Schajer, G. S., and Mote, C. D., Jr. (1983). "Analysis of roll tensioning and its influence on circular saw stability," *Wood Science and Technology* 17(4), 287-302. DOI: 10.1007/BF00349916

Schajer, G. S., and Mote, C. D., Jr. (1984). "Analysis of optimal roll tensioning for circular saw stability," *Wood and Fiber Science* 16(3), 323-338.

Stakhiev, Y. M. (2004). "Coordination of saw blade tensioning with rotation speed: Myth or reality," *Holz Roh Werkst* 62(4), 313-315. DOI: 10.1007/s00107-004-0490-1

Szymani, R., and Mote, C. D., Jr. (1974). "A review of residual stresses and tensioning in circular saws," *Wood Science and Technology* 8(2), 148-161. DOI: 10.1007/BF00351369

Szymani, R., and Mote, C. D., Jr. (1979). "Theoretical and experimental analysis of circular saw tensioning," *Wood Science and Technology* 13(3), 211-237. DOI: 10.1007/BF00350225

Umetsu, J. (1989). "Confirmation of φ splitting in the distribution of residual stress in tensioning circular saws," *Journal of the Japan Wood Research Society* 35(9), 856-858.

Umetsu, J., Noguchi, M., and Matsumoto, I. (1994). "Measuring residual stresses in tensioned circular saws using X-rays," *Journal of the Japan Wood Research Society* 40(3), 268-273.

Article submitted: July 23, 2015; Peer review completed: September 13, 2015; Revised version Received and accepted: September 14, 2015; Published: September 21, 2015.
DOI: 10.15376/biores.10.4.7501-7510