Effect of Trees Knot Defects on Wood Quality: A Review

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Abstract. This paper reviews the research progress of effect of trees knot defects on wood quality, including the research strategy, technology, model, and research directions. Firstly, the effect of the knot on the appearance, mechanical properties, mechanical processing properties, chemical composition and bonding properties of wood were summarized. Secondly, the relationship between the influence of the knot on the quality of the wood and the size, position, color, type, shape and distribution of the knot were analyzed. Then, the advantages and disadvantages of different non-destructive testing methods and different prediction models were analyzed and compared. The following conclusions on future research trends can be drawn from the literature review and analysis: 1) Improve the fitting degree of the prediction model of the influence of the knot on the wood quality; 2) Optimize the single detection method and multiple detection methods to combine organically, and the test results are combined with the artificial cultivation of trees to fundamentally reduce the impact of knots on wood quality; 3) Develop on-line technology to measure the effect of knots on wood quality, and make different wood products based on the test results to maximize the utilization of wood.

1. Introduction
Wood is a renewable natural green material. It has the characteristics of light weight, high strength, good elasticity, heat insulation and etc. It is a high-quality raw material for making furniture. But woods have different grades, and 90% of wood grades depend on the knot. In wood processing, knot is considered as a wood defect, will make wood quality, use value, strength, durability reduction. In order to meet people's demand for wood products, many scholars at home and abroad began to carry out relevant studies on improving wood quality. The improvement of wood quality is closely related to the state, size, position and tilt angle of knot, and optimizing knot is equivalent to improving the quality of wood [1].

2. Research status of knot features
Longuetaud F et al. [2] showed that, the knot refers to the branches buried inside the trunk and on the surface. In plant physiology, knots play an important role, and external branches are the main source of nutrients needed for tree growth. The leaves on the live branches transform their external CO₂ into organic matter and O₂ through their own photosynthesis. The organic matter is transported to the roots through the screen of the phloem of the trees and absorbed to promote the growth of the trees. From a physiological point of view, knots are necessary for tree growth, while in wood science, knots reduce the quality of wood. In order to improve the quality of wood, the law of the existence of the festival has become a basic research.

The basic features of the knot include its type, shape, distribution and color. Kong F C [3] and so on, from the texture of knot and the conjunctive morphology of surrounding tissues, which can be classified into living knot and dead knot. From the perspective of the material of the knot, they can be divided into
leakage knot, decay knot and sound knot. According to the section of the knots, they are divided into circular knot, strip knot and palmate knot. Common knot types and features are shown in figure 1. The knot prediction model established by Trincado G [4] shows that most of the knots are conical, and only a small number of knots appear cylindrical. Huang S Y [5] and others found that the distribution and formation of knots are not only related to environmental factors and site conditions, but also related to genes. For example, there is a large difference in the number of knots in different tree species. Larch, Camphor pine and other knots have a large number, while Poplar, Eucalyptus and other knots have a small number. Li J [6] research shows that the color of knot is darker than that of normal wood. Because the dead knot has been separated from the surrounding tissue, the color of the edge changes greatly, presenting a hard black scar. There is a clear boundary between the color and the surrounding, and the color of the living knot gradually changes and deepens.

Figure 1. Common Section Types and Characteristics

3. Research status of the influence of knot on wood quality

3.1. Effect of knot on the appearance of wood
In the research of Li J [6], the wood color of the knot is deeper than the normal material nearby. The unique pattern and deep color give people a beautiful stimulation, a dynamic floating feeling, giving the environment a sense of luxury. Crafts can be processed and utilized. However, the knot has destroyed the appearance consistency of the whole piece of plate. The research by Zhao P J [7] and others shows that the texture of the knot is obviously different from the surrounding, and it is distorted to varying degrees, showing a unique texture and changing physical and mechanical properties of wood.

3.2. Effect of knot on mechanical properties of wood
Jin R L [8] found that the density and water content of the knots are significantly different from the surrounding wood tissue. During the drying process, the knots may fall off and cause holes. In the mechanical properties test, Cao Y [9] and other studies have shown that the knots reduce the tensile and compressive strength of the wood, but improve the horizontal compressive strength and the shear strength. Zhang X Y [10] found that the knots of larch increased their flexural strength. In 2018, Rocha [11] et al. found in their study on the influence of eucalyptus' knots on its modulus of elastic (MOE) and the compressive strength (Fc) that the greater the number of knots, the greater the difference between MOE and Fc, while the effect of small knots (8.31mm^2) and normal wood was almost equal. Eucalyptus knots are more sensitive to hardness than strength.

3.3. Effect of knot on wood machining performance
Jiang H [12] and others believe that the hardness of knots is greater than the hardness of wood itself, and the knots may be carbonized due to high temperature during sawing. At the same time, the angle of the knot is large, which greatly shortens the service life of the wood tools when processing wood. In the processing of veneers, the boiling and softening of the knots before the wood is made is particularly important.
3.4. Effect of knot on chemical composition of wood
The study by Lukacevic M [13] microscopically shows that the internal fibers of the wood deviate from the knot, resulting in imperfections in the fibers inside the wood. Studies by Vek V [14] have shown that extracts from the knot are more abundant than other parts, and the essential oil content is significantly higher than other parts.

3.5. Effect of knot on wood glue performance
Lin L Y [15] and other studies have shown that the knot will reduce the gluing properties of the wood, the size of the knot has a significant impact on it, and the type of the knot is not significant. Xie L S [16] and others found that the knot has a significant effect on the normal shear strength, wood breakage rate, immersion peeling rate and boiling stripping rate of the seam. As the diameter of the knot increases, the glue seam shear strength and wood breakage rate can be reduced by 40% and 67%.

Generally, dead knot has a greater effect on wood quality than live knot. However, in the study of Ke B F [17], it was found that the effect of the dead knot on the bending strength of the live knot is small, (1) the texture slope of living knot is greater than that of dead knot; (2) cracking due to drying of the living knot and surrounding wood. Considering again that the live knot can resist several kinds of stress, while the dead knot cannot, it can be concluded that the influence of the dead knot and the live knot on the stress is basically equal.

4. Research status of knot detection
External knot measurements are relatively easy, while internal knot is not. Traditional knot detection destroyed the logs, reducing the economic value of the wood. Now, most of the use of non-destructive testing. Rummukainen H [18] et al. and Zhang H J [19] et al. used X-ray CT scanning technology to detect the internal conditions of trees. Burcham D C [20] et al., Zhang T [21] et al., Qian J C [22] et al. using ultrasonic detection technology to obtain internal knot parameters. Liu S T [23] et al. and Wang Z C [24] et al. used stress wave technology to detect internal knots, Wu F M [25] et al. and Bogosanovic M [26] et al. used microwave technology to obtain internal knots. Yu H Z [27] et al. and Ding W J [28] determined the position and size of the knot by near-infrared spectroscopy. But these methods have their own advantages and disadvantages, as shown in Table 1.

| Detection method | Principle | Advantage | Disadvantage |
|------------------|-----------|-----------|--------------|
| X-ray CT scan[18,19] | The xylem inside the wood and the part of the knot have different absorption capacity to the X-ray, which presents different images on the negative film, and determines the shape and size of the knot | (a)Easy to operate (b)Imaging resolution is high, the image is clear and intuitive | (a)Insensitive to cracks parallel to the surface (b)Fluorescent materials required for imaging, with radioactivity (c)Cost too high |
| Ultrasonic testing[20,21,22] | The type, size and position of the knot will be determined by receiving the reflected ultrasonic wave and measuring the corresponding wave velocity and waveform | Good controllability and repeatability | (a) easy to be interfered during detection (b) The qualitative and quantitative determination of defects is not very accurate (c) The coupling agent required for testing may cause contamination problems |
| Stress wave detection[23,24] | The tested wood is struck by pulse to produce stress wave, and whether the tested wood has defects is judged by the change rule of time or speed of stress wave propagation | (1) More suitable for complex and severe outdoor environment, with strong practical application (2) The testing | (1) The instrument is heavy and difficult to carry and transport (2) The physical properties of different parts of the tree and directions lead to different |
machine is cheap and easy to carry
(3) No uncontrollable factors and unknown pollution

(3) Unable to detect knot types

Microwave detection [2, 5, 26]

When the wood is scanned, the fibers in the knots are different from the surrounding wood, which causes the variation of the microwave to be very prominent and obvious, thereby measuring the position of the knot.

(1) High sensitivity of detection equipment
(2) High operational safety

The moisture content of wood has a serious impact on the detection of knots

Near infrared spectroscopy [27, 28]

When the infrared light passes through the knot, it will cause a difference in heat transfer, thus determining the position and size of the knot.

The speed of propagation is very fast
(3) Ensure that the tested wood structure is complete and abundant

(1) There is a lot of redundant and non-linear information in the detection, which leads to the inaccuracy of the later knot reduction model
(2) In the process of identification, it takes too long and is not practical

To improve the effect of knot detection, we can better study the effect of knots on wood quality. In addition to the above methods, non-destructive testing methods for wood knots include neural network technology [29], geological radar (GPR) technology [30], and resistance technology [31], but these methods also have limitations and need further improvement.

5. Application of the models in the study of knots

The current research involves a variety of prediction models for wood knots. In 2014, Gerhard [32] et al. used the morphological characteristics of local materials to analyze the properties of local materials. For example, a non-destructive tensile test is performed on wood containing knots, and the stress of the corresponding knot and the tensile stiffness of the wood are measured by an optical imaging device, thereby establishing a regression equation and analyzing the tensile stiffness of the other knots; The knot was subjected to a destructive tensile test to measure the tensile strength of the wood. The regression analysis was also used to determine the tensile strength of other knot woods.

In 2017, Hao [33] et al. established a multivariate regression model to predict the length of the knot by three factors: the diameter of the branches, the angle of the branches and the age of the branches. The purpose of this is to predict the influence of the formation of the wood on the wood material by the multivariate regression equation.

In the artificial red pine knot attribute based on the mixed effect model studied by Jia W W [34] et al. in 2018, different mixed effect models were established by using various parameters of the red pine knot, and the fitting accuracy was higher than that of the traditional regression model. For example, the basic model with the optimal age of death is introduced into the random parameters of the pitch base diameter, and the generalized linear mixed model has the highest fitting degree. The model is based on the common model and introduces random parameters of the tree effect level. Construct a single-level generalized linear mixed model.

Compare the prediction model, found that multivariate regression equation than a single regression equation add more independent random parameters, makes the predicted parameters data closer to the actual data, and generalized linear mixed model compared with the multiple regression equation can reflect the stand growth in average change trend also can reflect individual differences.

6. Discussion on future research direction

It can be seen from the above that the influence of the knot on the quality of the wood is closely related to the size, position, color, type, shape and distribution of the knot. 1) The effect on the
appearance is mainly that the color and texture of the knot destroy the consistency of the appearance of the sheet. 2) The influence on the mechanical properties of wood is mainly due to the difference in density and water content of the knots. Reduce the tensile strength, compressive strength and flexural strength of parallel to the grain, increase the compression strength of perpendicular to the grain and the shear strength of parallel to the grain. 3) The influence on the mechanical properties of wood is mainly due to the increase of wood hardness and greatly shorten the service life of wood tools. 4) The influence on the chemical composition of wood is mainly due to the obvious increase of the extract of the knot and the fiber breakage. 5) The effect on the gluing properties of wood is mainly due to the positive correlation between the size of the knot and the gluing performance.

Because the current destructive test method is used in the study of wood quality in the section, the test wood can not be used for processing in the later stage, which reduces the use value and economic value of the wood. At the same time, the prediction model of the influence of knots on wood quality is not high in fitting; the non-destructive testing method of the knot, the detection result is not accurate enough, and the detection process is long.

In the future, more scientific and technological means will be used to optimize the research methods of the influence of knots on wood quality. For example, without destroying the logs, the prediction model of the knots is used to know the influence of the knots on the quality of the wood. However, the current prediction model of the knots is not high enough. In the future, it is possible to improve the fitness by reducing errors and finding optimal prediction models for different parameters.

1) Optimize the method of detecting the knot, for example, optimize the single detection method and improve the detection result, organically combine various detection methods, exploit the advantages of each detection method, and make up for the deficiency of the single detection method. Combining the test results with the artificial cultivation of trees fundamentally reduces the impact of knots on wood quality.

2) At the current level of science and technology, the development of online detection technology for the impact of knots on wood quality provides an important basis for post-production wood products. At the same time, select different wood according to different purposes to maximize the utilization rate of wood. For example, when sawing plywood try to avoid knots. The wood with more knots can be used for making paper etc.

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