Study on Modification of Fast-growing Chinese Fir Stumpage

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Abstract. This paper focused on the modification of stumpage and the object was to analyse the distribution and diffusion of modifier in wood at different height positions, and further study the form of modifier in wood. In addition, the mechanical properties of modified wood (compressive strength parallel to grain, MOR and MOE) were also investigated. The results showed that the vessels and pores were filled with modifier and the mechanical performance of modified wood were improved in comparison of wood untreated. The concentration of modifier and the added promoter significantly.

1. Introduction
The fast-growing woods are the main materials of southern forest tree species, accounting for more than 90% of the harvest. However, the value of fast-growing woods are low due to their natural defects, which makes them difficult to replace high-quality woods. Conventional impregnation modification technology is not easy to large-scale promotion in remote areas because of large investment, complex process, high energy consumption and environmental pollution [1, 2]. Therefore, it is expected to ease the contradiction between supply and demand of high-quality woods owing to carrying out the stumpage modification technology to enhance their properties, prolong the service life and expand the scope of their applications. Stumpage modification dates back to Japan. In the 1990s, Iida Oiho and Zhao dyed on 58 species of hardwood and 3 species of softwood using sap flow injection [3, 4]. It is not only the dyeing speed but also the bright color of dyed wood with this method which attracts the attention of researchers. Despite of the defect of uneven dyeing, the dyeing effect of this method is unique owing to the dye diffusion along the sap flow pipeline, and it is suitable for a particular venue decoration such as interior decoration and wood crafts. In China, the history of wood dyeing was long, but it was not until the late 1980s, the research of stumpage dyeing was initiated. The research of stumpage modification is rarely reported at home and abroad. Thus in this paper, with copper quaternary ammonia (ACQ) as the main agent and polyethylene glycol as promoter on fast-growing Chinese fir stumpage modification, research was carried out in the distribution of modifier inside the timber and the mechanical performance change.
2. Materials and Method

2.1. Materials
The Chinese fir trees used for experiments are located in Experimental Forest Farm of Hunan Academy of Forestry. Transpiration of trees is the main force in the modification to import the modifier into the issues of the standing trees with the sap flow. Therefore the trees shall be chosen in the growth season. At the same time, the target trees which are more than 20 meters away from the waters are growing normally with kind growth of canopy. The main agent of the experiment is copper quaternary ammonia (ACQ) that the content of effective components is 15 wt.%. And the promoter is polyethylene glycol with a molecular weight of 400. Three different concentrations of copper quaternary ammonia (ACQ) are prepared, 2 wt.%, 4 wt.% and 6 wt.% respectively. And these solutions are divided into 2 groups that one group is single modifier and the other is compound modifier with polyethylene glycol added as promoter that its content is 5 wt.%.

2.2. Method
Drill two channels whose apertures are smaller than 10 mm in a same plane at 30 cm above the ground of the truck with drill bits. The depth of the channel is supposed to reach the tree pith. And then fix the bracket besides the target trees and keep the height between the planes of wooden bracket and the channels more than 80 cm away. The treated trees should be harvested 4~8 weeks after treatment to let modifier solidify and in order to achieve the best effects.

2.3. Retention Tests
It is necessary to analyze the retention in different height positions of the trees since the modifier is injected from the bottom of the trees that may cause significant gradient and uniform distribution of modifier in the tree trunk. Since the main agent ACQ contains copper, the modifier loading dosage could thus be determined by analyzing copper content. A 10 cm sample was intercepted every 2 meters from the bottom of the trees where the modifier was injected. The area of sapwood taken from the samples was stripped of bark and milled into wood powder which was tested by using the methods specified in GB/T 23229-2009.

2.4. SEM Tests
The samples used for SEM analysis were taken out by slip-propelled slicer from the middle of specimens. And the area and the thickness of these selected samples with surface structure intact, non-polluting and non-deformed were 8 mm×8 mm and 1 mm, respectively.

2.5. Mechanical Properties Tests
Compressive strength parallel to grain, modulus of rupture (MOR) and modulus of elasticity (MOE) of poplar wood and modified poplar wood were tested by using the methods specified in GB 1938-1991, GB/T1936.1-2009 and GB/T1936.2-2009 standard methods respectively.
3. Results and Discussion

3.1. Distribution of Modifier

![Figure 1](image-url) Retention variations of Chinese fir in different height positions

Figure 1 (a) shows that it is easy for the modifier to diffuse to the upper of the trees when its concentration is low and as a result the retention is rising with the height positions ascending. However, high concentration of modifier forms large gradient because the modifier could gather and solidify in the bottom of the trees that prevents modifier diffusion and distribution in the trees evenly. After adding polyethylene glycol, the concentration gradient in the trunk of the trees is not obvious. And when the concentration is 6 wt.%, the retention is rising along the trunk of the trees. It means that the promoter helps the modifier diffuse and distribute inside the trunk more easily and evenly.

3.2. SEM Analysis

![Figure 2](image-url) SEM image of the cross-sectional surface of Chinese fir wood (a) and treated samples (b, c)

Through the observation of the morphology, the modifier distribution can be effectively controlled in wood. And by regulations on types of modifier and injection volume, the change of properties of wood could be artificial.

From the organizational structure of wood, except lignin and skeleton composed of cellulose and hemicellulose, the rest is pores inside wood. These pores are generally divided into 3 groups, including micro pores, coarse pores and natural pores. And distribution of these pores staggers in wood. Modifier transmission in wood is mainly through pits, resin canals and cell gaps. Under transpiration, modifier is diffused with sap in wood and gradually fills these pores inside the wood. Moreover, the modifier could react with the active groups of macromolecules of wood interior that enhances the properties of wood.
Figure 2 shows that resin canals and part of pores inside Chinese fir wood are filled by that no matter it is single modifier or compound modifier. After modifier is transmitted into the wood pores, it can react with the inner wall to form the solidified layer, and then the excess modifier would condense into micelle shape and finally solidify into small particles. It is modifier filled in resin canals and pores inside wood that can effectively improve the mechanical properties of wood [5].

3.3. Mechanical Performance

![Graphs showing mechanical performance improvements](image)

**Figure 3.** Improvement rates of compression strength parallel to grain of treated wood in different conditions

![Graphs showing mechanical performance improvements](image)

**Figure 4.** Improvement rates of MOR and MOE of treated wood in different conditions

Figure 3 (a) shows that with ascending height positions of target tree, compression strength parallel to grain improvement rate gradually decreases. This is mainly because the single modifier mainly gathers
in the bottom of the tree forming a large concentration gradient, which results in the improvement rate of the compressive strength is not uniform. However, Figure 3 (b) shows that in the experiment of compound modifier with polyethylene glycol as promoter, at different height positions of modified trees, compressive strength of modified samples are ascending. It suggests that polyethylene glycol is a kind of excellent surfactant, which is of good dispersion. After the compound modifier entered the wood, the promoter would make the main agent spread in the wood more easily instead of gathering and solidifying in the bottom of the trees. And the modifier could be distributed in the trees more reasonable.

It can be seen from Figure 4 (a) and 4 (b) that the lower concentration of the modifier, the more reasonable the MOR and MOE improvement rate of different tree height positions. When modifier concentration is 6 wt.%, the mechanical properties at different height locations obviously decreases. It may be that low concentration modifier is difficult to aggregate in wood pores and high concentration modifier is easily collected in the catheters and pores in a short time, which clogs the flow of modifier to the direction of the treetop, thus affects the uniform distribution of modifiers inside the standing tree and the improvement rate of the MOR and MOE. Figure 4 (b) and 4 (c) shows that with the addition of polyethylene glycol, the improvement rate of MOR and MOE at different height positions become more reasonable. The improvement rate has no significant decrement in the bottom of the tree trunk and other locations, while the mechanical strength of the tree trunk has more significant improvement toward the treetop than the bottom after the polyethylene glycol is added. It might be that the added polyethylene glycol as a surfactant, can effectively diffuse the modifier inside the trunk. So it is not easy for the modifier to aggregate in the pores and catheter.

4. Conclusion

Through this study, a new method was applied to modification of fast-growing Chinese fir wood, and the properties of modified wood were analyzed and studied. By SEM analysis, the modifier could be effectively filled in the internal ducts and pores of wood. At the same time, in the series experiments, it was polyethylene glycol as promoter added that helped the diffusion and distribution of modifier in the wood samples interior, which significantly improved overall mechanical properties of the modified wood evenly. In future research, the improvement of the other properties of wood will be further investigated, and it is necessary to find one kind of more efficient and more environmental modifier that can be diffused and distributed more reasonable inside trees.

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