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Saudi Journal of Biological Sciences

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REVIEW

Review on antibacterial characteristics of bridge engineering biomaterials



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Received 8 July 2015; revised 14 August 2015; accepted 16 August 2015

Available online 1 September 2015

KEYWORDS

Antibacterial characteristics;
Engineering biomaterials;
Bridges

Abstract This review summarizes the research on timber construction materials used in bridge construction. It focuses on the application of antiseptic treatments and the use of timber engineering materials in decks and bridges. This review also provides an overview on the future research and prospects of engineered timber materials.

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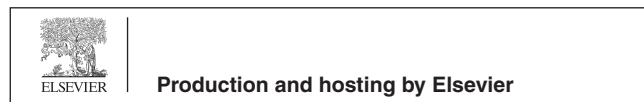
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1. Introduction

Timber bridges are in widespread use in China. Using timber in bridge construction can save resources, reduce costs, and benefit the environment. Timber materials that are used in civil engineering include traditional logs, sawn timber, and modern timber composites. After being integrated into high-tech manufacturing processes, bridges built with modern timber

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Peer review under responsibility of King Saud University.



construction materials are not only natural, esthetically pleasing, and environmentally friendly, but they also compare favorably with modern concrete and steel structure bridges in terms of handling large loads and being able to span long distances. Friedlander (2006) showed that timber has received renewed interest from bridge contractors and engineers because of the progress in science and technology; timber bridges are now also an esthetic choice for architects, engineers, and contractors. The use of timber preservatives ensures that such bridges will have long service lives. In addition to antiseptic treatments, the improvement of the laminated composite process has also increased the applicability and performance of timber used in modern vehicular bridges (Friedlander, 2006).

In the United States, modern timber bridges have become an important style of medium- and small-span highway bridges, especially for highway bridges with low transport volumes (Ashraf et al., 2012a,b). In Germany, timber is used as a load-bearing structure in viaducts serving pedestrians and cyclists. In addition, the innovation of timber bridges has become the byword of modernization (Frenette and Flach, 2008), and research into the use of antiseptic treatments and related timber construction materials in bridge decks and bridges has developed rapidly. It has been shown that wood extracts can improve the mechanical properties of construction materials (Zulkifley et al., 2013a,b). Many woody extracts, as well as the chemical composition of biomass, have been determined via improved molecular identification methods. Such studies have been very effective and are of great value.

2. Bridge decks

Bohannon (1972) reviewed research advances into timber bridge decks at the US Forest Products Laboratory (Bohannon, 1972). Tuomi (1976) pointed out that timber bridges are widely used in rural areas and on forest service roads. Timber bridges are durable, cost-effective, and require fewer technical tools and equipment to erect. Glued-laminated (glulam) bridge decks, which have been developed recently, can provide excellent structural performance, and there is a hope that these can prolong the service lives of bridges by protecting their upper structures (Tuomi, 1976). Wipf et al. (1996) studied the behavior of longitudinal glulam bridge decks of highway bridges by establishing a finite element model. Such bridges are more competitive with steel and reinforced concrete bridges within the range from small to medium spans (Wipf et al., 1996). Buttlar and Mozingo (1993) showed that the rigidity, toughness, and creep resistance performance of timber bridge decks reinforced with a steel sandwich plate are superior to those of ordinary timber bridge decks. Additionally, by analyzing dynamic and static models, they found that timber bridge decks reinforced with a double steel sandwich plate are better than single steel sandwich plate-reinforced timber bridge decks (Buttlar and Mozingo, 1993). Dagher et al. (1997) built a timber bridge deck reinforced with glass fiber, and confirmed that the glass fiber reinforced timber bridge deck had a sufficient prestressing force after 4.25 years of monitoring (Dagher et al., 1997). Larson et al. (1997) found that the asphalt pavement was worn on 1378 timber bridges in the US state of Minnesota. This study evaluated the degree of premature deterioration of the asphalt

of timber bridges, and it determined the main mechanism that caused the deterioration of the surface. Additionally, the authors put forth suggestions for improving the performance of asphalt pavements of bridges (Larson et al., 1997). Stenko and Chawalwala (2001) showed that a polysulfide epoxy resin coating layer is an economical and reasonable material for protecting trestle bridge and concrete bridge decks. In recent years, an epoxy cover layer was also successfully applied to fiber-reinforced plastic and timber bridge decks (Stenko and Chawalwala, 2001). A report by Rogers (2004) analyzed the performance of a thick layered, timber–concrete composite beam under a series of experimental load tests, and it showed that a thick-layered beam is a possible precursor for studying a thick-layered, timber–concrete bridge deck system in the future (Rogers, 2004).

3. Bridges

Gutkowski and Williamson (1983) summarized research activities directed toward timber bridges, and they tracked the evolution of the form of modern bridges (Gutkowski and Williamson, 1983). Williamson (1990) summarized the use of structural glulam timber, which was first introduced in the US in 1934, as a construction material. The development of fully waterproof adhesives in the 1840s led to the use of structural glulam timber in exposed, natural environments, which subsequently led to the use of laminated timber in bridges. Interestingly, some of the glulam timber highway bridges that were built in the 1940s are still in use today. The 50-year lifespans of these bridges illustrate the potential for structures of this kind. The multifunctional size, shape, and bearing capacity of glulam timber, combined with technological progress and improvements in pressure and anti-corrosion treatments, enabled glulam timber to be used as a substitute material in bridges (Williamson, 1990). Vandergrind (2004) showed that new forms of timber construction materials allow engineers to design larger span timber bridges that have better durability. Progress in material processing and construction methods (such as stress lamination) can lead to a longer service life than ever before. A form of timber composites now in use is that of parallel laminated strand lumber (PSL). The design stress of PSL is 35% higher than that of standard sawn timber or plywood (Vandergrind, 2004). Mettem (2003) described major breakthroughs in timber materials, including the development of third-generation structural timber composite materials, as well as the bonding of structural timber with completely invisible connections; laminated veneer lumber is a typical example of a third-generation structural timber composite material (Mettem, 2003). Manbeck et al. (2007) used red oak timber as a raw material to build a bridge, and they described the details of the bridge design, as well as an anti-corrosion timber treatment (Manbeck et al., 2007). Freedman (2009) put forth the optimal design and construction of various forms of stress-laminated timber bridges. Timber can also be combined with other materials to make up for its structural defects. Gilham (1995) introduced the design of a glulam beam using high-strength fibers, and they summarized the design method of the fiber-reinforced, glulam beam. They believe that the addition of high-strength fibers into the timber makes beams cheaper, and their beam not only used low-grade timber, but also showed better performance than a traditional glulam

beam. [Shenton et al. \(2001\)](#) stated that glulam is an engineering synthetic timber that is widely used in structural lumber. The use of plastic fiber-reinforced, laminated timber is rapidly changing the market for traditional structural timber, as it can be used in combination with low-grade timber to create stronger, smaller, and lighter structural components, thereby reducing costs. [Shmulsky \(2004\)](#) investigated the influence the thickness of the timber layer on the axial compressive strength of the parallel texture direction. The results showed that strength decreased with the decreasing thickness of the thin layer, which suggests that we can obtain stronger and stiffer timber beams and stringers by applying a thin timber layer to an extreme compression surface. Similarly, designers of glulam timber and fiber-reinforced polymer/timber bridges can more effectively use timber as a structural material for bridges if they employ such information. A research project by [Buell and Saadatmanesh \(2005\)](#) demonstrated how to strengthen an existing timber beam using advanced composite materials, which increases the load capacity of bridges. In most cases, timber bridges have been replaced by modern concrete or steel bridges because they cannot bear heavy truck traffic. Currently, the methods for strengthening bridges are not always economical and practical, which makes them costly to employ. This project adopted fibrous encapsulation or laminated beams and used composite materials to increase the load capacity of the beams. Reinforced by carbon fiber, the bending resistance and shear capacity of timber bridges improved as long as bidirectional carbon fiber was the main reinforcing material used. [Chen and Gutkowski \(1993\)](#) performed a laboratory study of a timber–concrete composite T beam. [Mettem \(2003\)](#) discussed the improved performance, as well as lower costs, of timber–concrete composite technologies. Using composite structures of this type significantly increased load bearing. Timber–concrete structures can be used in the upper structures of adjacent road bridges, as they have numerous advantages when compared with structures made with traditional timber or reinforced concrete. An analysis of the finite element method, based on theoretical research of differential equilibrium equations, showed that timber–concrete structures are very favorable in civil engineering constructions ([Mascia and Soriano, 2004](#)). In Brazil, timber–concrete composite bridges in cities and rural areas are regarded as feasible alternatives, mainly because of their high strength and stiffness, as well as their low construction and maintenance costs ([De Goes and Calil, 2008](#)).

4. Antiseptic treatments

[Milner \(1995\)](#) showed that although the reasons for the failure and fracture of timber can be analyzed from many angles, the biological corrosion of timber adhesive products is of particular importance. [Kainz et al. \(2000\)](#) showed that antiseptic chemical processing enables the use of timber in outdoor environments, and he measured the effect of various oil- and water-borne preservatives on the performance of stress-laminated southern pine decks. [Rogers et al. \(2001\)](#) discussed key problems that need to be solved when formulating restoration plans for historic timber bridges. These issues include the repair and reinforcement of the floor system, moisture proofing, and fire protection. Additionally, the use of a preservative

is recommended to prevent decay, as well as fungal and insect damage. [Friedlander \(2006\)](#) suggests that antiseptic timber treatments can prolong the service lives of timber bridges, and film-covering technology can increase the applicability of timber bridges. Because it is very expensive to replace the original material, timber preservation methods have been selected based on their minimal impacts on the environment, as well as their ease of use. [Wang and Qu \(2009\)](#) believe that fungal decay can reduce the strength of timber, as well as the geometric properties of structural timber, and that it is the main factor affecting the resistance of timber structures. [Dethlefs and Martin \(2010\)](#) believe that timber rot is an important performance index when evaluating timber bridges. [Blankenhorn et al. \(1999\)](#) proposed that creosote can be used as a preservative treatment for red oak and maple glulam timber bridges. [Xiao et al. \(2002\)](#) showed that the use of creosote as a preservative has a long history, especially in the application of industrial timber products. However, because of concerns about its potential impact on aquatic and terrestrial organisms, its use has been increasingly monitored. Because of its poor dimensional stability, the use of a timber bridge treated with chromated copper arsenate (CCA) was not recommended. [Bigelow et al. \(2009\)](#) believe that the durability of bridges depends largely on paying proper attention to construction and assembly details, together with the use of an appropriate preservative treatment for timber during construction.

5. Damage detection

Timber degradation, which is often internal, is one of the most common types of damage to timber bridges. An accurate assessment of the existing condition of a bridge is required to determine the appropriately rated load when deciding whether to repair or replace existing bridges. Knowledge of the status of a bridge may minimize the use of labor and materials during repair, thereby reducing replacement costs and prolonging the service life of the bridge ([Bradshaw et al., 2005](#)). [Gardner et al. \(1991\)](#) believe that timber bridges need to be regularly checked for internal defects caused by fungi and termites. The traditional method of checking includes a visual inspection and the use of a hammer and spiral drill to monitor the components of bridges. Such methods are not very effective, and radiographic procedures, which were developed to check the drive rod and structural timber of buildings, have been successfully applied to large timber bridges. [Pellerin et al. \(1996\)](#) evaluated the technical feasibility of using a stress wave nondestructive evaluation (NDE) method to locate the positions of decayed timber bridge components. The stress wave NDE technique was used to locate the decayed components of timber bridges in the eastern part of the US state of Oregon. A variation of the stress wave technique was used to perform an in situ evaluation of beams, bridge decks, and compression members. Removing the components that are suspected of having decay enables them to be analyzed in the laboratory. The visual assessment of components and subsequent laboratory tests showed that the stress wave technique is able to locate decayed components with great accuracy. [Morison et al. \(2002\)](#) noted that damage is often internal; thus, there are no obvious signs of decay on the surface, which can lead to many problems. NDE techniques have been developed to

the point where they can allow an evaluation of interior components of timber structure. However, it is tedious and time-consuming to test the entire structure using such methods. They put forth a testing method that can be used globally for timber bridge impact tests. Muller (2003) located the positions of the internal defects of a timber beam using various NDE techniques. In a technology trial, ground-penetrating radar was found to be the most reliable method for locating internal defects. Dackermann et al. (2009) proposed a damage identification procedure based on the global change in the vibration performance of structures. This mature method combines the damage index method with a neural network technique, and it has been used in numerical simulations and experimental analyses to assess the damage to timber beam structures. The damage detection results using this method proved its ability to determine the location and severity of the damage. Xu and Wang (2010) showed that effective methods are needed to obtain information pertaining to the location and the severity of defects. The finite element method and experimental modal analysis were used to obtain the curvature mode of standard samples of Korean pine, as well as to identify defects consisting of holes of various sizes. Further results of the two methods showed that the curvature mode of the defective part of the timber increased significantly as the size of the holes increased. Therefore, the modal analysis technology, both in theory and in practice, has been proved to be feasible.

6. Conclusion

Research and application of timber construction materials, especially in the area of bridge construction, started earlier in foreign countries. The US has a 100-year history of developing and using timber products for bridges, and its research on timber bridge decks, timber bridges, preservative treatments, as well as its use of nondestructive testing technologies to locate damage in timber products, led to the creation of modern timber bridge engineering materials based mainly on cork and supplemented by timber or reinforced fibers. In comparison, although the area of artificial forests and the stock volumes of forests in China are the largest in the world, our research on the domestic production of timber bridge engineering materials using plantation timber has just started because the use of modern timber processing technologies began relatively late. Therefore, learning from and using the experiences and achievements of foreign researchers in this field will improve the research and manufacturing of China's timber bridge engineering materials, opening the door for the extensive use of timber construction materials in the construction field in China. In my view, researching and manufacturing timber bridge engineering materials in China can be improved in the following two aspects:

- (1) The introduction of research and manufacturing technologies of timber bridge engineering materials. China should increase its adoption of these technologies by sending researchers to colleges, universities, research institutes, and famous enterprises abroad, where there is advanced technological training, as well as by inviting foreign research experts to our country to describe their research, and by cooperating with foreign scientific research units to learn about gluing and protection

treatments, the production process, relevant standards and specifications, and the use of NDE technologies. By doing so, homemade timber bridge engineering materials can be created, which will lead to new applications of timber materials in the architectural engineering field.

- (2) Increase in research of timber bridge engineering materials promote independent innovations in manufacturing technologies. Referencing foreign experiences and achievements regarding timber bridge engineering materials, as well as using advanced means to explore the bonding properties and corrosion resistance of different species, will improve the fire and corrosion resistance of plantation timber composite materials. This will lead to the creation of new forms of manufacturing technologies for timber bridge engineering materials. Additionally, developing our own timber construction materials and opening the door of our country's huge construction engineering market will enable timber materials to truly become important construction engineering materials in China.

Acknowledgment

Foundation Item: National Introduction of International Advanced Forestry Science and Technology Projects (2012-4-27); Program for New Century Excellent Talents (NCET-12-0725).

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