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Performance Study of Biomass Material-Based New Steel Beam-Column Connections

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Abstract

In this paper, the seismic performance of biomass-steel combination beam-column nodes is investigated, and an innovative method of combining agricultural and forestry residue biomass with steel is proposed to address the problem of high environmental impact of traditional building materials. Through theoretical analysis, numerical simulation and experimental study, the initial rotational stiffness calculation model of the connecting edge node of the outstretched end plate of the biomass-steel combination beam-column was established, the deformation characteristics of the node in the elastic phase were analyzed, and finite element structural analysis was carried out using ANSYS software. The results provide technical support for the application of biomass in load-bearing structures, which is of great significance in promoting the development of green buildings.

Keywords

Biomass; Steel Composite Structures; Beam-column Nodes; Finite Element Analysis.

1. Introduction

Combined structure is the main load-bearing system in the field of civil engineering, and there are mainly concrete-steel combined structure system, wood-bamboo-steel combined structure system and so on. With the rapid development of the national economy, the demand for traditional building materials such as concrete is growing at a high speed, but at the same time, the impact of traditional building materials on the environment and society is becoming more and more serious, which is not in line with the national "dual-carbon" strategic objectives. Since the 14th Five-Year Plan, China has vigorously advocated the development of energy-saving buildings and green buildings[1][2], and has requested the vigorous development of biomass-steel composite structures where conditions exist.

China is a country that is very poor in biomass timber, and the results of the 9th National Forest Resources Inventory in 2019 show that the country's forest area is about 2.2 million square kilometers, accounting for 4.5% of the world, and ranking 5th, but the per capita possession of forest savings is less than 1/4 of the world's level, and ranking 122nd in the world. In addition, the contradiction between the effective supply of forests and the growing social demand is still prominent, and China's dependence on foreign timber is close to 50%, making the situation of timber security grim. The existing timber forests account for only 13% of the harvestable area, and only 23% of the harvestable volume, with fewer resources available, and even fewer large-diameter timber and precious timber, so the structural contradiction between the supply of and demand for wood and bamboo timber is very prominent. At the same time, the situation of fragile forest ecosystem function has not been fundamentally changed, and the shortage of ecological products is still an outstanding problem that restricts the sustainable development of China's forest resources, which causes the contradiction between supply and demand in China's artificial timber market to be more prominent. At this stage, China has become the world's artificial wood manufacturing country, but the shortage of wood and bamboo raw materials is tightly restricting the development of China's artificial wood industry. Therefore, we urgently need to find biomass resources that can replace wood and bamboo resources and have a short growth cycle[3].

Agroforestry residue biomass mainly includes straw, rice husk, bagasse biomass, wood and bamboo processing residue and forest harvesting residue biomass, which has better performance, is a kind of low-energy, low-emission, less environmentally polluting building materials, and has a broad application prospect for the production of partition boards, enclosure structures, house decoration, building templates, and movable houses, etc[4] . However, limited to the weaknesses of agroforestry residue biomass material such as low flexural strength, low shear strength, and weak durability, it is difficult to promote its large-scale application. Relying on the high-end finished products of agroforestry residue biomass materials, prospectively combining agroforestry residue biomass materials and steel to form a combined structural system, giving full play to the excellent properties of agroforestry residue biomass materials such as flame retardant, formaldehyde-free release, water-resistant, insect-resistant, moisture-resistant and corrosion-resistant, and taking full advantage of the characteristics of high-strength, high ductility of steel, which provides a significant technical support for the promotion of agroforestry residue biomass materials for engineering applications and optimization and upgrading of the industrial structure. It is of great significance for guaranteeing the safety of wood and bamboo materials, ecological safety and realizing the green and sustainable development of forest industry.

2. Experimental Study on Seismic Performance of Combined Beam-Column Nodes

Combined structure has a long history of research in foreign countries, with a history of nearly 100 years, but the research of biomass - steel combined structure in China is more than 20 years. At present, biomass-steel composite structures are mainly studied in wood-steel composite members and bamboo-steel composite members, which mainly include the mechanical properties of composite beams and columns, the launching of composite connectors, and the seismic performance of composite beam-column nodes, etc., and the theoretical studies on biomass-steel composite beam-column nodes are very few.

2.1 Wood-steel Combinations

Validation and parametric studies of finite element models for steel-wood composite structures are being carried out by A. Hassanieh[5] et al. The results of the study show that their finite element model can adequately simulate the load-slip response and damage modes of the tested steel-wood composite structures. And the developed finite element model was validated by the existing tests conducted for steel-LVL composite structure and steel-CLT composite structure.Keipour.N[3]et al. conducted an experimental study on eight foot-scale steel-wood composite beam-column nodes. The results of the study show that the steel-timber composite structures have considerable ductility and seismic capacity and meet the existing design requirements for semi-rigid connections in Eurocodes EC3 and EC4. In addition, the negative moment load capacity of the STC connection is significantly higher than that of the pure steel connection without wood panels. Wen Yong[7] et al. conducted an experimental study on the bending capacity of thin-walled H-beam-wood combination beams as well as theoretical calculation and analysis. The test results show that the ultimate load carrying capacity of thin-walled H-beam-wood combination beams is significantly improved compared with that of pure wood beams, and the stiffness is larger and the ductility is better. Wu Xianzhe[8] et al. investigated the flexural load carrying capacity of thin-walled rectangular steel pipe combination beams with wood infill and carried out numerical simulations using ANSYS. The study shows that the combined beam has good combination effect and good ductility, and the width to thickness ratio of the steel tube flange is the main parameter affecting the ultimate flexural load capacity and ductility. He Jie designed eight steel-wood combination beams and two glued wood beams for[8], measured the deflection and strain values at different locations of the combination beams, and analyzed the mechanical properties of steel-wood

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combination beams in bending. The test results show that the ultimate bearing capacity of the steel-wood combination beams is much larger than that of the glued timber beams, and the deflection value at the mid-span position is smaller than that of the glued timber beams. Liu Xinglong[1][2]Three steel-wood composite beam column edge nodes were designed and fabricated, and all the three nodes were connected by welded end plates and bolts, and the steel-wood composite beams in each node were the same. The research results show that the shear deformation of steel in the core area of the node can be effectively reduced after filling in glued wood on both sides of the web of the H-beam column. In the study of the load carrying performance of steel-wood combination beams under short-term loading by Yang Ruyuan[1] et al. in 2007, the results of the study showed that the overall mechanical behavior of the steel-wood combination beams was affected by the distribution density of the shear connectors in the beams, and the mechanical properties of the connections. And it was found that when the spacing of the connectors was 150mm, the efficiency of member combination was good and economical.

2.2 Bamboo-steel Combination

Li Yushun[1] et al. conducted an experimental study on the flexural performance of three kinds of sectional forms of compressed steel plate-bamboo glue panel combination floor slabs. The results show that the side plates of bamboo veneer can play a good role of skeleton and connection, so that the composite cemented composite floor slabs reinforced by the side plates still have a good integrity when the deformation is large, and show a certain degree of ductility performance. Li Zhuo Lin[1] et al. in the existing cold-formed thin-walled steel - bamboo glue board combination box beam test based on its bending performance, using ABAQUS finite element analysis software, the establishment of cold-formed thin-walled steel - bamboo glue board combination of box beam three-dimensional nonlinear numerical analysis model to consider the interfacial bond slippage, and the combination of the numerical simulation of the beam of the bamboo glue board and the section of the steel material model definition, The key technologies such as finite element modeling, spring unit generation and post-processing are systematically studied to verify the reasonableness of the model. LU Li-cast[1] et al. completed the static double-sided shear test on a steel-bamboo composite structure formed by bolted connection. The test results show that: when the steel-bamboo structure is damaged, if the bamboo integrated material is thicker, the specimen will be double-hinged yielding; when the bolt diameter is small, the bolt end will be fractured; if the bamboo integrated material is thinner, the specimen will be single-hinged yielding, and the bamboo integrated material will be split prior to the bolt to produce damage. Xie Yazi[1]et al. In order to investigate the axial compression performance of side-pressing bamboo integrals columns, 6 groups of 18 specimens with different length to slenderness ratios were subjected to axial compression tests. The results show that the stressing process of the side-pressured bamboo integrals columns experienced elastic, elastoplastic and destructive phases, and with the increase of the length-to-fineness ratio, it transformed from the material strength destruction to the destructive destructive destructive destructive destructive destructive destructive destructive destructive destructive destructive destructive destructive destructive destructive destructive destructive with the obvious ductile nature.

2.3 Biomass

Agricultural and forestry residue biomass material is a man-made biomass material made from agricultural and forestry residue as raw material and inorganic material as binder, which has the excellent performance of flame retardant, no formaldehyde release, water resistance, pest control, moisture resistance, anticorrosion and so on, and the cost of production is lower than that of organic material, and the production process is relatively simple. Common agricultural and forestry residue biomass materials mainly include silicate inorganic materials, magnesium chloride cement materials, fly ash materials and gypsum materials.

Silicate material made of agricultural and forestry residues is a man-made material processed with silicate adhesive or silicate cement as binder, agricultural and forestry residues as reinforcing material, and some additives. Among them, silicate adhesive is characterized by easy availability of raw

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materials, high bonding strength, good temperature resistance, simple preparation process, etc. It is widely used in packaging materials, construction materials, metal and non-metal materials, etc[13] . Silicate material has excellent properties such as low toxicity, green environmental protection, high temperature resistance, good durability, etc., and it has good applications in wall decoration, floor laying and furniture making. However, compared with the commonly used organic adhesives to prepare the sheet, the silicate biomass material has a low gluing strength, which seriously restricts its popularization and use. The agroforestry residue magnesium chloroxydate cement material takes the agroforestry residue as the main compound, the magnesium chloroxydate cement as the adhesive, the inorganic filler and various additives as the modified materials, and the agroforestry residue magnesium chloroxydate cement material can be prepared by pressing molding or casting molding. The production process of this biomass material is simple, especially the addition of agroforestry residue fiber can greatly improve the thermal insulation performance of the cement board, which can be used as wall thermal insulation material[1][2]. However, the magnesium chloride cement board has the shortcomings of poor water resistance, easy to warp and deform, and return to halogen and white, thus affecting the production and wide use of agroforestry residue magnesium chloride water material to a certain extent. Agroforestry residue fly ash material is a kind of inorganic bonded man-made material processed with fly ash, cement, agroforestry residue and some additives as raw materials[1] . Compared with other building materials, it has many advantages such as high strength, environmental protection, light weight, heat insulation, water resistance, moth resistance, earthquake resistance, as well as can be nailed, can be sawed, can be sanded, can be decorated, non-polluting volatile stimulants, does not absorb static electricity and fast installation. Agricultural and forestry residue fly ash material is regarded as a new type of green and environmentally friendly building material, and it is a new way of deep processing of cement and comprehensive utilization of agricultural and forestry residue, which has a very broad market prospect. Gypsum material of agricultural and forestry residues is an artificial material formed by adding certain amount of chemical additives and water, adopting semi-dry production process, and completing the solidification of gypsum and agricultural and forestry residues under pressure, with gypsum as the binder and agricultural and forestry residues as the reinforcing materials. It is regarded as a new type of building material with the double advantages of wood and gypsum, and can be widely used in construction projects as non-load-bearing interior wall panels, ceilings, partition boards, fire prevention boards, ventilation ducts and packaging materials.

3. Finite Element Analysis

By using ANSYS finite element software, a finite element model was established for the node, and repeated loads were applied to the node model for numerical calculation. After the calculation is completed, the simulation results of the node model are compared with the test results, and it is found that the stress cloud of each component of the node model is basically the same as the stress condition of the node specimen under load, and the data results such as the load-displacement curve curve coincide with that of the test measured data results. It shows that the simulation effect of the established finite element model is good and has good applicability. Meanwhile, on the basis of verifying the correctness of the finite element model, the parametric analysis of the nodes was carried out by changing the plate thickness of the beam-column end plates and the density of the biomass material to study the effects of these parameters on the node bearing capacity and node stiffness. In the finite element modeling, the natural defects of the biomass material, the quality of beam-column gluing, the gaps between the components, the specimen processing, the assembly error and the bolt preload were ignored, which belonged to the idealized model. Therefore, in the early loading stage, the finite element model node has a large bearing capacity, and its load-displacement curve has a certain gap with the test measured curve, but the trend of the curve, the shape and the change rule is basically the same, and the numerical simulation value and the test value of the relative error is about 15%, which verifies the correctness of the model.

4. Conclusion and Outlook

In this paper, three biomass-steel combination beam-column nodes were designed and fabricated, and low-circumference repeated loading tests were conducted on the three node specimens, and the seismic performance of each node was comparatively analyzed in terms of damage characteristics, node strength, node ductility performance, energy dissipation capacity, stiffness and strength degradation, and other seismic performance. Numerical simulation analysis of the three nodes was also carried out by ABAQUS finite element analysis software, and finite element parametric analysis of the nodes was carried out under the premise of high model fit, aiming to develop a biomass-steel combination beam-column node with good seismic performance and high degree of assembly. Compared with the pure steel beam-column node, the biomass-steel combination beam-column node has higher load carrying capacity and stiffness, increased average yield load value and average ultimate load, increased node energy dissipation capacity, and better seismic performance.

Since the structural adhesive in the beams and columns was ignored in the finite element analysis, the effects of the natural defects and cracking of the biomass timber on the node force performance were not fully considered. In order to simulate more realistic results, in the future finite element analysis, try to overcome the technical difficulties, simulate the influence of structural adhesive and wood properties on the node force performance, and construct a secondary development platform for the design of biomass-steel composite structures based on ABAQUS. The bearing capacity and nodal stiffness of the biomass-steel combined beam-column node proposed in this paper are small, and it is suitable for single-story buildings. Combined with the related research on beam-column combination nodes, the setup can be strengthened by adding bracing between beams and columns, adding steel cleats at the end of beams, and attaching steel plates externally to improve the node bearing capacity and node stiffness to be applicable to multi-story buildings.

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