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The Bending Performance Experimental Study on Material Selection of Prestressed High Strength Glue-lumber Beam

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A new type of steel-wood composite component—prestressed high strength glue-lumber beam was developed by using self-developed screw jacking stretching equipment, bending test of a total of 9 glue-lumber beams were conducted, bending performance of glue-lumber beam was studied from the level of material selection. Material type (Ⅱc level SPF, Ⅲc level SPF, poplar, northeast larch), layer plate thickness, lamina lay-ups type were adjusted to study bending elastic modulus, ultimate bearing capacity and failure modes. Compared to imported Ⅱc level SPF timber, ultimate bearing capacity and bending elastic modulus of glue-lumber beam made of northeast larch were respectively increased by 86.18% and 69.48%; bending bearing capacity of glue-lumber beam made of northeast larch was higher, bending performance had a certain increasing trend with decrease of layer plate thickness, effect of interval layout of lamina lay-ups type was better; after prestressed, glue-lumber beam showed characteristics of plastic failure obviously when it was destroyed, self-developed screw jacking prestressed stretching equipment was easy to operate, and had better prospect of practical application.

1. Introduction

As typical modern deep processing wood product, common laminates glue-lumber gradually occupied an important role in modern timber structure field, which was confirmed (Guo (2013) and Fan (2003)). Through way of adhesive-connect thickening and finger-connect increasing, it can make length and size of component without limit of natural timber, and accomplish component type according to requirement of architects, which was confirmed (He et al(2009)). Thus, research of glue-lumber related structure form was of great significance, and research filed was gradual mature, which was confirmed (Liu and Yang (2008); Kohler and Svensson (2011); Long (2010)).
However, Xu (2011), Wei et al (2010), Jiang et al (2002) and Lin et al (2014) reported that, failure mode of common glue-lumber beam mostly showed brittle failure with beam bottom in tension and damage was sudden, which shorten personnel escape time when timber structure collapsed. Zuo et al(2014) , Ribeiro et al (2009) and Mujiman et al(2014) reported that, on the base of using fast-growing forest resources and for purpose of selecting high strength gluing wood , prism test block was used to study compression performance of glue-lumber. The paper aimed at changing material type, layer plate thickness, lamina lay-ups type of glue-lumber, then laminate glue-lumber applicable to compression area of prestressed high strength glue-lumber beam was preferably selected, which can provide material selection basis for subsequent further study.

2. The development of prestressed high strength glue-lumber beam

To give full play of strength of prestressed high strength glue-lumber beam, improve disadvantage of excessive deformation, and realize purpose of adjusting prestress in use, prestressed high strength glue-lumber beam was put forward, and screw jacking stretching equipment was put forward, which was suitable for new type of prestressed glue-lumber beam.

2.1 The composition of prestressed high strength glue-lumber beam

The prestressed high strength glue-lumber beam consisted of laminates glue-lumber, prestressing tendon and stretching anchorage device, as shown in Fig.1

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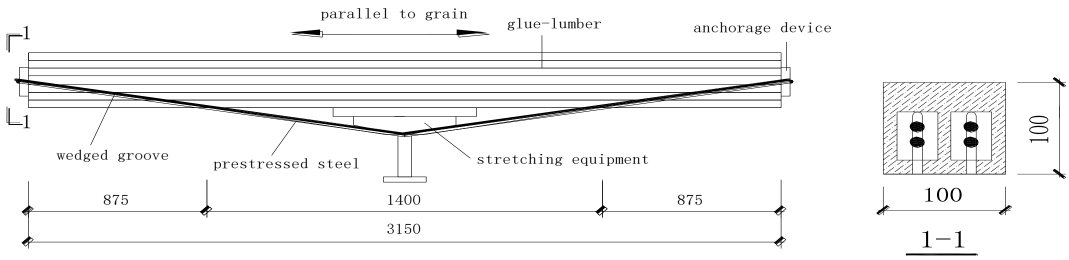


Figure 1: Schematic diagram of prestressed high strength glue-lumber beam

Screw jacking prestressing stretching equipment was set in bottom of beam, prestress applied to glue-lumber beam by stretching prestressing tendon. The anchorage was set in beam end to anchor prestressing tendon and transfer tensile stress. The end steel backing plate was set to prevent beam end from local pressure failure.

2.2 Screw jacking stretching equipment

Prestress was established by screw jacking stretching method, the equipment was shown in Fig.2. The equipment consisted of double channel steel steering block with screw in middle, screw cap, screw and steel backing plate with groove. Before prestressing, screw was screwed in screw bole of steering block, then make steering block move down by rotating screw cap with scale to drive screw joint rotation. Screw jacking stretching method was not only simple process, mechanical reliable, but also with another two outstanding advantages: firstly, by using vertical stretching, the smaller force bore by screw can make large pretension of prestressed steel, thus, stretching process completed only with screw jacking, without professional tensioning equipment such as hydraulic jack. Secondly, size of prestress can be adjusted at any time in process of use, which can overcome influence of creep to deformation of beam.

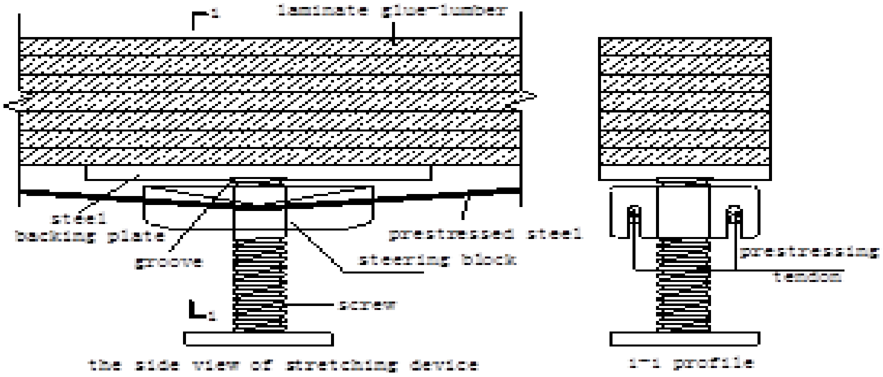


Figure 2: The stretching device figure of screw jacking

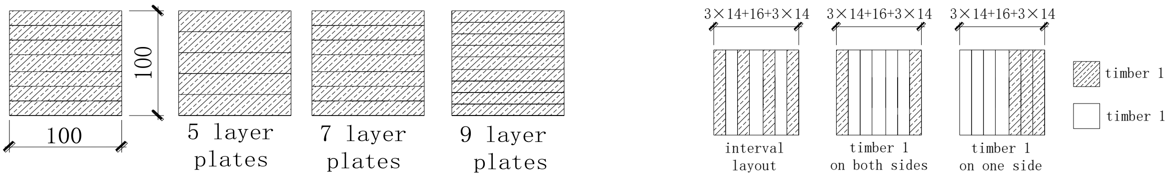
3. Test design

3.1 Testing block design and grouping

According to the mechanical need of structural components and relevant standards, the size of glue-lumber beam was determined to be 3150×100×100(mm)(GB/T 503292(2002); ASTM D143(2000); ASTM D198(2002)), bending performance of glue-lumber beam was studied from view point of material selection, specimens were divided into 3 groups by respectively adjusting material type, layer plate thickness, lamina lay-ups type three kinds of influencing factors, the lamina lay-ups type of the third group selected the similar material properties Ⅱc level SPF and Ⅲc level SPF to combine, the detailed information was shown in Table1 and Figure 3.

Table 1: Parameter statistics of bending specimens

Group number	Specimen number	material	layer plate thickness	lamina lay-ups type
1	B1	Northeast larch	14	—
	B2	poplar	14	—
	B3	Ⅱc level SPF	14	—
	B4	Ⅲc level SPF	14	—
2	B5	Northeast larch	20	—
	B1	Northeast larch	14	—
	B6	Northeast larch	11	—
3	B7	Ⅱc level SPF + Ⅲc level SPF	14	on one side
	B8	Ⅱc level SPF + Ⅲc level SPF	14	interval layout
	B9	Ⅱc level SPF + Ⅲc level SPF	14	on both sides



(a) material type (b) layer plate thickness (c) lamina lay-ups type

Figure 3: Section type of specimen

3.2 Material property

A total of four kinds of timber(Ⅱc level SPF , Ⅲc level SPF, poplar and northeast larch) were selected to make the beam, 《timber structure test method standard》(GB/T 50239-2002) and 《timber parallel to grain compressive strength test method》(GB/T 1935-2009) were comprehensive referenced to conduct the test, plain low relaxation prestressed steel wire of diameter φ7 was used as prestressed steel bar, mechanical property index of all materials were given in Table.2.

Table 2: Mechanical properties of the materials

material type	compresive strength/Mpa	tensile strength/Mpa	elastic modulus /Mpa
Northeast larch	32.13	—	12725.08
poplar	33.44	—	10515.09
Ⅱc level SPF	22.89	—	8888.39
Ⅲc level SPF	22.30	—	8807.83
prestressing tendon	—	1570	2.06×105

3.3 Loading scheme and measuring point arrangement

One-third loading was conducted by using jack, vertical load applied delivered from pressure sensor to DH 3816N static strain measurement system. A total of three displacement meters were set at both sides support and mid-span; a total of 30 strain gauges were arranged uniform along height at mid-span and one-third point section, 2 strain gauges were symmetrical arranged at top of beam mid-span, and on surface of prestressed steel; all measurement data were synchronous collected by static strain measurement system, loading device and measuring point arrangement were shown in Figure 4.

Loading to lower limit load 1.8kN with uniform speed 1mm/min~3mm/min when formal loading, after 15~20 second, loading to upper limit load 4.4kN, then unloading, repeating 5 times, then average value of similar 3 times data was obtained as deflection determination value Δw to measure bending elastic modulus; then step loading was adopted, collect data, take photos and record deflection when reached to 80% of failure load; after then, displacement controlled loading was adopted, deflection was 1.1w, 1.2w, 1.3w, 1.4w, 1.5w until beam was destroyed, lastly, observe and record the failure mode.

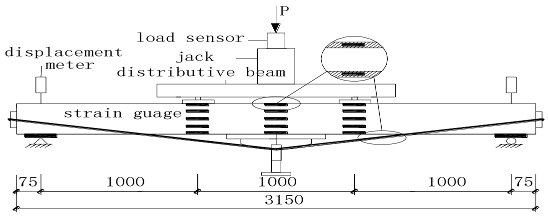


Figure 4: The loading device

4. Test results and analysis

4.1 Failure mode and failure mechanism

The typical failure mode of beam can be classified into three types, as shown in Figure 5.

(1)Laminates brittle broken failure in tensile area

Near one-third point of test specimen B3, B6, B8 became weak part because of mutual action of moment and shear, tensile stress at beam bottom outmost plate was the biggest, test specimens continuous made sound of “beep, pop” when reached to ultimate tension stress, near one-third point bottom laminate happened oblique tension crack, after keep loading, bearing capacity of glue-lumber beam decreased, the crack developed further and extended to mid-span and upper plate.

(2)Laminates bucking failure in compression area

From failure mode of B1, B2, B5 specimen can be seen that the kind of failure was ideal, compressive strength of timber was given full play and reflect advantage; the neutral axis was near bottom laminate, which would make most of timber beam section at compression status, the top beam plate was crushed when reached to ultimate load, then occurred the phenomenon that beam bottom layer plate failed in tension due to excessive deformation.

(3)Cracking failure between laminates scuffing surface

The kind of failure occurred in the timber beam combined by Ⅱc level SPF and Ⅲc level SPF, such as specimen B7, B9, as the performance of Ⅱc level SPF was slightly superior to Ⅲc level SPF, so the laminate deformation of glue-lumber beam laid-up by the two existed difference, glue-lumber laminate was already occurred to be cracking failure when the timber in compression area hadn't reached to ultimate compressive failure status, the kind of failure was one of the failure mode between tensile brittle broken failure and compression bucking failure.

The failure mode of glue-lumber beam changed from brittle failure to plastic failure after prestressing, the compressive strength of timber gained more fully utilized and the deformation was bigger, as shown in Figure 6. The deflection would be a little decrease after unloading and the deformation would recover, the prestressing tendon can support the damaged timber beam, which can prevent the glue-lumber beam from sudden collapse.

Figure 5: Typical failure mode

Figure 6: Bending deformation situation

4.2 Analysis of bending performance

Through analysis of the test data, the test results of glue-lumber beam were shown in Table 3. The indexes of ultimate load, bending elastic modulus and mid-span deflection were mainly included.

Table 3: The main test results

Group number	Specimen number	ultimate load Pu/kN	bending elastic modulus E/MPa
1	B1	53.06	54175
	B2	25.75	24980
	B3	28.50	31965
2	B4	28.11	23802
	B5	27.64	37110
	B1	53.06	54175
	B6	55.89	40245
3	B7	24.83	26988
	B8	20.72	18794
	B9	26.14	28200

The three influencing factors to bending performance were studied according to Table.3

(1)The influence of material type to bending performance of prestressed high strength glue-lumber beam

From Table.3 can be seen, in the four kinds of timber, the bending performance of beam made of northeast larch was obvious superior to the other three wood, compared to Ⅱc level SPF timber, the ultimate bearing capacity and bending elastic modulus respectively increased by 86.18% and 69.48%, compared to poplar, the two respectively increased by 106.06% and 116.87%, compared to Ⅲc level SPF timber, the two respectively increased by 88.86% and 127.61%.

(2)The influence of layer plate thickness to bending performance of prestressed high strength glue-lumber beam

From Table.3 can be known, defects of timber were more dispersing and material distributed uniformly with decrease of layer plate thickness, which made bending performance correspondingly increase, compared to 7 layer plates, ultimate bearing capacity of 9 layer plates increased by 5.33%, amplitude of increase was not obvious, but it increased obvious when compared to 5 layer plates, the ultimate load and bending elastic modulus respectively increased by 102.21% and 8.44%.

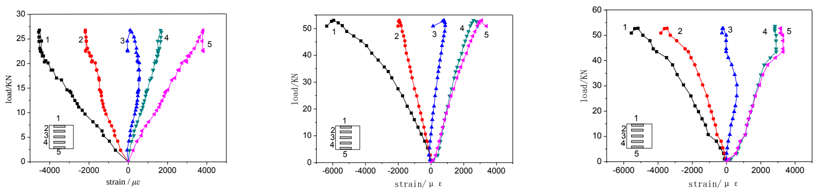
(3)The influence of lamina lay-ups type to bending performance of prestressed high strength glue-lumber beam

Known from Table.3, compared to interval layout, the ultimate load and bending elastic modulus increased by 26.15% and 50.04% when placed on both sides, test results of placing on both sides and one side were not much different, so influence of lamina lay-ups type was not big, interval layout can make defects disperse, scuffing surface cracking failure was easy to happen when placed on both sides and one side, which lead to bending performance can't be fully played.

4.3 Analysis of section strain

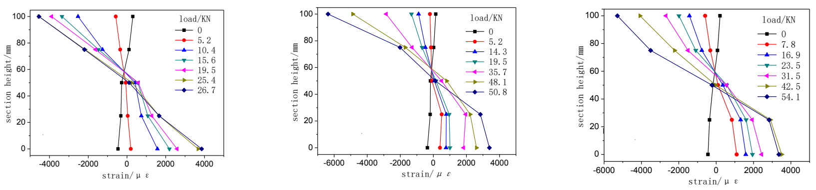
Known from Table 3, material of northeast larch was superior and influence of lamina lay-ups type to bending performance of beam was not big, so mid-span load-strain curve of second group component B1, B5, B6 was selected to analysis, as shown in Figure 7, the negative value was compression area and the positive value was tensile area, in the process of loading, the load-strain relative of each measuring point behaved basically linear change, the strain of each measuring point suddenly decreased sharply when the component reached to ultimate bearing capacity status, thereupon the component damaged, the maximum tension strain of timber in compression area was generally 3000~4000με, the maximum compression strain of timber in tensile area was generally 4500~6500με; Ultimate compression strain of 7 layer plates and 9 layer plates was larger than that of 5 layer plates, it showed that, when tensile area reached to ultimate tension strain, the smaller layer plate thickness, the fuller used of timber in compression area.

The figure of mid-span section strain changed along height of second specimen under different load level was given in Figure 8, it can be seen that in the process of loading, the average strain of glue-lumber beam section basically behaved linear change, so, plane section assumption can be used when the kind of component was designed and calculated.



(a) specimen B5 (b) specimen B1 (c) specimen B6

Figure 7: Load-span section strain curve of the 2 group specimen



(a#)specimen B5 (b#)specimen B1 (c#)specimen B6

Figure 8: The figure of the 2 group specimen span section strain change

5. Conclusion

(1) Aimed to phenomenon that common glue-lumber beam mostly showed to be brittle failure with beam bottom in tension, a new type of steel-wood composite component—prestressed high strength glue-lumber beam was developed by using self-developed screw jacking stretching equipment.
(2) Three typical failure mode of prestressed high strength glue-lumber beam were laminates bucking failure in compression area, laminates brittle broken failure in tensile area and cracking failure between laminates scuffing surface.
(3) Bending bearing capacity of beam made of northeast larch was higher than that made of the other three, compared to Ⅱc level SPF, ultimate bearing capacity and bending elastic modulus respectively increased by 86.18% and 69.48%, so the bending performance of domestic wood was superior to imported timber SPF that used widely in engineering.
(4) The defects of timber were more dispersing and material distributed uniformly with decrease of layer plate thickness, which made mechanical property of timber beam correspondingly increase, the deformation capacity of glue-lumber beam decreased along with the decrease of layer plate thickness; the influence of lamina lay-ups type to timber beam was not big, to prevent glue-lumber from cracking failure, the effect of interval layout was relative optimal, it is suggested that northeast larch of 7 layer plates was used to design when prestressed high strength glue-lumber beam was further studied.

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