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Experimental Study of Screw Withdrawal in Acacia Cross-Laminated Timber (CLT)

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ABSTRACT

This study examines the screw withdrawal strength in Acacia Cross-Laminated Timber (CLT) using screws of 5 mm diameter. CLT, typically made from softwoods, is gaining interest with hardwoods like Acacia for enhanced structural performance. The study evaluated screw withdrawal resistance across face, edge, and end grain orientations, following EN 1382 standards. The results showed that the face grain orientation exhibited the highest average withdrawal strength of 6.7 kN with a specific strength of 10.6 N/mm², while the edge grain had 6.5 kN and 10.3 N/mm². The end grain had the lowest strength with an average of 4.0 kN and 6.3 N/mm². Additionally, higher wood density was found to increase withdrawal strength, with heavier samples showing greater performance. These findings emphasize Acacia's potential for structurally optimized CLT applications

Keywords: Cross-laminated timber, screw, withdrawal strength, Acacia, moisture

INTRODUCTION

Cross-Laminated Timber (CLT) has emerged as a sustainable and high-performance construction material, offering advantages such as environmental benefits, strength, and ease of prefabrication. While traditionally made from softwoods, recent research has explored the use of hardwoods like *Acacia mangium* due to their superior mechanical properties and high density[1]. The growing interest in CLT applications necessitates an in-depth understanding of its connection performance, particularly the withdrawal resistance of fasteners. Among various fasteners, self-tapping screws (STS) are widely used due to their ease of installation, high load-bearing capacity, and ability to resist withdrawal forces without pre-drilling[2]

The withdrawal resistance of screws in CLT is influenced by multiple factors, including wood species, density[3], [4], [5], [6], [7], moisture content[8], [9], grain orientation[5], [6], and screw geometry[4]. While extensive studies have been conducted on conventional softwood-based CLT[10], [11], [12], research on alternative hardwood species[11], [13], such as Acacia, remains limited. Given Acacia's promising mechanical properties, investigating its performance in CLT applications is essential for expanding its structural use.

Acacia's high density and strength provide potential mechanical advantages over traditional softwood CLT panels. However, the behavior of fasteners in Acacia CLT, especially in relation to withdrawal resistance, remains largely unexplored. Fasteners, including screws, are critical to CLT joint performance, as their resistance to pull-out forces is fundamental to structural integrity, particularly in tensile load applications

RESEARCH METHODS

Materials

In this study, tests were conducted on cross-laminated Acacia wood using screws with an approximate diameter of 5 mm and a length of 3 inches. The test specimens were wood blocks cut from panels measuring 2400 mm x 1200 mm x 75 mm, then sectioned into 30 individual blocks, each measuring 75 mm x 75 mm x 75 mm.

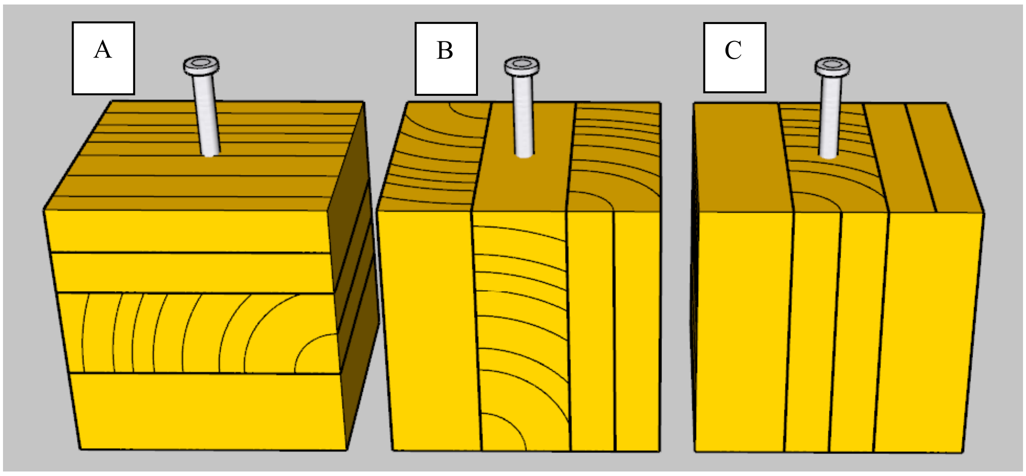

Figure 1. Illustration of Screw Placement: (A) Face Grain, (B) Side Grain, and (C) End Grain

Figure 2. Screw Material

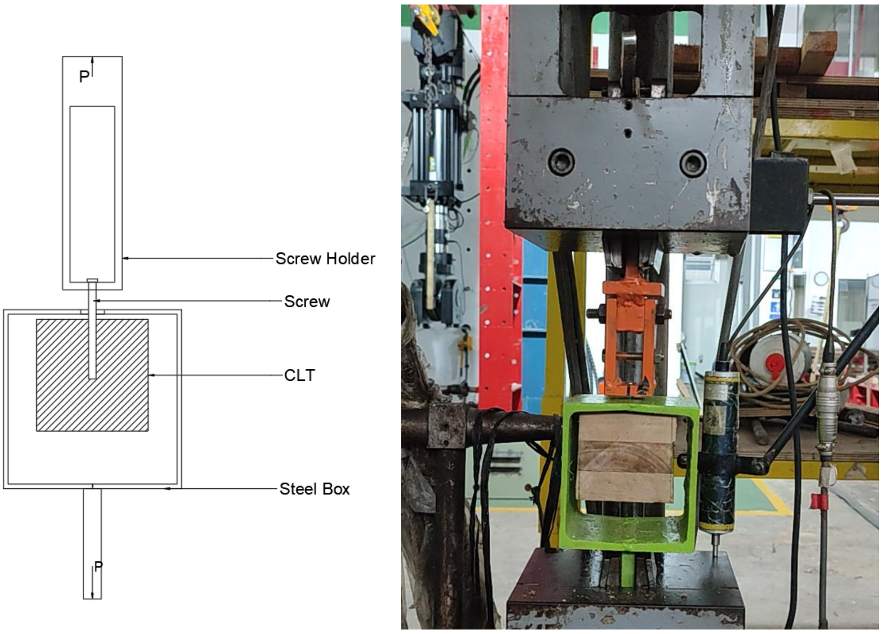

Figure 3. Set-up for Test

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Methods

The screw withdrawal strength test was conducted in accordance with EN 1382 [14], a standard procedure for determining the withdrawal strength of nails or screws in wood. The test utilized a Universal Testing Machine (UTM) with a loading duration of 60 ± 15 seconds. According to the EN 1382 standard, the test procedure requires the fastener to be embedded to a depth of 8d; therefore, the screw was embedded to a depth of 40 mm in the test specimen. The experimental setup used in the laboratory is shown in Figure 1.

RESULT AND DISCUSSION

Withdrawal Test

The screw withdrawal test results were calculated using the formula provided in EN 1382 by dividing the test values by the screw's surface area. The fax value was determined using the following formula:

$$f_{ax} = \frac{F_{ax}}{d.\pi.l_{ef}} \quad (1)$$

Here, d represents the diameter of the screw, and l_{ef} denotes the penetration depth of the screw into the wood. This calculation yields the withdrawal strength values for each screw, as presented in the table 1,2 and 3.

Effects of Face, Edge, and End Grain Orientations on Screw Withdrawal in Acacia Cross-Laminated Timber

Face grain

On the face grain from table 1 the average withdrawal force (Fax) was 6.7 kN, with a specific withdrawal strength (fax) of 10.6 N/mm². The highest values were recorded in sample 14, with a Fax of 9.5 kN and a fax of 15.1 N/mm². Face grain typically refers to the orientation where wood fibers are perpendicular to the screw surface. This is the most common orientation used in practical applications, such as installations on board surfaces. The withdrawal strength in this orientation is generally higher than in the end grain, as the screw more effectively cuts across the wood fibers, creating a stronger interaction between the screw and the wood material.

Table 1. Results of screw withdrawal testing on face grain (A)

No	Weight (gr)	Moisture Content (%)	F_{ax} (kN)	f_{ax} (Mpa)
1	270,7	18	5,3	8,5
2	266,3	16	7,4	11,8
3	249,1	16	6,0	9,6
4	303,0	16	5,7	9,1
5	342,0	18	8,5	13,5
6	308,0	16	6,9	11,0
7	240,5	18	7,1	11,3
8	252,2	18	6,0	9,6
9	247,6	18	6,4	10,2
10	261,5	12	6,4	10,2
11	268,3	14	8,8	14,0
12	261,7	16	6,6	10,4
13	311,0	16	7,9	12,6
14	312,0	16	9,5	15,1
15	254,2	16	6,6	10,4
16	287,9	16	5,0	8,0
17	280,2	16	7,1	11,3
18	277,5	20	6,6	10,4
19	273,5	18	6,6	10,4
20	304,0	18	7,4	11,8
21	253,7	16	7,1	11,3
22	266,2	18	4,7	7,4
23	262,7	18	4,8	7,7

No	Weight (gr)	Moisture Content (%)	F_{ax} (kN)	f_{ax} (Mpa)
24	278,1	18	5,2	8,2
25	279,2	16	8,1	12,9
26	273,3	20	6,6	10,4
27	276,8	20	5,7	9,1
28	272,5	12	7,9	12,6
29	263,5	16	5,5	8,8
30	267,7	18	6,7	10,7
Average	**275,5**	**16,8**	**6,7**	**10,6**

Edge grain

On the edge grain from table 2, the average withdrawal force was 6.5 kN, slightly lower than that of the face grain, with a specific withdrawal strength (fax) of 10.3 N/mm². The highest values were observed in sample 25, with a Fax of 9.8 kN and a fax of 15.6 N/mm². The edge grain exhibits strength close to that of the face grain, though slightly lower. In this orientation, the screw is installed parallel to the wood fibers, resulting in fairly strong withdrawal resistance, though not as optimal as in the face grain, as the wood fibers are not fully cut by the screw. The edge grain is commonly used when screws are placed on the side of wood sections, such as wood blocks.

Table 2. Results of screw withdrawal testing on edge grain (B)

No	Weight (gr)	Moisture Content (%)	F_{ax} (kN)	f_{ax} (MPa)
1	255,7	16	5,9	9,3
2	256,8	16	6,6	10,4
3	299,4	16	5,5	8,8
4	284,9	16	5,9	9,3
5	299,0	18	5,5	8,8
6	269,6	16	5,3	8,5
7	253,8	16	6,6	10,4
8	255,8	16	5,5	8,8
9	255,4	14	6,0	9,6
10	268,8	16	6,7	10,7
11	302,0	18	7,2	11,5
12	278,6	16	5,3	8,5
13	276,6	16	8,5	13,5
14	248,4	16	5,7	9,1
15	258,8	16	6,2	9,9
16	277,0	16	9,3	14,8
17	280,9	14	6,0	9,6
18	328,0	18	5,7	9,1
19	260,4	18	6,4	10,2
20	276,2	18	6,4	10,2
21	263,0	16	5,3	8,5
22	317,0	16	5,5	8,8
23	247,6	16	5,0	8,0
24	289,9	16	6,9	11,0
25	275,4	16	9,8	15,6
26	272,3	16	6,9	11,0
27	278,5	14	8,1	12,9
28	296,3	16	6,6	10,4
29	272,4	16	6,7	10,7
30	301,0	16	6,6	10,4
Average	**276,7**	**16,1**	**6,5**	**10,3**

End grain

In this orientation the results shows in the table 3, the average axial force (Fax) is 4.0 kN, and the axial stress (fax) is 6.3 N/mm², which is significantly lower than the values observed in the face grain and edge grain. The highest values were recorded in sample 19, with Fax reaching 6.2 kN and

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fax at 9.9 N/mm². This orientation involves screws installed at the wood end, parallel to the grain direction. Pull-out strength in the end grain is generally the lowest, as screws tend to pull along the wood fibers, making it easier for them to detach. In practical applications, the use of screws in the end grain should be avoided or at least supplemented with additional reinforcement to prevent structural failure.

Table 3. Results of screw withdrawal testing on end grain (C)

No	Weight (gr)	Moisture Content (%)	F_{ax} (kN)	f_{ax} (MPa)
1	247,4	16	3,5	5,5
2	280,9	14	4,5	7,1
3	289,5	14	4,1	6,6
4	280,3	16	4,0	6,3
5	241,4	14	3,6	5,8
6	265,9	16	3,6	5,8
7	268,0	14	4,0	6,3
8	259,5	16	4,0	6,3
9	287,7	16	3,5	5,5
10	269,7	18	5,5	8,8
11	285,3	20	3,5	5,5
12	272,4	18	5,3	8,5
13	254,4	16	2,2	3,6
14	273,6	20	4,0	6,3
15	286,9	16	4,3	6,9
16	282,8	14	3,8	6,0
17	256,0	16	2,2	3,6
18	242,2	20	2,9	4,7
19	273,1	16	6,2	9,9
20	271,5	18	4,7	7,4
21	291,9	16	5,9	9,3
22	269,5	16	4,8	7,7
23	274,9	18	3,8	6,0
24	283,6	18	4,0	6,3
25	252,1	16	3,3	5,2
26	266,3	16	3,5	5,5
27	255,3	16	3,6	5,8
28	285,0	18	3,6	5,8
29	269,2	18	3,3	5,2
30	266,4	18	3,5	5,5
Average	**270,1**	**16,6**	**4,0**	**6,3**

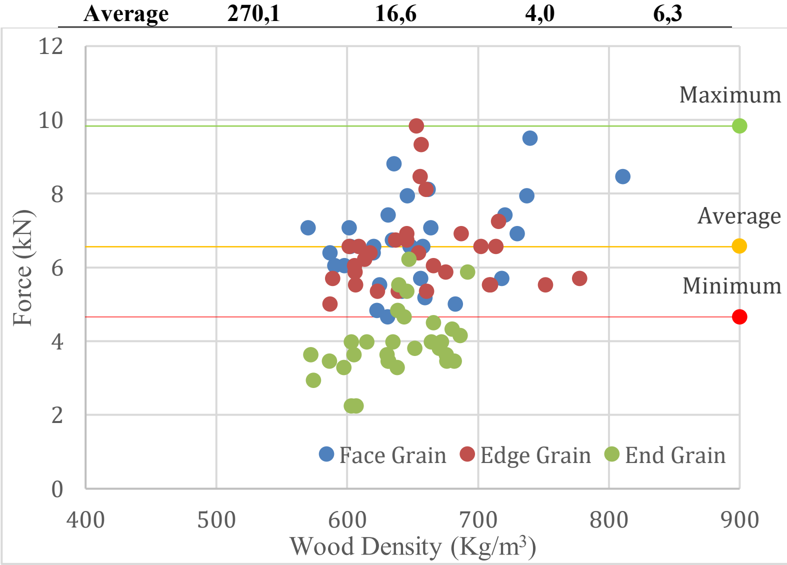

Figure 4. Relationship between screw withdrawal strength and wood density

Effects of Moisture Content

The moisture content in wood is a crucial factor influencing joint strength, including screw withdrawal strength. Key observations related to moisture content in this experiment include:

1. The average moisture content for face grain tests was 16.8%, 16.1% for edge grain, and 16.6% for end grain. While no significant differences in moisture content were observed across the three orientations, fluctuations in moisture content may still impact the test results.
2. Higher moisture content can cause the wood to soften, which may reduce the strength of interaction between the screw and the wood fibers, as the fibers tend to stretch or shift. For example, in sample 18 on the face grain, both Fax and fax were lower than the average values.
3. Conversely, lower moisture content can result in better withdrawal strength, as the wood tends to become stiffer and offers greater resistance against screw withdrawal forces. However, extremely low moisture content can make the wood brittle, leading to potential cracking or splitting under significant force.

Effects of Density

Wood weight is often closely related to its density; heavier wood tends to have higher density due to the greater concentration of wood fibers within a given volume. This experiment also analyzed the correlation between specimen weight and screw withdrawal strength..

Face grain

Sample 5, with a weight of 342.0 grams, demonstrated a Fax of 8.5 kN and a fax of 13.5 N/mm², which are among the higher values. In contrast, sample 22, weighing 266.2 grams, showed a significantly lower Fax of 4.7 kN and fax of 7.4 N/mm². These results indicate that weight correlates with withdrawal strength, with heavier samples tending to exhibit higher withdrawal values.

Edge grain

Sample 25, weighing 275.4 grams, reached a Fax of 9.8 kN and a fax of 15.6 N/mm², among the highest values in this group. By contrast, sample 23, with a weight of 247.6 grams, recorded a Fax of 5.0 kN and fax of 8.0 N/mm², one of the lowest values in this orientation. This pattern also suggests that weight positively influences withdrawal strength, with heavier specimens generally being stronger.

End grain

In the end grain orientation, sample 19, weighing 273.1 grams, reached a Fax of 6.2 kN and fax of 9.9 N/mm², the highest values observed for this orientation. Meanwhile, sample 13, with a weight of 254.4 grams, recorded only a Fax of 2.2 kN and fax of 3.6 N/mm², the lowest values in this orientation. This trend suggests that weight also impacts withdrawal strength in the end grain, although the overall strength is lower compared to the face and edge grain.

Comparison of Test Results with Previous Research

A comparison between the screw withdrawal performance in Acacia wood obtained from laboratory results and findings from previous researchers [15] highlights the influence of wood density on screw effectiveness. The average withdrawal capacity observed in the laboratory for 5 mm diameter screws in Acacia wood was 6.7 kN, which exceeds the 4.63 kN recorded for Pine and is nearly equivalent to the value for Larch wood at 6.73 kN. This suggests that Acacia, a denser wood, provides greater resistance against withdrawal forces. Similarly, the average withdrawal stress in Acacia was found to be 10.6 MPa, significantly higher than the 6.85 MPa observed in Pine and also exceeding the 9.97 MPa in Larch. The improved performance in Acacia can be attributed to its higher density, which facilitates better screw-thread engagement, enhanced mechanical locking, and improved stress distribution around the screw, thereby reducing the likelihood of failure during withdrawal. Overall, these findings indicate that using high-density woods like Acacia in screw applications can significantly enhance structural integrity and reliability compared to softer woods like Pine.

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CONCLUSION

The results of this study indicate that wood density influences screw withdrawal strength, as seen in the weight comparison of specimens. Heavier specimens, presumed to have higher density, tended to show greater withdrawal strength. Moisture content also affects withdrawal strength, with higher moisture levels tending to ly provides better withdrawal strength, though excessively dry wood can become brittle. Woweaken the wood as it becomes softer, even though its weight might increase. Wood with lower moisture content generalod orientation impacts withdrawal strength, with face grain and edge grain showing higher strength than end grain, regardless of weight or density. In the end grain, withdrawal strength remains lower because forces are transmitted parallel to the wood fibers, making detachment easier.

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