Mechanical and Physical Properties of Cross-Laminated Timber Made from Batai using Different Glue Spread Amounts

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Abstract. This study aimed to determine the mechanical and physical properties of the Cross-Laminated Timber (CLT) glued with different amounts of glue. Cost of glue is the utmost importance where it will help in reducing the CLT manufacturing cost. Four different amounts of glue spread were used where the glue that used was phenol-resorcinol formaldehyde (PRF); 150, 200, 250 and 300 g/m². The testing of the CLT was conducted by following BS EN 408:2010, BS EN 16351:2015, ASTM D 2718 method B, ASTM D 143-94 and Japanese Agricultural Standard (JAS) 1152:2007. The analysis of physical tests that have been carried out are density, moisture content, shrinkage and swelling of the CLT’s thickness. Meanwhile, the mechanical tests were compression parallel and perpendicular to the grain, three-point bending test (flatwise and edgewise of CLT) and shear test. The highest density was shown by the CLT that using 300 g/m² which the value was 316.41 kg/m³. Whereas the highest moisture content was shown by CLT that used 250 g/m² with 15.49% in value. The highest thickness shrinkage percentage was 2.50% CLT with 200 g/m² while the highest thickness swelling percentage was 5.60% which the CLT used 150 g/m². For the flatwise bending test, it shows that the CLT that used 300 g/m² has the highest MOE and MOR value which were 510.63 N/mm² and 8.39 N/mm². The MOE and MOR value for edgewise bending also shows that CLT that used 300 g/m² was the best with 1528.70 N/mm² and 13.48 N/mm². In compression perpendicular to grain test, the CLT with 150 g/m² shows the highest value of MOE which was 5.89 N/mm² while CLT that used 200 g/m² has the highest value of compressive strength with 9.10 N/mm². However, for compression parallel to grain test, the CLT that used 300 g/m² shows the best performance with 1002.78 N/mm² and 13.75 N/mm² of MOE and compressive strength value. Lastly, for the shear test, the highest shear strength value was 0.39 N/mm² which belongs to CLT that used 150 g/m². Thus, CLT that used 300 g/m² of glue spread amount is the best CLT which, the more the amount of glue, the better the performance of the CLT.

1. Introduction

The demand for solid wood has become increase from year to year and caused the hardship for the industry to fulfil the demand. An initiative by using fast-growing species like Batai wood (Paraserianthes falcataria) has been established as it only took a short period of time to be harvested. However, it has low density which make it not suitable to use in construction. So, this wood material is used to produce wood composite product such as Cross-Laminated Timber (CLT). CLT is a wood composite product made up of 3 or more layers of timber boards or laminas assembled orthogonally. It is excellent in strength and stiffness properties which make it popular as building material [1].
CLT can be said a simple product as it can be simply obtained by assembling only two basic materials like laminas and glue [2]. Glue plays an important role in this manufacturing and thus it is important to choose the suitable glue [3]. However, glue price is quite expensive especially the constructional adhesive which cause the manufacturing cost of CLT is high. In industry, the glue to be used for CLT must meet the requirements of AITC405-2005 [4].

The idea about the development of CLT using different amounts of glue spread was because to determine the properties of the CLT when using different amounts of glue spread as the demand for CLT is high for construction and the probability of the demand will continue to be raised in the future is high. So, it will be such a great benefit for the company that produces CLT if they can reduce the CLT’s manufacturing cost.

2. Materials and methods

2.1 Preparation of raw material
Batai (Paraserianthes falcataria) wood laminas have been used in this study. It was air-dried to reach the moisture content of 8-12%. The laminas were visually graded which laminas that have defects such as knots, insect damages of fissures were eliminated as it could affect the strength of the CLT.

2.2 CLT making process and cut into test pieces
In this study, 8 panels of three-layered CLT of 1000 mm × 1000 mm × 60 mm in size were produced by gluing the laminas orthogonally by using different amounts of glue spread; 150, 200, 250 and 300 g/m² which act as the parameter. The glue that used was Phenol-resorcinol Formaldehyde (PRF) which mixed with hardener at the ratio of 1:0.25. The press pressure used to press the CLT panel was 1 MPa for minimum 4 hours using 3D-clamping machine. Then, the CLT panels were randomly cut into test pieces in accordance to standard used for mechanical and physical testing.

2.3 Mechanical test
The mechanical properties of CLTs were determined according to BS EN408:2010, BS EN 16351:2015 and ASTM D 2718 method B using Universal Testing Machine. The test speed for both compression parallel and perpendicular to grain was 5 mm/min while 1 mm/min of load test speed was used for three-point bending test (flatwise and edgewise) and shear test. There were fifteen test pieces were tested for each types of glue spread amounts for each respective test. The testing of samples was shown in Figure 1.

![Figure 1. Mechanical testing of sample: Three-point bending test (a) & Compression test (b).](image)

2.4 Physical test
The physical properties of CLTs were determined according to JAS1152:2007. The physical test used were moisture content test, density test and dimensional stability (thickness shrinkage and swelling) test. Fifteen test pieces were tested for each types of glue spread amounts for each respective test.
3. Results and discussion

3.1 Mechanical test

Based on Figure 2, CLT using 300 g/m² has the highest value of elastic modulus (EM) which was 1002.78 N/mm² and CLT using 250 g/m² has the lowest EM value which was 873.44 N/mm². The result obtained also showed that there was a significant difference at \( p \leq 0.05 \) between the CLT made using different amounts of glue spread. Supposedly, the CLT using 250 g/m² has higher EM value than 150 and 200 g/m². This is because CLT using 250 g/m² has the highest percentage of MC. The mechanical properties of the wood product can be affected by factors like moisture content, defects such as knot and grain slope [5].

Figure 3 showed that CLT using 300 g/m² state the highest compressive strength which was 13.75 N/mm² while CLT using 250 g/m² is the lowest which was 12.77 N/mm². There is no difference at \( p \leq 0.05 \) among all the amounts of glue spread. Supposedly, the CLT using 250 g/m² has higher EM value than 150 and 200 g/m². This is because CLT using 250 g/m² has the highest percentage of MC. Moisture content of the CLT is one of the factors that affect this result obtained.

![Figure 2. Elastic modulus of CLT for compression parallel to grain test at different amounts of glue spread.](image)

![Figure 3. Compressive strength of CLT for compression parallel to grain test at different amounts of glue spread.](image)
From Figure 4, it shows that CLT using 150 g/m² amount of glue spread has the highest EM value which was 5.89 N/mm² while CLT using 250 g/m² has the lowest EM value which was 5.68 N/mm². There is no difference at \( p \leq 0.05 \) for the EM among all the glue spread amounts. Figure 4 also shows that CLT using 200 g/m² has the highest compressive strength while CLT using 250 g/m² has the lowest compressive strength which was 7.29 N/mm². There was a significant difference between at \( p \leq 0.05 \) between CLT using 200 and 250 g/m². The result showed that the moisture content surely affected the mechanical properties of CLT made with 250 g/m² which can be seen in Figure 4 that shows that CLT using 250 g/m² amount of glue spread has the highest percentage of MC.

Figure 4. Elastic modulus and compressive strength of CLT for compression perpendicular to grain test at different amounts of glue spread.

Figure 5 shows the modulus of elasticity (MOE) of CLT for flatwise and edgewise bending test at different amounts of glue spread. Based on Figure 4, the CLT using 250 g/m² has the lowest MOE for flatwise bending test which was 405.65 N/mm² while CLT using 300 g/m² has the highest MOE for edgewise bending test which was 497.37 N/mm². There was no difference at \( p \leq 0.05 \) of the MOE between all the CLT. In edgewise bending test, the CLT using 150 g/m² has the lowest MOE which was 891.49 N/mm² while CLT using 300 g/m² has the highest MOE which was 1528.70 N/mm². The result obtained showed that CLT using 150 g/m² has significant difference to other amounts of glue spread. From the results obtained, it shows that the CLT was stiffer when it is tested edgewise rather than tested on flatwise. This is because, the edgewise of the CLT is the strongest direction than the flatwise as the load was stressed parallel to the grain [6].

Figure 5. Modulus of Elasticity of CLT for flatwise and edgewise bending test at different amounts of glue spread.
Figure 6 shows the Modulus of Rupture (MOR) of CLT for flatwise and edgewise bending test at different amounts of glue spread. For flatwise, CLT using 150 g/m² amount of glue spread was the weakest CLT as it shows the lowest MOR value which was 6.57 N/mm² while CLT using 250 g/m² is the strongest CLT as it has the highest MOR value which was 9.05 N/mm². The result obtained also showed that there was a significant difference between CLT using 150 g/m² to 200, 250, and 300 g/m². For edgewise, CLT using 150 g/m² has the lowest MOR value which was 8.84 N/mm² while CLT using 300 g/m² has the highest MOR value which was 13.48 N/mm². The result also showed that there is significant difference between 150 to 200 and 300 g/m².

Thus, from both flatwise and edgewise bending results, we can observe that CLT made up with glue spread amount up to 250 g/m² shows a better performance than others that lower than 250 g/m² in glue spread amount usage. This is because the CLT’s strength is different from its grain or direction. The wood laminas have grains which indicate the strength properties of the CLT. The wood lamina has more strength along the grain than across it [7].

![Figure 6. Modulus of Rupture of CLT for flatwise and edgewise bending test at different amounts of glue spread.](image)

Referring to Figure 7, the CLT with 150 g/m² of glue amount glue spread has the highest value of shear strength which was 0.39 N/mm² while the lowest shear strength value is the CLT with 250 g/m²; 0.29 N/mm². There are no significant differences at $p \leq 0.05$ of the shear strengths between the CLT made with four different amounts of glue spread. The result obtained shows a slightly different from the theory of the more the amount of glue amount, the better the performance of the structural wood. From Figure 8, the above picture shows adhesive failure (failure mode) that most occurred in this test which was 98% of occurrence while the below picture shows the rolling shear, the failure mode that occurred 2%. Rolling shear likely occurs in the CLT where all the laminas are arranged in orthogonally. It is classified as wood failures which are considered as appropriate failure modes in resistance to shear test [8].
3.2 Physical test

Based on Figure 9, the glue spread amount of 250 g/m² shows the highest mean which was 15.49% followed by 200 g/m², 300 g/m² and 150 g/m² which each of it has the moisture content of 13.95%, 12.23%, and 12.16%. However, there is no significant difference at $p \leq 0.05$ among the difference of glue amount applied to the CLT. From the study, it shows that the different amount of glue spread did not give any effect to the moisture content of the CLT. This is because the glue used in this study which was PRF did not give any effect to physical properties. PRF is one of the thermosetting resins that very resistant to moisture and damp condition [9]. From Figure 9, the highest percentage of thickness shrinkage is the CLT with 200 g/m² which the value is 2.5% while the lowest percentage of thickness shrinkage is the CLT with 150 g/m² which is 1.99%. The result also shows that there is no difference between all the glue spread amounts. But the CLT with 250 and 300 g/m² shows a similar percentage of thickness shrinkage which was 2.23%. Such inconsistency can be due to the combined effects of the tangential and radial shrinkage variation found in the CLT [10].

Figure 9 shows the CLT with 150 g/m² amount of glue spread stated the highest percentage of thickness swelling which is 5.6% followed by 200, 250 and 300 g/m² which the percentage value is 5.31, 5.09 and 4.67%. There is a significant difference between glue spread amount of 150 and 300 g/m² ($p \leq 0.05$). From the result obtained, it shows that the glue spread amount affects the swelling thickness of the CLT. This is because the increase of the glue amount will cause the reduction of the thickness swell of the structural product. The penetration of PRF into the wood cell wall caused the dimension of the CLT to become stable which causes the reducing of the thickness swell [11].

Based on Figure 10, the CLT made by using 300 g/m² of glue amount has the highest density which was 316.13 kg/m³ following by the 250 g/m², 200 g/m², and 150 g/m² which each of the density
were 315.41 kg/m$^3$, 312.92 kg/m$^3$ and 312.36 kg/m$^3$. However, there is no difference at $p \leq 0.05$ among the difference of glue amount applied to the CLT. Basically, the glue amount used to make any wood product will affect the density of the product produced. Based on the data analyzed from Figure 10, the higher the amount of glue used to make the CLT, the higher the density of the CLT. Batai wood is a low-density wood which it has great ability to penetrate the adhesive deep into the wood. The high amount of adhesive caused the amount of adhesive absorbs into the wood is high and caused the density of the CLT to become increase too [12].

![Figure 9. Moisture content, thickness swelling and shrinkage of CLT at different amounts of glue spread.](image1)

![Figure 10. Density of CLT at different amounts of glue spread.](image2)

4. Conclusion
This study was set out to determine the mechanical properties of the CLT made using different amounts of glue spread; 150, 200, 250 and 300 g/m$^2$. The findings can be summarized as follow: The mechanical properties of the CLT increased as the glue spread amount used increased. However, the mechanical properties also influenced by the moisture content of the CLT. Thus, CLT using 300 g/m$^2$ has the best mechanical and physical properties among others.

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