Effect of shape of test specimen on the shear strength of bamboo from eastern region of sumatera utara

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Abstract. Wood is the most common forest-based product used in the construction industry, but due to reducing area of forest in the world, substitution materials for wood are needed. Bamboo has a huge prospect for the future as a wood substitute, and extensive and continuous research of bamboo, especially in mechanical properties of bamboo must be carried out to support bamboo as a material substitution for woods. This research focused on the shear strength of bamboo by comparing two types of standard tests used to determine the shear strength of bamboo. The standards are ISO 22517 and ASTM D 143. The compression test to determine the compressive strength is also conducted in this research. The bamboo species that used in this research are the species that grow in various district in the eastern region of Sumatera Utara. The result of the test shows that the highest shear strength for the specimens tested by ISO 22157 standard is Bambusa vulgaris with 6.32 MPa from Asahan and Tanjung Balai, and for the specimens tested by ASTM D 143 standard is Bambusa vulgaris with 12.31 MPa from Batubara. From the result it can be seen that all samples tested with ASTM D 143 standard have higher shear strength than those who tested with ISO 22157, with conversion ratio of 0.63. For compression test, the highest compressive strength is Gigantochloa robusta with 65.41 MPa from Asahan and Tanjung Balai.

1. Introduction
For forest-based products in Indonesia, wood is one of the most commonly used materials almost in every aspect, especially in the construction industry. The price of wood material is increasing each day as the forest itself has been reduced, so that the substitution material is needed. Bamboo has a shorter cycle of growth than wood, can be harvested every 3-5 years while softwoods have 20 years at most to be harvested [1], and it’s mechanical properties comparable to some wood species [2]. Therefore, it makes bamboo more suitable than wood. In Indonesia, bamboo has been used in rural life. Bamboo planted around the countryside or even gardens to be used as goods for daily use [3].

Bamboo is an orthotropic material with high strength along and low strength transversal to its fibers. The structure of bamboo is a composite material, consisting of long and aligned cellulose fibers immersed in the ligneous matrix [4]. Like other materials, the mechanical properties of bamboo are very dependent on the correlation of proportions and fiber distribution in the cross-section. Mechanical property is strongly influenced by the density which depends on the fiber content, fiber diameter, and thickness of the wall on the bamboo [5]. For the durability, untreated bamboo has a design life reach 10-15 years if it keeps appropriately [6]. For having bamboo in the construction, it is lack of design guidance and standardization which means that the engineering design of bamboo has not yet been fully addressed. Further application of bamboo relevant to construction includes its use as scaffolding, farmhouse, and bridges.
This research aims to determine the mechanical properties of the bamboo species, especially the shear strength which is obtained by the shear test. Shear is important in bamboo because its the weakest point. Bamboo is as strong as wood in tension but much weaker in shear. In the bamboo construction of joints, holes are needed, and these give the effect of shear in the bamboo [7]. Several studies have tested bamboo’s mechanical properties [8] [9] [10], but most only test the compressive and tensile strength of bamboo, rarely test the shear strength.

Test specimens and shear tests are conducted by following ISO 22157 standards as a test standard for bamboo, and also be compared with the test by following the ASTM D 143 standard as a test standard for small clear sample for woods. As an additional test, the compression test for bamboo also conducted along with the shear test because it is using the same bamboo specimen size. The specimen for the test was taken from 7 species of bamboo grow in Simalungun, Batubata, Asahan and Tanjung Balai. The species were selected for test specimen because they are suitable as the material the construction [11].

2. Method

2.1. Preparation Of Bamboo

There are 7 bamboo species involved in this research, which are sourced from Simalungun, Batubata, Tanjung Balai and Asahan district in Sumatera Utara province. Those 7 bamboo species include Bambusa blumeana, Bambusa vulgaris, Dendrocalamus asper, Gigantochloa atter, Gigantochloa robusta, Schizostachyum bracycladum, Schizostachyum zolingeri. For the availability in each section (Simalungun, Batubara, Tanjung Balai and Asahan) is shown in table 1.

| Species                     | Simalungun | Batubara | Asahan And Tanjung Balai |
|-----------------------------|------------|----------|--------------------------|
| Bambusa blumeana            | X          | X        | X                        |
| Bambusa vulgaris            | X          | X        | X                        |
| Dendrocalamus asper         | X          | X        | X                        |
| Gigantochloa atter          | X          | X        | X                        |
| Gigantochloa robusta        | X          | X        | X                        |
| Schizostachyum bracycladum  | X          | X        | X                        |
| Schizostachyum zolingeri    | X          | X        | X                        |

These bamboo culms from every species were selected and dried for about three weeks. The moisture content more or less than 15% to have good mechanical properties and is less vulnerable to fungus attacks [12]. The moisture content to conduct mechanical properties testing is 12% more or less regarded as the standard and references[13][14]. The selected bamboo culm must be free from fungus and has no defect for the mechanical properties test. Figure 1 shows the bamboo culm being pile in the area to get it dried.
2.2. Mechanical testing of bamboo

Each of bamboo culm was cut into small specimens. The small specimens were taken from the internode and node of the bamboo culm. There are 2 tests in this research which are, shear, and compression test following ISO 22147-1:2004[13], ISO 22157-2:2004 [15], and ASTM D 143 [16]. The specimen was taken from the top, middle, and bottom sections of the culm and each specimen will be marked respectively. For bamboo specimens to be tested with ASTM D 143 standard, modifications must be made to the specimen. In ASTM D 143 shear parallel to grain test, the specimen size is specific, where the specimen width is equal to the height of the shear plane to be compressed to get the shear strength. But in bamboo, the thickness of the specimen has to be modified equal to the thickness of the bamboo culm. Additional area also added to the bottom of the specimens where the area is to be attached to the test equipment.

![Figure 2. (a) compressive and shear test specimen according to ISO 22157 (b) Modified Shear Test Specimen according to ASTM D 143.](image)

Figure 3 shows the conditions when the specimens test conducted. Figure 3a shows when the compression test is conducted and the maximum load will occur along with the failure on the specimen which is shown with the crack and the deformation on the specimen. Figure 3b shows failure starts to occur when the constant load is given at the Universal Testing Machine and the specimen will be split. The maximum load for each test carried out is recorded and then the average value of each type of test is calculated to determine the compressive and shear strength from each of bamboo species.
3. Result and Discussion

3.1. Shear strength

Failure pattern caused by the shear test comes along with the visual crack of the specimen [19]. Shear test failure crack at the specimen tested by the modified ASTM D 143 standard is shown in figure 4a, and the failure tested by ISO 22157 standard is shown in figure 4b. Table 2 shows that the highest average value of the shear strength tested by ISO 22157 standard is Bambusa vulgaris, with 6.32 MPa from Asahan and Tanjung Balai district, and for the modified ASTM D 143 is Bambusa vulgaris with 12.31 MPa from Batubara. From this result, it can be seen that the average shear strength value obtained from the modified ASTM D 143 testing is higher than the ISO 22157 results. The bottom section has the highest value followed by middle and top respectively. For the ISO 22157 test, the difference from node to internode average shear strength values are 1.006 MPa, 0.96 MPa, and 1.01 MPa for Asahan and Tanjung Balai, Batubara, and Simalungun specimens respectively. For the modified ASTM D 143 test, the difference from node to internode average shear strength values are 0.98 MPa, 0.99 MPa, and 0.84 MPa for Asahan and Tanjung Balai, Batubara, and Simalungun specimens respectively.

Figure 3. (a) Compressive test setup (b) Shear test setup according to ISO 22157 (c) Shear test setup according to modified ASTM D 143.

Figure 4. Specimen failure after the shear test (a) Modified ASTM D 143 (b) ISO 22157
Table 2. Shear strength according to ISO 22157 and modified ASTM D 143.

| Origin          | Species                | Test Condition | Shear Strength (MPa) (ISO 22157) | Shear Strength (MPa) (modified ASTM D 143) |
|-----------------|------------------------|----------------|----------------------------------|--------------------------------------------|
|                 |                        |                | Top | Middle | Bottom | Top | Middle | Bottom |
| Asahan and      | *Bambusa blumeana*    | Node           | 3.81| 5.01   | 5.15   | 5.57| 6.39   | 6.75   |
| Tanjung Balai   |                        | Internode      | 4.67| 6.71   | 7.01   | 6.47| 8.14   | 8.23   |
|                 | *Bambusa vulgaris*     | Node           | 5.20| 5.73   | 7.63   | 7.11| 9.06   | 8.91   |
|                 |                        | Internode      | 6.22| 6.39   | 6.77   | 7.40| 8.14   | 9.24   |
|                 | *Dendrocalamus asper*  | Node           | 5.05| 5.71   | 6.74   | 7.72| 8.98   | 10.14  |
|                 |                        | Internode      | 5.54| 6.41   | 6.46   | 9.36| 7.92   | 7.31   |
|                 | *Gigantochloa atter*   | Node           | 5.00| 5.15   | 6.19   | 5.44| 5.85   | 9.56   |
|                 |                        | Internode      | 4.84| 5.39   | 5.63   | 9.15| 10.78  | 12.37  |
|                 | *Gigantochloa robusta*| Node           | 5.04| 5.63   | 7.11   | 12.88| 9.67   | 9.98   |
|                 |                        | Internode      | 5.41| 6.50   | 6.61   | 9.58| 10.15  | 10.52  |
|                 | *Schizostachyum bracycladum*| Node       | 4.12| 4.46   | 4.77   | 9.26| 9.76   | 15.08  |
|                 |                        | Internode      | 4.19| 4.28   | 4.64   | 10.24| 10.46  | 11.18  |
|                 | *Schizostachyum zolingeri*| Node      | 5.74| 6.07   | 6.30   | 6.82| 9.16   | 9.75   |
|                 |                        | Internode      | 4.33| 4.38   | 4.52   | 6.41| 6.78   | 8.93   |
| Batubara        | *Bambusa vulgaris*     | Node           | 5.81| 5.77   | 5.93   | 11.55| 13.69  | 14.44  |
|                 |                        | Internode      | 4.68| 4.95   | 5.57   | 9.29| 11.13  | 13.78  |
|                 | *Dendrocalamus asper*  | Node           | 4.15| 4.50   | 6.53   | 4.41| 7.09   | 7.69   |
|                 |                        | Internode      | 5.01| 6.49   | 6.67   | 8.01| 8.33   | 8.57   |
|                 | *Schizostachyum bracycladum*| Node   | 3.61| 3.59   | 4.99   | 9.46| 9.53   | 9.74   |
|                 |                        | Internode      | 3.83| 3.86   | 4.83   | 8.28| 8.29   | 9.70   |
|                 | *Schizostachyum zolingeri*| Node    | 4.61| 5.41   | 6.13   | 7.56| 7.83   | 8.09   |
|                 |                        | Internode      | 5.16| 6.22   | 6.57   | 7.95| 8.14   | 8.62   |
| Simalungun      | *Bambusa blumeana*    | Node           | 5.59| 6.16   | 6.98   | 7.28| 8.20   | 9.08   |
|                 |                        | Internode      | 4.71| 6.62   | 7.51   | 12.26| 12.41  | 13.37  |
|                 | *Bambusa vulgaris*     | Node           | 5.87| 6.27   | 6.84   | 9.07| 10.04  | 11.08  |
|                 |                        | Internode      | 5.52| 5.91   | 6.22   | 9.07| 10.92  | 11.81  |
|                 | *Dendrocalamus asper*  | Node           | 4.67| 5.83   | 7.64   | 6.69| 8.01   | 8.10   |
|                 |                        | Internode      | 5.51| 5.67   | 7.79   | 9.04| 10.21  | 12.86  |

3.2. Conversion Ratio modified ASTM D 143 standard to ISO 22157 standard

The average shear strength value obtained from testing following the modified ASTM D 143 is significantly different from the value following ISO 22157, with the difference ratio varies from 0.41 to 0.94. Table 3 presents the ratio between shear strength tested with ISO 22157 and the modified ASTM D 143, for nodes and internodes, from the top, middle, and bottom section. The average value of the overall ratio calculated in Table 3 is 0.63. This average value can be recommended for use when researchers use the modified ASTM D 143 standard which is intended for wood in testing the bamboo specimens and wants to convert the result obtained to ISO 22157 standard as the reference in testing bamboo.
Table 3. The conversion ratio of ASTM D 143 to ISO 22157.

| Origin                  | Species             | Test Condition | Ratio       |
|-------------------------|---------------------|----------------|-------------|
|                         |                     |                | Top | Middle | Bottom |
| Asahan and Tanjung Balai| *Bambusa blumeana*  | Node           | 0.68 | 0.78   | 0.76   |
|                         |                     | Internode      | 0.72 | 0.82   | 0.85   |
|                         | *Bambusa vulgaris*  | Node           | 0.73 | 0.63   | 0.86   |
|                         |                     | Internode      | 0.84 | 0.79   | 0.73   |
|                         | *Dendrocalamus asper* | Node          | 0.65  | 0.64   | 0.66   |
|                         |                     | Internode      | 0.59  | 0.81   | 0.88   |
| Batubara                | *Gigantochloa atter* | Node           | 0.92  | 0.88   | 0.65   |
|                         |                     | Internode      | 0.53  | 0.50   | 0.46   |
|                         | *Gigantochloa robusta* | Node          | 0.39  | 0.69   | 0.71   |
|                         |                     | Internode      | 0.56  | 0.64   | 0.63   |
|                         | *Schizostachyum bracycladum* | Node          | 0.44  | 0.46   | 0.32   |
|                         |                     | Internode      | 0.41  | 0.41   | 0.42   |
|                         | *Schizostachyum zolingeri* | Internode   | 0.68  | 0.65   | 0.51   |
|                         | *Bambusa vulgaris*  | Internode      | 0.50  | 0.42   | 0.41   |
|                         |                     | Node           | 0.50  | 0.44   | 0.40   |
|                         | *Dendrocalamus asper* | Internode    | 0.94  | 0.63   | 0.85   |
|                         |                     | Internode      | 0.63  | 0.78   | 0.78   |
|                         | *Schizostachyum bracycladum* | Node          | 0.38  | 0.38   | 0.51   |
|                         |                     | Internode      | 0.46  | 0.47   | 0.50   |
|                         | *Schizostachyum zolingeri* | Internode   | 0.61  | 0.69   | 0.76   |
|                         | *Bambusa blumeana*  | Internode      | 0.77  | 0.75   | 0.77   |
|                         |                     | Internode      | 0.38  | 0.53   | 0.56   |
| Simalungun              | *Bambusa vulgaris*  | Node           | 0.65  | 0.62   | 0.62   |
|                         |                     | Internode      | 0.61  | 0.54   | 0.53   |
|                         | *Dendrocalamus asper* | Node          | 0.70  | 0.73   | 0.94   |
|                         |                     | Internode      | 0.61  | 0.56   | 0.61   |
|                         |                     |                | 0.63   |

3.3. Compressive strength

Table 4 shows that the highest average compressive strength came from the bottom section, followed by the middle section and then the lowest came from the top section. The node and internode sections compressive strength is not significantly different, with the difference of the average values are 0.88 MPa, 0.98 MPa, and 0.95 MPa obtained from Asahan and Tanjung Balai, Batubara, and Simalungun respectively. The latest research in the mechanical properties of bamboo showed that nodes did not give a significant effect on tensile strength, flexural strength and compressive strength [17] but it only restricted further deformation of the specimen [18]. The highest average compressive strength is from *Gigantochloa robusta* with 65.41 MPa for Asahan and Tanjung Balai, *Dendrocalamus asper* with 53.12 MPa for Batubara, *Bambusa vulgaris* with 56.83 MPa for Simalungun. It can be seen that the highest compressive strength for *Bambusa bleumana* and *Bambusa vulgaris* are from Simalungun, for *Dendrocalamus Asper* is from Batubara, and for *Schizostachyum bracycladum* and *Schizostachyum zolingeri* are from Asahan and Tanjung Balai. Figure 5 shows the specimen condition after the compression test conducted.
### Table 4. Compressive strength according to ISO 22157.

| Origin                  | Species              | Test Condition | Compressive Strength (MPa) |
|-------------------------|----------------------|----------------|-----------------------------|
|                         |                      |                | Top | Middle | Bottom |
| Asahan and Tanjung Balai| Bambusa blumeana    | Node           | 39.97 | 51.75 | 60.97  |
|                         |                      | Internode      | 51.94 | 60.48 | 61.57  |
|                         | Bambusa vulgaris     | Node           | 37.69 | 40.07 | 49.50  |
|                         |                      | Internode      | 43.56 | 49.44 | 58.92  |
|                         | Dendrocalamus asper  | Node           | 43.99 | 44.19 | 46.58  |
|                         |                      | Internode      | 49.85 | 50.48 | 51.90  |
|                         | Gigantochloa atter   | Node           | 32.17 | 39.55 | 41.39  |
|                         |                      | Internode      | 34.68 | 48.86 | 48.93  |
|                         | Gigantochloa robusta| Node           | 58.31 | 62.16 | 72.64  |
|                         |                      | Internode      | 60.99 | 66.52 | 71.85  |
|                         | Schizostachyum bracycladum | Internode | 37.85 | 38.35 | 46.21  |
|                         |                      | Node           | 46.30 | 46.36 | 49.46  |
|                         | Schizostachyum zolingeri | Internode | 30.41 | 31.50 | 32.88  |
| Batubara                | Bambusa vulgaris     | Node           | 43.80 | 51.06 | 53.98  |
|                         |                      | Internode      | 44.54 | 53.93 | 56.56  |
|                         | Dendrocalamus asper  | Node           | 55.04 | 57.94 | 59.22  |
|                         |                      | Internode      | 46.55 | 47.69 | 52.27  |
|                         | Schizostachyum bracycladum | Node | 31.96 | 36.29 | 38.43  |
|                         |                      | Internode      | 35.53 | 44.75 | 47.83  |
|                         | Schizostachyum zolingeri | Internode | 23.12 | 24.43 | 30.24  |
| Simalungun              | Bambusa vulgaris     | Node           | 44.97 | 51.06 | 57.77  |
|                         |                      | Internode      | 51.79 | 63.68 | 67.27  |
|                         | Dendrocalamus asper  | Node           | 53.44 | 61.88 | 62.61  |
|                         |                      | Internode      | 47.55 | 56.74 | 58.75  |
|                         | Batubara             | Node           | 46.77 | 47.42 | 52.80  |
|                         | Dendrocalamus asper  | Internode      | 51.79 | 53.84 | 56.81  |

**Figure 5.** Specimen failure after compression test
4. Conclusion

Shear strength is an important element in the mechanical properties of bamboo but its testing is often ignored. In this study shear test was carried out to obtain bamboo shear strength according to ISO 22157 standard and also modification of the ASTM D 143 standard. This was done to see the comparison of the result of the test between these two methods and also to open up the possibility of carrying out tests other than using ISO 22157 standard as the reference for bamboo shear testing. From the test result, it can be seen that shear test with modified ASTM D 143 standard gives higher average shear strength compared to the shear test result with ISO 22157 standard, with the highest average value of the shear strength tested by ISO 22157 standard is Bambusa vulgaris, with 6.32 MPa from Asahan and Tanjung Balai district, and for the modified ASTM D 143 is Bambusa vulgaris with 12.31 MPa from Batubara. The average value of the overall ratio from comparison between ISO 22157 and modified ASTM D 143 is 0.63. For compressive strength, the highest average compressive strength is from Gigantochloa robusta with 65.41 MPa for Asahan and Tanjung Balai.

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