JURNAL TENGKAWANG (2024)
Vol. 14 (1): 10 - 22

PENGARUH JENIS KONSTRUKSI KLASIK DAN MODERN TERHADAP KEKUATAN PRODUK BERBASIS KAYU

The Influence Of Classic And Modern Types Of Joint Construction On The Strength Of Wood-Based Product

Agung Ari Purwanto [1)], Bahtiar Rahmat [1*)], Wahyu Widiyanto[1)], Arip Wijayanto[1)], Soleh Muhamad[1)], Desy Mulyosari[1)], Nurmadina[2)]

[1] Furniture Production Engineering Study Program, Politeknik Industri Funritur dan Pengolahan Kayu, Jl. Wanamarta Raya, No. 20, Kabupaten Kendal, Indonesia

[2] Teaching Factory Unit, Politeknik Industri Funritur dan Pengolahan Kayu, Jl. Wanamarta Raya, No. 20, Kabupaten Kendal, Indonesia

[*]e-mail: bahtiar.rahmat@poltek-furnitur.ac.id

Abstract

In furniture products, joints represented susceptible areas where damage or structural issues might arise. Consequently, selecting the appropriate joint technique was crucial to reduce the likelihood of failures in furniture joint connections. The objective of this study was to furnish insights into the failure patterns under diagonal compression loads for various wood joints (both traditional and contemporary) constructed with a Medium-Density Fiberboard (MDF). The chosen joint techniques included Dowel (D), tongue and groove (T), Minifix (M), and Insert nut (N). Two compression test scenarios were implemented to evaluate the performance of each joint under external loads. The findings revealed that the Insert nut (N) joint emerged as the most preferable method, demonstrating resilience against the highest external loads and ease of installation, particularly suitable for knock-down furniture items. Conversely, the minifix joint (M) is not recommended due to its intricate construction process, and the compression test results indicated that it exhibited the lowest resistance to external loads.

Keywords: Furniture, knock-down, properties, compression test.

Abstrak

Dalam produk furnitur, sambungan merupakan area yang rentan terhadap kerusakan atau masalah struktural yang mungkin timbul. Oleh karena itu, pemilihan teknik sambungan yang tepat sangat penting untuk mengurangi kemungkinan kegagalan dalam sambungan furnitur. Tujuan dari penelitian ini adalah untuk memberikan wawasan tentang pola kegagalan di bawah beban kompresi diagonal untuk berbagai jenis sambungan kayu (baik yang tradisional maupun kontemporer) yang dibuat dengan Medium-Density Fiberboard (MDF). Teknik sambungan yang dipilih meliputi Dowel (D), tongue and groove (T), Minifix (M), dan Insert nut (N). Dua skenario uji kompresi diterapkan untuk mengevaluasi kinerja setiap sambungan di bawah beban eksternal. Temuan menunjukkan bahwa sambungan Insert nut (N) muncul sebagai metode yang paling disukai, menunjukkan ketahanan terhadap beban eksternal tertinggi dan kemudahan pemasangan, khususnya cocok untuk furnitur yang dapat dirakit. Sebaliknya, sambungan minifix (M) tidak disarankan karena proses konstruksi yang rumit, dan hasil uji kompresi menunjukkan bahwa sambungan ini menunjukkan resistensi terendah terhadap beban eksternal.

Kata kunci: Furnitur, knock-down, properti, uji tekan.

INTRODUCTION

Indonesia has tropical forests covering an area of 120.6 million hectares, with an allocation of 68.8 million hectares for production forests, 22.1 million hectares for conservation forests, and 29.7 million hectares for protection forests (Kementerian Lingkungan Hidup dan Kehutanan Indonesia, 2018). The wood used by the wood processing industry mostly comes from natural production forests. As a high-value product with global competitiveness, furniture is one of the strategic commodities for the Indonesian economy. Indonesia has relatively abundant natural resources and is supported by diverse styles and designs that can provide distinctive local character in each region (Kementerian Perindustrian, 2015).

According to data from the World Integrated Trade Solution (2017), international trade in wooden furniture has a dominant contribution compared to furniture made from other materials, reaching 71%, while metal furniture contributes 22%, plastic furniture contributes 3%, and other materials contribute 4% (Kementerian Perindustrian, 2015). In addition to wood, some of its derivative products such as MDF (Medium-Density Fiberboard), particleboard, and plywood are also commonly used in the manufacturing of furniture products. Medium-Density Fiberboard (MDF) is a material produced by combining wood fibers and resin, with various applications, including but not limited to furniture (constituting more than 50% of its usage), construction, flooring, interior design, and more. MDF, as defined by ASTM, is described as a composite panel product primarily composed of cellulose fibers, with its structural integrity primarily achieved through the application of adhesive systems that cure under heat and pressure (Zimmer & Bachmann, 2023).

In general, joint systems were the weakest points in furniture construction, so a detailed analysis of the factors influencing the capacity and effectiveness of construction in wood joint systems is necessary (Tankut & Tankut, 2011). Wooden furniture products will experience various types of loads during their use, so the application of construction systems that are not suitable for wooden furniture products could potentially cause stress or damage to weak areas, such as at the joints (Rahmat et al., 2023). Traditional wood joints that were entirely made of wood play a crucial role in influencing the structural performance of wooden structures (Milch et al., 2017). These joints were often considered the most crucial components in the structure because they frequently became the primary cause responsible for compromising the overall structural integrity in about 80% of failure cases (Santos et al., 2009).

Understanding the mechanical properties of wooden dowels is crucial to ensure the right structural and geometric design. The overall performance of the joint were influenced by various geometric parameters of the fastener, especially the diameter and shear force ratio (Kunecký et al., 2015). Fasteners with a low shear force ratio maintain their shape under the joint load, causing joint failure primarily when the load-bearing capacity of the connected elements is exceeded (Fukuyama et al., 2008).

In addition to conventional wood joints, recently, compact models of wood joints have been developed. These joints have the same, and in some cases, even greater strength than classic wood joints (Rizkiyah et al., 2020). Furthermore, due to the lack of a systematic approach to designing joints in composite-based furniture that included economical and production-efficient fasteners such as mini-fixes, many manufacturers have shifted their focus to knock-down fasteners as opposed to conventional fasteners (Çetin Yerlikaya, 2012).

Therefore, the objective of this research is to provide background information on the failure load behavior in diagonal compression of different wood joints (classic and modern) made with MDF. The specific aim of this study is to investigate how various wood construction methods, including Dowel (D), Tongue and groove joint (T), Minifix (M), and Insert Nut (N), influence the failure load in L-shaped furniture corner joints. Consequently, the results of this testing are expected to serve as reference data for furniture manufacturers in choosing the appropriate joint type for their products.

METHOD

All samples were made from Medium Density Fiberboard (MDF) with an eighteen-millimeter thickness. All samples were made from the same MDF board with an initial size that complies with ISO 14001 standards, measuring 1220mm x 2440mm. These MDF panels underwent moisture content (MC) and specific gravity (SG) testing in accordance with ASTM D1037. In this study, component assembly was performed using dowel joints (D), tongue and groove joints (T), inserted nuts (N), and minifix joints (M).

Tongue and groove joint are common type of connection used in wood-based panel products. This joint is chosen for its high load-carrying capacity, stiffness and good ductility ratio (Yin et al., 2022). The tongue and groove joining process involve an element with a tongue (long protrusion) that fits into the groove (depression or channel) on another element. This creates a strong connection and helps prevent shifting or rocking between the two connected elements. The tongue used in this test has dimensions of length x width x thickness measuring 50mm x 20mm x 5mm. Dowels made of pine wood with a nominal diameter of 8mm and a length of 40mm were prepared for use in other classic joints. These dowels were inserted into the holes pre-drilled in the MDF board using a hammer, tapping gently to prevent stretching in the surrounding area of the dowel. Figure 1 (A) shown the detailed size of tongue .

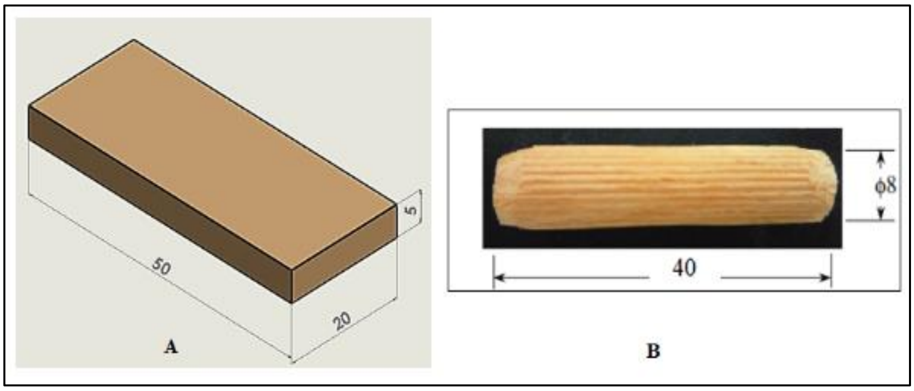

Figure 1. Size of Tongue (A) and size of Dowel (B)

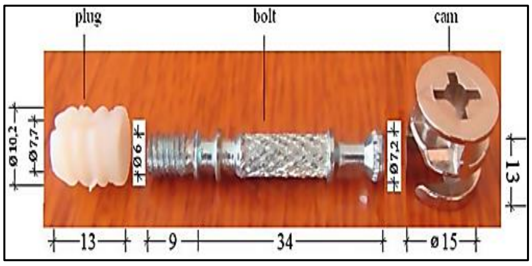

Figure 2. Size of Minifix

Figure 1 (B) shown the detailed size of dowel. The minifix and insert nut are two modern joints chosen as comparisons in this test. The plastic plug minifixes with a diameter of 15mm were chosen for this study. This size was selected because of ease to obtain in the market. Figure 2 shown the detailed size of minifix.

The next selected modern joint is the insert nut, paired with a JCBC bolt. The specifications for the JCBC bolt used are 45mm long, with diameter of 6mm. The insert nut specifications include a length of 25mm, with an internal threaded diameter of M6. To prepare the testing specimens, two pieces of MDF are cut to the sizes of (200mm x 50mm x 18mm) and (182mm x 50mm x 18mm), respectively. Two MDF pieces are prepared for each joint method. Each joint method is prepared for 3 testing repetitions, resulting in a total of 24 prepared specimens. Figure 3 shown the detailed shape of insert Nut.

The dowel joint is prepared by creating holes with a diameter of 8mm, with a depth of 32mm in the horizontal board, and a depth of 10mm in the vertical board. The distance between two holes is 32mm, where the hole's center from the edge is 9mm, and the distance from the base is 9mm. The L-shaped joint specimen with dowel can be seen in Figure 4(A).

Figure 3. Insert Nut with Ø6mm

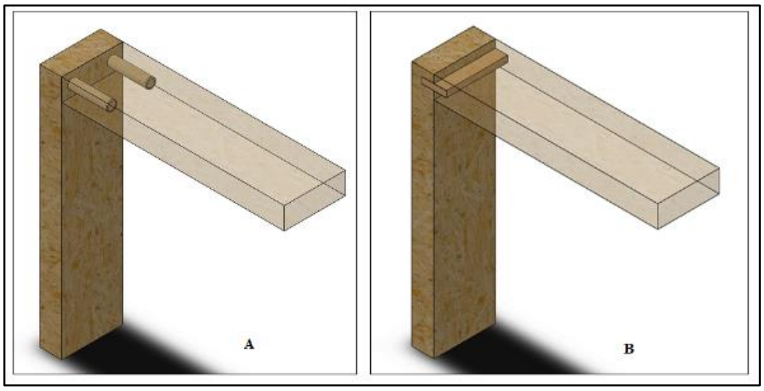

Figure 4. (A) Specimen with Dowel Construction, (B) Specimen with Tongue and Groove Construction

For the tongue and groove joint, specimens are prepared using a sliding table saw machine. The groove is made on both the vertical & horizontal boards with the same depth of 10mm, and the groove position from the top side of the vertical and horizontal boards is 6.5mm.

The L-shaped joint specimen with the tongue and groove connection can be seen more clearly in Figure 4(B). For all specimens using wood dowel and tongue and groove construction, the adhesive used is cyanoacrylate glue. This is done to achieve only the bonding effect without any hardening effect from the adhesive itself (Tuhkanen et al., 2018).

Identically sized specimens are also prepared using minifix and insert nut constructions. Both use two insert nuts and minifix for each specimen. The hole positions for the JCBC bolt are also made the same as the holes in the dowel specimens but with a hole diameter of 6mm. The distance between two holes is 32mm, where the hole's center from the edge is 9mm, and the distance from the base is 9mm. For the modern construction, the holes in the vertical board are made through, while for the horizontal board, they are made with a depth of 30mm, ensuring that the JCBC bolt can be properly installed.

Simple compression test specimens with insert nut construction are prepared by creating two holes in the vertical board with a diameter of 6mm and a depth of 18mm or through. The distance between holes is 32mm, with the center point of the hole 9mm from the edge and 9mm from the base. Holes are also made in the horizontal board with a diameter of 8mm, with the center point of the hole 9mm from the top edge and 9mm from the side. The hole depth is 30mm. The L-shaped joint test specimens with minifix and insert nut construction can be seen more clearly in Figures 5(A) and 5(B).

All compression tests were conducted using an Instron 3369 universal testing machine (UTM) with a maximum loading capacity of 50kN. During testing, ASTM-D 1037 standards were selected as a reference. The testing continued until specimens experienced failure. Two compression test schemes were performed, labeled as Compression

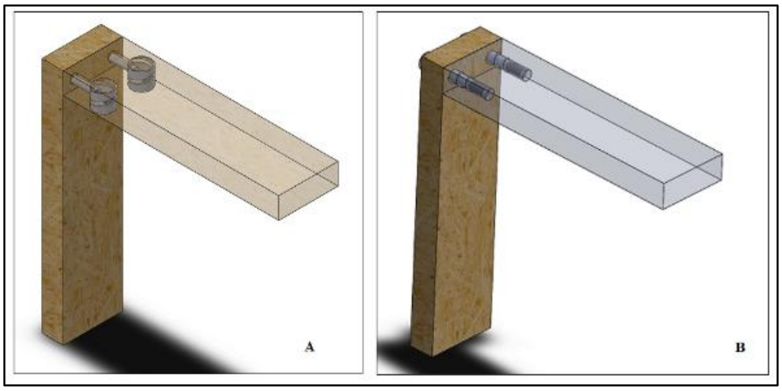

Figure 5. (A) Specimen with Minifix Construction, (B) Specimen with Insert Nut Construction

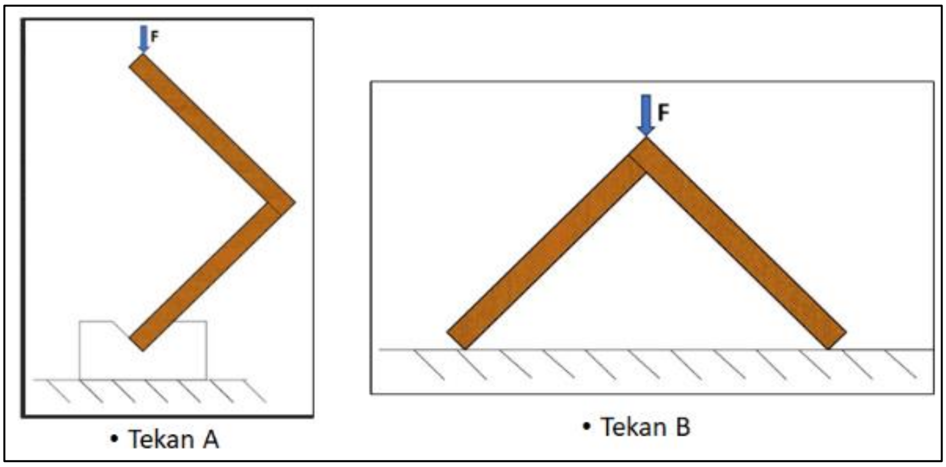

Figure 6. Compression Test Schemes A and B

Test Scheme A and Compression Test Scheme B. Details of the positions for Compression Test Schemes A and B can be observed in Figure 6 (ASTM International D1037, 2016).

The compression test is intended to assess the wood's (specimen) ability to withstand external forces acting on or applied to the specimen. In theory, this calculation involves the width of the specimen (b), the thickness of the specimen (d) in millimeters, and the maximum loading force (Pmax) in kilograms. The following equation is used to calculate the compressive strength (Rc) in MegaPascals (MPa):

$$Rc = \frac{P\,max}{bd} \qquad (1)$$

The results of the density and moisture content tests for the MDF test samples were analyzed using experimental design in the form of a simple single-factor completely randomized design (CRD) with three replications for each MDF in the testing connection. Subsequently, the results of the joint compression test specimens were analyzed using an experimental design in the form of a simple single-factor completely randomized design (CRD) involving four types of wood joint constructions with three replications. The obtained data were analyzed using analysis of variance (ANOVA), and if there were significant differences, a Duncan test would be conducted as a follow-up.

RESULT AND DISCUSSION

Test of MDF Board Density

Density refers to the ratio between the mass and the air-dried volume of the board. This density figure is a crucial element in assessing the quality of a board. Density is also commonly referred to as density (Bowyer & Shmulsky, 2003). The initial hypothesis is that there is no difference in the density of MDF boards across all joints. The density level will impact the resulting characteristics. After testing, the average density values for various panel types ranged from 0.72 to 0.73 g/cm^3. The results of statistical analysis indicate that the density test values for the joints are not significantly different from the density test values for all other joints, with a p-value of 0.8906.

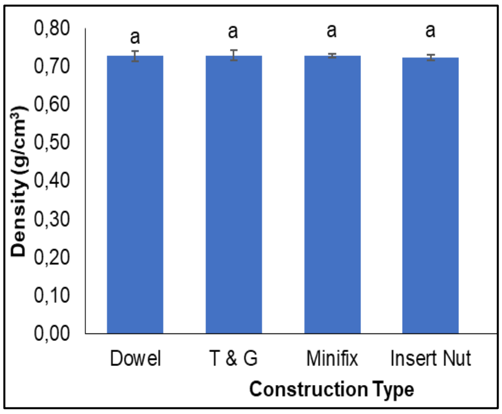

Figure 7. Results of the statistical test for MDF density

This is attributed to the fact that the test material used is derived from the same MDF panel, resulting in relatively consistent density.

The samples used for density testing are taken from specimens that have been joined using four types of constructions and have undergone compression testing. This range of values complies with the MDF standards outlined in JIS A 5905 for fiberboard, which stipulates that the density of MDF should exceed 0.35 g/cm3 (Nasution et al., 2015). Figure 7 illustrates the results of the density test for MDF boards.

Test of MDF Board Moisture Content

Moisture content is one of the key factors in the use of materials. The percentage of moisture content can be calculated by comparing the weight of water present in the wood to its dry weight, and then expressed as a percentage (Wahyudi et al., 2014). The moisture content of MDF in this test was measured using a moisture meter before conducting the test.

The initial hypothesis is that there is no difference in the moisture content of MDF boards across all joints. The samples used for moisture content testing are taken from specimens that have been joined using four types of constructions and have undergone compression testing.

After conducting the test, the MDF used in this study has moisture levels ranging from 7.28% to 7.56%. Figure 8 illustrates the results of the moisture content test for MDF boards.

The moisture content for a maximum acceptable level of MDF is typically set at 13%. The measured moisture levels in this study, ranging from 7.28% to 7.56%, fall well below this maximum threshold, indicating that the MDF used in the research has a satisfactory moisture content (Vachlepi, 2015).

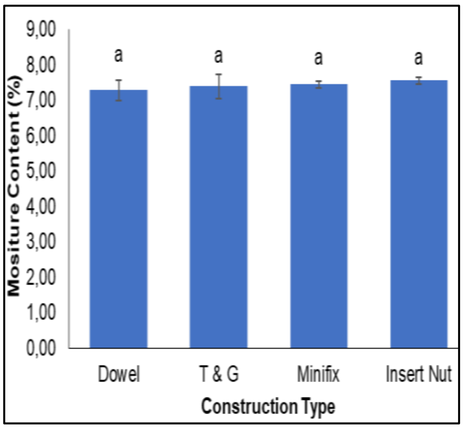

Figure 8. Results of the statistical test for MDF Moisture Content

The results of the statistical analysis indicate that the moisture content test values for MDF boards do not show a significant difference compared to the moisture content test values for all other joints, with a p-value of 0.409. MDF consists of wood fibers that exhibit hygroscopic properties, meaning they can easily absorb or release water. Moisture content reflects the amount of water contained in a material. The higher the moisture content of MDF, the greater the mass of the material, but elevated moisture levels can reduce the strength of the material (Roliadi et al., 2012).

Result of Compression Test Scheme A

Compression testing with scheme A has been conducted, and for the test results, a clearer observation can be made in Figure 9. The alternative hypothesis is that there is a significant difference in the compressive strength of scheme A test among different joint methods. The compression test results for scheme A on several specimens with various constructions obtained values ranging from 15.62 to 30.58 Kgf. The statistical analysis indicates that the compression test with scheme A using Minifix (M) shown a significant difference compared to the joint test values from all types of joints tested overall, with a p-value of 0.00203. However, the statistical analysis results indicate that the Dowel (D), Tongue & Groove (T) and insert nut (N) joints do not show a statistically significant difference.

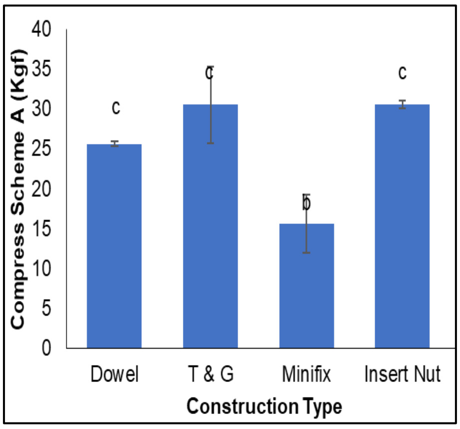

Figure 9. Results of the statistical test for Compression Test Scheme A

Specimens with minifix construction exhibit the lowest load-bearing capacity. The minifix joint (M) experienced construction failure when subjected to a load of 15.62 Kgf. On the other hand, the highest load of 30.58 Kgf was obtained for specimens with insert nut (N) construction. Statistical test results on specimens with dowel (D) and tongue&groove (T) construction do not show a significant difference. The external loads that dowel and tongue&groove joints are capable of withstanding are 25.64 Kgf and 30.53 Kgf, respectively.

In addition to being made of metal, the insert nut joint has components that are fastened simultaneously, thereby enhancing the bond strength between the two components (known as the hardening effect) in the assembled joint (Tuhkanen et al., 2018). Furthermore, the positioning of the metal bolt in the middle and across the specimen also plays a key role. This creates a broader surface to support external loads, thereby enhancing its ability to withstand pressure from external sources more effectively (Fabbri et al., 2022). Figure 10 illustrates the pattern of damage or construction failure that occurred in each specimen after the compression test with scheme A.

Result of Compression Test Scheme B

Compression testing with scheme B has been conducted, and for the test results, a clearer observation can be made in Figure 11. The alternative hypothesis is that there is a significant difference in the compressive strength of scheme B test among different joint methods. The compression test results for scheme B on several specimens with various constructions obtained values ranging from 3.76 to 9.88 Kgf.

The statistical analysis again indicates that the compression test with scheme B using the minifix joint (M) shown a significant difference compared

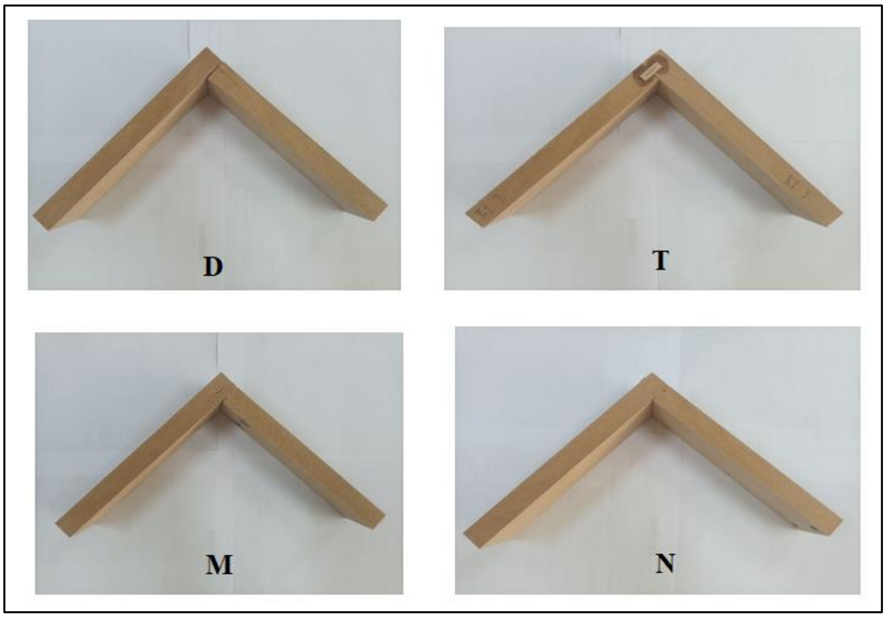

Figure 10. Specimen of compression test results scheme A; (D) dowel, (T) tongue&groove, (M) minifix, (N) insert nut

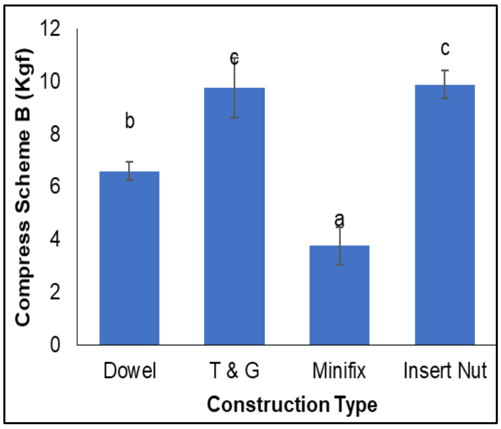

Figure 11. Results of the statistical test for Compression Test Scheme B

to the joint test values from all types of joints tested overall, with a p-value of 0.000672. However, in the compression test with scheme B, the statistical analysis results show no significant difference in the tongue&groove (T) and insert nut (N) joints.

The maximum load value for the minifix joint is 3.76 Kgf. The diameter of the minifix only about 6mm, and the overall cross-sectional area for the minifix joint is 129mm^2. minifix joint has the smallest cross-sectional area when compared to the other joints, indicating lower external force resistance capabilities (Atar et al., 2009). In the insert nut (N) joint method, it proves to be the joint capable of withstanding the highest external load. The maximum load is 9.88 Kgf, while the tongue&groove (T) joint is capable of withstanding an external load of up to 9.77Kgf. This is attributed to the material composition of the insert nut, which is made of metal, combined with the length dimensions of the insert nut. Thus, from a cross-sectional area perspective, the insert nut has the largest cross-sectional area, enabling it to better withstand external loads (Fabbri et al., 2022). Image 11 clearly illustrates the statistical test results of the compression test with scheme B for various types of joints. The compression test with scheme B on specimens using the wooden dowel joint method (D) shows a maximum load value of 6.59 Kgf.

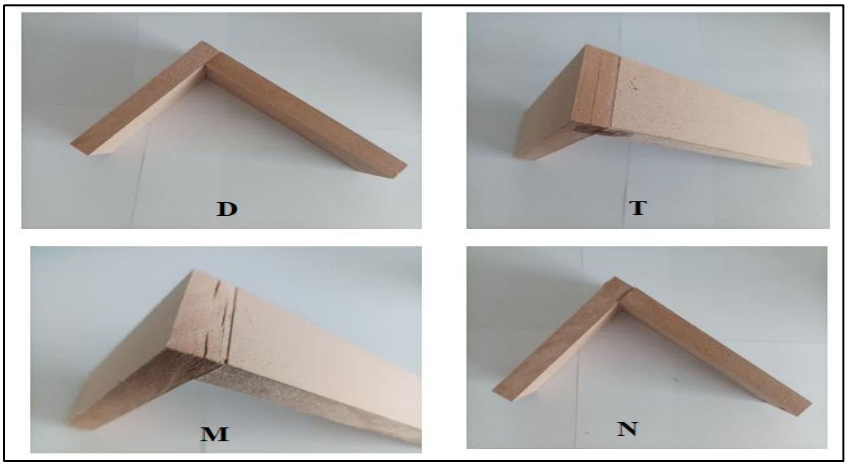

Figure 12. Specimen of compression test results scheme B; (D) dowel, (T) tongue&groove, (M) minifix, (N) insert nut

This value is considered moderate when compared to minifix joints as well as insert nut (N) and tongue&groove (T) joints. This is because, in practice, the dimensions of the hole in which the dowel is inserted are well-fitted, combined with the cylindrical shape of the dowel that has grooves, thereby enhancing the dowel's shear stiffness against external forces (Milch et al., 2017). Figure 12 illustrates the pattern of construction failure that occurred in each specimen after the compression test with scheme B.

CONCLUSION

A series of tests has been conducted on several specimens with various joints, including both classic and modern joints. Based on statistical analysis, the density and moisture content test results for MDF panels indicate that the density and moisture content values for the tested MDF are not significantly different from the density and moisture content values for the entire MDF.

The results of scheme A & B testing indicate that the Insert nut (N) joint is better at withstanding external loads compared to other joint methods. Based on the test results, the Insert nut (N) joint is highly recommended for use in knock-down furniture products. Apart from being readily available in the market and exhibiting excellent external load-bearing capabilities, the Insert nut (N) joint is also a very easy and practical method for the assembly process.

REFERENCES

ASTM International D1037. (2016). Annual Book of ASTM Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials. *Annual Book of ASTM Standards*, (July 1999), 1–31.

Atar, M., Ozcifci, A., Altinok, M., & Celikel, U. (2009). Determination of diagonal compression and tension performances for case furniture corner joints constructed with wood biscuits. *Materials and Design*, *30*(3), 665–670. https://doi.org/10.1016/j.matdes.2008.05.023

Bowyer, J., & Shmulsky, R. (2003). *Forest Products and Wood Science: an Introduction, 4th edition.*

Çetin Yerlikaya, N. (2012). Effects of glass-fiber composite, dowel, and minifix fasteners on the failure load of corner joints in particleboard case-type furniture. *Materials and Design*, *39*, 63–71. https://doi.org/10.1016/j.matdes.2012.02.024

Fabbri, A., Minghini, F., & Tullini, N. (2022). Monotonic and cyclic pull-pull tests on dowel-nut connector in laminated veneer lumber made of European beech wood. *Construction and Building Materials*, *359*, 129461. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2022.129461

Fukuyama, H., Kairi, M., Hirsi, H., Inayama, M., & Ando, N. (2008). Shear characteristics of wood dowel shear joint and practical application example. *10th World Conference on Timber Engineering 2008*, *3*, 1198–1205.

Kementerian Lingkungan Hidup dan Kehutanan Indonesia. (2018). *Status hutan dan Kehutanan Indonesia 2018*. Jakarta.

Kementerian Perindustrian, B. P. (2015). *Laporan kinerja Kementerian Perindustrian*. Jakarta.

Kunecký, J., Sebera, V., Hasníková, H., Arciszewska-Kędzior, A., Tippner, J., & Kloiber, M. (2015). Experimental assessment of a full-scale lap scarf timber joint accompanied by a finite element analysis and digital image correlation. *Construction and Building Materials*, *76*, 24–33. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2014.11.034

Milch, J., Tippner, J., Brabec, M., Sebera, V., Kunecký, J., Kloiber, M., & Hasníková, H. (2017). Experimental testing and theoretical prediction of traditional dowel-type connections in tension parallel to grain. *Engineering Structures*, *152*, 180–187. https://doi.org/10.1016/j.engstruct.2017.08.067

Nasution, U. H., Afifuddin, Y., & Hakim, L. (2015). Studi Komparasi Sni 01-4449-2006 Dengan Jis a 5905 : 2003 . *Peronema Forestry Science Journal*, *4*(1), 78–83.

Rahmat, B., Mulyosari, D., Purwanto, A. A., & Widiyanto, W. (2023). Pengaruh Posisi Sambungan Konstruksi Kayu Terhadap Dedain Produk Mebel Berbahan Dasar Kayu. *Jurnal Kreatif : Desain Produk Industri Dan Arsitektur*, *11*(1), 8. https://doi.org/10.46964/jkdpia.v11i1.336

Rizkiyah, N. A., Windharto, A., & Kurniawan, A. (2020). *Eksperimen Rotan Resin-Infusion untuk*. *9*(2), 298–303.

Roliadi, H., Indrawan, D. A., Pari, G., & Tampubolon, R. M. (2012). Potensi Teknis Pemanfaatan Pelepah Nipah Dan Campurannya Dengan Sabut Kelapa Untuk Pembuatan Papan Serat Berkerapatan Sedang. *Jurnal Penelitian Hasil Hutan*, *30*(3), 183–198. https://doi.org/10.20886/jphh.2012.30.3.183-198

Santos, C. L., De Jesus, A. M. P., Morais, J. J. L., & Lousada, J. L. P. C. (2009). Quasi-static mechanical behaviour of a double-shear single dowel wood connection. *Construction and Building Materials*, *23*(1), 171–182. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2008.01.005

Tankut, A. N., & Tankut, N. (2011). Section modulus of corner joints in furniture frames as engineering design criteria for their efficient construction. *Materials & Design*, *32*(4), 2391–2395. https://doi.org/https://doi.org/10.1016/j.matdes.2010.10.027

Tuhkanen, E., Mölder, J., & Schickhofer, G. (2018). Influence of number of layers on embedment strength of dowel-type connections for glulam and cross-laminated timber. *Engineering Structures*, *176*, 361–368. https://doi.org/10.1016/j.engstruct.2018.09.005

Vachlepi, A. (2015). Produksi Medium Density Fibreboard (Mdf) Dari Kayu Karet Di Sumatera Selatan : Potensi, Mutu Dan Proses Pengolahannya. *Warta*

Perkaretan, *34*(2), 177. https://doi.org/10.22302/ppk.wp.v34i2.259

Wahyudi, I., Priadi, T., & Rahayu, I. S. (2014). Karakteristik dan Sifat-Sifat Dasar Kayu Jati Unggul Umur 4 dan 5 Tahun Asal Jawa Barat. *Jurnal Ilmu Pertanian Indonesia*, *19*(1 SE-Articles), 50–56. Retrieved from https://journal.ipb.ac.id/index.php/JIPI/article/view/8406

Yin, T., Zhang, J., Wang, Z., Zheng, W., Huang, Q., & Gong, M. (2022). Shear performance of tongue-and-groove joints for CLT. *Construction and Building Materials*, *322*, 126449. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2022.126449

Zimmer, A., & Angie Lunelli Bachmann, S. (2023). Challenges for recycling medium-density fiberboard (MDF). *Results in Engineering*, *19*(July). https://doi.org/10.1016/j.rineng.2023.101277