Bulletin of the *Transilvania* University of Brasov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 18(67) No. 1 – 2025
https://doi.org/10.31926/but.fwiafe.2025.18.67.1.5

ASSESSMENT OF QUALITY PARAMETERS OF FINGER-JOINTED TIMBER PRODUCTS: A REVIEW

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Abstract: *Wood is a renewable natural resource used in diverse sectors. Wood processing operations generate a substantial quantity of residues which possess higher potential of alternative uses. Finger-jointing, a method which connects two small pieces of timber together, is identified as a sound technique to minimize wastage. In the present context, where deforestation continues to threaten the existing timber resources, the finger-joint technique has gained higher recognition as a viable tool for sustainable utilization of wood. With the increasing demand and decreasing volume of high-grade timber material, finger-jointing has become an industry with great economic benefits and finger-joint technology will boost the increased utilization of timber materials. The outcomes of this review paper will therefore improve the quality of finger-jointed products through the generated technical information and thereby enhance the finger-jointing industry in practice.*

Key words: *adhesives, Finger-joint, failure modes, quality, strength, waste, wood.*

1. Introduction
1.1. Context and Importance

Timber, one of the oldest materials used by humans, has played a pivotal role in the development of civilizations. From the construction of ancient dwellings and ships to modern-day buildings and infrastructure, timber has been a fundamental building block for human societies. Despite the advent of new materials such as steel, concrete, and plastics, timber remains an essential resource in a wide range of applications, particularly in the construction, furniture, and paper industries. Its natural properties, including strength, versatility, and aesthetic appeal, make it an irreplaceable

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material, even in contemporary times.

However, timber is not just a material but a renewable resource that, when managed sustainably, can be replenished. As a result, forests around the world have been a crucial supply source for timber products for centuries. In recent decades, the global demand for timber has increased significantly, driven by a combination of factors, including population growth, industrialization, and urbanization. With the growing global population, there has been a steady rise in the demand for timber-based products, such as construction materials, furniture, and paper products. This escalation in demand has placed substantial pressure on the world's forests, which are already facing numerous threats due to deforestation, land-use changes, and unsustainable harvesting practices.

In addition to increasing human demand, the versatility of timber has led to innovations in product manufacturing, one of the most notable being the development of engineered wood products (*EWPs*), such as laminated timber, cross-laminated timber (*CLT*), and finger-jointed timber. These products have extended the uses of wood, allowing it to be used in more sophisticated and demanding applications that require higher durability, strength, and precision. Finger-jointed timber, for instance, offers the benefits of reduced material waste, enhanced structural integrity, and the possibility of using smaller, more abundant pieces of wood, making it an increasingly popular option in the modern construction and furniture industries.

However, the increased demand for timber poses a significant challenge to the sustainability of forest resources. Deforestation, illegal logging, and the degradation of forest ecosystems are growing concerns. As natural forests face threats from over-exploitation, there is an urgent need to adopt sustainable forest management practices to ensure the continued availability of timber in the future. Additionally, as the demand for timber grows, so does the need for innovation in timber product design and manufacturing processes, ensuring that timber resources are used efficiently and sustainably.

The pressure on forest resources to meet the rising demand for timber has spurred interest in developing alternative solutions, such as the use of sustainably sourced timber, improved wood processing techniques, and the promotion of wood recycling. One such innovation is the rise of finger-jointed timber products, which allow for the efficient use of smaller timber pieces that might otherwise go to waste. By utilizing these smaller pieces, finger-jointed timber helps reduce the need for large, mature trees, thus alleviating some pressure on forests.

As the world faces these challenges, it is more important than ever to assess the quality and performance of timber-based products, especially engineered ones like finger-jointed timber. By understanding the factors that contribute to the durability, strength, and sustainability of these products, we can ensure that they meet the demands of the modern world without further compromising forest resources. Thus, the assessment of the quality parameters of finger-jointed timber products is not only crucial for ensuring the performance of these materials in construction and manufacturing but also for promoting sustainability in timber use and forest management. This expanded section adds a broader context regarding the historical and ongoing importance of timber while highlighting the pressures on forest resources and the role of innovations like finger-jointed timber in addressing these challenges.

1.2. Purpose of the Review

The global timber industry faces numerous challenges, one of the most pressing being the underutilization of wood resources. In sawmills and furniture factories, a significant amount of timber ends up as waste, often in the form of trimmings, edgings, and short lengths of sawn timber. These by-products, commonly referred to as off-cuts, are typically discarded or burned, creating both disposal problems and economic inefficiencies. The off-cut wood is often seen as a waste product, and despite its potential value, it is rarely incorporated back into the production cycle. This practice reflects a broader issue of resource underutilization, where valuable raw material is discarded rather than being transformed into useful products.

In the context of increasing global timber demand and growing environmental concerns, this wastage presents a significant challenge. The disposal of off-cut wood not only contributes to environmental pollution but also exacerbates the inefficiency of timber resource management. As forests face growing pressure from deforestation and climate change, there is a critical need for industries to adopt more sustainable practices that ensure the optimal use of available timber resources.

One promising solution to this problem is the use of the finger-jointing technique, a method that enables the efficient utilization of shorter lengths of timber. The finger-jointing process involves joining smaller, shorter pieces of wood together to form longer, continuous sections that are as strong as solid timber. This technique not only makes use of off-cuts and short pieces that would otherwise go to waste but also allows for the production of high-quality timber products with minimal environmental impact.

The primary purpose of this review is to assess the quality parameters of finger-jointed timber products and evaluate their potential as a sustainable solution to the timber industry's waste problem. By exploring the mechanical properties, durability, and other key characteristics of finger-jointed timber, the review aims to highlight how this technique contributes to the optimal use of wood resources. Finger-jointed timber products can reduce reliance on large, mature trees, thus lessening the pressure on natural forests and contributing to more sustainable forest management practices.

Additionally, this review will examine the environmental benefits of finger-jointing in terms of reducing waste, conserving timber resources, and promoting sustainability in the industry. By addressing the challenges of off-cut disposal and waste timber management, finger-jointed timber offers a viable means of improving the overall efficiency of the timber production process. As such, this review also aims to explore how finger-jointed timber can contribute to mitigating the effects of climate change by reducing the need for virgin timber and promoting the recycling and reuse of wood materials.

Furthermore, the review will investigate the potential economic benefits of finger-jointed timber products, especially in the context of industries facing rising costs of raw materials and the increasing need for environmentally responsible manufacturing practices. As the demand for sustainable and eco-friendly products continues to grow, the ability of the timber industry to innovate through practices such as finger-jointing could play a crucial role in shaping the future of timber-based manufacturing.

The purpose of this review is to evaluate the viability of finger-jointed timber as a solution to the timber industry's waste management issues while assessing its quality and performance in various applications. Through a comprehensive analysis of the quality parameters and environmental advantages, this review seeks to contribute valuable insights into how finger-jointed timber can help meet the dual challenges of timber resource conservation and climate change mitigation. This expanded section not only highlights the current challenges faced by the timber industry regarding waste but also emphasizes the potential benefits of the finger-jointing technique in creating sustainable solutions. It underlines the dual purpose of the review: assessing quality parameters and exploring sustainability impacts.

1.3. Scope of the Review

This review focuses on the finger-jointing technique, a method that has gained significant attention in the timber industry due to its potential to optimize the utilization of small or waste timber pieces. The finger-jointing process involves cutting interlocking "fingers" at the ends of timber pieces, which are then glued together to form longer, continuous sections of wood. This innovative jointing system allows for the effective use of shorter or irregularly shaped timber pieces, which would otherwise be discarded as off-cuts or waste byproducts in sawmills and furniture factories. By employing this technique, the timber industry can maximize the utility of each individual piece of wood, significantly reducing the amount of timber that goes to waste.

The scope of this review encompasses a detailed examination of the finger-jointing technique's various aspects, focusing particularly on its ability to improve resource efficiency in timber production. In doing so, the review highlights how the method helps reduce the strain on forest resources by lowering the demand for large, mature trees. Instead of relying exclusively on whole, long timber pieces, finger-jointing allows for the use of smaller, less desirable pieces, thus conserving the valuable natural timber supply and supporting sustainable forest management practices.

Additionally, the review explores the mechanical properties, durability, strength, and aesthetic quality of finger-jointed timber, ensuring that this technique does not compromise the performance of the wood in various applications, such as construction, furniture manufacturing, and other industries. By examining how the finger-jointing process affects the timber's overall quality, this review seeks to provide insights into the technique's viability as a long-term, sustainable solution to timber resource management. Moreover, the review will investigate the environmental impact of finger-jointed timber, particularly in relation to waste reduction and carbon footprint, as well as its potential for contributing to the fight against climate change by promoting more efficient use of wood resources. Ultimately, this review aims to provide a comprehensive understanding of how the finger-jointing technique not only supports the efficient utilization of wood but also contributes to more sustainable and environmentally responsible timber production practices. This expanded version provides a deeper dive into the scope of the review, emphasizing both the technical and environmental aspects of the finger-jointing process. It clarifies how the technique supports sustainability by maximizing the use of available timber and reducing pressure on natural forest resources [30].

2. Overview of Finger-Jointed Timber Products

2.1. Definition and Description

Finger-jointed timber refers to a type of engineered wood product created by joining smaller pieces of timber together using a finger-jointing technique. This process involves cutting interlocking "fingers" at the ends of individual wood pieces, which are then aligned and glued together to form a continuous length of timber. The resulting jointed timber maintains the strength and durability of solid wood but is made from smaller, often leftover or off-cut pieces that would otherwise be discarded or underutilized.

The finger-jointing technique essentially allows for the efficient use of shorter, irregularly shaped pieces of wood, providing a way to reduce waste in the timber industry. The process begins with selecting smaller timber pieces, which are then precisely cut at the ends to create interlocking fingers, often in a staggered pattern to enhance strength and minimize stress concentrations at the joints. These pieces are then bonded together using a strong adhesive, forming a unified piece of timber that can be used for a variety of applications, just like solid wood.

The finger-jointed timber produced through this process is a versatile material that can be used in a range of industries, including construction, furniture manufacturing, cabinetry, and paneling. Because the jointing technique ensures the timber's structural integrity, finger-jointed wood can be engineered to meet specific strength requirements, making it suitable for both aesthetic and functional applications. It is particularly useful in situations where longer pieces of timber are required but larger, mature trees are not readily available or economically viable.

In essence, finger-jointed timber combines the natural qualities of wood with innovative manufacturing techniques to produce a high-quality, sustainable material. It allows manufacturers to make efficient use of timber resources by utilizing shorter lengths that might otherwise be discarded, while still delivering a product that meets or exceeds the strength and performance characteristics of traditional solid timber. This technique not only promotes sustainability by reducing waste but also helps to conserve valuable forest resources by decreasing the need for larger, virgin timber. By ensuring that smaller pieces of timber are put to effective use, finger-jointed timber products represent an important innovation in the quest for more sustainable and resource-efficient manufacturing practices in the timber industry.

2.2. Application - Investigation and Insight into Assessment of Quality Parameters

Wood quality has received more attention lately, and the most current Forest producers' science and innovation plan states that both forest producers and wood processors have made it a shared research priority. It is critical to comprehend how selections affect the quality of the final result. To quantify the effects of different actions on the quality of the final product, knowledge and modelling tools that link forest farmers, wood processors, and tree breeders are needed. Strength, dimension stability, durability, colour, visual aspects, and connector performance are some of the primary performance parameters for structural wood products and their chosen look [20].

Using lower-value trees with technologies like residue recovery and kerfless cutting to produce building materials that are larger, more homogeneous, and more efficient than ever before is revolutionizing the timber industry by maximizing resource use, reducing waste, and enabling scalable sustainable construction solutions. TFinger-jointed timber, glued-laminated timber (Glulam), structural composite timber, and I-joist are the four main types of engineering timber [10]. The new needs can be satisfied by engineered wood, such as finger joint timber, which is known to offer a superior, reliable, and affordable substitute for conventional building materials [43]. The raw wood material is ground using various techniques into pieces with certain dimensions during the production of Engineered Wood Products. The pieces are then joined using adhesives or, in certain situations, mechanical fasteners [10].

2.3. Types of Finger-Joint Studies on Adhesives

Heating thermoplastic adhesives softens them without chemical alteration and they maintain sufficient strength for several applications at regular temperatures. Thermosetting adhesives create permanent solid structures that resist heat when used in heavy duty structural applications. Neoprene solvent solutions form the basis of these adhesives commonly used for hard surface countertop laminate installation [17].

The work of Frihart and Hunt [6] presents a classification system for wood adhesives based on their anticipated structural performance under different environmental conditions as shown in Table 1. Wood adhesive bonding has become crucial in furniture production to maximize wood material efficiency. Polyvinyl acetate (*PVAc*) holds the position of the most widely used adhesive in non-structural applications. *PVAc* can create lasting and robust connections between hardwood pieces. *PVAc* produces strong lasting bonds for both hardwood and hardwood-based products. *PVAc* adhesives are typically unsuitable for load-bearing joints under extreme temperature or humidity but manufacturers can adjust their formulas to enhance performance in these situations. Modified *PVAc* thermosetting polyvinyl emulsions demonstrate enhanced resistance to heat and moisture compared to standard *PVAc* adhesives, which enables them to function effectively in non-structural interior applications and protected exterior settings. Ordinary *PVAc* adhesives which appear as milky white fluids for room temperature use follow the EN-204 standard classification D1, D2, D3, D4 [11, 37].

Singh et al. [39] found that finger-jointed *Eucalyptus* wood, bonded with *PVAc* glue and using a 21 mm length, 7 mm pitch, and 1.4 mm tip thickness finger profile, only reached 23.57% of its potential tensile strength. Muthumala et al. [32] examined the tensile strength of finger-jointed jack, kumbuk, mahogany, pine, and teak. Their research indicated that using polyvinyl acetate-D3 glue resulted in greater tensile strength compared to D2 glue, and that a 4-hour fixation period maximized joint strength across all species tested [32].

Table 1

Wood adhesives categorized according to their expected structural performance at various levels of environmental exposure [6]

Structural integrity	Service environment	Adhesive type
Structural	Fully exterior	Phenol-formaldehyde
	(withstands long-term water soaking and drying)	Resorcinol-formaldehyde Phenol-resorcinol-formaldehyde Emulsion polymer isocyanate Melamine-formaldehyde Isocyanate
	Limited exterior (withstands short-term water soaking) Interior (withstands short-term high humidity)	Melamine-urea-formaldehyde Epoxy Polyurethane Urea -formaldehyde Urea –formaldehyde Casein
Semi structural	Limited exterior	Cross-linked poly (vinyl acetate) Cross-linked soybean
Nonstructural	Interior	Poly (vinyl acetate) Starch

The materials preparation procedure functions as a critical component for creating effective bonding surfaces. A study by Singh et al. [38] demonstrated that the use of a blunt knife to plane surfaces leads to poor bonding performance compared to using a sharp knife. Microscopic analysis revealed that planning damaged cell walls, which affected glue bond strength [38]. Kumar et al. [13] explored the use of finger-jointing to make Mango wood suitable for applications like furniture. Their research, comparing Poly Vinyl Acetate (*PVAc*) and Urea Formaldehyde (*UF*) adhesives, revealed that finger-jointed Mango wood exhibited greater elasticity in both bending and compression compared to solid (unjointed) wood, regardless of the adhesive used.

Vassiliou et al. [41] studied how finger length (4.5, 6.5, and 9 mm) and wood origin (Albania and Greece) affected the bending strength of finger-jointed beech wood

(*Fagus sylvatica* L.), comparing both steamed and un-steamed material bonded with *PVAc* adhesive. Their findings indicated that longer finger lengths (9 mm) resulted in higher modulus of rupture (*MOR*) values than shorter finger lengths, and that steaming the wood also increased *MOR* [41].

Alamsyah et al. [1] investigated how the extractives in *Acacia mangium* (Willd.) affect the curing of Resorcinol Formaldehyde adhesive. They recommended extending the curing time and treating the wood surfaces with methanol to enhance wettability and improve bonding performance for structural applications [1]. Wood surface chemicals, such as natural extractives and preservatives, can hinder proper bonding. They interfere with adhesive wetting and penetration, preventing complete contact with the wood. Excessive drying can exacerbate this issue by drawing extractives to the surface, further compromising the bond and reducing its strength [6].

3. Quality Parameters in Finger-Jointed Timber

3.1. General Aspects

The quality of finger-jointed timber is determined by several key parameters that affect its performance, durability, and suitability for different uses. One of the most important factors is its mechanical properties, such as tensile strength, shear strength, flexural strength, and compression strength, which measure the timber's ability to withstand forces like tension, bending, and compression. The strength of the adhesive used in the joints, as well as the precision of the finger cuts, directly impacts these mechanical properties. Another key parameter is durability, which includes resistance to moisture, decay, and fungal growth. Finger-jointed timber must be able to resist environmental factors like humidity and water, particularly when used in outdoor or humid conditions. Dimensional stability is also important; this refers to how well the timber maintains its shape despite changes in moisture levels, preventing issues like warping or swelling. Aesthetic quality plays a significant role in applications where appearance matters, such as furniture, where the smoothness of the surface and the alignment of the joint fingers are essential. The bonding strength of the adhesive used is critical for ensuring the timber’s overall strength and longevity. Additionally, the acoustic and thermal properties of finger-jointed timber – such as its ability to absorb sound or insulate heat – can also be important depending on its application. Finally, sustainability is an increasingly important factor, as finger-jointed timber makes efficient use of smaller, off-cut pieces of wood, reducing waste and helping to alleviate pressure on forest resources. These quality parameters all contribute to the performance and environmental impact of finger-jointed timber, ensuring it meets the necessary standards for various industries. This version simplifies the explanation while maintaining the key quality parameters that define finger-jointed timber.

3.2. Finger Geometry

Habipi et al. [9] investigated the impact of finger-tip slope position and finger length on the bending strength of finger-jointed poplar (*Populus alba* L.) and silver fir (*Abies alba* Mill.) using polyvinyl adhesive. Their study [9] concluded that finger length had a significant effect on bending strength.

North American structural finger joints commonly utilize lengths of 22 and 29 mm, which are longer than those typically used in New Zealand, Australia, and Europe. For instance, New Zealand commonly uses finger lengths between 9.5 and 13 mm [19]. The finger length and finger orientation showed a significant influence on flexural strength. Previous research studies also reported a similar trend as joint configuration has a significant effect on the mechanical properties of wood [11, 19, 44].

Meng et al. [18] revealed that finger-joined lumber had a lower characteristic ultimate tensile strength and mean modulus of elasticity (*MOE*) than unjoined lumber and finger-jointed lumber had more uniform properties than un-joined lumber. The sharpness of cutter knives did not have a significant effect on *MOE* [18]. Cavalli et al. [4] used tensile tests to assess the strength of 21mm structural finger joints bonding *Eucalyptus grandis* (W. Hill.) and *Eucalyptus urophylla* (S.T. Blake) hybrid wood beams with polyurethane glue. Their research indicated that while denser woods generally have more fibers per unit area, other wood characteristics can influence the bond, preventing this relationship from being universally applicable [4].

Mantanis et al. [16] explored finger-jointing green black pine (*Pinus nigra* J.F. Arnold) with phenol resorcinol formaldehyde adhesive, considering the impact of finger orientation. Their findings showed that green gluing this species is practical, as the finger-jointed wood achieved *MOR* and *MOE* values similar to solid wood, indicating its viability [16]. A Sri Lankan study [24] investigated the optimal finger joint configuration for seven commonly used wood species: grandis (*Eucalyptus grandis* W. Hill.), jack (*Artocarpus heterophyllus* Lam.), kumbuk (*Terminalia arjuna* (Roxb.) Wight and Arn.), mahogany (*Swietenia macrophylla* King), pine (*Pinus caribaea* Morelet), satin (*Chloroxylon swietenia* DC.), and teak (*Tectona grandis* L.f.). The research found that horizontally oriented wood samples with 19 mm finger lengths exhibited the highest modulus of rupture (*MOR*) and modulus of elasticity (*MOE*) [24].

Vassilios et al. [42] investigated the potential of finger-jointed beech wood for non-structural applications, focusing on its use in furniture. Their study examined the influence of *PVA* adhesive type (D1, D2, and D3), finger length (4 and 10 mm), finger joint orientation (horizontal, vertical), and wood treatment (steamed, un-steamed) on bending strength (*MOR*). They found that D3 adhesive yielded the highest *MOR*, followed by D2, with D1 producing the lowest. Longer finger lengths (10 mm) resulted in higher *MOR* than shorter lengths (4mm), and horizontal finger orientation outperformed vertical. Steaming generally increased *MOR* compared to un-steamed wood. Modulus of elasticity (*MOE*) was primarily affected by wood treatment; steaming slightly increased *MOE* (5.4%) compared to solid wood, while un-steamed wood showed no significant difference [42].

3.3. Joint Efficiencies

Muthumala et al. [31] studied the joint efficiencies of seven finger-jointed timber species with 13 mm finger length and reported that Mahogany (*Swietenia macrophylla*) timber has the highest joint efficiency and Kumbuk (*Terminallia arjuna*

(Roxb.) Wight and Arn.) timber species have the lowest joint efficiency.

Singh et al. [39] reported that joint efficiency percentage of 19 mm long finger length in Grandis hybrid species was higher (46.5%), than 13 mm long finger length (41.4%) which is in agreement with the present results as we observed 63.32% and 41.66% joint efficiency, respectively for horizontally oriented 19 and 13 mm long finger-jointed Grandis specimens [39]. Some research [21] was conducted to assess the finger joint efficiencies of seven species of wood; namely grandis (*Eucalyptus grandis* W. Hill.), jack (*Artocarpus heterophyllus* Lam.), kumbuk (*Terminalia arjuna* (Roxb.) Wight and Arn.), mahogany (*Swietenia macrophylla* King), pine (*Pinus caribaea* Morelet), satin (*Chloroxylon swietenia* DC.), and teak (*Tectona grandis* L.f.). Unjointed timber specimens resulted in the highest flexural strength as opposed to the finger-jointed specimens. The highest joint efficiency percentage of bending strength, Modulus of Rupture (*MOR*), and Modulus of Elasticity (*MOE*) were MOR recorded in the test specimens with 19 mm finger length than 13 mm finger length. Joint efficiency is higher in horizontally oriented finger-jointed specimens than in vertically oriented specimens [21]. Özçifçi and Yapici [35] studied how different woodworking machines (circular saw, band saw, and thickness planer, for example) affect the bond strength of various wood species. Their research concluded that rougher wood surfaces, produced by certain machines, resulted in weaker bonds [35].

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3.4. Studies with regards to Strength and Stiffness Properties

Özçifçi and Yapici [35] found that finger jointing did not significantly alter the MOE of several wood species, including Oriental beech, oak, Scots pine, poplar, and Uludagˇ fir. Similarly, Vassiliou et al. [41] observed that finger jointing had little impact on the *MOE* of both steamed and un-steamed timber.

Studying the shear strength of copper azole-treated glulam, Gaspar et al. [7] recommended minimizing preservative use during glulam production due to its detrimental effect on bond line strength. Ong [34] researched the performance of glue-laminated beams made from Malaysian Dark Red Meranti using Phenol resorcinol formaldehyde (*PRF*) adhesive, focusing on factors affecting glulam beam strength. This research aims to better understand the mechanical properties of finger joints, lamination bond strength, and the bending behaviour of glulam beams made from this specific Malaysian hardwood [34].

One of the studies conducted by Juvonen [12] looked at three finger lengths (7.5, 15 and 20 mm), and each joint length resulted in a specific assembly pressure which gave an optimum bending strength. The joint efficiency for all three joint lengths investigated, which can be seen in Figure 1, has a maximum for a specific assembly pressure.

This is in line with what has already been found by other authors on different woody species, namely that it is preferable not to apply high assembly pressures. The diagram efficiency-pressure seems to indicate a decline in performance where the pressure applied is higher than the optimal one. Figure 1 shows that the pressure giving the maximum strength for the 7.5 mm finger joint is 8 MPa for 15 and 20 mm joints, this value is varied to 6 MPa [12]. Lara-Bocanegra et al. [14] reported that the for the low end pressure (4 MPa) condition, a small gap appeared on the surface in the fingertip. However, under end pressure of 6 MPa, no gap in the end of the finger-tip was observed [14].

In the literature [5, 36], strength evaluation of finger-jointed sections has been mainly found to be concentrated on temperate species. As far as hardwoods are concerned, there are some reports from Sri Lanka, compiled by Muthumala et al. [31], and from Ghana, compiled by Ayarkwa et al. [2].

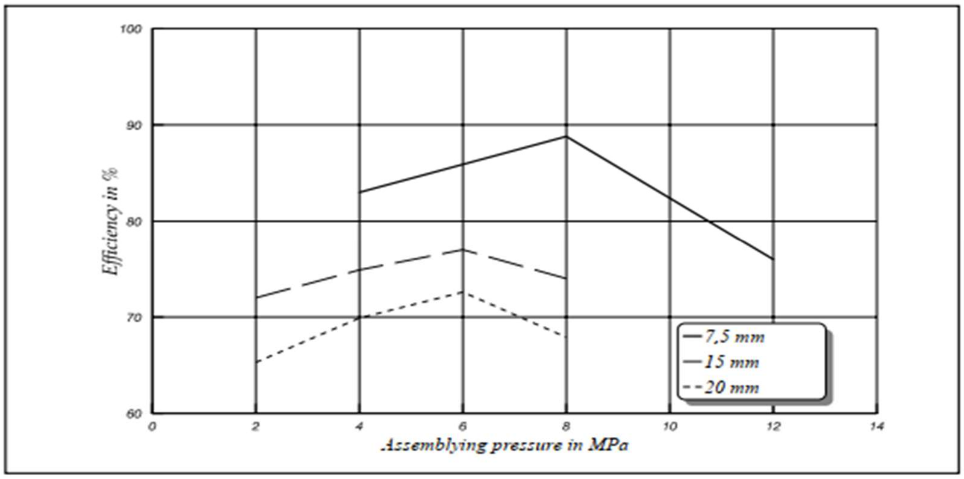

Fig. 1. *Finger joint efficiency as a function of assembly pressure [12]*

BS EN 15497:2004 [3], as supported by Olsson et al. [33], offers guidelines for interpreting knot diameter and specifying the minimum distance between a knot and a finger joint. For round or oval knots, the diameter is measured across the board's width (Figure 2a). For arris knots, the diameter is measured along the board's length (Figure 2b) [33]. This definition is thus different from how knots are generally measured in visual grading [40]. Figure 2c shows a splay knot. Figure 2d shows the case, and corresponding alternative margin requirements, when a knot is removed, the shaded part (Figure 2d) of the board will not be used.

BS EN 15497:2004 [3] permits a minimum distance of 1.5 times the knot diameter between a knot and a finger joint, provided the grain runs parallel to the board's length. However, this standard requires practical interpretation to ensure accurate measurement and implementation.

Careful timber selection for edge joining significantly impacts the appearance, strength, and durability of finished furniture. Considering growth ring orientation is crucial for maximizing both the visual appeal and structural integrity of the joined timber. Therefore, understanding how timber is sawn from a log is essential for effective selection.

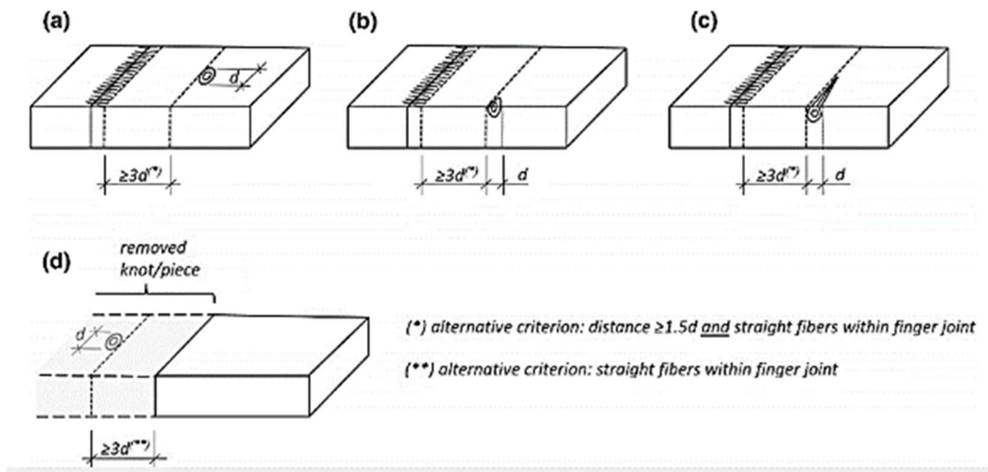

Fig. 2. *Details of finger-jointed timber showing the minimum distance between knot and finger-joint in cases where the knot is [33]: a. a round knot (oval knot); b. an arris knot; c. a splay knot; d. a case where the knot is removed*

The 2013 Learner's Guide to Joint Solid Timber [15] acknowledges the complexity of determining grain direction, noting numerous exceptions to the rules. It recommends planning the wood surface and observing the result, as difficulty planning indicates the grain's opposite direction. For finger-jointed planks, the guide advises aligning the grain direction of each piece (Figure 3).

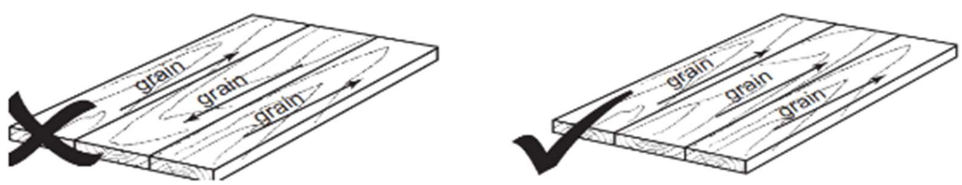

Fig. 3. *Panel joined incorrectly and correctly joint solid timber [15]*

4. Factors Affecting Quality

4.1. General Aspects

The quality of finger-jointed timber can be influenced by several factors that impact its overall performance, strength, and durability. One of the main factors is the quality of the raw timber used. The type of wood, its moisture content, and whether it has defects like knots or cracks can significantly affect the quality of the final product. If the timber is of low quality or improperly dried, the jointing process may lead to weak spots in the finished product.

Another important factor is the precision of the finger-jointing process. The fingers at the ends of the timber pieces need to be precisely cut and aligned for the adhesive to bond effectively. Any irregularities in the cutting process can result in weak joints that may compromise the timber's strength and durability. The adhesive used is also crucial. High-quality adhesives that are moisture-resistant and durable are essential for creating strong, long-lasting joints. If low-quality adhesives are used, the joints may fail over time, especially under conditions of high humidity or temperature changes.

The moisture content of both the timber and the adhesive also plays a major role. Timber that is too wet or too dry can affect the bonding strength and stability of the joints. Additionally, environmental conditions during the production process, such as temperature and humidity, can influence the performance of both the timber and the adhesive. For example, high humidity can cause the wood to swell, while excessive dryness can cause it to shrink, leading to joint failures.

Storage and handling of the timber also affect its quality. Improper storage can expose the timber to moisture or pests, leading to degradation before it is processed. Finally, the treatment and finishing of the timber – such as the application of preservatives or coatings – can influence its durability, especially in outdoor or high-moisture environments. Factors like the quality of raw timber, the precision of the finger-jointing process, the type of adhesive, moisture content, environmental conditions, and proper storage all contribute to the overall quality of finger-jointed timber. Ensuring each of these factors is carefully controlled is essential for producing high-quality, durable finger-jointed timber products.

4.2. Grade Stress Studies

Muthumala et al. [29] investigated the performance and strength grading of finger-jointed specimens compared to clear wood, following BS 5268-2:2002. For satin, mahogany, jack, and grandis, finger-jointing did not significantly alter the strength class. Both clear and finger-jointed satin and teak achieved a D40 grade, while jack, mahogany, and grandis reached D30. Finger-jointed teak exhibited properties similar to both D35 and D40. kumbuk's grade stress class decreased from D40 to D30 after finger-jointing. Finger-jointed pine met C22, C24, and C27 strength class requirements [29].

4.3. Failure Modes on Finger Joint

A 2021 study of Muthumala et al. [25] found that finger-jointed specimens under compression parallel to grain typically failed through crushing, splitting, shearing, and end rolling. Compression perpendicular to grain resulted in crushing, splitting, and wrinkling. The study also noted significant correlations between density and compression test results for both unjointed and finger-jointed wood, and identified common failure modes and flexural properties in finger-jointed wood [25]. Unjointed specimens typically failed due to minor damage at the midpoint, splintering, and cross grain failure. Finger-jointed specimens, however, did not exhibit splintering or cross grain failure. Instead, they showed slight bending at the midpoint, fractures within the finger joint itself, and glue line failures [22]. Muthumala et al. [27] studied shear failure in *Pinus caribaea* Morelet (softwood) and *Tectona grandis* L.f. (hardwood) using butt and tongue-and-groove joints. Most specimens failed due to fiber and wood grain failures. The study concluded that butt joints are better suited for softwood, while tongue-and-groove joints are more appropriate for hardwood. Glue line failures were exclusive to the hardwood species. Additionally, butt joints proved more challenging to bond in hardwood than in softwood [27]. Gavrilov and Kolesnikov [8] research on finger-jointed wood under parallel compression found that the finger joint reduced both the peak load and the load during the post-peak plastic deformation stage.

4.4. Timber Classification for Finger Joint Products

Muthumala et al. [26] created a classification system for 32 timber species based on their physical, mechanical, and anatomical properties. Using factor analysis, they developed a Total Wood Index (*TWI*) and categorized the woods into low, medium, high, and very high groups. They suggest using these *TWI*-based groups to select compatible timber species for finger-joint manufacturing, ensuring optimal matching and attractive aesthetic results [26]. Sri Lankan researchers have also developed a timber classification system specifically for finger-jointed and mixed timber products, using the strength properties of commonly used wood species [28]. When mixing different timber species together, they should be similarly matching timber pieces based on the dimensional effects. Muthumala et al. [23] developed a classification system for 32 selected clear timber species, based on their shrinkage effect in three different environmental conditions, to assist the finger joint technique, and shrink index values were determined and grouped into five classes, as very low, low, medium, high, and very high.

5. Conclusions

Investigations by some researchers revealed the performance and quality parameters of finger-jointed wood products. Findings on strength, stiffness, finger-geometry, dimension stability, durability, visual features failure modes, and connector performance of finger-jointed wood will be beneficial for finger-jointed furniture manufacturing works and help in minimizing possible wood defects and dimensional effects of the products. As a further step towards developing finger-jointed wood products, it is recommended that the guidelines outlined in this paper be used to develop the finger-joint technique and to assess the quality parameters using these findings.

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