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FINGER-JOINTED TIMBER: PRODUCTION AND REQUIREMENTS

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INTRODUCTION

Finger-jointing is a technique of joining two or more pieces of wood at the end grain, to increase the length of the product according to the user's requirements. This technique is commonly used in the timber industry producing both structural and non-structural products. Finger joints for structural uses are incorporated into the fabrication of glued-laminated timber (glulam) and cross-laminated timber (CLT). While for non-structural timber products, they are found in furniture, moulding products, floor boards, window and door frames, etc.

Finger joints are used to replace sections of the timber pieces, where strength-reducing defects and areas with unattractive appearance are removed. This improves the strength and quality of the timber pieces, which increases the values and grade of the timber, especially for timber from fast-growing plantation trees that has considerably large amount of natural defects.

In recent times, Malaysia has been promoting the use of timber from sustainable fast-growing plantation trees such as *Acacia mangium* and rubberwood. Due to its fast-growing nature, the wood from these trees inherit large number of knots (Lim et al. 2011). Finger-jointing technique complements well with this timber where knots are cross-cut and later finger-jointed to longer length, producing higher quality pieces. To produce finger joints with acceptable quality, some with performance almost comparable to solid timber, proper manufacturing of the joints must be followed. These production and test requirements can be found in various standard practice available in different countries. This paper discusses the production of finger joints, testing methods and performance requirements.

FINGER JOINTS PRODUCTION

Typical profile of a finger joint is shown in Figure 1 and categorised into two commonly used vertical and horizontal joints (Figure 2). The fabrication of finger joints involves important processes such as selection and preparation of timber pieces, cutting of finger profiles, bonding and curing of joints and final planing to remove the glue residues. The descriptions of the finger-jointing processes are shown in Table 1.

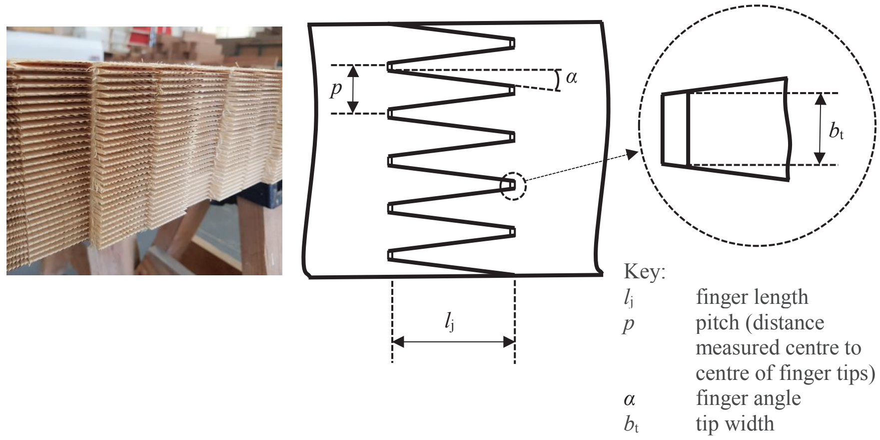


Figure 1 Actual (left) and typical diagram (right) of finger joint profile

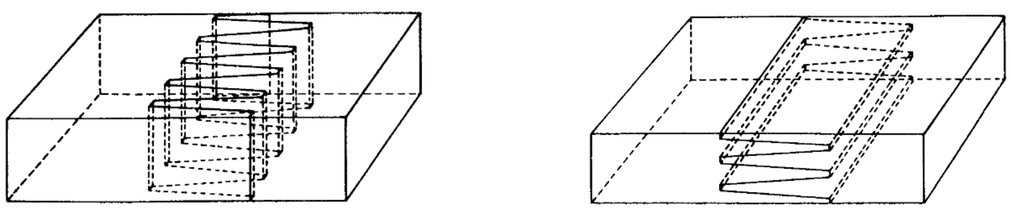


Figure 2 Vertical (left) and horizontal (right) finger joints (Jokerst 1981)

Table 1 Typical stages in finger joints production

Process	Descriptions
Drying	Timber pieces are dried in kiln drying plant or air-dried under shade. Air-drying will take longer time to reach the intended moisture content. The moisture content is normally below 18% and the variation between pieces is less than 5%.
Selection of timber	Timber areas with undesirable defects are cut off. Pieces with matching colour, as well with consistent moisture content and density are selected.
Initial planing	Timber is planed to produce pieces with acceptable squareness. Irregular timber shapes will produce skewed finger-jointed pieces, especially pieces with multiple finger joints.
Finger cutting	The ends of the timber pieces are cut with a finger-profiler machine. The cutting shall have proper feed speed, knife rotation speed and sharp knives to prevent burning of surface. Burnt finger surfaces reduce bondability.
Gluing	Application of glue on the finger surfaces shall be as soon as possible, typically not later than 6 hours after finger cutting. Process shall follow glue specifications such as recommended open- and close-assembly time, single- or double-side spread, glue spread rate, adequate glue squeeze-out, etc. and having a clean bonding surface. The period of applying glue to the timber surface before assembly is called open-assembly time, while the period of assembling the surfaces and the application of intended pressure is called close-assembly time.
Cramping	Specific pressure parallel to timber grain is applied on different finger length, as recommended by glue manufacturers or production standards. The duration of applying pressure is short, typically less than 20 second, as the fingers will maintain an interlocking condition after being released from pressure.
Curing	Release of cramping pressure. Finger-jointed pieces are left to cure. Curing period follows glue specification. Pieces shall not be processed inside curing period.
Final planing	Joints are completely cured. Finger-jointed pieces are planed to remove glue residue. Poor quality finger-jointed pieces are rejected, cut and re-joined.

The processes in the production of finger-jointed products are important. Proper techniques, machine and working procedures are important to produce finger joints of high or intended quality. Factors influencing the quality of the finger joints, which include finger geometry, gluing and cramping, are further discussed below:

1) *Finger geometry*

Finger joints efficiency is influenced by many factors such as the geometry of finger profile, cramping pressure applied, density of timber, machining, type of glue, etc. BS EN 14080:2013 recommends the geometries of finger profile in the manufacturing of glulam as shown in Table 2. It also suggests that the finger length shall be more than 10 mm and the reduction factor, v shall be less than 0.18. Typically, the finger length produced for non-structural uses is shorter as compared to structural finger joints. Some of the non-structural finger joints have finger length of less than 10 mm. Understandably, furniture manufacturers use shorter finger length to reduce material wastage and thus minimising cost. Furthermore, the recommended width of the finger tip shall not be wider than 1.5 mm when used in structural applications (Barboutis et al. 2013).

Table 2 Recommended finger geometries (BS EN 14080:2013; BS EN 15497:2014)

Finger length l_j (mm)	Pitch p (mm)	Tip width b_t (mm)	*Reduction factor v
15	3.8	0.42	0.11
15	3.8	0.6	0.16
20	5.0	0.5	0.10
20	6.2	1.0	0.16
30	6.2	0.6	0.10

*Reduction factor, $v = b_t / p$

2) *Gluing*

The common glues used for finger joints are phenol-resorcinol based (PR), polyurethanes (PU), melamine-urea-formaldehyde (MUF), polyvinyl acetate (PVAc), emulsion polymer isocyanate, etc. The type of glue used depends on the end-uses, whether for structural or non-structural applications. For example, phenol-resorcinol-formaldehyde (PRF) is typically used for producing structural finger joints in the manufacturing of structural products such as glulam and CLT. While, PVAc is commonly used for non-structural finger joints such as furniture products. The application of glue onto the timber surface is performed using brush, glue applicator or a dummy finger profile. The dummy finger profile is simply soaked into the glue and later brushed onto the actual fingers to be jointed.

The quality of bond is influenced by surface quality of the timber, moisture content, timber extractive, preservative, glue viscosity etc. For example, surface contaminated with dust or timber extractive (Figure 3) will decrease glue penetration and wettability, resulting in poor bonding performance. During application of glue, open- and close-assembly time as well as the surrounding temperature will influence the viscosity of the applied glue. Optimum open- and close-assembly time is normally recommended by the glue manufacturer. Deviation, such as prolonged assembly time, will increase the viscosity of glue, resulting in thick joints and weak bondlines. It is also important to allow the joint to achieve full curing before applying any stress or machining.

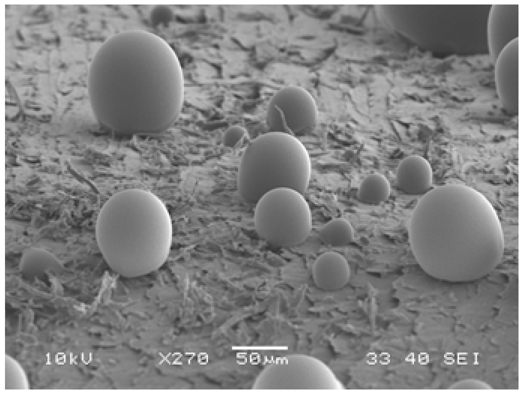


Figure 3 Magnification (×270) using scanning electron microscope (SEM) shows tiny droplets of extractive on the timber surface (Ong, 2018)

3) *Cramping*

Example of cramping parallel to grain is shown in Figure 4. The recommended cramping pressure for different length of finger profiles, specifically for producing structural finger joints is shown in Figure 5. The graph shows an inverse relationship between cramping pressure and finger length. Higher cramping pressure is needed when finger-jointing timber pieces with short finger length. The application of glue can be made at one end or both ends of the timber piece. Importantly, effective spreading of glue is achieved when squeeze-out is observed when cramping, ensuring good bonding of finger joints. Excessive glue squeeze-out is not encouraged because of wastage and difficulty in cleaning when the adhesive hardens. Typically, initial trial run is conducted to determine the optimum amount of glue spread needed for a particular batch of finger joints production.

Figure 4 Cramping parallel to grain. Glue squeeze-out (circled)

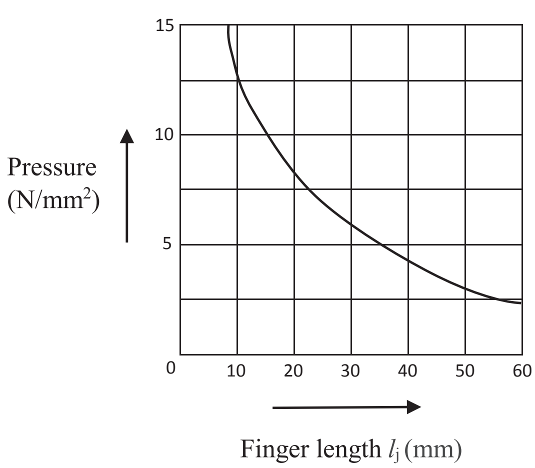


Figure 5 Recommended cramping pressure as a function of finger length (BS EN 14080:2013)

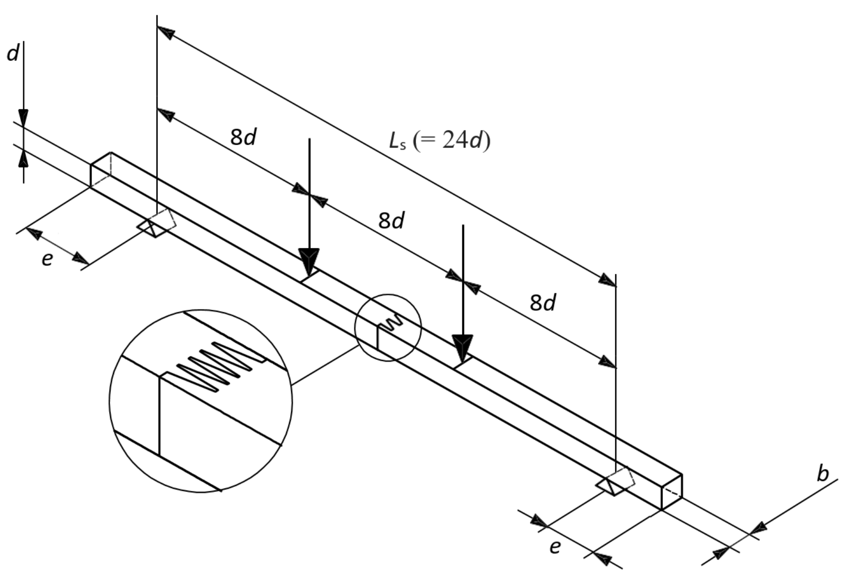
The amount of glue spread and cramping pressure depend on the type of wood species and density. Some species with higher density require higher cramping pressure, while some with higher porosity allow easy glue penetration into the wood surface. However, over-exerting pressure will create starved joints, resulting in weaker bonds. Starved joints are pockets of non-glued areas due to glue being expelled by over-exertion. High density species usually have difficulties in obtaining good bond. Their physical anatomy usually consists of thicker cell walls and smaller lumens, which the glue could not penetrate easily, thus, require higher cramping pressure.

TESTING AND REQUIREMENTS

The performance of finger joints is typically evaluated using standardised or non-standardised testing methods, according to the needs of the user. Standardised tests are normally used to ensure repeatability and relativeness when comparing results between batches of product. The tests are used as an indicator of the performance of finger joints for specific uses such as for structural or non-structural purposes, interior or exterior, etc. Some of the test methods are mechanical resistance tests (i.e. bending and tensile), bonding and resistance to fire test. There are publications or standards related to the testing of finger joints such as testing manual by Tan et al. 2010, BS ISO 17087:2006, ASTM D5572-95 (for non-structural finger joints), BS EN 15497:2014 and BS EN 14080:2013 (for structural finger joints).

1) *Bending test*

The performance of a finger-jointed timber is typically evaluated using 4-point bending test (Figure 6 & 7). Furthermore, the finger-jointed specimens could be exposed to various conditions and treatments (before test) to determine their suitability for dry use or wet use, which are common for performance evaluation of non-structural finger joints. The procedure and requirements for these exposure conditions and treatments are well described in Tan et al. 2010 and BS ISO 17087:2006.



Key:

L_s distance between reaction points

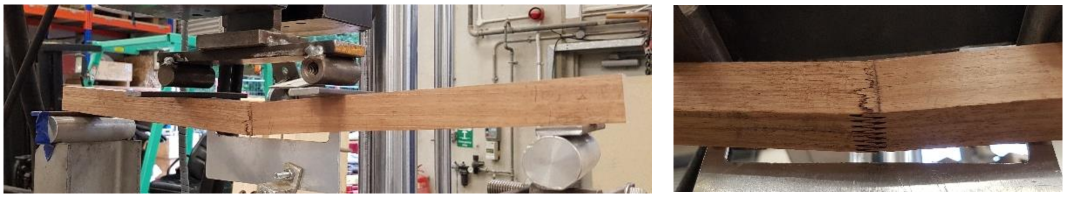
b width of specimen

d depth of specimen

e overhang length of specimen at each end

Figure 6 Schematic and dimensions of 4-point bending test (BS ISO 17087:2006)

Before test



After test

Figure 7 Example of an actual 4-point bending test

2) *Tensile test*

Some finger-jointed specimens tested in tension require detailed processing, such as reinforcing at both ends of the specimen or processed into dumbbell-shaped specimen (Figure 8). The purpose of the tensile test is to evaluate the performance of the finger joints in tension, but strong finger-jointed specimen will result in failure away from the joint, typically at the gripping end sections of the specimen (Figure 9). This failure will not represent the actual tensile stress of the finger joints, thus the needs to reinforce the gripping end sections, with the intention of shifting the focus of failure to the joint. Similar to the bending test, specimens for tensile test could also be exposed to various conditions and treatments before test, to determine the performance classification, specifically for non-structural finger joints. The classification requirements of both bending and tensile tests for non-structural finger joints are given in Table 3. Observations on wood failure is also regarded as one of the test requirements.

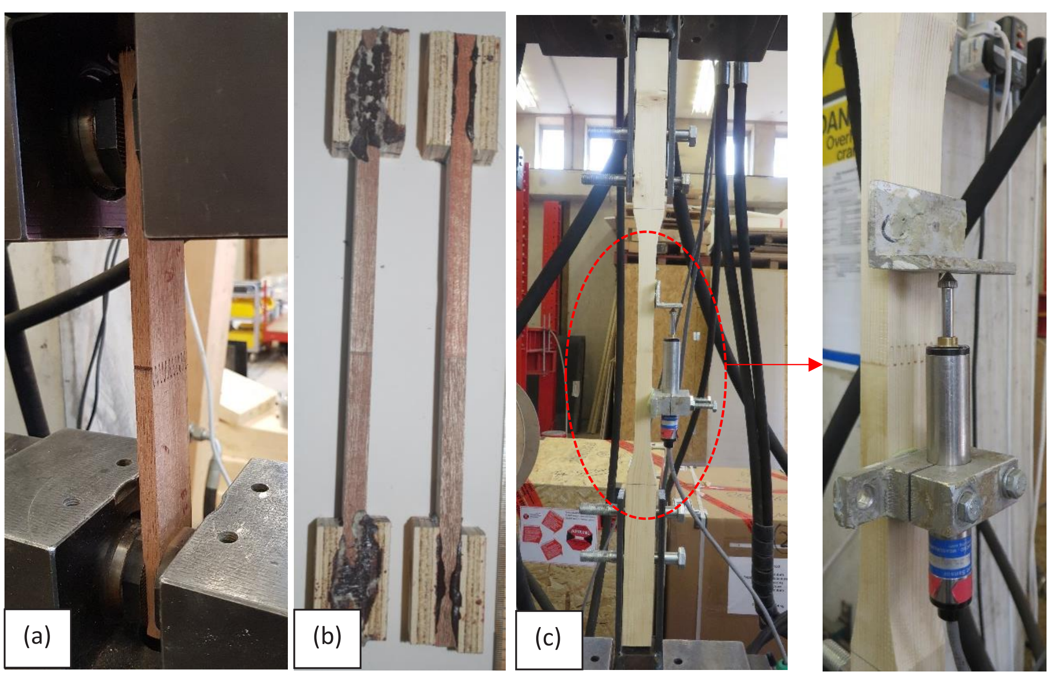


Figure 8 Specimen with (a) no reinforcement, (b) reinforced at the end sections and (c) dumbbell-shaped specimen

Figure 9 Failure at/near finger joints (left) and crushing at the gripping end section (right)

Table 3 Performance classification and requirements for non-structural finger joints (Tan et al. 2010)

Service condition	Tension test			Bending test
	Strength (MPa)	Wood failure (Hardwood)		Modulus of Rupture (MPa)
		Group average (%)	Individual minimum (%)	
Dry use				
Dry	13.8	30	15	13.8
Water soak	6.9	15	-	6.9
Elevated temperature (104 °C)	6.9	-	-	-
Temperature / humidity (65 °C, 16% EMC)	5.2	-	-	-
Wet use				
Dry	13.8	30	15	13.8
Boil	11.0	25	-	9.7
Elevated temperature (104 °C)	6.9	-	-	-
Vacuum-pressure	11.0	25	-	9.7

CONCLUSION

The importance of recognising the profile of finger joints, types of test and requirements is pertinent to the manufacturers when producing finger-jointed products. Although some of the tests are difficult to perform most of them are commonly conducted by local research institutes or universities. Manufacturers with limited testing facilities could also conduct proof loading test (typically in bending) to initially gauge the performance of their finger-jointed pieces. Proof loading test could also be used to inspect the quality of the finger-jointed timber and eliminate weak pieces from the production lines. Other tests should also be considered such as the bonding test, resistance and reaction to fire test, lap shear test etc., depending on the end uses of the finger-jointed products.

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Finger joints are commonly used in the production of timber pieces or products which make use of short pieces and joining them to produce longer intended length. Some of the timber products that make use of the finger joints technology are furniture, moulding products, floor boards, window and door frames, glue-laminated timber (glulam), cross-laminated timber (CLT) etc. Thus, it is important to evaluate the performance of the finger joints, both non-structural and structural. This article briefly introduces the typical profiles of a finger joint, the common tests conducted to evaluate its performance and requirements as classified in various standards.

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