Improving quality of wood products

Specification on joining methods for various types of components and products to maximise wood recovery and strength of products

Dr Benoit Belleville

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Introduction

This report is one of the milestone reports within Activity 3.2 of ACIAR funded project “Enhancing key elements of the value chains for plantation-grown wood in Lao PDR” which objective is to enhance the competitiveness and capacity of the Lao PDR wood processing industry through the development of an industry-led value-added timber market strategy.

This report provides information on joining methods for various types of components and products to maximise wood recovery and strength of joints. The report does not attempt to present all the possible joints in woodworking but aims to discuss selected types of joints, commonly used in high value wood products, and highlight important factors which need to be taken into account while designing and making wooden products.
Woodworking joints

Joinery is a part of woodworking that involves joining wood pieces together and usually requires connectors or adhesive. The characteristics of wooden joints are related not only to the properties of the joining materials but also the way they are used in the joints. Therefore, different joinery techniques are used to meet different requirements.

“Wooden items are rather more prone to fall apart than to break. The weakest point in any wooden construction is at a joint. The successful woodworker focuses not just on each piece of wood but on the interrelationship of pieces of wood and especially on how they are joined together.”

Hoadley (2000)

It is important to use sharp tools when preparing wood for joinery and square ends, edges and faces before making a joint. Four considerations determining the success of any given joint [1]:

1. The stress system involved or what the joint is being asked to do mechanically;
2. The grain direction of the joined parts;
3. Dimensional change in response to moisture;
4. The surface condition of the mating parts.

**Stress situation:** The difference in the strength of various joints depends on the stress situation. Most compression joints give little trouble and shear stress is not too difficult to accommodate. Joints subject to tension and bending are typically the most troublesome. Understanding the direction and relative magnitude of stress when designing and constructing is important. This analysis comes from examination of the structure in which the joint will be used and the loads encounter in service (Fig 1).

Figure 1: End grain to end grain joints under different loading stress. A: Compression; B: Tension; C: Shear; D: Bending
Grain direction: The second element is the grain direction in each adjacent surface of the joint, as related to the stresses involved. The most difficult surface combination to fasten is end grain to end grain. As a result, woodworkers have elaborated system of scarf joints, many with mechanical interlocks, whose principal purpose is to convert adjacent end-grain surfaces to long-grain surfaces.

End grain to side grain or angle joint is another common situation and the solution typically involves a mechanical interlock formed on the end grain piece or made by adding a third piece of wood to cross the joint.

Side joints can be as strong as the wood itself when they are adhesive bonded, even when the grain directions of adjacent members are not parallel. But here the third element comes strongly into play, the dimensional properties of the wood in response to changing moisture conditions. Each type of joint will be further discussed in the following pages.

Dimensional change in response to moisture: Dimensional change is usually no problem in the case of end-grain to end-grain or parallel side grain to side-grain joints because the orientation of the growth rings is usually the same in both pieces. In these joints, if the growth rings are not similarly oriented, the difference between radial and tangential movement might cause visual difficulties, if not structural problems.

Wood swells much more across the grain (tangential and radial shrinkage approx. 4-8%, respectively) than along the grain (longitudinal shrinkage is less than 0.01%) [1]. Moisture changes in these joints produce large internal stresses (Fig 2).

Figure 2: Wood swells much more across the grain (tangential and radial shrinkage) than along the grain (longitudinal shrinkage) and moisture changes in these joints produce large internal stresses.
Alternating wood arrangement (growth rings) helps avoiding visual difficulties or structural problems related to dimensional change in response to moisture (Fig 3).

Figure 3: Alternate wood arrangement (growth rings) to avoid visual or structural problems related to dimensional change in response to moisture [2].

End-to-edge-grain joints where growth rings are visible should be protected (e.g. sealed) from changes in moisture content in service (Fig 4) [3].

Figure 4: End-to-edge-grain joints where growth rings are visible should be protected from changes in moisture content in service. A: plain; B: miter; C: dowel; D: mortise and tenon; E: dado tongue and rabbet; F: slip or lock corner; G: dovetail; H: blocked; I: tongue-and-groove (USDA 2010).
**Surface condition:** The last element is the surface condition of the adjacent parts, including the precision of fit and evenness of bearing, the trueness of the surfaces, and the severity and extent of damage to cell structure resulting from the surfacing process. Uneven surfaces may concentrate enough stress to overcome the strength of wood or glue, while the same joint would survive very well if it had fit properly. Poorly fitted parts may also allow unintended motion, ending in destruction. Finished surface quality is also affected by the extent of knife wear.

**Side joint**
There are five ways to joint wood in length side: gluing, screwing, tongue-and-groove, biscuit join and using dowel or round wooden peg (Fig 5) [2].

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**Gluing**

**Screwing**

**Tongue-and-groove**

**Biscuit joint**

**Dowel**

Figure 5: Ways to joint wood in length side (Kristianto 1987)
In order to improve joinery strength by broadening the gluing surface area, the type of tongue-and-groove can be modified to make various shapes (Fig 6). The modified wood cut includes: teeth-like shapes and a biscuit-shaped lamella. The wood piece shape can also be modified to improve its appearance (Fig 7).

Figure 6: Tongue-and-groove can be modified to make various shapes (Kristianto 1987)
Angle joint
Angle wood joint is an important kind of wood joint for connecting wooden furniture components. Joining two pieces of wood and forming a right angle can be performed using nail, tongue-and-groove, biscuit and dowel, as well as dovetail joints.

Nail jointing is done by pushing the nail into the wood using a hammer (Fig 8). Nails should be tilted and about 150–200 mm left between nails for better holding ability [2]. If a closer distance between nails is needed, the nails should be arranged alternately. Nail depth is approximately 2/3 thickness of the second board.
**Tongue-and-groove joints** are used to join two pieces of wood, one with tongue shape and another with groove shape (Fig 9). The tongue and groove joint can be modified accordingly.

![Diagram of tongue-and-groove joints](image)

Figure 9: Angle joint variation using tongue-and-groove (Kristianto 1987)
**Wood joint with biscuit** joins wood using a biscuit made with plywood, plastic or solid wood, and that is applied almost perpendicular to the angle of the wood joint area for maximum strength (Fig 10). Biscuit dimensions should be appropriate for the wood joint dimension for an optimum result.

![Figure 10: Wood joint with various shapes of biscuit (Kristianto 1987)]
**Dowel joints** use a dowel inserted in the wood joint area to strengthen the joint. The dowel is round with a diameter of about 1/3–3/5 the board thickness [2]. The distance between dowels should be 150-200 mm (Fig 11). In order to improve wood joint strength, the use of a wooden dowel can be combined with a groove (Fig 12). The wooden dowel can also be applied to an angle wood joint (Fig 13).

![Figure 11: Examples of dowel joints (Kristianto 1987)](image1)

![Figure 12: Wooden dowel combined with a groove to improve wood joint strength (Kristianto 1987)](image2)
**Dovetail joint** is a joint between two pieces of wood that each have dovetail-like shapes that match each other (Fig 14). When a large number of pins and tails can be cut with precision, as is possible with machines, the glued surfaces alone can develop adequate strength. Joint strength increases as the number of tails increases, as long as enough wood remains across the narrow part of the tails [1].

In designing the joint, the slope of the tails must be a compromise [2]. If the angle is not great enough, the wedging locking action will be lost. If the angle is too great, the splayed tips of the tail will be too fragile, and a component of end grain will be introduced. This impairs the side-grain integrity of the gluing surfaces. An angle of 11° to 12° has proven satisfactory (Fig 15).
Figure 14: Dovetail joints (Kristianto 1987)

Figure 15: Designing the angle cut of the dovetail (Kristianto 1987)
**Mortise and tenon**

Fastening of end-grain to side-grain joints can be accomplished using the mortise and tenon. The basic joint is fashioned by forming the end-grain component, the tenon, into a round or rectangular cross section and inserting it into a hole, or mortise, of the same size and shape in the side-grain component.

The best orientation of growth rings in a mortise and tenon is with radial/longitudinal grain direction matched along the mortise cheeks both vertically and horizontally (Fig 17) [1].

![Figure 16](image)

**Figure 16**: The best orientation of growth rings in a mortise and tenon is with radial/longitudinal grain direction matched along the mortise cheeks both vertically and horizontally, as in A. Joint D, the worst orientation of grain, is apt to split (Hoadley 2000).

In Figure 17, although open mortise and tenon joints A and B, aka bridle joints, have the same amount of wood in each component, joint B has triple the bonding surface and more balanced dimensional restraint [1].

The strength of the joint is more sensitive to changes in tenon length than tenon width because tenon width has a greater effect on joint rigidity than tenon length [4].
Figure 17: Although joints A and B have the same amount of wood in each component, joint B has triple the bonding surface and more balanced dimensional restraint (Hoadley 2000).

The multiple mortise and tenon is preferable to a single wide tenon (Fig 18) [1]. Tenon depth more than offsets the loss of width, and the increase in tenon height and the number of side-grain to side-grain interfaces greatly improves the strength of the joint.

Figure 18: Multiple mortise and tenon (B) is better than a single wide tenon (A) (Hoadley 2000)
**Finger jointing**

A finger joint is a woodworking joint made by cutting a set of complementary cuts in two pieces of wood, which are then glued (Fig 19).

Figure 19: Finger jointing short pieces of wood has become a popular method of reducing wood waste by using shorts to maximum profit.

Because finger joints usually involve using an adhesive, an easy explanation for failure is that the adhesive is not good or was not properly applied. This may be true, but usually, using the wrong finger joint processing method causes the failure. More often, the fault lies in a poorly machined and poorly fitted dry joint. Finger jointing with the best adhesive will not guarantee a good quality joint if the dry fit is poor [2].

Six important factors in finger jointing:

1. Cutter heads
2. Knife grinding
3. Cutting machine
4. Adhesive applications
5. Joint assembly
6. Joint cure out

**Cutter heads checklist:**

- Knife sets must be checked and measured;
- Knife stack must be set at the same height;
- Cutter head (Fig 20) must to be clean and properly balanced.
Knife grinding
Generally, knives have to be sharpened after cutting approximately 9,100 meters of boards [2]. This may vary depending on the timber species being cut. Knives should last at least one year. After grinding, the heads should be balanced every 3–6 months.

Cutting machine
Trim saws should be at least 0.5 cm thick for good rigidity [2]. Chain carrier lugs should be square with the trim saws and the cutter heads, and they should be checked periodically.

Adhesive application
Adhesive should be prepared properly (weight, proportion and mixed thoroughly). Adhesive should be spread sufficiently and uniformly on every finger. Adhesive should cover 1/2 to 2/3 the length of the finger on both sides of the finger in a thin, continuous film [2]. Too much adhesive may result in the excess being squeezed out. Excess squeeze-out is messy and wasteful, economically.

Joint assembly
End pressure. In-feed machinery should be set to force adjacent fingers together with about 2,400–2,700 kPa for structural joints [2].

Continuity
Once the joints have been forced together, the pressure should be held constant until the joint is cured. Frequent starts and stops disturb the partially-cured joints [2].

Line speed. In-feed speed should be set to allow time for the adhesive to cure completely, and to allow the length of pieces being run to assemble properly [2].

Alignment in-feed. In-feed should be aligned so that the crowder wheels match the fingers accurately [2].

Joint cure-out.
For melamine-urea adhesives, the joint temperature should reach a minimum of 80°C [2].

Wet wood. Wet wood is probably the most common reason that joints are under cured. The recommended wood moisture content for joints is 12–14% [2].
Conclusions
The present report aimed to discuss selected types of joints commonly used in high value wood products and also highlight factors that need to be taken into account while designing and making wood products.

As noted by Hoadley (2000), the weakest point in any wooden construction is usually at a joint. The success of any given joint implies considering the stress system involved, the grain direction of the joined parts, dimensional change in response to moisture and finally the surface condition of the mating parts.

Selecting the appropriate joint is very important when joining wooden components and a good woodworker should keep in mind that even if each individual component has sufficient strength to withstand an induced stress the product will fail if one joint fails.
References

Author/s:
BELLEVILLE, B

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