A Conceptualization in Computer Simulation of Processing Radiata Pine Finger-jointed Wood and Glued-laminated Lumber

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Abstract

The quality and strength properties of shooks for finger-jointing have been recorded as varying within the same species and same tree for New Zealand radiata pine. Many of the feed stocks are either resources from juvenile wood or compression wood. Records show that the quality of timber produced is of lower density with greater variability within the same wood and higher longitudinal shrinkage. Another major challenge faced by the finger-jointing industry is processing costs. Processing cost, notably raw material and adhesives costs, are volatile (DSM, 2008) and have been increasing over past years. The industry has limited alternatives to stay competitive. Improving production management is one of the few ways to gain a positional advantage in the industry.

This presentation will describe the conceptual framework for establishing a computer simulation system to optimise material utilization for production of glued-laminated lumber (glulam). This study proposes a new processing method where the application of a computer simulation system is introduced to describe the finger jointing processing flow. The aim is to produce a computer simulation system which enables optimisation of combinations of different shook stiffness to produce finger-jointed timber which meets the minimum stiffness requirement; at the same time, the arrangement of shooks before jointing shall be cost effective for production. The next phase of optimisation is the arrangement of finger-jointed timber for the production of glulam according to its respective jointed stiffness. Due to the lack of relevant mathematical models available, especially in optimising shook stiffness combination, the study will include experimental work to relate stiffness and shook lengths.

Keywords  finger-jointed lumber, glulam, shook, length effect, stiffness, computer simulation.
Introduction

New Zealand radiate pine is globally renowned for its success in timber plantation. *Pinus radiata* has been widely planted for timber production in the country since 1913. As of to-date, the plantation area covers approximately 1.2 million hectares in New Zealand (Anon, 2005). Timber produced has been widely used as feedstock in most timber manufacturing, accounting for approximately 75% of laminating stock in the country.

Radiata pine is favoured as plantation stock due to short harvesting period and the produce is suitable for wide range of applications. It has a harvesting rotation 30 years. However, reports recorded harvesting age has been reduced to less than 30 years old due to fast growing demand from the global market and timber supply no longer able to cope when using the conventional planting method and cutting regime. *P. radiata* that are harvested at rotation period less than 35 years are likely to have poorer corewood. The current harvesting trend less than 30 years has resulted in a high proportion of low stiffness juvenile wood (Jayawickrama, 2001). In addition, compression wood is commonly found. Literatures claim that fast growth stems have twice the level in having compression wood (12%) than slower growth stems (6%) (Cown, Ilic & Butterfield, 2003). It has been estimated about 15% of the volume of radiate pine wood may be downgraded by compression wood (Timell, 1986).

Variation within-tree as a result from compression wood has been reported as pronounced amongst *P. radiate*. In Cown’s report, he highlighted genetic heredity, topographic of the plantation site, environmental factor, and silviculture practices amongst the contributing factor toward formation of compression wood. Wood near the pith of *P. radiate* is typically inferior for almost all purposes (Cown et al., 2003).

Another concern faced by the timber processing manufacturers is the progressive increase in raw material costs. Besides increasing wood stock price, the overall raw material cost notably adhesives have been volatile (DSM, 2008) due to depletion in fossil fuel supply. The industry is left with limited strategy to stay competitive in the global market whilst meeting demanding requirements from customers. The best resolution is therefore to optimise utilization of resources in hand.

Research Overview

In this study, finger-jointing process is selected as case study. The targeted end product is a structural glued-laminated lumber (Glulam). Glulam is selected over other engineered wood products as it is seen as the new frontier structural lumber replacing solid wood.

Prior to manufacturing of Glulam beam, structural grade finger-jointed lumber has to be produced. Defects in lumber have to be removed and cut into within range of lengths. The short-length defect free wood, herein known as shook, will be sent for finger-profiling and later jointed into finger-jointed lumber. Finger-jointed lumber will be layered to thickness and laminated to form Glulam.
The overview of this project is to optimize the combination of shooks based on the respective Young’s Moduli. The idea is to optimize the utilization of raw material without underestimate or overestimate of the elasticity of raw material. The jointed shooks - finger-jointed lumber should meet the minimum requirement(s) at the minimal feed cost. The information on how these shooks should be matched will be fed into the computer simulation system for continuous decision making. Using the projected value for individual shooks, the production cost for a piece of finger-jointed lumber and Glulam can thus be estimated.

**How The Research Idea Fits?**

In this study, a computer simulation system is proposed to optimise utilization of feedstock so as to improve the production cost in finger-jointing operation. The proposed computer simulation make use of the dynamic stiffness information on each individual shook piece to decide which combination of shooks meets the order requirement(s) at the lowest production cost per jointed piece. The simulation system also provides the overall costing information per processing batch to assist in better production control.

An overview of a typical finger-jointed blanks processing pathway adapted from a local finger-jointing mill in South Island New Zealand (Fig.1). The manufacturing process starts from “Sized timbers” where timbers at certain grades and dimensions are purchased and processed. Sized timbers are sent to a density detector to group timbers according to density. Timbers meeting at least MSG 10(or F8) will be sorted for structural finger-jointed wood while the others for non-structural processing.

Later, timbers are kiln-dried to between 8-12% moisture content for suitable gluing condition. Timbers are sent to a defect scanning device known as Woodeye® to locate undesirable defects for docking. AS/NZS 1491:1996 criteria is used as guideline to determine the allowable knot sizes and distance surrounding the knots and defects. Defective sections are subsequently cross-cut and sorted into bins according to the level of “defect free” sections.

The dotted and shaded boxes in Fig.1 denote the proposed processes to be included into a typical finger-jointing process. In the proposed processes, the Modulus of Elasticity (E) of each piece of shook (short length defect free timber) will be measured prior to finger profiling. The main aim is to obtain and determine the Young’s Modulus; With this information, a customized computer simulation system will workout the best shook jointing sequence which meets requirements according to the respective E; meanwhile, the lowest material cost will be selected by the simulation system. By using the Law of Mixture (Bodig & Jayne, 1982) as in Eq. 1, the system will work out the best Young’s Modulus combination for manufacturing of a Glulam beam.

$$E_{total} = \frac{F}{AE} = \frac{1}{A} \sum E_i A_i$$  \hspace{1cm} \text{Eq. 1}$$

where  
$$E_{total}$$  = The effective MOE of the laminate  
$$A$$  = The total cross-sectional area of the lamella  
$$E_i$$  = MOE of $$i^{th}$$ lamella  
$$A_i$$  = The cross sectional area of $$i^{th}$$ lamella
Gap Analysis

In developing a computer simulation system choosing the optimum shook arrangement sequence requires several logical inputs or mathematical functions. The decision making system requires a logical function or a mathematical equation which can predict the total E of a finger-jointed blank based on dynamic E of the individual shook.

There are two main research challenges in meeting the overall goal before they can be collated to fit into the computer simulation application. First is to find a suitable type of dynamic wave and means to accommodate the shear effects occur in a low slenderness ratio (L/D ratio) specimen. Secondly is to verify the predicted total E for jointed shookes using the Law of Mixtures.

Research Methodology

There are four main focal areas proposed:
The first focal area aimed to optimise shookes’ elasticity combination tested at several shook length combinations. This is to find the best shook combination based on individual E values which belongs to the corresponding E range in producing the optimum total E of a finger-jointed piece.

Fig.1: Flow diagram for finger-jointing process (green shaded box) and proposed processing method in the highlighted dotted boxes.
The second area involves finding the best combination of finger-jointed layers (lamella) based on the corresponding E range of the obtained E value for each jointed timber from focal area 1 to form glulam beams. The Law of Mixture could be used to predict the best lamella combination for a piece of glulam beam.

The last two focal areas require verification of other processing variables to be included in the algorithms. This would involve verification work to ensure the processing variables are as declared. Finally, all the logical inputs and mathematical functions will be collated and drafted into an algorithm for system development.

**Challenges**

The proposed resonance tool to calculate the dynamic E measures the natural frequencies. The first harmonic natural frequency is used to predict the E. Flexural wave is selected for measurement. The principal of derivation of the dynamic E function based on first harmonic natural frequency is based on the Kirchhoff’s thin wall theory. Hence, testing samples are expected to meet the minimum slenderness ratio based on the aforementioned theory. There is no specific study found in the literature on short slenderness ratio specimens relating dynamic and static E. Short and thick specimens are usually avoided as it is claimed that shear effect in the test specimens would be high. It is therefore a challenge in this study to identify the discrepancy between dynamic and static E and later suggest calibration factor for the mathematical function between dynamic and static E.

Secondly, length effect is recognised to have an impact as the length of the same dimension of lumber increase. Using the weakest-link theory, it is said the longer the specimen, the greater the probability of generating a low tensile strength value (Showalter, Woeste, & Bendtsen, 1987). Hence, the concern here is that we could not equate the total E value for a finger-jointed lumber to be the same E as in each shook assuming each shook has same E value and the joint-efficiency is negligible. Since size effect is an issue, ways to countermeasure this have to be addressed in this study.

**Conclusions**

The proposed process system will be a useful tool in the manufacturing of finger-jointing and Glulam in selecting the appropriate shooks combination in a manufacturing environment without penalizing the apparent inferior shooks. The proposed system helps to optimize the use of available raw materials and thus improve the quality of production and cost control.

**Acknowledgements**

Special acknowledgement to Mr. Alan Hartley for his generosity in advice and testing samples contributions. My gratitude to the Ministry of Natural Resources and Environment of Malaysia for his sponsor for this study and to the Department of Chemical and Process Engineering for initiating this project.
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