

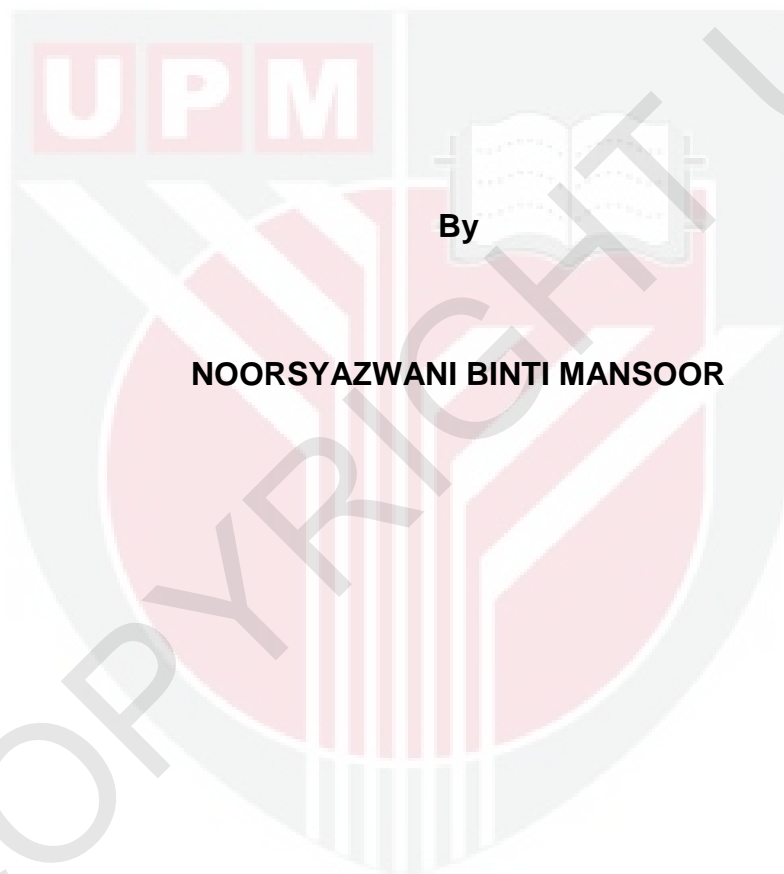


***MECHANICAL & PHYSICAL PROPERTIES OF HYBRID CROSS
LAMINATED TIMBER (HCLT) FABRICATED USING SOLID WOOD &
PLYWOOD***

NOORSYAZWANI BINTI MANSOOR

FH 2019 63

**MECHANICAL & PHYSICAL PROPERTIES OF HYBRID CROSS
LAMINATED TIMBER (HCLT) FABRICATED USING SOLID WOOD &
PLYWOOD**



By

NOORSYAZWANI BINTI MANSOOR

**A Project Report Submitted in Partial Fulfillment of the Requirement
for the Degree of Bachelor of Wood Science and Technology in the
Faculty of Forestry
Universiti Putra Malaysia**

2019

DEDICATION

For my beloved family:

Hj Mansoor Bin Hj Kadir

Hjh Mumin Binti Hj Madia

Also my siblings.

My supervisor:

Dr. Adlin Sabrina Binti Mohamad Roseley

To all my friends and Officers in FRIM & UPM

Thank you for helping me and your encouragements supports,

And the sacrifices that you have given.

Thank you for everything. May Allah Bless All of us.

ABSTRACT

Hybrid cross laminated timber (CLT) using the structural composite lumber (SCL) were developed in this study using Dark Red Meranti (solid timber) and plywood. The usage of plywood as cross and outer layers of hybrid CT was done to improve the mechanical and physical properties of the generic CLT. The objective of this study was to evaluate the mechanical and physical properties of HCLT fabricated with the combination of local species of lumber and plywood. Three samples of CLT with different configurations of layup were prepared with the same size dimension. These samples were then cut into dimension according to the BS EN408 standard for mechanical testing and BS EN391 standard for physical testing. As for the mechanical testing, 4-point bending tests were conducted and MOE & MOR values of the tested samples were determined. The delamination test was conducted to obtain the percentage of total and maximum delamination of the HCLT boards. It was found that the highest value of MOE and MOR was obtained from samples fabricated using solid wood. The property of HCLT using plywood material as outer layer has depicted a slight reduction of MOE and MOR values. The percentage of total and maximum delamination is lower when the outer layer of CLT was replaced by the plywood.

ABSTRAK

Kayu berlapis silang hibrid Hibrid (CLT) dengan menggunakan struktur kayu komposit telah dijalankan dalam kajian ini. Penggunaan papan lapis sebagai lapisan dalam dan lapisan luar CLT telah digunakan bertujuan untuk meningkatkan sifat mekanikal dan fizikal generik CLT. Objektif kajian ini adalah untuk menilai sifat mekanikal dan fizikal hibrid CLT dengan gabungan spesies lokal kayu dan papan lapis. Tiga sampel CLT dengan konfigurasi yang berbeza telah disediakan dengan saiz dimensi yang sama. Ketiga-tiga sampel ini kemudian dipotong mengikut dimensi yang ditetapkan melalui standard BS EN408 bagi ujian mekanikal dan BS EN391 bagi ujian fizikal. Bagi ujian mekanikal, ujian lenturan 4 titik dijalankan dan nilai MOE & MOR dicatatkan. Manakala, bagi ujian delaminasi bagi ujian fizikal dijalankan dan peratusan jumlah delaminasi dan maksimum delaminasi bagi ketiga-tiga sampel direkodkan. Kajian mendapati bahawa nilai MOE & MOR menurun apabila menggunakan gabungan kayu dan papan lapis bagi hibrid CLT dan nilai peratusan jumlah dilaminasi dan peratusan maksimum delaminasi menurun apabila lapisan luar CLT digantikan dengan papan lapis.

ACKNOWLEDGEMENT

Alhamdulillah and thank to Allah S.W.T with all His Gracious and His Merciful for giving me strength and the ability to accomplish this project successfully. I would like to take the utmost opportunity to express my sincere and gratitude to my supervisor Dr. Adlin Sabrina binti Mohamad Roseley, who is always giving me supports and guidance.

Thanks also to Mr. Mohammad Haffis bin Hamid who has assisted me with the laboratory testing. Not forgetting my sincere appreciation to Mr. Muhammad Adzam bin Ahmad and all staffs in Forest Research Institute Malaysia (FRIM) for their help in field work.

Last but not least, special thanks to my beloved family, especially my parents, Mr. Mansoor Kadir, Mrs. Mumin Madia, and also my lovely siblings. Finally, I would like to thanks to many of my friends who support and encourage me throughout this study specially to all my classmates in faculty of Forestry. Hope our love lasting and never die.

APPROVAL SHEET

I certify that this research project report entitled "Mechanical & Physical Properties of Hybrid Cross Laminated Timber (HCLT) Fabricated Using Solid Wood and Plywood" by Noorsyazwani Binti Mansoor has been examined and approved as a partial fulfillment of the requirements for the Degree of Bachelor of Wood Science and Technology in the Faculty of Forestry, Universiti Putra Malaysia.

Dr. Adlin Sabrina Binti Mohamad Roseley
Faculty of Forestry
Universiti Putra Malaysia
(Supervisor)

Professor Dr. Mohamed Zakaria Bin Hussin
Dean
Faculty of Forestry
Universiti Putra Malaysia

Date: January 2019

TABLE OF CONTENTS

| | Page |
|--|-------------|
| DEDICATION | ii |
| ABSTRACT | iii |
| ABSTRAK | iv |
| ACKNOWLEDGEMENT | v |
| APPROVAL SHEET | vi |
| TABLE OF CONTENTS | vii |
| LIST OF TABLES | viii |
| LIST OF FIGURES | ix |
| LIST OF ABBREVIATIONS | xi |
| CHAPTER | |
| 1 INTRODUCTION | 1 |
| 1.1 Background of Study | 1 |
| 1.2 Problem Statement & Justification | 2 |
| 1.3 Objectives | 2 |
| 2 LITERATURE REVIEW | 3 |
| 2.1 Introduction to Cross Laminated Timber | 3 |
| 2.2 Concept of Hybrid CLT | 10 |
| 2.3 Plywood | 13 |
| 3 METHODOLOGY | 18 |
| 3.1 Material | 18 |
| 3.1.1 Type of Solid Wood & Plywood | 18 |
| 3.1.2 Structural Adhesive | 20 |
| 3.2 Sample Preparation | 21 |
| 3.3 Equipment and Test Configuration | 25 |
| 3.3.1 Mechanical Testing | 25 |
| 3.3.2 Physical Testing | 26 |
| 3.4 Evaluation and Analysis | 28 |
| 3.5 Experimental Design | 30 |
| 3.6 Statistical Analysis | 31 |
| 4 RESULTS AND DISCUSSION | 32 |
| 4.1 Mechanical Testing | 32 |
| 4.2 Physical Testing | 38 |
| 4.3 Failure Mode of CLT & HCLT | 43 |
| 5 CONCLUSION AND RECOMMENDATIONS | 46 |
| 5.1 Conclusion | 46 |
| 5.2 Recommendation | 47 |
| REFERENCES | 48 |

LIST OF TABLES

| | | Page |
|---------|---|-------------|
| Table 1 | Physical and Mechanical Properties of Wood | 18 |
| Table 2 | Physical and Mechanical Properties of Plywood | 19 |
| Table 3 | Mechanical Properties of Structural Adhesive | 20 |
| Table 4 | ANOVA Table for the Different Configuration Layup of CLT & HCLT | 46 |



LIST OF FIGURES

| | Page |
|-----------|--|
| Figure 1 | Layup of CLT panels. 3 |
| Figure 2 | Differences between CLT panels and glulam panels. 4 |
| Figure 3 | CLT applications, 3(a) the application of CLT panels in walls element, 3(b) the application of CLT panels in floor and roof systems. 7 |
| Figure 4 | Projects of CLT in Garlick Residence, Oroville, WA, United States. 8 |
| Figure 5 | Multi-building family in Judenburg, Austria. 8 |
| Figure 6 | CLT building: Jewi head office, Wörrstadt, Germany. 9 |
| Figure 7 | Building of Viken Skog BA in, Hønefoss, Norway. 9 |
| Figure 8 | Long-span four point flexure test. 10 |
| Figure 9 | Layer of CLT panels, 9(a) 3-layer CLT panels (SPF-SPF-SPF), 9(b) 3-layer HCLT panels (SPF-LVL-SPF). 12 |
| Figure 10 | The position of layer in plywood. 14 |
| Figure 11 | The plywood panels. 14 |
| Figure 12 | The ply orientation of plywood and LVL 15 |
| Figure 13 | The application of plywood as ceiling material in home office farmhouse. 17 |
| Figure 14 | Multi-family residential construction in Canada 17 |
| Figure 15 | Type of machinery, 15(a) the jointer, 15(b) the table saw. 21 |
| Figure 16 | Type of machinery, 16(a) the thicknesser, 16(b) the hydraulic press. 23 |
| Figure 17 | 3 different configuration lay-up of CLT panels. 24 |
| Figure 18 | Test arrangement for measuring global modulus of elasticity in bending. 25 |
| Figure 19 | Hydraulic press machine. 26 |

| | | |
|-----------|---|----|
| Figure 20 | Pressure vessel with sample used for physical testing. | 27 |
| Figure 21 | Load versus displacement graph of PSP sample | 32 |
| Figure 22 | Load versus displacement graph of SPS sample | 33 |
| Figure 23 | Load versus displacement graph of SSS sample | 33 |
| Figure 24 | Effect of configuration layup on MOE | 35 |
| Figure 25 | Effect of configuration layup on MOR | 36 |
| Figure 26 | Effect of configuration layup on total delamination | 38 |
| Figure 27 | Effect of configuration layup on maximum delamination for layer (a) and (b) | 41 |
| Figure 28 | Failure mode of generic CLT (a), SSS sample | 42 |
| Figure 28 | Failure mode of Hybrid CLT (b), SPS sample | 43 |
| Figure 28 | Failure mode of Hybrid CLT (c), PSP sample | 44 |

LIST OF ABBREVIATIONS

| | |
|----------|--|
| ANOVA | Analysis of Variance |
| ASTM | American of Standard Technology Method |
| CLT | Cross Laminated Timber |
| GPa | Giga Pascal |
| ft | Feet |
| g/mm^2 | Gram per millimetre square |
| HCLT | Hybrid Cross Laminated Timber |
| kPa | Kilo Pascal |
| kg/m^3 | Kilogram per metre cubic |
| LSL | Laminated Strand Lumber |
| LVL | Laminated Veneer Lumber |
| MDa | Maximum Delamination (a) |
| MDb | Maximum Delamination (b) |
| MOE | Modulus of Elasticity |
| MOR | Modulus of Rupture |
| MPa | Mega Pascal |
| N/mm^2 | Newton per millimetre square |

| | |
|-----|--------------------------------|
| PRF | Phenol-Resorcinol Formaldehyde |
| RH | Relative Humidity |
| SCL | Structural Composite Lumber |
| SPF | Spruce-Pine-Fir |
| TD | Total Delamination |



CHAPTER 1

INTRODUCTION

1.1 Background of Study

Cross Laminated Timber (CLT) is a relatively new building system of interest in the North American construction and is helping to define a new class of timber products which is “mass” timber. CLT is an innovative wood product that was introduced in the early 1990s in Austria and Germany and it has been gaining a popularity in residential and also non-residential applications. The using of the CLT panels in buildings has increased in Europe for a past few years. The technology of CLT has many advantages such as easy in handling during the construction and it has a high level of prefabrication which can facilitate a rapid project completion.

The concept of hybrid CLT (HCLT) is demonstrated by replacing one or more layers of lumber with SCL. In this study, the SCL used is plywood. The replacement of layers of CLT panels with the SCL is to improve planar shear and bending properties of CLT. In this study, the configuration lay-up of CLT panels will be different as the layers of CLT will be replaced with plywood to evaluate the mechanical and physical properties of this HCLT.

1.2 Problem Statement and Justification

The generic CLT is prone to the planar shear failure and excessive deflection when subjected to out of plane loading with short spans. Planar stress is defined as shear stress leading to shear strains in a plane perpendicular to the grain direction of wood. To address this issues, many studies have been conducted including the measurement of planar shear properties of CLT, improvement of planar shear properties of CLT and evaluation of CLT configuration on the shear properties of CLT. The literature indicates that planar shear failure can be a limit factor for the strength of CLT subjected to out of plane loading. Based on the previous research, it was found that CLT specimens, for example SPF-SPF-SPF (Spruce-pine-fir) had higher planar shear properties than the HCLT fabricated with LVL, for example SPF-LVL-SPF (Wang et al., 2017).

1.3 Objectives

The objective of this research is to evaluate the mechanical and physical properties of HCLT fabricated with combination of local species of lumber and plywood. In order to achieve this specific purpose, the following specific objectives are required to be fulfilled.

1. To evaluate the mechanical and physical properties of hybrid CLT from solid wood and plywood.
2. To determine the failure mode of hybrid CLT from solid wood and plywood.

REFERENCES

Aditi, (2013). *Glulam/CLT – What's the Difference?*. Retrieved from www.archrethink.co.uk/2013/09/glulamclt-what-difference.html

Anonymous, (2011). *Plywood*. Retrieved from www.woodsolutions.com.au/wood-product-categories/plywood

Anonymous, (2018). *The Original Engineered Wood Product*. Retrieved from www.apawood.org/plywood

BS British Standard (2004). Standard test method for physical properties of sample. BS EN391: 2001.

BS British Standard. (2005). Standard test arrangement for measuring modulus of elasticity in bending. BS EN408: 1995.

Deziel, C. (2018). *What Are Standard Size of Plywood?*. Retrieved from www.hunker.com/12464023/what-are-standard-sizes-of-plywood

Davids, W. G., Willey, N., Lopez-Anido, R., Shaler, S., Gardner, D., Edgar, R., & Tajvidi, M. (2017). Structural performance of hybrid SPFs-LSL cross-laminated timber panels. *Construction and Building Materials*, 149, 156-163.

Dias, F. M., & Lahr, F. A. R. (2004). Alternative castor oil-based polyurethane adhesive used in the production of plywood. *Materials Research*, 7(3), 413-420.

Gong, M., Tu, D., Li, L., & Chui, Y. H. (2015, September). Planar shear properties of hardwood cross layer in hybrid cross laminated timber. In *Wood Science-Annual Meeting* (p. 85).

Karacabeyli, E. (2013). *Handbook Cross Laminated Timber* (Douglas. B.). United States, U.S: FPInnovations.

Neuvonen, E., Salminen, M., Heiskanen, J., Hochstrate, M., Weber, M. (1998). *Laminated Veneer Lumber, Overview of the Product, Manufacturing and Market Situation*. Retrieved from www.hochstrate.de/micha/finnland/reports/replvl.html

Sharifnia, H., & Hindman, D. P. (2017). Effect of manufacturing parameters on mechanical properties of southern yellow pine cross laminated timbers. *Construction and Building Materials*, 156, 314-320.

Wang, Z., Fu, H., Gong, M., Luo, J., Dong, W., Wang, T., & Chui, Y. H. (2017). Planar shear and bending properties of hybrid CLT fabricated with lumber and LVL. *Construction and Building Materials*, 151, 172-177.

Wang, Z., Gong, M., & Chui, Y. H. (2015). Mechanical properties of laminated strand lumber and hybrid cross-laminated timber. *Construction and Building Materials*, 101, 622-627.

Zaklady, P. (2015). *Physical and Mechanical Characteristics of Plywood*. Retrieved from www.biaform.com.pl/en/about-us/physical-and-mechanical-characteristics-of-plywood/

