STUDYING THE PROPERTIES OF ENGINEERED WOOD PRODUCTS

by

Shubham Bhardwaj

Faculty of Natural Resources Management

Lakehead University

April 2023

STUDYING THE PROPERTIES OF ENGINEERED WOOD PRODUCTS

by

Shubham Bhardwaj

An Undergraduate Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management

Lakehead University

April 2023

_________________________ _________________________

Dr. Mathew Leitch — Major Advisor

Robert Glover — Second Reader

LIBRARY RIGHTS STATEMENT

A CAUTION TO THE READER

ABSTRACT

Glulam and OSB are great building alternatives to typical materials in terms of their strength, aesthetics, and economical nature. North America mostly uses Spruce, Pine, and Fir (SPF) owing to their superior strength characteristics and accessibility. But there is scope for underutilized species like larch, poplar, or birch to be used in Glulam manufacturing and engineered products like OSB. The focus of this thesis is to examine if use of the above-mentioned species will be a good alternative to typical SPF species. It also provides an overview of those species, their general distribution and utilization. The comparison is done based on the physical and mechanical properties of these wood species and the 3 properties MOE (modulus of elasticity), MOR (modulus of rupture) and density. It was found that these species have favourable strength characteristics as compared to spruce and would be beneficial if used in the Glulam industry. This was a preliminary study and if tested on a larger scale with advanced technology, this can help create a more resilient lumber market, diversify Canadian wood business, and increase Glulam industry's efficiency.

CONTENTS

LIBRARY RIGHTS STATEMENT i
A CAUTION TO THE READER ii
ABSTRACT iii
TABLES v
FIGURES vi
ACKNOWLEDGEMENTS vii
INTRODUCTION 1
LITERATURE REVIEW 3
2.1 SPECIES DESCRIPTION 3
2.1.1 White spruce *(Picea glauca* (Moench) Voss*)* 3
2.1.2 Poplar (Trembling Aspen) (*Populus tremuloides* Michx.) 5
2.1.3 Larch *(Larix laricina* (Du Roi) K. Koch) 7
2.2 PHYSICAL AND MECHANICAL PROPERTIES OF WOOD 9
2.2.1 Physical Properties 9
2.2.2 Mechanical Properties 11
2.3 ORIENTED STRAND BOARD (OSB) 13
2.4 GLULAM 17
MATERIALS AND METHODS 20
RESULTS 23
DISCUSSION 33
CONCLUSION 38
LITERATURE CITED 39
APPENDIX 44

TABLES

Table Page

1.Strength Properties of white spruce, poplar and larch 13

2. Strength Properties among common North American commercial species…………13

3. Thickness and weights available for OSB panel……………………………………15

4. Strength properties of OSB samples of spruce, poplar and larch……………………15

5. Strength properties of glulam samples of spruce, poplar and larch…………………18

6. Average MOE and MOR for different sample species………………………………25

7. Average density values for all sample groups……………………………………....28

8. ANOVA of MOE for all samples…………………………………………………...33

9. ANOVA of MOR for all samples…………………………………………………..33

10.ANOVA of MOE for all samples………………………………………………….33

FIGURES

Figure Page

1.White spruce in Denali National Park and Preserve 4

2.White spruce distribution Map... 5

3.Poplar stands in Ontario…………………………………………………………..6

4.Poplar distribution map in North America……………………………………..7

5.Larch stands in Minnesota………………………………………………………..8

6.Larch distribution map…………………………………………………………9

7. A visual represenatation of MOE perpendicular to grain……………………………12

8.The manufacturing process of Glulam…………………………………………..19

9. Glued samples kept for drying………………………………………………………21

10. Spruce samples glued with OSB as neutral axis layer……………………………..21

11. A 3-point flexure machinery set up at LUWSTF…………………………………23

12. Graph showing avergae MOE for sample species…………………………………26

13. Graph showing average MOR for sample species…………………………………26

14.Graph showing average densities for sample species……………………………….29

15.Graph showing comparison of strength properties of OSB samples………………..30

16. Graph showing comparison of strength properties of spruce solid & OSB samples.31

17. Graph showing comparison of strength properties of spruce solid wood and laminated wood samples…………………………………………………………..32

ACKNOWLEDGEMENTS

I would like to acknowledge and thank my thesis supervisor Dr. Mathew Leitch for his contribution and assistance in suggesting the topic, providing me with guidance and helping me in Wood Science workshop for sample collection, data analysis and everything that led to the completion of this thesis.

Secondly, I would thank my second reader for providing feedback and insight into the thesis.

INTRODUCTION

Glue laminated Timber (Glulam) is a structural engineered wood product composed of wood laminations or lams. These are bonded together with durable and moisture-resistant adhesives (The Engineered Wood Association, 2018). Glulam can be manufactured in various forms ranging from simple, straight beams to complex, and curved members. Glulam is generally available in four appearance classifications: premium, architectural, industrial, or framing (APA, 2018). Large glulam members are manufactured from various varieties of trees harvested from second-growth forests and plantations (The Engineered Wood Association, 2008). Using glulam reduces the overall amount of wood used as compared to solid-sawn timbers. Creating engineered wood in the form of glulam has helped in creating structurally improved wooden posts and beams (Gilfillan et al., 2003).

Timber manufactured using the laminated process increases its strength, enables it to be used for longer spans, for heavier loads and can also be designed into complex shapes as compared to concrete or steel (Timber Engineering Europe Ltd., 2015). One of the limitations of glulam would be its size as it is constrained due to transportation limitations and handling of glulam (Moody and Hernandez, 1997).

Glulam is manufactured for primary use in non-residential structural applications, architectural or aesthetic designs etc. (NRCAN, 2020). Canada's forest products consist of solid wood products, wood pulp, paper products and bioproducts. The primary species used for wood products include spruce (*Picea*), pine (*Pinus*), and fir (*Abies*) (Government of Canada, 2020).

From an economic point of view, companies could be able to potentially increase profit using lesser-valued wood in glulam production (Gilfillan et al., 2003). For example, a Quebec based company, Nordic, uses small diameter black spruce for manufacturing higher valued glulam beams (Canadian Wood Council, 2022). Another benefit of using value-added wood products is to mitigate climate change (Canadian Wood Council, 2022).

Exploring underutilized wood species for glulam can be efficient and has the potential for creating more capital since Canada has resources available. This diversifies the species used in the Canadian lumber industry and helps create a more resilient industry. In addition to this, engineered wood products such as OSB (Oriented Strand Board) could also be utilized into the glulam structures serving as a filler material. OSB is another kind of engineered wood made with adhesives and compression of wood strand layers in specific orientations.

RESEARCH OBJECTIVE

The purpose of the research is to explore literature and test OSB, underutilised tree species (poplar and larch), and glulam to determine if OSB and underutilised species can be used as a neutral axis layer, or compression and tension layers, in glulam.

HYPOTHESIS

The hypothesis for this research is that OSB can be used as a neutral axis material in glulam structures in the neutral axis layer and underutilised tree species (poplar and larch) could also be used in the compression and tension layers.

LITERATURE REVIEW

2.1 SPECIES DESCRIPTION

2.1.1 White spruce *(Picea glauca* (Moench) Voss*)*

White spruce is one of the widest ranging and commercially important trees found in Canada. It is medium sized with straight trunks ending in a conical crown (Barnes, 2004; Abrahamson, 2015, Figure 1). White spruce has one of the largest ranges that stretches from Newfoundland to Alaska, up to north of the US throughout the boreal forest, bogs, and pulp lands (Gilman and Watson, 2012, Figure 2). It grows best on well drained soils. It is shade tolerant to some extent but grows fastest in full sunlight. Some species that are found growing along white spruce are birch, red maple, black spruce, balsam fir, and eastern white pine (Barnes, 2004).

White spruce usually grows to be 24 metres tall and under ideal conditions can grow to more than 30 metres tall. Its trunk can reach about 60 centimetres in diameter (Ontario Ministry of Natural Resources (OMNR) , 2014).

Figure 1. White spruce in Denali National Park and Preserve (Barbara Logan, 2005).

This species has naturally adapted to forest fires and grows well if the silvicultural system emulates a natural disturbance. Some silvicultural practices used for white spruce management are clearcutting and the shelterwood system (Navratil, 1996). White spruce is used in making pulp, lumber, furniture, and canoe paddles, for example (Barnes 2004). It is a high-value tree where its appeal to the wood industry comes from its light wood colour, low resin content, adequate fibre length-diameter ratio and strength (Wellwood, 1960). It is used to create wood products like dimensional lumber, sheets, trusses, subflooring joists, etc. (Wellwood, 1960). Various wood engineered products like Glulam, Laminated Veneer Lumber (LVL), Cross-Laminated Timber (CLT) and wooden beams are also made from this species (Government of Canada, 2021).

Figure 2. White spruce distribution (USDA, 1971).

2.1.2 Poplar (Trembling Aspen) (*Populus tremuloides* Michx.)

It is a deciduous tree mostly distributed in North America as far south as Mexico up to British Columbia and as far as Canada’s East coast (Barnes, 2004, Figure 3 and 4). The native species of poplar in Ontario are trembling aspen, large-toothed aspen, and balsam poplar (Government of Ontario, 2016).

Figure 3. Poplar stands in Ontario (OMNR, 2016).

Trembling aspen is a tall and fast-growing tree ranging from 20-25 m in height with a trunk 20 to 80 cm in diameter and can reach 36.5m in height and 137 cm in diameter (Barstow and Stritch, 2018).

Silvicultural practices for trembling aspen include clearcutting, uniform shelterwood, group and single tree selection (Perala, 1972). Logging methods for this species include full tree and tree-length (OMNR, 1998). Since, trembling aspen is a suckering tree species, roots grow out from the residual trees left and if the competition is low then there could be 100% stocking in the stand (Kemperman, 1976). North Europe manages poplar in plantations under short rotations known as short rotation forestry (SRF) (Tullus et al., 2012). Intensive silvicultural practices are applied after plantation until harvest and some examples include fertilization, irrigation, and competition control like thinning and weed management (Dickmann, 2006). It is mainly used for pulp, paper, and composite board products like OSB in Ontario (Government of Ontario, 2016;

Barnes, 2004). It accounts for 18-22% of Ontario's annual harvest and growing stock volume (Government of Ontario, 2016).

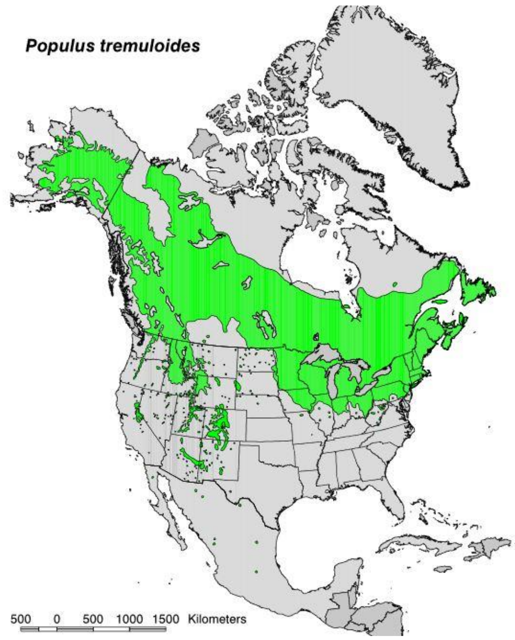

Figure 4. Poplar distribution in North America (USDA, 1971).

2.1.3 Larch *(Larix laricina* (Du Roi) K. Koch)

Eastern larch also known as tamarack is a deciduous conifer native to Canada (Figure 5). It is a small to medium-sized tree reaching an average height between 15 m and 23 m (Parker, 1993). The distribution ranges from eastern Yukon and Northwest Territories east to Newfoundland, south to northeastern British Columbia and central Alberta and south from Minnesota to Cranesville Swamp, West Virginia and as an isolated population in central Alaska (Little, 1979; Figure 6).

Tamarack forms extensive pure stands in northern Minnesota and much of Canada. In northeastern United States it is found in open and forested bogs but rarely dominates and it forms isolated pure stands throughout the rest of its range in the U.S. (Johnston, 1983;

Damman, 1987). Black spruce is usually found associated with tamarack. They could co-dominate wet, lowland sites with shallow permafrost in Alaska (Vierecket al., 1992).


,

Figure 5. Larch stands in Minnesota, USA (US NOAA, 2001).

Larch wood is not only tough but also flexible and therefore it is used for lumber, pulp, poles, snowshoes etc. (Government of Ontario, 2016). It is used to construct buildings for rough dimension, small timbers, planks and boards, railroad crossties etc. Its visual appeal is the reason for it being manufactured into fine veneer, flooring, sashes, and doors (Naturally wood, 2021). Larch is also used for lamstock because of its high-strength properties.

Figure 6. Distribution of Larch (Du Roi and K. Koch 1971).

2.2 PHYSICAL AND MECHANICAL PROPERTIES OF WOOD

Physical and mechanical properties of wood play an important role in understanding the strength of the wood. Physical properties describe the quantitative characteristics of how wood reacts to the influence of the physical environment (Winandy, 1994). Mechanical properties are the characteristic response of wood when external forces are applied (Winandy, 1994). To test the physical and mechanical properties, clear and straight grained wood is used to avoid skewed results due to defects (Forest Products Laboratory, 2010). These properties between wood can differ based on their orthotropic nature, source of sample and growing conditions.

2.2.1 Physical Properties

Physical properties of wood include moisture content, thermal expansion, directional properties, colour, texture, density, dimensional stability, specific gravity, and resistance (Winandy, 1994). Physical properties affect the wood's strength, which forms the basis for wood's structural applications.

2.2.1.1 Density

For this research study, densities of the wood samples (poplar, larch, spruce and OSB) were studied to compare their physical strength. Density is one of the most important physical properties of the wood as it influences the wood strength, stiffness, and its market value (Saranpaa, 2003). Wood density is measured as the mass of wood divided by its volume at a specific moisture content (12% for this thesis) and expressed as kg/m^3 (Forest Products Laboratory, 2010). The simplest method of calculating the density of the wood is to first measure the weight of a wood sample at 12% moisture content as per ASTM standards (ASTM D2395-02, 2008). After weight, the volume of sample is found by the water displacement method. The equation $D = M/V$, where D is the density of the wood sample, M represents the mass and V is the volume, is used to find the sample density. Density can also be measured at oven dry, 12% moisture content, fiber saturation point (FSP) and green.

The density of each tree species changes once moisture is introduced and as the moisture content increases, the strength properties change (Panshin 1970). The FSP is different for every species and ranges between 25% and 30% moisture content (Panshin 1970).

2.2.1.2 Directional Properties

Directional properties are important because wood is orthotropic and anisotropic therefore physical properties will be different when tested along 3 different axes (Forest Products Laboratory, 2010). The change in dimensional strength characteristics is a direct result of how the cells are arranged in the wood (Forest Products Laboratory, 2010). With this orientation there is little change with fluctuating moisture content in the longitudinal axis but a large change in the lateral axis (Forest Products Laboratory

2010). For practical purpose, directional properties of wood are distinguished between perpendicular to grain and parallel to grain (Longitudinal). Perpendicular to grain values mostly apply to assess its both tangential and radial properties.

For utmost rigidity, strength, and service, each type of fastening requires joint designs are adapted to the strength properties of wood along and across the grain and to dimensional changes that may occur with changes in moisture content (Forest Products Laboratory 2010).

2.2.1.3 Moisture Content

Moisture content is defined as the weight of water in a sample piece and is usually represented as a percentage (Winandy, 1994). The formula for measuring the moisture content is: MC = (moist weight- dry weight)/ dry weight) x 100% (Winandy, 1994; ASTM D4442-07, 2007). The moisture content of a sample may vary depending on the tree species and usually it varies between 30% to 200% (Forest Products Laboratory, 2010). Moisture content can increase and decrease wood's strength properties and therefore it is important to make sure the structural lumber does not fluctuate and loose strength. Indian rosewood (*Dalbergia latifolia*) which is native to most provinces in India weighs about 849 kg/m3 at 12% moisture content (Forest Products Laboratory, 2010). Its texture is uniformly and moderately coarse. Indian rosewood has high strength properties and is a heavy wood and it gets hard for its weight after drying (Forest Products Laboratory, 2010).

2.2.2 Mechanical Properties

Mechanical properties of wood are the measures of wood's potential to resist external forces that tend to change its shape and size (Winandy, 1994). Some of the mechanical properties of wood include strength in tension and compression, shear, cleavage, hardness, modulus of elasticity (MOE), modulus of rupture (MOR) and toughness. Samples must be free from any defects to get global standards for testing and comparing mechanical properties (Winandy, 1994). These properties help to determine maximum load or carrying capacity a wood sample can withstand (Winandy, 1994). The properties discussed below include MOR and MOE.

2.2.2.1 Modulus of Elasticity (MOE)

MOE is the potential of a wood sample to bend under low stress and return to its original form (Forest Products Laboratory, 2010). It can be measured in all 3 axes but most measured is the measurement perpendicular to the grain (Winandy, 1994; Figure 7). These measurements are important for products such as floor joists (Shmulsky, 2019).

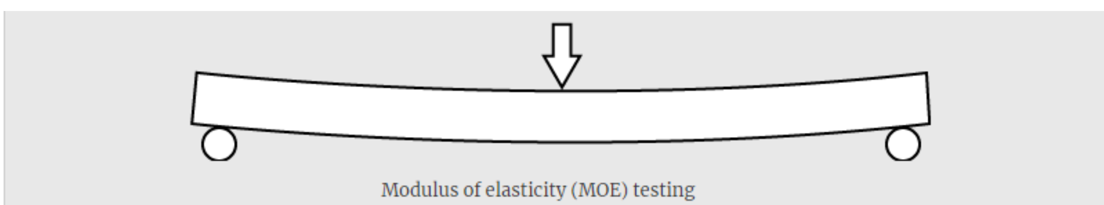

Figure 7 . A visual representation of MOE perpendicular to the grain (Meier, 2008).

2.2.2.2 Modulus of Rupture (MOR)

The maximum load that a wood sample can withstand before it breaks is known as its modulus of rupture (MOR) (Winandy ,1994). MOR becomes useful when multiple species are compared (Meier, 2008).

Table 1. Strength Properties of white spruce, poplar, and larch.

Species	MOE (MPa)	MOR(MPa)	Density (kg/m^3)
White spruce	12650	63.2	381
Poplar	13180	78.2	419
Larch	11920	79.9	558

Table 2. Strength properties among common North American commercial species (Hiziroglu 2016).

Species	MOE(MPa)	MOR(MPa)	Density (kg/m^3)
Douglas fir	13000	85	480
Sitka spruce	10000	70	400
White pine	8000	59	350
Eastern red cedar	6000	60	470
Red pine	11000	75	460

2.3 ORIENTED STRAND BOARD (OSB)

Oriented strand board (OSB) can be defined as an important engineered wood product composed of cross-oriented layers consisting of thin and rectangular strands (Wanzhao et al., 2020). It is a kind of composite wood panel. Manufacture of OSB employs less expensive and fast-growing trees. It commercially became popular in U.S. around the late 19th century (Zerbe, 2015). In terms of fire resistance, OSB has not been as efficient as Glulam. However, studies are being conducted to create a more fire resistant OSB sheet using chemical compounds like boron and phosphorous (Ayrilmis, 2020).

Most used species for OSB manufacturing consists of aspen and pine strands which are usually 1-2 inches in width, 1/4 – (1- 1/8) inches in thickness and 6-9 inches in length (CWC 2021). Southern Yellow Pine is often used in U.S. to create OSB. Some other species that can be used as a filler layer include Birch, Maple, Sweetgum, Poplar (CWC, 2021). Panel quality of OSB depends on each manufacturing step including the species type as each species has its own fibre characteristics, thereby affecting the final product's strength properties (CWC 2021). Table 3 presents some OSB thicknesses and weights for a panel and Table 4 shows some of the strength properties of OSB samples examined for the purpose of this thesis.

Table 3. Thickness and weights available for OSB panels (CWC 2019).

Thickness	OSB(CSA 0325) 1220 x 2440 mm (4 x 8 ft) Panel Weight		
mm.	in.	kg	lb
9.5	3/8	18	40
11	7/16	21	46
12	15/32	23	50
15	19/32	29	63
18	23/32	34	76
22	7/8	42	92
28.5	1-1/8	54	120

Notes: Weight calculated based on 640 kg/m3 (40 lbs/cu.ft.) density and nominal thickness.

Table 4. Strength properties of OSB samples of spruce, poplar and larch.

OSB Sample	MOE (MPa)	MOR (MPa)	Density (Kg/m^3)
Spruce	8867	28.31	471
Poplar	11294	21.50	540
Larch	10130	25.70	627

The manufacturing process of OSB includes a series of steps which consists of log processing, wafering, drying, blending, orienting, pressing and final trimming (CWC, 2019). Logs are brought from storage yards and soaked in hot water ponds to fasten debarking and strand formation (CWC, 2019). The strands are then brought to wet storage bins where they are screened post drying to get rid of fine particles. Drying of strands takes place in large cylinders with a consistent moisture content of 3-7 percent (CWC, 2019).

After drying the strands or wafers are blended with resin and wax. This process is carefully metered to ensure proper resin coverage is achieved (CWC, 2019). After this the strands are passed to a forming machine where they are arranged in various layers in the form of a mat where the outer layers are oriented parallel with the panel running in the long direction and the core layers sit randomly (CWC, 2019). Post layer formation, the mats are pressed, and this can range up to 24 sheets at a time under high pressure. Proper layup of the mat and press are necessary to ensure proper thickness of panels. These are then trimmed to various dimensions and later graded and sorted after inspection (CWC, 2019). Panels are kept in heated storage where resin undergoes final curing (CWC, 2019). Customized processing like addition of tongue and grove or sanding can be done at this stage (CWC, 2019). The final moisture content after the manufacture process is about 4% (CWC, 2019).

OSB can be used in various forms like subfloors, underlayment, furniture, roofs, and wall sheathing (CWC, 2021). Experiments are being done to use it has a filler layer in Glulam products.

2.4 GLULAM

Glulam is an engineered structural building product which is made up of two or more layers of lamstock (lumber) that are glued together. The laminations are oriented parallel to the length of the beam or column (American Institute of Timber Construction, 1983). Different grades of lumber are used to design different styles of glulam or even different species depending on the final use of the product (AWC, 2018). Common species which are used to construct lumber in Canada include Douglas fir, larch, spruce (except Sitka), pine, and fir (CWC 2020).

Glulam is popular in the commercial and residential building industry as it is stronger than steel and serves as a clean alternate because of its carbon storage characteristics. It also provides greater stiffness ratings as compared to normal lumber (APA, 2021). Glulam could be made into any configuration and style. It has the capability to span up to 500 feet in certain dome structures and 100 feet in other custom applications (APA, 2021).

Some of the examples of glulam been used as constructing material include the Mistissini Bridge in Quebec, the Reveley Nursery Facility at the University of Idaho, Pharmacy Brunet in Wakefield QC, and the Brock Commons residence mass timber building at the University of British Columbia (APA, 2021; Element5, 2021; UBC, 2015). Glulam can be used in the residential world for garage door headers, columns, I-joists, ridge beams, and open space designs (APA, 2021). It is common to find high. ceilings in today's houses, and Glulam provides a very strong yet appealing look when used as a ridge beam.

Table 5. Strength properties of glulam samples of spruce, poplar, and larch.

Species Sample	MOE (MPa)	MOR(MPa)	Density(Kg/m^3)
Spruce	10038	44.11	392
Poplar	12350	64	475
Larch	11978	59.60	560

The manufacturing process of Glulam is quite extensive and varies from company to company depending on the tree species used for Glulam stock (Figure 8). The lumber used in Glulam manufacturing is lamstock, which is a special grade of wood directly from lumber mills with square corners and not rounded (CWC ,2020). The lumber then undergoes drying to a moisture content between 7 and 15 percent and multiple pieces are put together to obtain a high strength dimensional lumber in many cross-sectional shapes and lengths (CWC, 2020). Maintaining adequate moisture content before lamination prevents shrinkage and maximises adhesion. The next step involves the sorting of lamstock based on strength and stiffness and later assessed into beams or columns (CWC, 2020). Consistent performance of finished lumber is maintained with the blending process of strength characteristics known as grade combination (CWC, 2020). In this process the outermost layers consist of high strength wood pieces and the weaker pieces are put into the neutral axis layer (CWC, 2020). A waterproof adhesive is then used for laminating the end-jointed lumber strips (CWC, 2020).

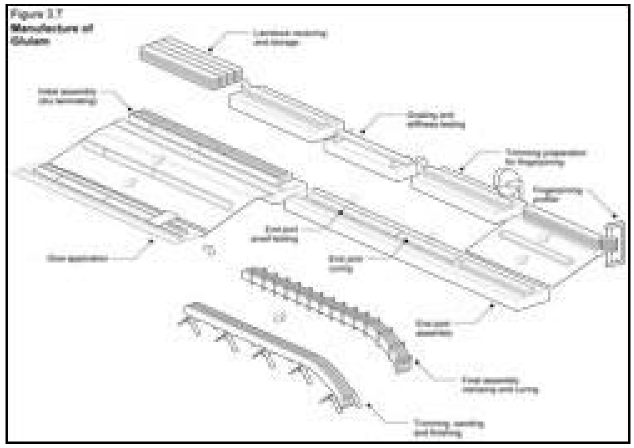

Figure 8. Manufacturing process of Glulam (CWC, 2019).

Some manufacturing processes also produce glued lumber with a bow in the upward direction to reduce its deflection under heavy load and is called cambering (about 2 to 4 mm per metre of length) (CWC, 2020). Finger joints are used as a joinery to end joint individual pieces in glulam beams and has numerous benefits related to strength (BFP, 2021).

MATERIALS AND METHODS

The initial methods and materials used for studying the wood properties included OSB board, and wood boards of Larch, Spruce, and Poplar. Ten 2 x 2 x 30cm wood pieces were cut for each species (Larch, Spruce, and Poplar) and OSB was also cut into ten 2 x 2 x 30cm pieces. The ASTM D 3737–08 (ASTM International, 2010) standard for testing wood pieces was followed. This ensures that the results from this study can be compared to the published values.

The wood pieces were cut at the Lakehead University Wood Science and Testing Facility (LUWSTF). The first batch included 40 sample sticks of just the solid wood with no glue line in the middle (controls). These sticks were sampled and then kept in the conditioning chamber for about a week with 65% RH and 20-degree Celsius temperature to attain a moisture content of 12%. An optimum percentage of 12 is the best level of moisture content. Second batch included the glued wood where all the 4 sample categories (poplar, spruce, larch and OSB) were glued separately into a three-layer beam, and the last batch included the glued wood where OSB was used as a neutral axis layer between wood pieces of larch, poplar, and spruce individually. Every category included 10 samples forming a total of 120 samples with 40 solid sticks, 40 3-layer glued sticks with no OSB centre layer, and 40 glued sticks with OSB as the centre neutral axis layer. Examples of glued sample glulam's are shown in Figures 9 and 10. The samples were then kept in the conditioning chamber again to maintain the optimum moisture content of 12% until testing occurred.

Figure 9 . Glued samples kept for drying.

Figure 10 . Picture showing spruce sample glued with OSB as a neutral axis layer.

For testing MOE and MOR, the testing procedure involved a 3-point flexure tool on a universal wood testing machine (Tinius Olsen Hk10 and 50) set up as shown in figure 11 below. The samples were tested under the ASTM D 7341 (ASTM International, 2021) standards to generate the design capacities which outline code recognition and the capacity per unit dimension. The samples were placed in the testing tool on the machine where it was connected to the computer system to showcase the values and patterns obtained from the machine runs. Results were obtained using the Test Navigation Software, which were further categorized and tabulated to be compared with solid control sample values. The samples were further cut into blocks of fixed measurement to perform density tests following the mechanical test of each sample stick. Water displacement method was used to calculate the volume of each sample and weight was measured on a scale. The values were added into excel and the density formula of mass/volume was used to obtained density of the wood blocks at 12% MC. The average values of MOR, MOE and density for all tests were put together in a table and then compared with the solid wood control samples.

The values obtained from all the samples were then statistically compared using ANOVA through STATA 16.1 software to see if there is any significant difference between the samples and to analyze which combination of wood samples could be the best alternative of typical species that are currently being used in glulam manufacturing.

Figure 11 . A 3-point flexure machinery set up at the Lakehead University Wood Science and Testing Facility.

RESULTS

The values for MOR, MOE, and density for glued categories of wood samples were compared with the solid wood sample values. The values for all the results are presented in tables as well as in charts below. For the solid samples, MOE for spruce, larch and poplar ranged between 11000 MPa and 13500 MPa (Table 6, Figure 12). The OSB on the other hand had 6040 MPa (Table 6, Figure 12). Under normal conditions MOE values above 6000 MPa show promising elasticity properties of wood. Similarly for MOR the numbers lied between the standard values found among common North American commercial species. The OSB MOR value was lower (26.30 MPa) in this case as well (Table 6, Figure 13). The highest value of MOE was shown by poplar at 13,180 MPa, followed by spruce 12,650 MPa and larch at 11,920 MPa. OSB wood samples showed the least strength of elasticity with value of 6040 mPa (Table 6, Figure 13).

The average values of MOR for the 3 tested species were highest for larch at 79.90 MPa (Table 6, Figure 13). Poplar displayed a MOR of 78.20 followed by spruce at 63.20 MPa and OSB at 26.30 MPa (Table 6, Figure 13).

The second category of samples was individually glued samples of wood as a combination of 3 layers of spruce, 3 layers of poplar, 3 layers of larch, and 3 layers of OSB. These were labelled as SpruceLam, Larchlam, PoplarLam and OSBLam. During testing some of the pieces broke off due to glue coming off which led to reduction in the number of samples at the final readings. For SpruceLam the result for MOE was 10,038.50 MPa and 44.11 MPa for MOR (Table 6; Figure 12 and 13, respectively). LarchLam displayed an MOE of 11,978.50 MPa and MOR of 59.60 MPa (Table 6; Figure 12 and 13, respectively). Grand mean values for PoplarLam's MOR and MOE were 64 mPa and 12,350 MPa, respectively (Table 6; Figure 12 and 13, respectively). The average values of MOE and MOR were again small for OSBLam. Average MOE for OSBLam was 4170 MPa and average MOR was 14.70 MPa (Table 6; Figure 12 and 13, respectively).

Lastly, the values for glued samples with OSB as the neutral axis layer showed prominent numbers. The spruce OSB spruce sample set (SprOSBSpr) had 8867.50 MPa as its MOE and 28.31 MPa as its MOR (Table 6; Figure 12 and 13, respectively). The second sample set was Larch OSB Larch (LarOSBLar) and its values were 10,130 MPa for MOE and 25.70 MPa for its MOR (Table 6; Figure 12 and 13, respectively). Poplar OSB poplar set (PopOSBPop) showed highest value of MOE AT 11,294.28 MPa amongst all the other OSB glued wood and its average MOR value was 21.50 MPa (Table 6; Figure 12 and 13, respectively). A unique set of samples were made where OSB formed the outer layer and spruce was the middle layer (OSBSprOSB). The mean MOE value for this set was the lowest 5660 MPa and the average MOR value was 22.50 MPa (Table 6; Figure 12 and 13, respectively).

Table 6. Average MOE and MOR for different sample species.

Sample species	No. of samples	MOE (MPa)	MOR(MPa)
Spruce	10	12650.00	63.20
Larch	10	11920.00	79.90
Poplar	10	13180.00	78.20
OSB	10	6040.00	26.30
SpruceLam	7	10038.50	44.11
LarchLam	7	11978.50	59.60
PoplarLam	10	12350.00	64.00
OSBLam	10	4170.00	14.79
SprOSBSpr	8	8867.50	28.31
LarOSBLar	10	10130.00	25.70
PopOSBPop	7	11294.28	21.50
OSBSprOSB	10	5660.00	22.50

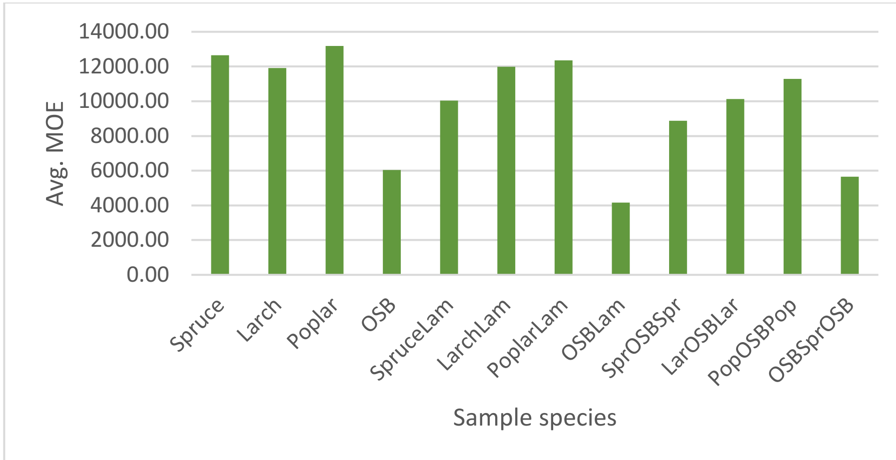

Figure 12. Graph showing average MOE (MPA) for all samples.

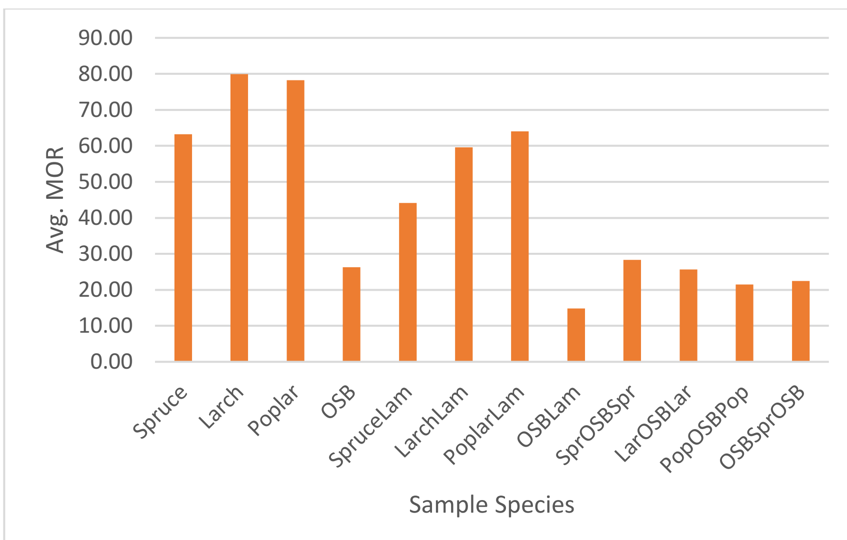

Figure 13. Graph showing average MOR (MPA) for samples.

The grand mean densities of all the different sample sets are shown in figure 14 and table 3 below. The average density was expressed in kg/m^3 and for solid sample species it ranged between 300 and 600 kg/m^3 (Table 7, Figure 14). Spruce had an average density of 381.80 kg/m^3, poplar's grand mean density was 434.40 kg/m^3, larch at 557.85kg/m^3, and OSB's average density was 613.21kg/m^3 (Table 7, Figure 14).

The average densities for the 3-layer samples were in the same range as that of the solid samples for each different species. For SpruceLam the mean density was 391.93 kg/m^3, 475.23 kg/m^3 for PoplarLam , around 600 kg/m^3 for LarchLam, and 698.46 kg/m^3 for OSBLam (Table 7, Figure 14).

The third set of samples followed the same pattern with SprOSBSpr having an average density of 471.45 kg/m^3, PopOSBPop displayed a mean density of 540.16 kg/m^3, while LarOSBLar had the highest average density of 627.86 kg/m^3 (Table 7, Figure 14). The average density value for OSBSprOSB was 588.12 kg/m^3 (Table 7, Figure 14).

Table 7. Average density values for all sample groups.

Sample Species	Average Density (g/cm^3)	Average Density (kg/m^3)
Spruce	0.381	381.80
Larch	0.557	557.85
Poplar	0.434	434.40
OSB	0.613	613.21
SpruceLam	0.391	391.93
LarchLam	0.559	559.29
PoplarLam	0.475	475.23
OSBLam	0.698	698.46
SprOSBSpr	0.471	471.45
LarOSBLar	0.540	540.16
PopOSBPop	0.627	627.86
OSBSprOSB	0.588	588.12

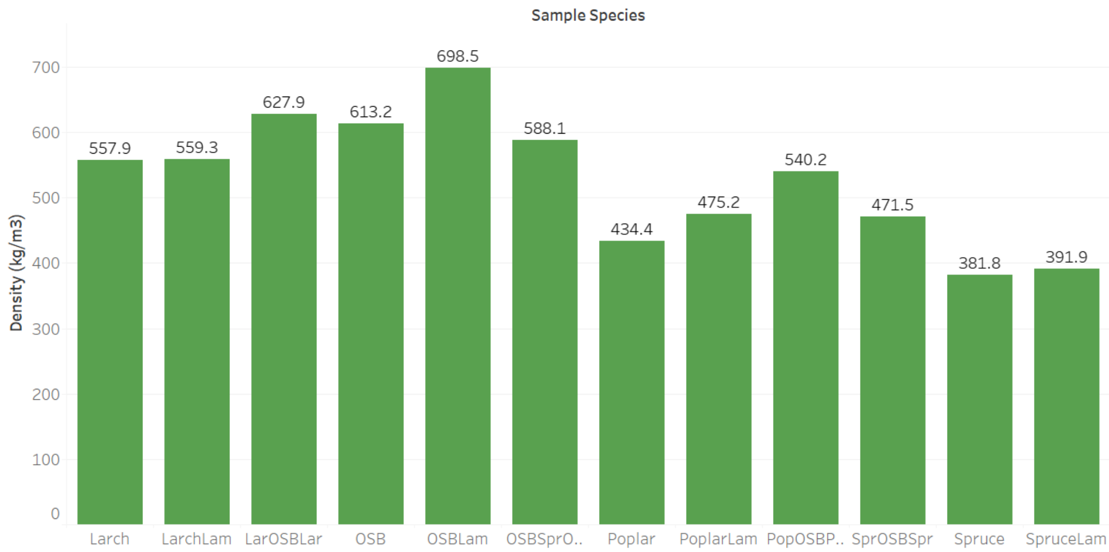

Figure 14. Graph showing the average densities for all samples groups.

After comparing the strength properties of all samples together, samples were also compared in specific categories in which they were tested. Statistical comparison of results included comparison of strength properties (density, MOE, and MOR) of all 3 sets of OSB samples (SprOSBSpr, PopOSBPop and LarOSBLar). Second comparison type was done between strength properties of spruce solid wood and laminated wood samples (SpruceLam, PoplarLam and LarchLam). Lastly, strength properties of spruce solid wood were compared with OSB strand samples of spruce, poplar and larch.

Figure 15 shows density, MOE, and MOR values for different OSB samples. Density for different OSB samples ranged between 471.5 Kg/m3 and 627.9 Kg/m3 with LarOSBLar having the highest value of 627.86 Kg/m3 and SprOSBSpr with the lowest value of 471.5 Kg/m3. PopOSBPop has the highest MOE of 11,294 MPa and SprOSBSpr stands with the highest MOR of 28.31 MPa followed by LarOSBLar at 25.70 MPa.

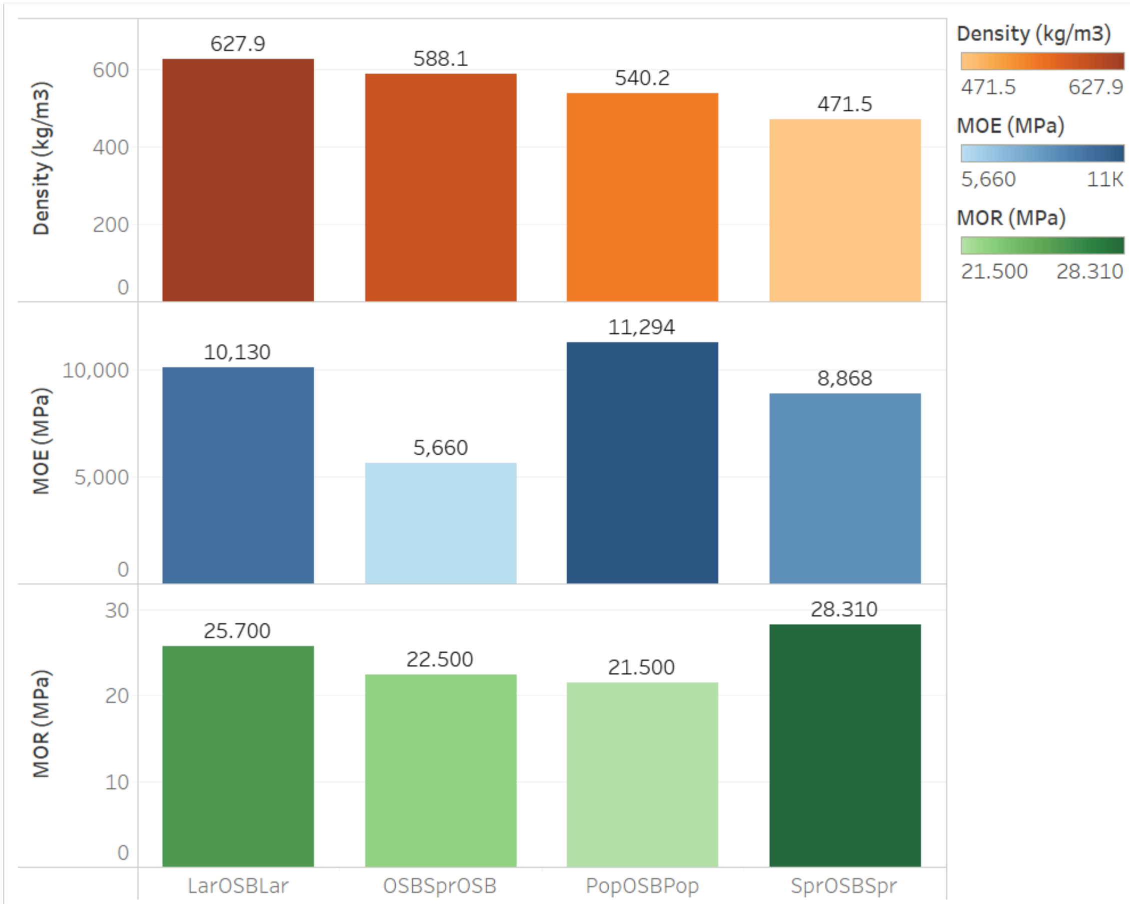

Figure 15. Graph showing comparison of strength properties of different combinations of OSB samples.

Figure 16 below compares the strength properties (density, MOE and MOR) of spruce with 3-layer OSB samples of spruce, poplar and larch. LarOSBLar had the highest density of 627.90 Kg/m^3 whereas spruce solid wood sample had the lowest density 381.80 Kg/m^3 . MOE for all the samples ranged between 8867.50 MPa and 12,650 MPa with spruce with the highest MOE and SprOSBSpr with the lowest MOE value. Spruce solid wood sample had the highest MOR of 63.20 MPa while SprOSBSpr, PopOSBPop and LarOSBLar ranged between 21.50 MPa and 28.31 MPa.

Figure 16. Graph comparing strength properties of spruce solid sample and OSB samples.

Comparison of spruce solid wood and different samples of laminated wood (SpruceLam, PoplarLam and LarchLam) can be seen in Figure 17 where laminated sample of larch (LarchLam) stands with the highest density of 559.30 Kg/m^3 while spruce solid wood sample had the lowest density of 381.80 Kg/m^3. Spruce had the higest MOE (MPa) of 12,650 MPa and PoplarLam was close as well at 12,350 MPa. PoplarLam showed the highest MOR (MPa) value of 64 MPa followed by spruce wood sample at 63.20 MPa. SpruceLam sample showed the lowest value for MOR which was 44.11 MPa.

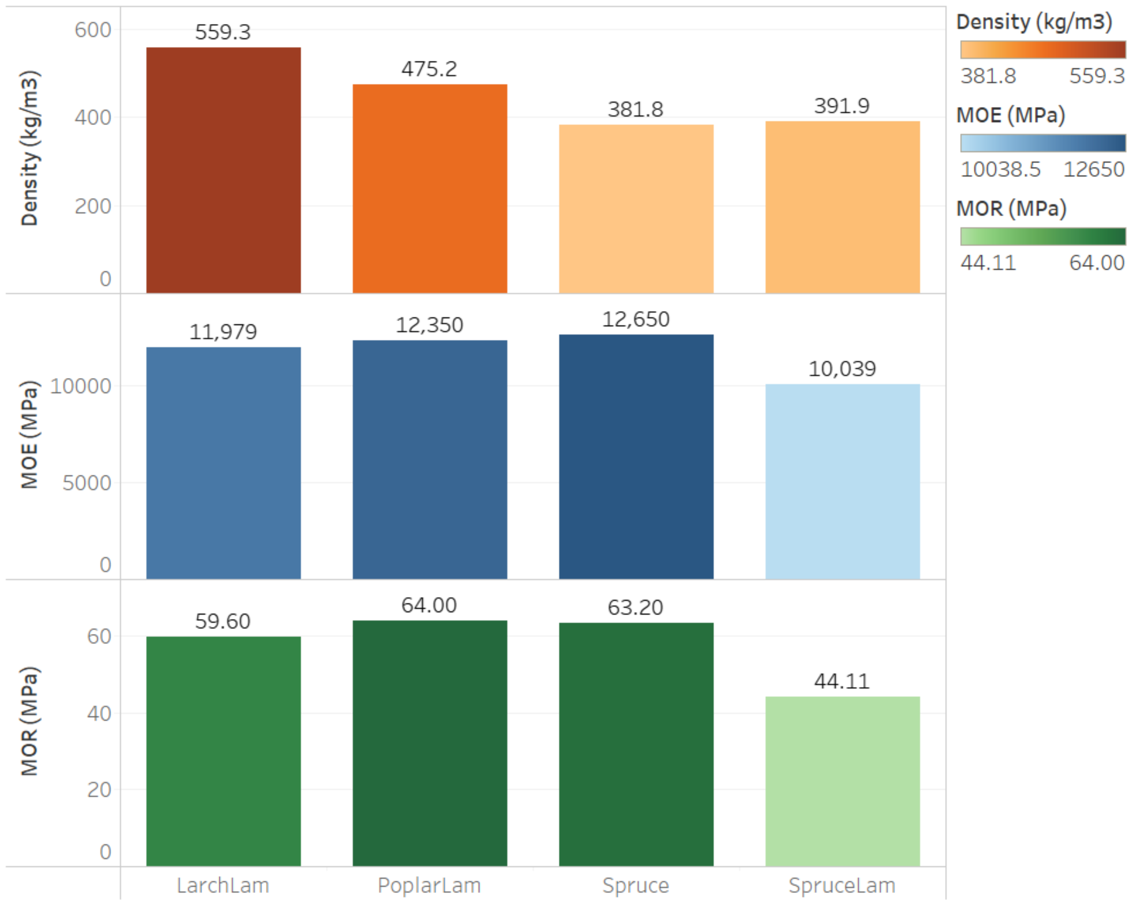

Figure 17. Graph comparing strength properties of spruce solid wood and laminated wood samples.

The results obtained from analysis of variance (ANOVA) are shown in the tables below. Table 8. Shows the significant difference in variance of mean MOE between all sample types. The p-value was less than 0.05 (level of significance) which proves that there is significant difference in MOE between samples. Similarly, the p-value was less than 0.05 for MOR and density analysis of samples as seen in Table 9. and Table 10. Respectively. This indicates that MOR and density are also statistically significantly different.

Table 8. ANOVA of MOE for all samples.

Source	SS	df	MS	F	Prob > F
Between groups	131658158	8	16457269.7	2.60	0.0152
Within groups	443845273	70	6340646.76		
Total	575503430	78	7378249.11		

Table 9. ANOVA of MOR for all samples.

Source	SS	df	MS	F	Prob > F
Between groups	35795.4651	8	4474.43313	62.86	0.0000
Within groups	4982.36108	70	71.1765868		
Total	40777.8261	78	522.792643		

Table 10. ANOVA of Density for all samples.

Source	SS	df	MS	F	Prob > F
Between groups	520122.366	8	65015.2957	119.34	0.0000
Within groups	38134.549	70	544.779272		
Total	558256.915	78	7157.13993		

DISCUSSION

The global wood market has a wide variety of wood from softwood lumber to veneer logs. The global glulam and OSB industry have been more and more successful in recent years due to new applications for these engineered wood products (Albee, 2019). The results obtained above tell that the samples glued with OSB as the middle layer showcased promising values. As described earlier a good quality wood has an average MOE range above 6000 MPa and all the OSB laminated wood samples had their average MOE greater than or around 6000 MPa (CWC, 2021). MOR values for poplar samples were quite low but they show potential of holding a good amount of load by enhancing the mechanical properties of the species by modification and reinforcement (Wang et. al 2019). Large dimensional lumber is increasingly becoming hard to locate and harvest (Wilson 1991). This indicates that Glulam has the potential to provide a solution for speciality sized lumber. Glulam and OSB products can be used to create impressive dimensions as solid wood beams are becoming difficult to acquire (

Williston 1991). The objective of this study was to examine if OSB could perform well as a neutral axis layer as an alternative to typical species used in terms of mechanical and physical strength. Some of the samples have as a result given feasible values. Larch performed the best in terms of its average MOE (10,130 MPa) and MOR (25.70 MPa) when glued with OSB. In terms of average density Larch glued with OSB (627.86 kg/m^3) showed greater average density as compared to the solid samples tested in set 1. These results show considerate values for MOE and MOR when OSB is one of the layers (neutral axis layer and not the compression or tension layers). CLT prepared with poplar as the transverse layer has lower density, but better interlaminar shear performance in the major strength direction (Mingyue Li 2022). Also, this was a preliminary study involving only 10 samples for each category where some samples were outliers due to defects not seen in the samples prior to testing. After comparing statistics for different combinations of samples, it was discovered poplar species would be a feasible alternative for manufacturing engineered wood instead of the typical spf species.

On comparing 3- layered OSB samples it was determined that poplar had the highest density (627.90 Kg/m^3) , highest MOE (11,294 MPa) out of all the four comaprisons (SprOSBSpr, PopOSBPop and LarOSBLar). For MOR, spruce glued with OSB strand had the highest value of 28.31 MPa. It should also be noted that poplar did not show a high value of MOR, but it is shows good range of strength properties which makes it a good choice for glulam manufacture. It will be evident to say that if studied and researched with more samples, results would be statistical more feasible and show acceptable strength values for these engineered wood products made with OSB in the neutral axis layer.

Poplar(laminated) had highest values for MOR and density 64 and 559.30 Kg/m^3 when compared with spruce solid wood sample and other laminated samples (LarchLam and SpruceLam). Although MOE value for laminated poplar sample (12,350 MPa) was lower than solid sample of spruce(12,650 MPa) but it was still close. When OSB layered samples were compared with solid spruce sample, PopOSBPop had the highest density of 627.90 Kg/m^3 showing that this species would be able to provide better strength, physical and mechanical structure if used in glulam industry. Spruce resulted in higher MOR (63.20 MPa) and MOE(12,650 MPa) but poplar was quite close (11,294 MPa) to spruce solid sample for MOE value. Use of underutilized species in glulam manufacturing would have lower design values, they will have the advantage of being produced from a raw material that need not be in a log size large enough for peeling into veneer (Smulski 1997). The results show that underutilized species like poplar have the potential to be used as alternative species for engineered wood. Engineered wood products are environmentally conscientious and will be beneficial in various aspects of the wood industry. One such examples is at University of British Columbia where an eighteen - story wood building was completed in 2016 using engineered wood products (CLT and glulam), showing potential of OSB in tall mass timber buildings (UBC 2016). This means such engineered wood products have potential to succeed commercially as a value-added product if tested and manufactured properly. This could bring a revolution in the wood products market and shift the industry's focus to a more affordable, competitive, and sustainable building movement. One such study was done by Ali (2014) where beech and poplar strands were used as core layer to manufacture OSB and the results showed that poplar panels showed higher MOR and MOE with different level of fines content (Akrami et. al 2014). This was clearly depicted in our results too.

The ANOVA analysis shows that the sample values obtained from lab experiment are statistically significantly different between samples. From the literature review, it was evident that poplar would be the best substitute to be used as a neutral axis layer in engineered wood manufacturing instead of the species that are currently used (spruce in this case). After comparing the ANOVA analysis between spruce wood sample and poplar- OSB (PopOSBPop) sample, it was found that average MOE between these two samples had no significant difference (as p-value is >0.05). This shows that the MOE values between spruce and poplar-OSB are similar(also seen in Figure 16.).ANOVA results for density and MOR between spruce samples and poplar-OSB (PopOSBPop) samples show significant difference (p-value is < 0.05) where poplar-OSB samples had greater density and smaller MOR mean value as also seen in Figure 16.

These results support our hypothesis that poplar (an underutilizes species) would be a good potential replacement for species currently been used commercially. Also, it was a preliminary study and with these results a larger study can be extrapolated by increasing sample numbers and using feasible sample sets. Smaller studies like this help show the potential to focus on larger studies and find substitutes of mainstream wood products.

The appeal for mass timber production which includes Glulam, OSB, Cross Laminated Timber (CLT), and Laminated Veneer Lumber (LVL) arises from finding alternatives to typical solid lumber species , concrete and steel (Albee 2019). Changes in the International Building Codes (IBC) have significantly increased Glulam utilization (MTCC 2021). OSB has continuously competed with plywood in the residential and industrial sectors; however, OSB now accounts for more volume than plywood in the residential sector (Omar 2020).

CONCLUSION

The Glulam market and the wood-based panel markets are rising worldwide. This is opening doors in providing materials necessary for new research and finding new ways of product utilization. There is a surplus of underutilized wood in Canada which has the potential to reduce the economic stress laid on the typical SPF species.

Every year new applications of engineered wood panels (OSB) are found, and their manufacturing techniques are also improving. This enhances the physical and mechanical properties of the engineered wood. These attributes when combined with the benefits of larch, poplar or birch could work as a success in Glulam production.

Complete reliance on SPF species for engineered wood production could leave glulam industry at risk of natural disasters like forest fires, disease, and insect infestation. This would impact the Glulam industry, residential and industrial building markets as Canadian forest industry is no stranger to natural disasters. Therefore, use of alternative species (Larch, Poplar, Birch etc.) and OSB in manufacturing of glulam products could increase the industry's resilience to these natural risks. This would ultimately save exploitation of trees, save wood, and help develop an environmentally sustainable building movement.

LITERATURE CITED

Abrahamson, I. 2015. Picea glauca, white spruce. *In*: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. https://www.fs.fed.us/database/feis/plants/tree/picgla/all.html .

Akrami, A., Fruehwald, A. & Barbu, M.C. The effect of fine strands in core layer on physical and mechanical properties of oriented strand boards (OSB) made of beech (Fagus sylvatica) and poplar (Populus tremula) . Eur. J. Wood Prod. 72, 521–525 (2014). https://doi.org/10.1007/s00107-014-0802-z

Albee, R.R. 2019. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/tt44ps646. April 16, 2021.

American Institute of Timber Construction. 1983. Inspection Manual AITC 200-83. American Institute of Timber Construction, Englewood, Colorado. 79 pp.

APA. 2021. The Engineered Wood Association. Glulam. https://www.apawood.org/glulam. March 20, 2021.

ASTM D4442-07. 2007. Standard test method for direct moisture content measurement of wood and wood-based materials. ASTM International, West Conchohocken: Pennsylvania, 6 pp.

ASTM D2395-02. 2008. Standard test method for specific gravity of wood and wood-based materials. ASTM International, West Conchohocken: Pennsylvania, 9 pp.

ASTM D4442-08. 2010. Standard Practice for Establishing Allowable Properties for Structural Glued Laminated Timber (Glulam). ASTM International, West Conchohocken: Pennsylvania, 28 pp.

ASTM D 7341. 2021.Standard Practice for Establishing Characteristic Values for Flexural Properties of Structural Glued Laminated Timber by Full-Scale Testing. ASTM International, West Conchohocken: Pennsylvania, 5 pp.

(AWC) American Wood Council. 2018. Manual for Engineered Wood Construction. First web version 2018. https://awc.org/pdf/codesstandards/ publications/archives/AWC-2018-Manual-1810.pdf. November 2021.

Ayrilmis, N. 2020. Effect of Boron and Phosphorus Compounds on Fire and Technological Properties of Oriented Strandboard. Materials International. Vol 2. Issue 2. ISSN: 2668-5728.

Barnes, B. V and W. H. Jr. Wagner. 2004. Michigan trees revised and updated: a guide to the trees of the Great Lakes region. University of Michigan Press. United States. 447pp.

Barstow, M. & Stritch, L. 2018. *Populus tremuloides*. The IUCN Red List of Threatened Species 2018: e.T61960127A61960136.

(BFP)Brink Forest Products Ltd. 2021. Benefits – Straightness and Stability. http://brink.bc.ca/products/benefits/. November 2021.

(CWC) Canadian Wood Council. 2020. Glulam manufacture. https://cwc.ca/how-tobuild-with-wood/wood-products/mass-timber/glulam/. November 2021.

(CWC) Canadian Wood Council. 2021. Oriented Strand Board (OSB). https://cwc.ca/how-to-build-with-wood/wood-products/panel-products/orientedstrand-board-osb/#:~:text=OSB%20is%20also%20manufactured%20using,in%20limited%20quantities%20during%20manufacture. November, 2021.

(CWC) Canadian Wood Council. 2019. Oriented Strand Board (OSB) Manufacture. https://cwc.ca/wp-content/uploads/2019/03/Oriented-Strand-Board-OSBManufacture.pdf. November 10, 2021.

Damman, Antoni W. H.; French, Thomas W. 1987. The ecology of peat bogs of the glaciated northeastern United States: a community profile. Biological Report 85(7.16). Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Research and Development, National Wetlands Research Center. 100 p.

Dickmann, D. I. 2006. Silviculture and biology of short-rotation woody crops in temperate regions: Then and now. Biomass and Bioenergy, 30(8-9), pp.696-705. 2010. Wood handbook—Wood as an engineering material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 508 p.

Element5. 2021. Projects. Our Work. https://elementfive.co/projects/ . March 20, 2021.

Forest Products Laboratory. 2010. Wood handbook. Wood as an engineering material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 508 pp.

Gilman, E. F., Watson, D. G. 1994. United States Forestry Service: Picea glauca. Retrieved August 23, 2012, from http://hort.ufl.edu/database/. documents/pdf/tree_fact_sheets/picglaa.pdf.

Government of Ontario. 2016. Poplar (aspen)-*Populus app*. Queen's Printer for Ontario. October 29, 2020. 56 pp .

Government of Canada. 2021. Taxonomy of Wood Products. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/forest-industrytrade/forest-products-applications/taxonomy-wood-products/14510. November, 2021.

Government of Ontario.2016. Larch (Tamarack)-*Larix laricina*. Queen's Printer for Ontario. November, 2021 52pp.

Hiziroglu, S. 2016. Strength Properties of Wood for Practical Applications. Oklahoma State University. FAPC-162. March 13, 2021.

Johnston, William F.; Brittain, Robert E. 1983. Tamarack. *In*: Burns, Russell M., technical compiler. Silvicultural systems for the major forest types of the United States. Agric. Handb. No. 445. Washington, DC: U.S. Department of Agriculture, Forest Service: 99-101.

Kemperman, J. A. and B.V. Barnes. 1976. Clone Size in American Aspens. Can. J. bot. 54, 2603-2607. Pp 5.

Little, Elbert L., Jr. 1979. Checklist of United States trees (native and naturalized). Agriculture Handbook. 541. Washington, DC: U.S. Department of Agriculture, Forest Service. 375 p.

Meier, E. 2008. Wood! Identifying and using hundreds of woods worldwide. https://www.wood-database.com/book/. March 8, 2021.

(MTCC) Mass Timber Code Coalition. 2021. Understanding the Mass Timber Code Proposals. A Guide for Building Officials. https://www.awc.org/pdf/tmt/MTCCGuide-Print-20180919.pdf. April 18, 2022.

Mingyue Li, H., Ren. 2022.Study on the interlaminar shear properties of hybrid cross-laminated timber (HCLT) prepared with larch, poplar and OSB,Industrial Crops and Products, Volume 189. 115756 ISSN 0926-6690. https://doi.org/10.1016/j.indcrop.2022.115756

Navratil, S. 1996. Silvicultural systems for managing deciduous and mixed wood stands with white spruce understory. Silvicultural of Temperate and Boreal Broadleaf-Conifer Mixture, Catalog ID: 18923. 35-46.

OMNR. 1998. A silvicultural guide for the tolerant hardwood forest in Ontario. Ont. Min. Nat. Resources. Queen's Printer for Ontario. Toronto. 500pp.

OMNR. 2014. White Spruce. Ont. Min. Nat. Resources. Queen's Printer for Ontario. Toronto.
From https://www.ontario.ca/page/white-spruce. May, 2023.

Panshin, A.J. and D. D. Zeeuw. 1970. Textbook of wood technology. Volume I. Structure, identification, uses, and properties of the commercial woods of the United States and Canada. Textbook of wood technology. Volume I. Structure, identification, uses, and properties of the commercial woods of the United States and Canada., (3rd ed.). 705 pp.

Perala, D. A. 1972. Biotic And Silvicultural Factors. USDA Forest Service General Technical Report NC, 97 pp.

Parker, William H. 1993. Larix laricina. *In* Flora of North America Editorial Committee (ed.). Flora of North America North of Mexico (FNA). 2. New York and Oxford – via eFloras.org, Missouri Botanical Garden, St. Louis, MO & Harvard University Herbaria, Cambridge, MA.

Saranpää, P. 2003. Wood density and growth. Wood quality and its biological basis, Blackwell Publishing, Hoboken, New Jersey, United States. Pp 117.

Shmulsky, R., and P. D. Jones. 2019. Forest Products and Wood Science: An Introduction. Seventh Edition. John Wiley and Sons Ltd. Pp504.

Smulski, S., et al. 1997. Engineered wood products, a guide to specifiers, designers, and users. PFS Research Foundation. pp 25.

Wellwood, R. W. 1960. The Utilization of Spruce in Canada. The Forestry Chronicle. University of British Columbia, Vancouver, B. C. pubs.cif-ifc.org 127-135. November,2021.

Wanzhao et al.2020. Understanding the mechanical performance of OSB in compression tests. Construction and Building Materials 260. 119837.

Wang, Y., Liang, C., Zhang, B., Qu, S., Gao, Y. and Zhang, X., 2019. Experimental study on mechanical behavior of modified fast-growing poplar. Volume 41, Issue 5. Pp 99-108.

Winandy, J. E. 1994. Wood Properties. USDA- Forest Service, Forest Products Laboratory, Wisconsin. Vol 4, 549-561.

Williston, E. M. 1991.Value-added wood products. Miller Freeman. San Francisco, California. Pp151-169.

Thompson, Robert S.; Anderson, Katherine H.; Bartlein, Patrick J. 1999. Digital representations of tree species range maps from "Atlas of United States trees" by Elbert L. Little, Jr. (and other publications), [Online]. In: Atlas of relations between climatic parameters and distributions of important trees and shrubs in North America. Denver, CO: U.S. Geological Survey, Information Services (Producer). Available: esp.cr.usgs.gov/data/little/ [2015, May 12]. [82831]

Tullus, A., L. Rytter., T. Tullus., M. Weih and H. Tullus. 2012. Short-rotation forestry with hybrid aspen (Populus tremula L.× P. tremuloides Michx.) in Northern Europe. Scandinavian Journal of Forest Research, 27(1), 10-29.

UBC. 2016. Structure of UBC's tall wood building now complete. University of British Columbia. https://news.ubc.ca/2016/09/15/structure-of-ubcs-tall-wood-building now complete/. April 13, 2022.

Viereck, L. A.; Dyrness, C. T.; Batten, A. R.; Wenzlick, K. J. 1992. The Alaska vegetation classification. Gen. Tech. Rep. PNW-GTR-286. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 278 p https://doi.org/10.2737/PNW-GTR-286.

(UBC) University of British Columbia. 2015. Structure of UBC's tall wood building now complete. https://news.ubc.ca/2016/09/15/structure-of-ubcs-tall-woodbuilding-now complete/. March 20, 2021.

Zerbe, J. I., C. Zhiyong and G.B. Harpole. 2015. An evolutionary history of oriented strandboard (O.S.B.). General Technical Report FPL-GTR-236. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 6 pp.

APPENDIX

```
Anova  Friday May 19 01:43:26 2023   Page 1

                                                        ___  ____  ____  ____  ____(R)
                                                       /__    /   ____/   /   ____/
                                                      ___/   /   /___/   /   /___/
                                                        Statistics/Data analysis

                                                          User: Shubham
--------------------------------------------------------------------------------
      name:  <unnamed>
       log:  C:\Users\shubh\OneDrive\Desktop\2.smcl
  log type:  smcl
 opened on:  19 May 2023, 01:42:13

1 . oneway Density SampleSpecies, tabulate

     Sample |       Summary of Density
    Species |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  LarOSBLar |   627.86697   29.277317          10
      Larch |   557.85873   21.716448          10
   LarchLam |   564.36351   16.570666           7
  PopOSBPop |   549.38636   27.076696           7
     Poplar |   434.40219   12.703318          10
  PoplarLam |   475.99522   6.2248908          10
  SprOSBSpr |   471.45158   33.579265           8
     Spruce |   381.80289   32.437831          10
  SpruceLam |   390.25991   12.683694           7
------------+------------------------------------
      Total |   494.67014   84.599881          79

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups     520122.366      8   65015.2957    119.34     0.0000
 Within groups      38134.549     70   544.779272
------------------------------------------------------------------------
    Total          558256.915     78   7157.13993

Bartlett's test for equal variances:  chi2(8) =  29.1509  Prob>chi2 = 0.000

2 . log close
      name:  <unnamed>
       log:  C:\Users\shubh\OneDrive\Desktop\2.smcl
  log type:  smcl
 closed on:  19 May 2023, 01:42:46
--------------------------------------------------------------------------------
```

Anova Thursday May 18 02:25:27 2023 Page 1

Statistics/Data analysis

User: Shubham

```
      name:  <unnamed>
       log:  C:\Users\shubh\OneDrive\Desktop\1.smcl
  log type:  smcl
 opened on:  18 May 2023, 02:23:54
```

1 . oneway MOE SampleType, tabulate

SampleType	Summary of MOE Mean	Std. Dev.	Freq.
1	11923	1842.5167	10
2	10121.429	3947.216	7
3	10129	1939.8821	10
4	13182	1512.7664	10
5	12348	2271.983	10
6	11294.286	3033.5395	7
7	11572	4054.3935	10
8	10038.571	1174.5556	7
9	8867.5	1031.9849	8
Total	11173.911	2716.2833	79

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	131658158	8	16457269.7	2.60	0.0152
Within groups	443845273	70	6340646.76		
Total	575503430	78	7378249.11		

Bartlett's test for equal variances: chi2(8) = 25.5192 Prob>chi2 = 0.001

2 . oneway MOE SampleSpecies, tabulate

Sample Species	Summary of MOE Mean	Std. Dev.	Freq.
LarOSBLar	10129	1939.8821	10
Larch	11923	1842.5167	10
LarchLam	10121.429	3947.216	7
PopOSBPop	11294.286	3033.5395	7
Poplar	13182	1512.7664	10
PoplarLam	12348	2271.983	10
SprOSBSpr	8867.5	1031.9849	8
Spruce	11572	4054.3935	10
SpruceLam	10038.571	1174.5556	7
Total	11173.911	2716.2833	79

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	131658158	8	16457269.7	2.60	0.0152
Within groups	443845273	70	6340646.76		
Total	575503430	78	7378249.11		

Bartlett's test for equal variances: chi2(8) = 25.5192 Prob>chi2 = 0.001

Anova Thursday May 18 02:25:28 2023 Page 2

```
3 . pwmean MOE, over(SampleType) mcompare(tukey) effects
```

Pairwise comparisons of means with equal variances

over : SampleType

	Number of Comparisons
SampleType	36

MOE	Contrast	Std. Err.	Tukey t	Tukey P>|t|	Tukey [95% Conf. Interval]	
SampleType						
2 vs 1	-1801.571	1240.936	-1.45	0.873	-5773.535	2170.392
3 vs 1	-1794	1126.112	-1.59	0.805	-5398.498	1810.498
4 vs 1	1259	1126.112	1.12	0.970	-2345.498	4863.498
5 vs 1	425	1126.112	0.38	1.000	-3179.498	4029.498
6 vs 1	-628.7143	1240.936	-0.51	1.000	-4600.678	3343.249
7 vs 1	-351	1126.112	-0.31	1.000	-3955.498	3253.498
8 vs 1	-1884.429	1240.936	-1.52	0.843	-5856.392	2087.535
9 vs 1	-3055.5	1194.423	-2.56	0.223	-6878.647	767.6474
3 vs 2	7.571429	1240.936	0.01	1.000	-3964.392	3979.535
4 vs 2	3060.571	1240.936	2.47	0.266	-911.3919	7032.535
5 vs 2	2226.571	1240.936	1.79	0.686	-1745.392	6198.535
6 vs 2	1172.857	1345.962	0.87	0.994	-3135.342	5481.056
7 vs 2	1450.571	1240.936	1.17	0.960	-2521.392	5422.535
8 vs 2	-82.85714	1345.962	-0.06	1.000	-4391.056	4225.342
9 vs 2	-1253.929	1303.222	-0.96	0.988	-5425.324	2917.467
4 vs 3	3053	1126.112	2.71	0.163	-551.498	6657.498
5 vs 3	2219	1126.112	1.97	0.569	-1385.498	5823.498
6 vs 3	1165.286	1240.936	0.94	0.990	-2806.678	5137.249
7 vs 3	1443	1126.112	1.28	0.933	-2161.498	5047.498
8 vs 3	-90.42857	1240.936	-0.07	1.000	-4062.392	3881.535
9 vs 3	-1261.5	1194.423	-1.06	0.978	-5084.647	2561.647
5 vs 4	-834	1126.112	-0.74	0.998	-4438.498	2770.498
6 vs 4	-1887.714	1240.936	-1.52	0.842	-5859.678	2084.249
7 vs 4	-1610	1126.112	-1.43	0.882	-5214.498	1994.498
8 vs 4	-3143.429	1240.936	-2.53	0.235	-7115.392	828.5347
9 vs 4	-4314.5	1194.423	-3.61	0.016	-8137.647	-491.3526
6 vs 5	-1053.714	1240.936	-0.85	0.995	-5025.678	2918.249
7 vs 5	-776	1126.112	-0.69	0.999	-4380.498	2828.498
8 vs 5	-2309.429	1240.936	-1.86	0.642	-6281.392	1662.535
9 vs 5	-3480.5	1194.423	-2.91	0.103	-7303.647	342.6474
7 vs 6	277.7143	1240.936	0.22	1.000	-3694.249	4249.678
8 vs 6	-1255.714	1345.962	-0.93	0.990	-5563.913	3052.485
9 vs 6	-2426.786	1303.222	-1.86	0.641	-6598.182	1744.61
8 vs 7	-1533.429	1240.936	-1.24	0.946	-5505.392	2438.535
9 vs 7	-2704.5	1194.423	-2.26	0.378	-6527.647	1118.647
9 vs 8	-1171.071	1303.222	-0.90	0.992	-5342.467	3000.324

Anova Thursday May 18 02:25:29 2023 Page 4

9 vs 3	2.665	4.001841	0.67	0.999	-10.14422	15.47422
5 vs 4	-14.18	3.772972	-3.76	0.010	-26.25665	-2.103347
6 vs 4	-56.62143	4.157613	-13.62	0.000	-69.92925	-43.31361
7 vs 4	-15.97	3.772972	-4.23	0.002	-28.04665	-3.893347
8 vs 4	-34.09571	4.157613	-8.20	0.000	-47.40354	-20.78789
9 vs 4	-49.9	4.001841	-12.47	0.000	-62.70922	-37.09078
6 vs 5	-42.44143	4.157613	-10.21	0.000	-55.74925	-29.13361
7 vs 5	-1.79	3.772972	-0.47	1.000	-13.86665	10.28665
8 vs 5	-19.91571	4.157613	-4.79	0.000	-33.22354	-6.607891
9 vs 5	-35.72	4.001841	-8.93	0.000	-48.52922	-22.91078
7 vs 6	40.65143	4.157613	9.78	0.000	27.34361	53.95925
8 vs 6	22.52571	4.509564	5.00	0.000	8.091353	36.96008
9 vs 6	6.721429	4.366367	1.54	0.833	-7.254581	20.69744
8 vs 7	-18.12571	4.157613	-4.36	0.001	-31.43354	-4.817891
9 vs 7	-33.93	4.001841	-8.48	0.000	-46.73922	-21.12078
9 vs 8	-15.80429	4.366367	-3.62	0.015	-29.7803	-1.828276

```
6 . log close
      name:  <unnamed>
       log:  C:\Users\shubh\OneDrive\Desktop\1.smcl
  log type:  smcl
 closed on:  18 May 2023, 02:24:33
```