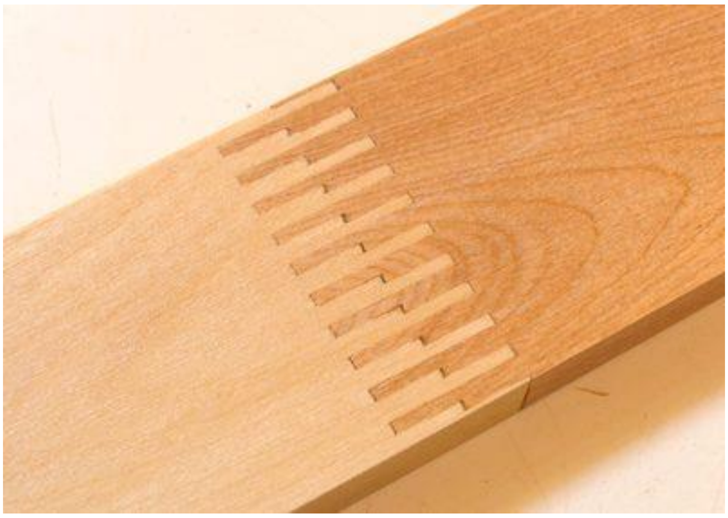
Leaflet no. 37-2020

The Republic of the Union of Myanmar

Ministry of Natural Resources and Environmental Conservation

Studies on Finger Jointing of Short Sections of Eucalyptus Timber



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2020, December

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LIST OF ABBREVIATIONS

Urea Formaldehyde (UF)
Phenol formaldehyde (PF)
Melamine Formaldehyde (MF)
PVAc – Poly Vinyl Acetate
PLA – Polylactic acid
PVC – Polyvinyl chloride
MOR – Modulus of Rupture
MOE – Modulus of Elasticity
df – Degree of Freedom
F – Fissure test
Sig. – Significant

Studies on Finger Jointing of Short Sections of Eucalyptus Timber

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Abstract

The aim of the thesis was to show and test the strength of finger jointing of short sections of Eucalyptus timber. To learn the nature of finger joints and test strength of finger joints on various condition, two kind of adhesive used in operation. The relation of MOE and strength of finger joint are also we tested on this thesis. In detail, we used in the total sample, 21 specimens. 1. Solid uncut sample (SOLID) - 7 pcs, 2. Sample of finger joint by using Urea formaldehyde (UF) - 7 pcs, 3. Sample of finger joint by using Urea formaldehyde with 4% of Nanoclay (UF+4%NC) -7 pcs. All sample sizes were kept as of 50 x 50 mm^2 cross section with 750 mm length by making the sample of 51 mm thick planks. To format the finger joint, it was preparing by commercial finger shaping machine at 20 mm length, 5mm pitch and 1mm tip of thickness. Also, calculating the data, it operate depends on temperature during curing finger joint, MOE, MOR. The rate of finger joints strength testing was operated by Universal testing machine (in Indian standards IS-1708, BIS, 1986). After analyzing the results, the strength depends on the pressure of pressing in jointing the finger joints and dimension of finger joint and type of adhesive.

Keywords: MOR, MOE, UF, Nanoclay

ယူကလစ်သစ် အစိတ်အပိုင်းများဖြင့် Finger Joint များပြုလုပ်ခြင်းကိုလေ့လာခြင်း

လွင်လွင်အောင်၊ လက်ထောက်သုတေသနအရာရှိ
သစ်တောသုတေသနဌာန၊ သစ်တောဦးစီးဌာန

စာတမ်းအကျဉ်း

ဤစာတမ်းတွင် ယူကလစ်သစ် ဖြတ်ပိုင်းအတိုများအား လက်ယှက်ထိုး သစ်ချောင်းများ (Finger Joint) ပြုလုပ်ပြီး ၎င်းတို့၏ အင်အားပိုင်းဆိုင်ရာ ဂုဏ်သတ္တိများကို စမ်းသပ်လေ့လာ ထားပါသည်။ ယူကလစ်သစ်ဖြတ်ပိုင်းအတိုများအား လက်ယှက်ထိုး သစ်ချောင်းများပြုလုပ်၍ ၎င်းတို့၏ အသုံးချနိုင်မှုကိုဖော်ထုတ်ရန် လေ့လာခြင်းဖြစ်ပါသည်။ စမ်းသပ်မည့် ယူကလစ် သစ်နမူနာများအား (50mm x 50mm x750 mm) အရွယ်များ ခွဲစိတ်စမ်းသပ်ခဲ့ပါသည်။ ယူရီးယား ဖော်မယ်ဒီဟိုက်ကော်နှင့် ယူရီးယား ဖော်မယ်ဒီဟိုက်နှင့် နာနိုကလေး ရောနှောထားသော ကော်(၂)မျိုးကို အသုံးပြု၍ ပြုလုပ်ထားသော Finger Joint တို့၏ တောင့်တင်းခိုင်မာမှုကို ယူကလစ် သစ်သားထည် (solid wood) ၏ အင်အားနှင့် နှိုင်းယှဉ်လေ့လာထားခြင်း ဖြစ်ပါသည်။ ထို့နောက် Finger Joint ဖြတ်တောက်ပုံဖော်ရာတွင် Commercial Finger Shaping Machine စက်အား အသုံးပြုခဲ့ပါသည်။ Finger Joint များ၏ အင်အားပိုင်းဆိုင်ရာ ဂုဏ်သတ္တိများကို Universal Timber Testing Machine စက်ဖြင့် Indian Standards IS-1708, BIS 1986 အရ စမ်းသပ်ခဲ့ပါသည်။ စမ်းသပ်တွေ့ရှိချက် ရလဒ်များမှာ Finger Joint ၏ အင်အားသည် Finger Joint ပြုလုပ်ရာတွင် အသုံးပြုခဲ့သော ဖိအားနှင့် Finger Joint ၏ အတိုင်းအတာ၊ အသုံးပြုသော ဓါတုကော် အမျိုးအစား အပေါ်တွင် မူတည်နေကြောင်း တွေ့ရှိခဲ့ရပါသည်။

Studies on Finger Jointing of Short Sections of Eucalyptus Timber

1. Introduction

A finger joint joins the two ends of wood by cutting complementary fingers and gluing them. The cross-section of the joint resembles the interlocking of fingers between two hands; hence, we call the name "finger joint". And finger joint is one of the strongest wood joints used for structural and non-structural applications. It is commonly used for furniture production and some construction uses as floor boards, timber roof and door and it ensures there is no movement or warping problems. It is commonly classified by wood specialists as high quality product, because of its desirable properties such as straightness, dimensional stability, and interchangeability with un-jointed lumber and unlimited length. It plays in important role in saw mill recovery by reducing the wastage. It is one of the most suitable solutions to less down the high cost of lumber and board. It can save wood and give a very profitable to saw-millers. The strength of the finger - joint depends on several wood-related facts such as species, density, natural defects like moisture content and temperature of lumber, finger geometry, machining process parameters, assembly pressure, curing time and adhesive type and pre-treatment of wood. Thus, the better quality glue we used, the stronger of finger joint we got.

Small pieces of wood can be edge glutted to make wider and longer pieces. By using the technique of end-jointing (finger joint), we can get any length of board. And the strength of finger joint wood stronger than conventional dimension lumber and a butt or lap joint, and often contributes to the aesthetics of the two pieces or one piece. Moreover, the chances of warping and twisting is less on the finger joint and got best straight by removing large nodes from wood pieces and putting them back together afterwards. So, during the past decade, practice of end gluing has become an integral part of the lumber industry and saw mill. The use of finger joints methods in wood has become common practice of enjoining the short pieces to get high grade lumber of any desired length (Strickler, 1967). These joints are being used in primary structural members that are designed and used for all loading conditions. The finger joint is not a new type of end joints. It has been used for many years. It's been used in the automotive industry in wood steering wheels and spokes of wood wheels.

An automobile steering wheel of the mid twenties contains four finger joints. In detail explanation, in 1955 Norman discussed finger jointing of small cuttings, or scrap, for use in cabinets and door and door window units; he stated in 1947 his company went to melamine adhesive and high frequency curing to get away from cold clamping and the dark color of resorcinol. This indicates the company had been making finger joints prior to 1947. The first reference found in which finger joints were used in a structural application by (Egner and Jagfeld, 1966) of the Otto Graf Institute in Stuttgart, Germany. They discussed the results of tests on finger-jointed bridge members after 10 years of use in a bridge constructed in the early forties.

For structural and non-structural applications; Nonstructural joints are commonly used in non-load bearing structures like paneling and molding. The main reason for non-structural joints is a tight and near appearance and members require only sufficient strength for handling and machining. Historically, nonstructural joints came first into use and then structural finger joints. Finger-jointed material has also found extensive usage in non-structural markets such as with molding stock, siding, window frames, and fascia boards (Jokerst, 1981). (Walford, 2000) examined the effect of finger length on the tensile strength intended for both non-structural and structural applications. He found that shorter joints are slightly stronger than longer ones but require greater precision in manufacture. Also, he found that a small tip improves the strength of joints. And Richard's (1963) research indicates sharp-tipped fingers have a significant positive effect on strength.

The main idea of the development of structural finger joint came 20 years back from laminated beam industry. The development was mainly aimed at reducing the waste of high quality lumber that resulted from scarf joints. Whereas, the primary criterion for structural finger joint is load bearing strength where, strength requirement varies according to working material being used. Strength requirements vary through a wide spectrum from studs on the low end of machine stress rated (MSR) lumber and glulam beams at the high end. Tensile strength and stiffness are special interest in the use of glulam timber and the most relevant strength properties, since failure frequently initiates in the tensile zone of a beam (Fisette and Rice, 1988; Burk and Bender 1989).

Finger-joints are a type of structural end joint used in glue laminated timber (glulam) to form long, continuous laminations out of individual pieces of lumber, and also in other engineered wood components such as trusses and I-joints (Burk and Bender, 1989). The strength of the timber is enhanced by finger jointing. Structural finger joints were developed to reduce the waste of high quality lumber that resulted from the machining of scarf joints, and it is one of the most economic ways of wood utilization (Strickler, 1980).

The finger has been shown to have the required strength for structural application (Madsen and Littleford 1962; Selbo 1963).Nowadays, every industrial of wood based products and value added products are concentrating on finger joint technique on various purposes like to make commercial products, to less down use of wooden parts, to reduce waste of wood by making good quality wood products at the same time. In finger jointing of wooden pieces, the finger profile parameters and the adhesive used are two major parameters which play important roles in deciding the strength of the joint. Enough of works have been reported on both aspects. The efficiency of a joint also depends on the wood species that is being used. The bonding properties of cell components in wood influence the bonding method, the geometric shape and size of pieces and also the conditions to which the joined pieces will be exposed while in use (Marra 1992). Albino et al. (2010) found that the bond strength had a strong dependence on the position of the stem from where *Eucalyptus grandis* samples were prepared. Bustos et al. (2003) reported that the finger-joint of high flexural and tensile performance can be produced by using an Isocyanate type of adhesive. Obucina et al. (2014) showed through their studies that an excessive increase in the quantity of adhesive in the adhesive film results in reduction of the glued joint's strength. One of the most common adhesive used by wooden industries is the Poly Vinyl Acetate (PVA). However, this adhesive has been shown to be inferior to Urea Formaldehyde (UF) in the case of Eucalyptus (Kishan Kumar et al. 2013). There have been reports of this adhesive's better performance as a wood adhesive by adding Melamine Formaldehyde (MF) and Melamine Urea Formaldehyde (MUF) (Kaboorani and Riedl 2011). Qiao et al. (2000) have also reported on the improved water resistance of PVA by blending it with MUF.

Finger-joint geometry is one of the most important variables determining joint strength. There are four parameters which describe the finger's profile geometry, teeth length, pitch, fingertip and slope angle. Finger-joint profile is the governing factor in determining joint strength among wood density, adhesive, finger-joint profile and end pressure. The critical finger profile parameters to achieve high strength are found to be slope and tip sharpness. Literature indicates that the tensile strength of the finger-joined lumber increases with decreasing slope and increasing tip sharpness. Walford examined the effect of finger length on the tensile strength of *radiata* pine lumber intended for both non-structural and structural applications. The finger length used in his study ranged from 3.5 mm to 16 mm. He found that shorter joints are slightly stronger than longer ones, but require greater precision in manufacture. As well as finger joined lumber made of low density wood tends to fail in wood, but those made of high density wood fail in joints in which glue line strength governs. Also, he found that a small tip improves the strength of joints. With regard to structural finger joints of Douglas-fir wood, the tensile strength parallel to the grain for 38 mm fingers results,43% higher than 22 mm ones, while the fatigue strength is almost the same. Other studies with softwoods have found that the tensile strength of lumber joined with a 21 mm long finger profile presents a significantly lower value than those with 18 and 24 mm finger profile groups of 11.3 and 8.5%, respectively, due to the wide finger tips.

For broad leaves of low to medium density destined for structural products, the optimal finger's length appears to be 18 mm, while the slope 1 in 16 to 1 in 20 produces elevates joint strength comparable to clear wood strength when is properly bonded. Other studies on finger joints from high density hardwoods like beech and oak, confirm that the highest bending strength (MOR) is obtained for the higher finger lengths. Between pitch and tip width, the last one results as a geometrical parameter of great importance in strength of finger-joint. Smaller to be the tip width, the stronger is the finger-joint. The recommended tip width is from 0.5 to 0.7 mm. If finger's length becomes larger without increasing finger pitch, the strength of connection increases, but the best results are obtained for values of length/pitch from 4 to 5. Gaps between fingers tips and bases appear as a necessity for accumulation of excessive adhesive. According to the German Standard 68140-1, this gap varies from 0.03 of a finger's length. Anyway, many authors have found that modulus of elasticity (MOE) and sometimes and the ultimate
tensile strength (UTS),are not significantly influenced by finger's profile geometry.

Many studies have showed that wood species with density higher than 700 kg/m3 give uncertain performance, while those with lower density appear to be more predictable in their performance. In a finger joint connection, finger tips are positioned in a straight line oriented vertically regarding to edges of wood pieces. It means that two pieces are in contact between them through the shorter contact vector. The selection of wood species is conditioned by massive usage of fir as raw material for wooden constructions and processing industry as well as by the growing interest in poplar, taking into account that this wood presents good opportunities for application, because of its low cost and weight.

While we use Nano clay, about the Nano technology in detail are, nanotechnology offer the potential to transform the forest products industry in virtually all aspects, ranging from production of raw materials, to new approaches for producing engineered wood and wood-based materials, to new applications for composite and paper products, to new generations of functional Nano-scaleligno-cellulosics. Other potential uses for nanotechnology include developing intelligent wood and paper-based products with an array of nan0-sensors built in to measure forces, loads, moisture levels, temperature, pressure, chemical emissions and attack by wood decay fungi.

Nanotechnology can be used to improve processing of wood based material into products by improving water removal and eliminating rewetting; reducing energy usage in drying and tagging fibers, flakes, and particles to allow customized property enhancement in processing

Nanotechnology to decrease production time of wood composites

- Hot presses are considered as bottle necks in all industries
- Minimum pressing time depends on heat transfer. Which in turn varies with thickness, press temperature, closing rate and mat moisture distribution
- Complete curing of resin in less time required
- In this connection high thermal conductivity of Nano-particles has been reported to decreases press time
- Better conductivity and less temperature gradient
- Nanotechnology to improve water resistance
- Wood has a thermo-hydro-mechanical behavior and its properties depend on the combined action of temperature, relative humidity and mechanical loading variations
- Water-repellant property of Nano-particles significantly decrease the water intake
- Also gas and liquid permeability in boards is also reduced.
- Nanotechnology for improving resistance to biological agents and fire resistance;
- Nano-particles like Nano silver and Nano-wollastonite improve the heat transfer
- They also form a layer to prevent the penetration of flames to wood structure

Nanotechnology to improve the thermal conductivity; Heat treatment is one of the successful method which alters the basic structure of wood. Due to heat treated wood can be made more durable. For uniform heat treatment Nano-particles can be utilized

Nanotechnology is critically important to the economical and sustainable production of new generations of forest-based materials and to help move society toward a biomass-based economy.

I based on five steps of making finger-jointed

(1) Selection and preparation of material,

(2) Formation of joint profile

(3) Application of adhesive,

(4) Assembly of a joint, and

(5) Curing of adhesive.

In this study, the ever-reliable urea formaldehyde glue was used for joining the fingers. An effort was made to incorporate Nano clay in 4 % concentration into this resin to look for any possible positive effect on the bending strength properties of eucalyptus.

Literature Review

In most of the works the effectiveness of various adhesives in finger jointing of different wood species was studied with a biased thinking that the role of adhesives is more crucial for strength enhancement of the jointed sections (Barboutis and Vasileiou 2013; Danawade et al. 2014). Bardak et al (2018) reported that the bonding strength of Urea Formaldehyde (UF) enhanced when nano-SiO_2 was added to the adhesives but nano-TiO_2 added UF did not exhibit this phenomenon. Thus, this is also an area worth exploring in finger jointing.

The efficiency of finger jointing in replacing precious solid wood sections has been well illustrated the world over. However, the use of finger jointed sections in structural members of the furniture is less investigated. MOR efficiencies between 50 % and 100 % in finger jointed sections of Eucalyptus and mango wood depending on the quality of the original material using the common Urea formaldehyde and the carpenters' favorite Poly Vinyl Acetate (PVAc) adhesives have been reported using different finger profiles (Kishan Kumar et al. 2011; 2013; 2015).

The type of adhesive, curing time and the pressure of application influence the strength of the assembled joints. The bonding properties of cell components in wood depend upon a number of parameters relating to the physiochemical characteristics of the adhesives, the bonding method, the geometric shape and size of pieces apart from the conditions to which the bonded pieces would be exposed to while in use (Marra 1992). A polymer is a very large molecule which is comprised of repeating units and those units connected with each other to form long chains which can be linear, branching or cross-linked. There are two main types of polymers used in the wood composite industry: thermoplastics and thermosetting resins Thermoplastics are usually linear polymers which may change in structure as temperature changes, such as glass transition, crystallization and melting. Polylactic acid (PLA) and Polyvinyl chloride (PVC) are the most commonly used thermoplastic resins for fabricating wood plastic composites (Pavlidou and Papaspyrides, 2008).

Thermosetting resins are three-dimensional cross-linked networks which are hard, infusible and insoluble after curing. Thermosetting resin is more difficult to characterize than a thermoplastic resin because it remains stable after curing. Urea formaldehyde (UF), Melamine formaldehyde (MF) and Phenol formaldehyde (PF) resins are the predominant thermosetting resins used as wood adhesives in the production of hot pressed wood composites. Thermosetting resins are usually a mixture of low molecular weight condensates or intermediates generated by primary addition reactions, and monomers which are all soluble in water. These low molecular weight condensates will further react at higher temperatures and form the final cross-linked, rigid network (Pizzi and Mittal 1994).

Barboutis and Vassiliou (2008) found that the bending strength (MoR) of European Chestnut (*Castanea sativa*) wood finger-joints ranged from 55.3 N/mm^2 to 83.5 N/mm^2 using short and long fingers in the range of 4 mm to 20 mm when joined with PVAc. They concluded that there is strong relationship existing between the tensile shear strength and bending strength (MoR) of the finger-jointed Chestnut wood. Studies by Murphy and Rishel (1972) revealed that the finger length of 3.2 mm showed highest strength (MoR) property of 30.5 N/mm^2 on White pine and 55.8 N/mm^2 with finger length of 9.5 mm on Yellow poplar when joined with PVAc.

In *Pinus* spp., an MoR retention in the range of 75 % was reported when the fingers were joined using Resorcinol-Formaldehyde (Vrazel and Sellers Jr. 2004). The lesser moisture uptake, melting point, dry time and higher tensile strength of a UF based blend with natural rubber have demonstrated the UF resin's utility as a joiner and a good binder to even paint coatings (Osemeahon et al, 2007).

On three African hardwoods, efficiencies ranging from 72-94% have been achieved with much thinner finger tips using melamine formaldehyde adhesive (Ayarkawa *et al*. 2000b). However, with Resorcinol formaldehyde adhesive, these hardwoods showed efficiencies in the range of 43-94% depending on the finger parameters and the end pressure used during joint mating (Ayarkawa *et al*. 2000a). Bustos et al. (2003) reported that the finger-joint of high flexural and tensile performance can be produced by using an Isocyanate type of adhesive.

The PVAc adhesive is reported to give better MOR for *Eucalyptus benthamii* sections compared to PU when samples were joined with 10 mm fingers, while the modulus of elasticity was not affected by the adhesive used (Martins et al. 2013). Kaboorani and Riedl (2011) reported that the shear strength of wood joints increased by adding Nano-clay to PVAc.

Urea formaldehyde (UF) resins are the most important type of adhesive resins for the production of wood products, wood joineries and panel boards. They are very useful due to their high reactivity and good performance in the production and by their low price; however, they lack in water resistance of the hardened resin owing to the reversibility of the amino-methylene link leading to susceptibility to hydrolysis. This can be overcome by introducing other components like melamine to the UF resin molecules (Dunky, 1998).

Various useful properties like relatively low cost, ease of use under a wide variety of curing conditions, low curing temperatures, resistance to microorganisms and to abrasion, good thermal properties, and absence of color of the cured resin make the use of urea-formaldehyde resins as a major adhesive by the wood based industry popular. However, UF resin has a disadvantage of poor resistance to moisture and water at higher temperatures making it not very useful for exterior applications (Connor 1996).

The question of the effect of gluing areas on the strength of finger joints has been addressed by various workers (Selbo, 1963; Kishan Kumar et al. 2010, 2013). A most suitable profile for getting maximum flexural MoR for finger jointed Eucalyptus using UF adhesive was reported recently by Singh et al. (2018).

End-jointed lumber and strength of finger joints

A joint is often the weakest point in a finished wooden product. The edge to edge grain joint interface is popular, necessary and satisfactory among and laminate industries (Janowiak et al. 1993), So, finger joint came into existence and 19 % of all end to end joints required by glue-lum industry in 1968 were finger joints. The strength of finger joint comes from the long grain to long grain contact between the fingers, which provide a solid gluing surface. The strength of finger jointed lumber decreases as the number of finger joints increases, ultimately the jointed lumber becoming weak. Reported strength values indicate that finger joints can be used as a replacement for mortise and tenon or dowel joints. Finger joints also attributes advantages such as reduced variability in strength, self alignment, material reduction, ease of machining and automation (Murphey and Rishel 1972).

Janowiak et al. (1993) carried out extensive studies with resorcinol adhesive over melamine bonding on three hardwoods: Red oak, Red maple and Yellow poplar to measure factors that affects the end jointed lumber performance shows that, for all finger joint adhesive combined the tensile strength values ranged from 2700 psi to 13770 psi, and bonding strength values varied from 5040 psi to 14630 psi when they studied with these three species. They found slightly higher values of tensile strength for red oak and red maple as compared to Yellow poplar. However, bending strength properties were same of for all three species. After clear investigation, it was appeared that, neither a adhesive or finger jointing methods had influence on overall strength of end-jointed lumber.

Joint configuration

Bustos et al. (2003) studied three different joint configurations in black spruce namely Feather, Male-Female, and Reverse to evaluate the behavior of finger jointed lumber with use of Isocyanate adhesive. Three joint types show same geometry parameters except for the shouldering. The male-female and reverse configurations have an edge shoulder which creates stress concentration area. Feather configuration minimizes this area. The results indicated that, profile of structural finger joints had a significant role on MOR i.e. bending strength properties but not on ultimate tensile stress.

The analysis indicates that the Feather performs better in both bending and tension strengths than male-female and reverse configuration. Differences were found due to higher bonded area and non-existence shouldering compared to other two. Two types of orientations are used for finger jointing in wood. Also, finger joints of high flexural and tensile performance can be produced using Isocyanate adhesive.

Orientation of Finger joints

Janowiak et. al. (1993) studied bending and tensile strength, performance of both vertical and horizontal finger joints using Resorcinol Formaldehyde (RF) and Melamine Formaldehyde (MF) bonding on three hardwood species namely: Red oak, Red maple and Yellow poplar. Results show that, similar end to end joint can be made by using vertical and horizontal orientation with either the MF or RF but vertical finger joints show slightly higher tensile strength compared to the horizontal. However, no large differences involved in bending strength properties of the wood specimen examined against either MF or RF. Finger joint efficiency in both bending and tensile strength varied from 64 to 97 % was considered very well.

Vassiliou, et al. (2007), demonstrated experimentally on Beech wood using Poly Vinyl Acetate (PVA: D1, D2 and D3) adhesive grades, finger length (4 to 10 mm), and two types of finger orientation: vertical and horizontal to know the bending strength of finer jointed steamed and un-steamed wood respectively. They found that, MOR values fluctuated from 33.51 to 82.24 N / mm² and was affected due to the type of adhesive used, finger length and orientation of finger joints. Bending strength (MOR) of testing samples was affected by the orientation of the fingers. Also, it was found that in most of the cases the specimens with horizontal fingers appeared to have 5 % higher MOR values than specimens with vertical fingers. However, MOE values don't affect greatly by any of the considered factors.

They carried out the same experiment with Oak, and they concluded that, increase in length of finger from 4 mm to 10 mm to 15 mm caused an increase in MOE values of vertical orientation. Vertical fingers showed higher MOE values than vertical orientated fingers for 10-15 mm long.

Mainntains et al. (2010), worked on Black Pine (*Pinus nigra*) using a phenol resorcinol formaldehyde adhesive to know the effect of finger joint orientation (vertical or horizontal fingers). The results from the measurements of modulus of rupture and modulus of elasticity of green glued finger-jointed specimens indicated that, for the fingers 4 mm long, MOR values in horizontal orientation were slightly than vertical, respectively. But, reverse values were observed for a 10 mm finger length, i.e. higher values for vertical finger orientation. Thus, the bending strength was dependent on the finger length, since higher strength values were obtained for the longer fingers (i.e., 10 mm length fingers) and MOE values were independent.

Adhesive type and their effect on strength properties

Adhesive play a crucial role of strength of finger jointed wood. According to Janowiak et al. (1993), adhesives proved to be nearly equivalent in both bending and tensile strengths for three species, namely: Red oak, Red maple and Yellow poplar. They carried out experiment to know the effect of Melamine Formaldehyde and Resorcinol formaldehyde on bending and tensile strength of finger joints.

Bustos et. al. (2003) showed that the finger joints of high flexural and tensile performance can be produced by using Isocynate adhesives. They showed that Isocynated based adhesives produce high tensile bonds and cure at ambient conditions. The bonds obtained were resistant to creep, moisture and heat exposure treatments.

Effect of glue line voids on tensile strength of finger jointed wood

Pellicane et al. (1994) carried out 100 experiments to improve the fundamental understanding of the behavior of finger jointed lumber loaded under uniaxial tension stresses where a model of the thin glue-line was developed. These joints contained a variety of manufacturing defects such as unglued fingers and fingertips, shaved fingers, starved joints, water-soaked fingers, damaged fingers and saw dust contaminated adhesive.

The results conclude that, joint strength varies significantly as a function of the defect placed in the joint specially, voids along the glue-line and joints with shortened or missing fingers which shows a reduction in strength as compared to others. However, processing variables such as moisture, glue contamination, finger thickness and damage had a less significant effect on strength compared to control group.

Effect of finger geometry and end pressure on the flexural properties of finger jointed tropical African hardwood

Ayarkwa et al. (2000) had did work on the finger joints from three African tropical hardwood, Obeche (*Triplochiton scleroxylon*), Makore (*Tieghemella heckelii*), and Maboi (*Baillonella toxisperma*), where prepared using three profiles, three end pressures, and resorcinol-formaldehyde adhesive, to assess the effect of the study variables on the flexural performance of the joint. Finger profile geometry was found to have a statistically significant influence on modulus of rupture (MOR), but not on modulus of elasticity (MOE) of finger joints from the three tropical African hardwoods. The finger profile F2 (18 mm or 0.72 in). Finger length exhibited the significantly strongest and the most efficient finger joint among the three finger profile studied for each hardwood. End pressure, however, was generally found to have no significant influence on MOR and MOE of the finger joints. Although the strongest finger joints seemed to have been produced when the profile f2 was combined with the end pressure of 12 N / mm² (1740 psi), for each species, end pressure of 12 N / mm² resulted in lower joint efficiencies than 4 N/mm² (580 psi) end pressure in Obeche and 8 N/mm² (1160 psi) in Moabi. From the view-point of economy, therefore, profile F2 combined with end pressure of 4 N/mm², 12 N/mm² and 8 N/mm²seems the best combination of the production variables for optimum finger joints in Obeche., Makore and Moabi, respectively. Among the three hardwoods, finger joints from the low density Obeche exhibited the highest joint efficiency of 88 % and wood failure of 61 %, followed by that from the medium density Makore of 78 and 29 %, respectively. Finger joints from the highest density Moabi exhibited the lowest joint efficiency of 60 % and wood failure of 14 %. The results have shown that the finger joints from the high density Moabi exhibited the lowest joint efficiency of 60 % and wood failure of 14 %, the results have shown that finger joint of high failure performance could be produced from the low density Obeche and medium density Makore wood using the type of resorcinol formaldehyde glue studied.

Fatigue strength of finger joints

Glued laminated construction has made it possible to manufacture structural wood members of almost any size and shape. Both research and good service performance have shown these engineered glued wood members to be reliable structural components. With the growth of the glued laminated timber construction industry, the use of finger joints in wood has become common practice. These joints are being used in primary structural members that are designed and used for all loading conditions.

Two types of finger joints used for end jointing dimension lumber were evaluated for fatigue strength. Joints have been studied under static loading conditions. Research was carried out to learn the strength of such joints subjected to cyclic loading. Ten specimens of the two different finger joint configurations were evaluated under cyclic loadings at each level of 40, 50, 60, 70, 80, and 90 % of static strength. The resultant fatigue strength curves showed that the relative strength of the two joints in tension parallel to the grain of load was approximately equal to 40 % of static strength. The fatigue strength in tension parallel to the grain of finger joints is about 80 % of that in 1:8 slope scarf joints.

These data provide information necessary to determine safe design loads and to predict a safe service life of finger joints in structural members subjected to cyclic loading. They fill a current need for glue laminated members and serve a potential need for other structural applications of finger jointed dimension lumber (Bohannan, 1969).

High stress finger joints for laminated beams

Strickler and Pellerin, (1971) experiment end jointed high stress tensile members in designing tension proof loading of finger joints for laminated beams. Thus, the critical sections of the tensile laminations for 18 laminated beams, 16 inches deep 24 feet long and having proof loads 1.4 times more were loaded in tension. Results conclude that, beams with staggered finger joints were significantly stronger than stacked fingers. And, fingers joints stacked vertically of the high stress tensile zone resulted in significantly lower tensile values for beams with staggered distribution.

Finger jointing of Veneers: Laminated Veneer Lumber (LVL)

Casilla et al. (1979) carried out experiments on western hemlock veneers by using phenol formaldehyde resin with phenol resorcinol formaldehyde adhesive to measure the effect of finger joints compared to butt joints and use of preheated veneers in LVL. Research results conclude that, these LVL specimens fabricated with finger joints had about 16 and 25 % greater MOR and MOE respectively than fabricated unbounded butt joints (Casilla and Chow, 1979). Preheating the veneer before finger jointing resulted in a marked increase in initial tensile strength and wood failure as compared to unheated veneers.

The results indicated that veneers taken directly from a dryer can be finger jointed successfully with more strength. They also showed that the tensile strength of finger jointed wood increases with increase in pressing time. For a pressing time of 15 seconds, the increase in strength of preheated veneers is about 16 %

Quality Control In Finger-Jointed Products

The importance of quality control in any finger-jointing operation cannot be overemphasized. Two primary goals for quality control in any organization are to detect sub stand- and products and prevent them from being put into service, and to pinpoint the cause of a problem, combat and solve it.

The success of finger joints, either the structural or the nonstructural type, depends on joints being of consistent quality. Both types will be judged on a basis of poorest joints produced, not best. The quality of joints must never drop below a minimum satisfactory level.

The only way to be reasonably sure that the finger joints being produced will meet requirements is to develop a quality-control program that monitors each phase of the operation. A quality-control program should include visual inspection, direct measurement of selected variables, and physical testing of selected samples. Visual inspections and the measurement of selected variables during processing are to prevent or keep to a minimum production of unacceptable joints. Physical testing of joints after production is a check on visual inspection, on measurements, and on procedures.

In the literature the physical testing aspects of quality control in finger jointing have received the most attention. Testing of finger joints can be conveniently divided into two categories, destructive and nondestructive.

In destructive testing, samples are taken from production at selected intervals and stressed to failure in bending or tension. The load at failure is then compared with an established minimum value. After testing, the failed joint is visually inspected to determine percentage of wood failure; this also is compared to a minimum value. Of the two test modes, bending or tension, the tension is generally considered more critical. The tension test, however, does require more effort to prepare specimens and the testing equipment is somewhat more sophisticated.

When finger joints were first considered for structural use, the tensile specimen used was the necked-down type with the joint located at the center of the length. Special equipment and jigs were required to manufacture this type. A test specimen was developed by Selbo (102, 104) and evaluated by Bohannan and Selbo (8) that greatly simplified the making of tension specimens. All that is required to produce suitable tensile specimens is a small table saw equipped with a well-sharpened hollow-ground blade. Specimens are cut about 3/32 inch thick by 12 inches long. The width is a multiple of one- half the pitch of the joint being tested. The finger profile appears on the wide face of the specimen, and several specimens must be tested from each joint for evaluation. The test machine must also be equipped with wedge-type grips that tighten on to the specimens as load is in- creased. The bending test commonly used to evaluate finger joints is quick and simple. Although strength evaluation is not as critical as the tension test, much can be learned about the manufacturing process by inspecting a failure. In the bending test two- point loading is used, and the extent of preparation required is crosscut-ting a selected joint from a board to a required length. Specimens the full width and thickness of the material being joined are used, and specimen length depends on the length of the finger joint being tested. The recommendation is the load points should be at least 2 inches outside the tips of the fingers (1).

Nondestructive testing of finger joints has always been of interest. With nondestructive testing it will be possible to evaluate all joints produced, rather than a small percent- age. Thus, the probability of a poor joint being placed in service will be greatly reduced. It was this desire to test all, or at least a high percentage of the finger joints produced, that resulted in development of one of the early lumber stress-grading machines (9). Other test methods mentioned in the literature for nondestructive testing of finger joints are acoustic emissions (86) and stress-wave attenuation (52).

In the work on acoustic emissions by Porter and others (86), pieces of Douglas-fir 2- by 6-inch material finger-jointed at mid length were loaded in bending on the wide face. The predicted failure was the asymptote of a curve of the cumulative number of acoustic emissions plotted against the load. The accuracy of the prediction of failure increased with in- creasing load. According to the authors, a load just beyond the proportional limit should provide an estimate of the failure load to an accuracy of ± 10 percent. In finger joints purposely made without adhesive on some of the fingers, the accuracy of prediction decreased. The authors also found that the MOE of the finger joints was poorly correlated with the MOR. Caution should be taken in stressing any structural member beyond its a stress large enough to indicate they are capable of withstanding a design load. In a series of studies at Washington State University, it was concluded "tensile proof loading of high-stress tension laminations for glue-laminated beams offers a practical method of assuring reliability for strength in such beams" Tensile proof loading affords reliability equally well for finger joints and for the wood itself. In trying to implement a tension proof-loading system, Eby (28) reported some difficulties. The problem was in trying to develop a system capable of tension proof-loading material from automated continuous finger-jointing lines operating at speeds to 150 feet per minute. It was decided the only viable alternative was to develop a system for proof- loading finger joints in bending. Before this could be accomplished several questions had to be answered on how proof-loading affected:

1 Fully cured finger joints,

2 Partially cured finger joints,

3 Bending strength of fully cured joints that had been proof- loaded immediately out of the RF energy field

4 Tensile strength of fully cured joints that had been proof- loaded immediately out of the RF energy field, a through d on both horizontal and vertical configurations for each species, adhesive, and process combination. In an investigation at Washington State University designed to answer the questions 1 through 4 Pellerin (83) concluded the following: fully cured joint for either horizontal or vertical fingers.

5 Tensile strengths for horizontal and vertical finger joints are almost identical.

6 Stacking of end joints in the critical tension zone (1/8 of depth plus 1 lamination) has no detrimental effect on a beam if end joints in the two outermost laminations are proof-loaded to 3,600 lb/in.^{2} in bending while only partially cured.

Based on this information a bending proof-loading system has been implemented in several laminating plants. The American Institute of Timber Construction has a quality control test specifically for bending proof loadings (2) and tentative code approval has been received for the use of this material (48). This is probably one of the most important advancements in the quality control of finger joints since they were first accepted for structure use.

2. Objective

- To study about finger join from various aspects
- The strength of finger joint and the influence factor on the strength of finger joint
- Nature of Eucalyptus Finger Joint
- The stage of preparing to do finger joint
- To compare and show the strength of finger joint depend on the usage of adhesive
- The difference between the solid wood of Eucalyptus and the Eucalyptus finger joint wood
- At the same time Nanoclay effect to show and test on Eucalyptus finger joints
- To study detail about the functional component parts of tooth and length , slope and wide of finger joint
- To approve that the finger joint can less down the waste of wood and can create value added products in little volume of wood

3. Material and Methods

Selection and Preparation of Materials

Developing quality finger joints necessarily begin with selection and preparation of material to be end- jointed. No adhesive joint can be stronger than the wood being bonded. Therefore, if strength is of primary concern, only material with potential to develop the needed strength should be selected. Instead of listing all the defects and abnormalities to avoid, it is probably best to say that the joint profile must be in normal, clear, straight-grained wood of average or high density. In most grading rules and specifications, definite limits are placed on how close a knot or other strength-reducing defects can be to a finger joint. These limitations reduce the interactions of defects with the joints, and keep knots far enough removed from a joint so that the associated grain deviations will not cause problems.

Wood to be used for finger joints normally should be dried to a moisture content (MC) suitable for gluing. The usual recommendation is to dry the wood to about the average MC it will attain in service. Satisfactory adhesion is obtained with most adhesives if the wood is in an MC between 6 and 17 percent. With some adhesives it is possible to go beyond this range, with the precise upper and lower limits varying with the adhesive type and formulation. Satisfactory joints have been experimenting with resorcinol-type adhesives with woods at or above the fiber saturation point, and with casein glues at very low MC. The usual problem encountered with gluing wood at high MC is that the adhesive is absorbed by the wood, and results in a starved joint. Wood at a high MC or that contains wet pockets can also cause problems if radio-frequency (RF) energy is used to cure the adhesive. If MC is too high, energy is expended to heat the water instead of the glue, and the result might be under-cured glue lines.

Several attempts have been made to develop systems for finger-jointing green or high MC wood. Then shorts could be salvaged and some lumber produced could be upgraded. The short lengths could be upgraded by cutting out grade-limiting defects and end-jointing the pieces back together.

If this could be done before drying, it would be much more attractive economically than if done after drying.

For end-jointing high MC wood (above 20 %) have one feature in common all employ heat in some manner to accelerate the adhesive cure. Heat apparently accelerates adhesive cure, thus reduces excessive penetration of the resin in- to the wet wood. It is quite probable the MC at the immediate surfaces being bonded is actually quite low in relation to the remainder of the piece being joined. This, plus the accelerated cure, would increase the probability of success.

Figure1. Choice of defect, crack and node

Sample sections of *Eucalyptus hybrid* were cut from kiln-seasoned (up to 10-12 %) planks using a circular saw. The sections were selected from visually inspected defect free portions. Approximately 51 mm thick planks were used for making the samples. The sample sizes were kept as of roughly 50 x 50 mm^2 cross section with 750 mm length.

Figure 2. Preparation for test samples

Figure 3. Measure the Width, Thickness and Weight

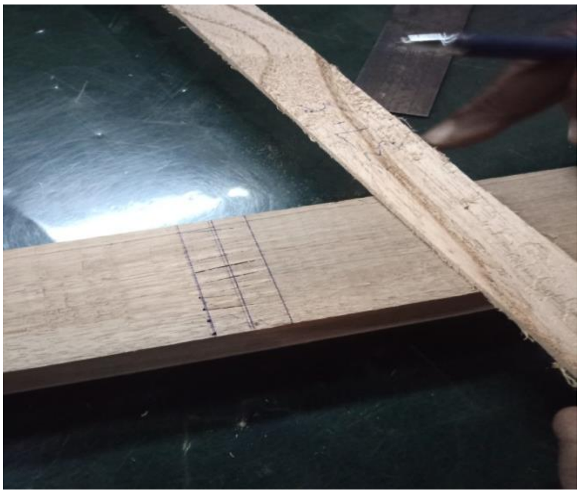

Figure 3.1 After drawing the Centre line to make finger joint

Forming Finger-Joint Profile

Before actually forming a joint, one last preparatory step remains– squaring the ends. If lumber is rough sawed this last step must be preceded by machining at least one edge to serve as a reference plane. Squaring of ends is usually done with a trim saw just before a piece reaches a joint-forming head. The piece is already clamped into position to cutting the joint, and the location of the trim saw is important because it determines the length of the fingers. If a trim saw is not properly located, fingers will be too short or too long. If fingers are too long, they will bottom out when pressure is applied, and good contact between adjacent surfaces will not be obtained. The result could then be a thick, weak glue line. If fingers are too short, there will be gaps at tips of the fingers, possible splitting at the roots of the fingers, or maybe excessive squeeze out of the adhesive. In joints in which appearance is a primary need the gaps could cause rejection.

Essentially three methods are used to form a profile of a finger joint. The most common method employs cutting tools, the second uses dies, and the third combines both cutting tools and dies. The cutting tool is normally a revolving head made up of a series of stacked knives, shaped saw blades, or a head that holds replaceable bits. The knives, blades, orbits are ground to the desired shape of the joint. The size and the number of cutters in a head depend on the geometry of a joint and the thickness or width of material being joined. If stacked knives are used to form structural end joints, the tolerances in the knives and their assembly in the head is extremely critical. A few thousandths of an inch variation can result in poor fitting, low-strength joints.

Die-formed joints are produced by forcing squared ends of pieces of wood against a metal die the shape of a desired joint. The die may or may not be heated. In die forming, the specific gravity (SG) of a wood is a limiting factor in sizes and shapes possible. The cell wall substance of woody material has an SG of about 1.5; this represents the upper limit of compressibility. If the SG of a wood is 0.5, ordinary pressure methods can reduce the volume to about one-third of normal. The higher the SG, the less a wood can be compressed without seriously weakening fibers. This then limits size and geometry of joints that can be formed with only dies. Because of size limitations, joints made in this manner are considered suitable for only nonstructural uses. To make a joint suitable for structural uses and still retain some of the advantages claimed for die-formed joints, joint must be reshaped by using a cutting tool. This preforming operation removes a portion of the material so that the remain material can then be shaped with the die to the desired geometry. This two- step method effectively removes the major limitations on sizes and shapes possible with die forming. Another method that we used in my testing is the separate application of hardener and resin by spraying and spreading.

Figure 4. Preparation of finger by commercial finger shaping machine

Figure 5. Cleaning the finger joint sample

Application of Adhesives

Several approaches are available to apply adhesive to a surface of a joint. The simplest and least precise method is dipping a joint into a container of adhesives. However, most finger-jointing operations are more sophisticated than this and make use of some type of mechanical applicator. A common type is a revolving metal drum with a surface having the same profile as the finger joint. The surface of the drum is continuously coated with fresh adhesive. Then, as the joint passes the revolving drum, the adhesive is wiped onto the joint surface. A variation of this is to use a shaped brush that revolves and wipes the adhesive onto joint surface.

A second type also shaped with a matching profile of a joint. As the joint passes the nozzle, a quantity of adhesive is extruded onto the join surfaces. For the joining the fingers, a commercial Urea Formaldehyde (UF) resin was used. The UF adhesive was prepared from the UF resin powder by mixing it with 2% of ammonium chloride (NH_4Cl) hardener and making an aqueous solution with 57.6 % solid content. Seven samples were prepared this way and were designated as "**UF**" samples. A commercial Nanoclay containing metallic oxides {(0340399) [1332-58-7] Clay Nano powder (Nano Clay) Part-C} was used in the study as Nano filler. This Nano clay, with 4 % concentration of the UF powder was mixed with distilled water in a beaker by gentle stirring using a glass rod to break any kind of lumps formed. After 10 minutes of stirring, the solution was placed in a Loba-Life (3.5 l)

Ultrasonic Water Bath. The sonicated solution was added to UF resin powder in distilled water as above. The set of seven samples joined with this resin was designated as "**UF+4%NC**".

The adhesives were applied to all fingers using a brush after shaping the fingers. Subsequent to adhesive application, the sections on which fingers were profiled were mated and pressed at an end-pressure of 6 N/mm^2 on a pneumatic press. The samples were made in such a way that the joints occupied their central position. The jointed samples were cured at room temperature for at least 48 hours. Prior to the bending measurements, the samples were given a light planning to remove any surplus adhesive.

Figure 6. Using Urea Formaldehyde and Urea Formaldehyde + Nano Clay

Assembly of Joints

After an adhesive has been applied, the next step is aligning the joint and applying bonding or mating pressure. Again, several systems are available by which pressure can be applied. In one system, the required pressure is applied by having the in-feed mechanism in the bonding or a curing area move at a faster rate than the out-feed end of the line. This is commonly called a Crowder. The Crowder system is often used if te material being joined continues to move as it passes through an RF curing tunnel.

Regardless of how pressure is applied it is important it be of sufficient magnitude to force the two halves tightly together and the pieces be properly aligned while the adhesive cures. The required end pressure on a finger joint depends on the viscosity of glue and the quality of the fitting of the fingers. Well- fitted fingers have shown a high joint strength at insignificant end pressures. For close contact of fingers, end pressure must be maintained between 3 to 6 kilograms per square centimeter (kg/cm^2) (43 to 85 $lb/in.^2$).

My experiment way, the adhesives were applied to all fingers using a brush after shaping the fingers. Subsequent to adhesive application, the sections on which fingers were profiled were mated and pressed at an end-pressure of 6 N/mm^2 on a pneumatic press. The samples were made in such a way that the joints occupied their central position.

Figure 7. After assembling the joint

Figure 8. After joining, using the Compress Machine

Curing the Adhesive

The final step in manufacturing finger-jointed wood products is curing the adhesive. Most of the adhesives commonly used in finger jointing will cure at room temperature (70° and above). However, the time required to cure these adhesives can be greatly reduced by adding heat. Thus, to speed up production, most systems for finger jointing employ some method of supplying heat to the adhesive.

The heat necessary to accelerate adhesive cure can be supplied either before or after application of the adhesive to the joint. The use of heat supplied before applying an adhesive is commonly called stored or residual heat gluing. Applying the adhesive to a preheated surface limits the amount of time allowed to get joints under pressure. The amount of heat energy available to cure an adhesive is also limited; this may restrict the types of adhesives that can be used. With this approach care must be taken not to expose joint surfaces to a too-high temperature for too long or the wood will be permanently damaged.

Applying heat to a joint after applying an adhesive is somewhat more flexible than using the stored-heat method. The amount of heat energy available to cure a resin is not limited as it is with preheated material. Allowable assembly time is also much less sensitive; therefore, unexpected minor delays will not result in reject material. However, the equipment required to apply heat after joint assembly is expensive to purchase, operate, and maintain.

As our condition, the jointed samples were cured at room temperature for at least 48 hours. Prior to the bending measurements, the samples were given a light planning to remove any surplus adhesive.

Figure 9. Curing the finger joint at room temperature

Description of test - Static Bending Test

For comparison of the effectiveness of the two types of the adhesive joints, a set of seven samples of clear (un-jointed) samples of Eucalyptus also was prepared with the same dimensions. This set was designated as "**solid**". Thus, in total there were 21 samples in the study. The static bending measurements on the jointed samples were carried out on a Universal testing machine following the broad directions laid down in Indian standards (IS-1708) (BIS, 1986). Central loading was adopted to make the bending measurements. The loading was done in a horizontal mode to the jointed specimens with fingers being parallel to the face on which the load was applied. The span of the test was kept at 700 mm. The load was applied continuously such that the movable head moved at 2.5 mm per minute and deflections were noted against applied loads until the joint failed. From the load-deflection graphs on a spread sheet, the load and deflection at the limit of proportionality were recorded. The Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) were calculated for each sample using the following formulae:

$$MOR = \frac{3P'l}{2bh^2} \quad \text{N/mm}^2$$

$$MOE = \frac{Pl^3}{4Dbh^3} \quad \text{N/mm}^2$$

Where

P = Load at limit of proportionality (N)
P' = Maximum load at which the joint failed (N)
l= Span of sample (mm)
b = Breadth of sample (mm)
h = Height (thickness) of sample (mm)
D = Deflection at limit of proportionality (mm)
All statistical analyses were performed using the SPSS statistical package

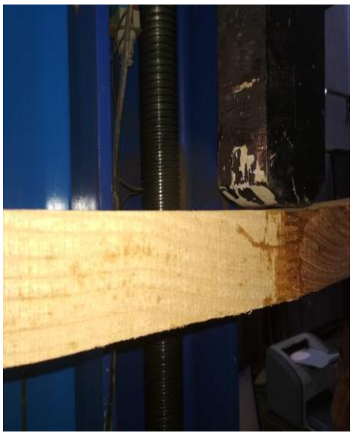

 

Fig 10. Bending Measurement

4. Result and Discussion

Table 1 presents the mean values of MOR and MOE of the 21 samples used in the study.

Table 1. Mean bending parameters of samples used in the study

Sample designation		No. of Samples	Bending parameter	
			MoR	MoE
Solid (Un-jointed)	Mean value (N/mm^2)	7	83.6	8572
	Std. Dev. (N/mm^2)		4.5	412
	CV (%)		5.4	4.8
UF	Mean value (N/mm^2)	7	49.0	11160
	Std. Dev. (N/mm^2)		3.4	755
	CV (%)		6.9	6.8
UF+4%NC	Mean value (N/mm^2)	7	43.2	7953
	Std. Dev. (N/mm^2)		8.7	393
	CV (%)		20.1	4.9

Table 1 reveals that samples joined with UF result in nearly 49 N/mm^2 of MOR whereas those joined with nanoclay added UF yield less than 44 N/mm^2 of MOR. Thus, numerically, UF seems to be yielding better bending strength for the joints and nanoclay addition in 4 % does not seem to enhance the bending strength. The jointed samples are showing much less MOR values compared to un-jointed solid samples. All the 21 MoR values were subjected to One-way ANOVA, which indicated significant differences between the obtained MOR values. The ANOVA table is presented in table 2.

Table 2. One-way ANOVA of MoR values

Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Between Sample sets	6661.418	2	3330.709	93.336	< **0.001**
Error	642.331	18	35.685		

A p- value of less than 0.001 suggests that there are significant differences between the MOR values. Hence, Duncan's homogeneity test was conducted on the 21 MOR values obtained and the results obtained grouped the values into two distinct subsets which is shown in table 3.

Table 3. Duncan's subsets for MOR values

Sample designation	No. of Samples	Subsets of mean MoR (N/mm^2)	
		1	2
UF+4%NC	7	43.2	
UF	7	49.0	
Solid (Unjointed)	7		83.6
Sig.		0.085	1.000

It can be seen from table 3 that though, the Nano clay added samples resulted in numerically lesser MOR values, their strength is statistically similar to that of samples joined with UF only. The improvement caused by Nano addition is still a subject of study over the world. For example, improvement in the bonding strength of oak was reported by the addition of SiO_2 nanoparticles in UF (Bardak et al. 2018). However, the study reported that addition of TiO_2 Nano particles failed to give enhanced strength. The positive result of the present study is that, the MOR has not reduced significantly due to addition of 4 % Nano clay in UF. These results are illustrated in fig.10.

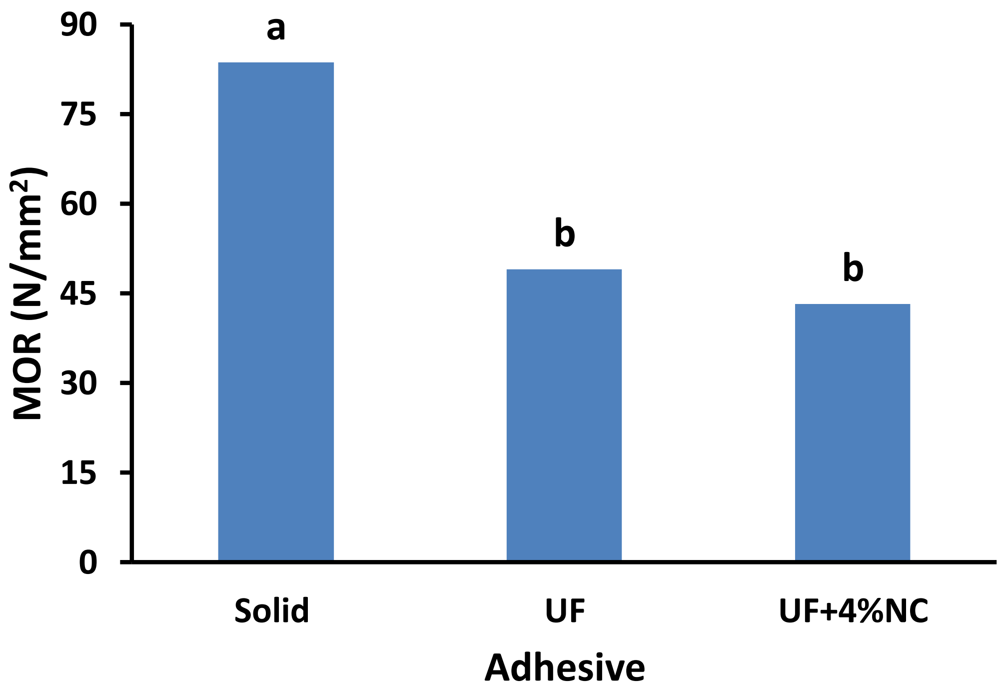

Figure 11. Bending strength of solid and finger jointed wood of Eucalyptus

Fig. 11 clearly illustrates the need of looking for a different Nano filler or different concentration in bringing about significant improvement in the bending strength of eucalyptus sections finger jointed with UF adhesive.

Table 1 reveals that samples joined with UF result in nearly 11160 N/mm^2 of MOE whereas those joined with Nano clay added UF yield 7953 N/mm^2 of MOE. Thus, numerically, UF seems to be yielding better bending strength for the joints and Nano clay addition in 4 % does not seem to enhance the stiffness of the joint. Unlike in the case of MOR, the samples jointed with UF alone are showing much higher MOE values compared to un-jointed (8572 N/mm^2)solid samples. All the 21 MOE values were subjected to One-way ANOVA which indicated significant differences between the obtained MOE values. The ANOVA table is presented in table 4.

Table 4. One-way ANOVA of MOE values

Source of variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Sample sets	4.051E7	2	2.026E7	68.034	< **0.001**
Error	5359612.286	18	297756.238		

A p- value of less than 0.001 suggests that there exist significant differences between the MOE values. Hence, Duncan's homogeneity test was conducted on the 21 MOE values obtained and the results obtained grouped the values into three distinct subsets which is given in table 5.

Table 5. Duncan's subsets for MOE values

Sample designation	**No. of Samples**	**Subsets of mean MOE (N/mm^2)**		
		1	2	3
UF+4%NC	7	7953		
Solid (Un-jointed)	7		8572	
UF	7			11160
Sig.		1.000	1.000	1.000

It can be seen from table 5 that the nanoclay added samples have indeed resulted in lesser MOE values. However, it is important to note that these samples have retained 92.8 % of the MOE of the solid samples. On the other hand, the UF joined samples have shown an enhancement by 130.2 % in MOE. Thus the positive result of the present study is that, the MOE addition of 4 % nanoclay in UF has resulted in retaining more than 90 % of the MOE compared to solid samples.

These results are illustrated in fig. 12.

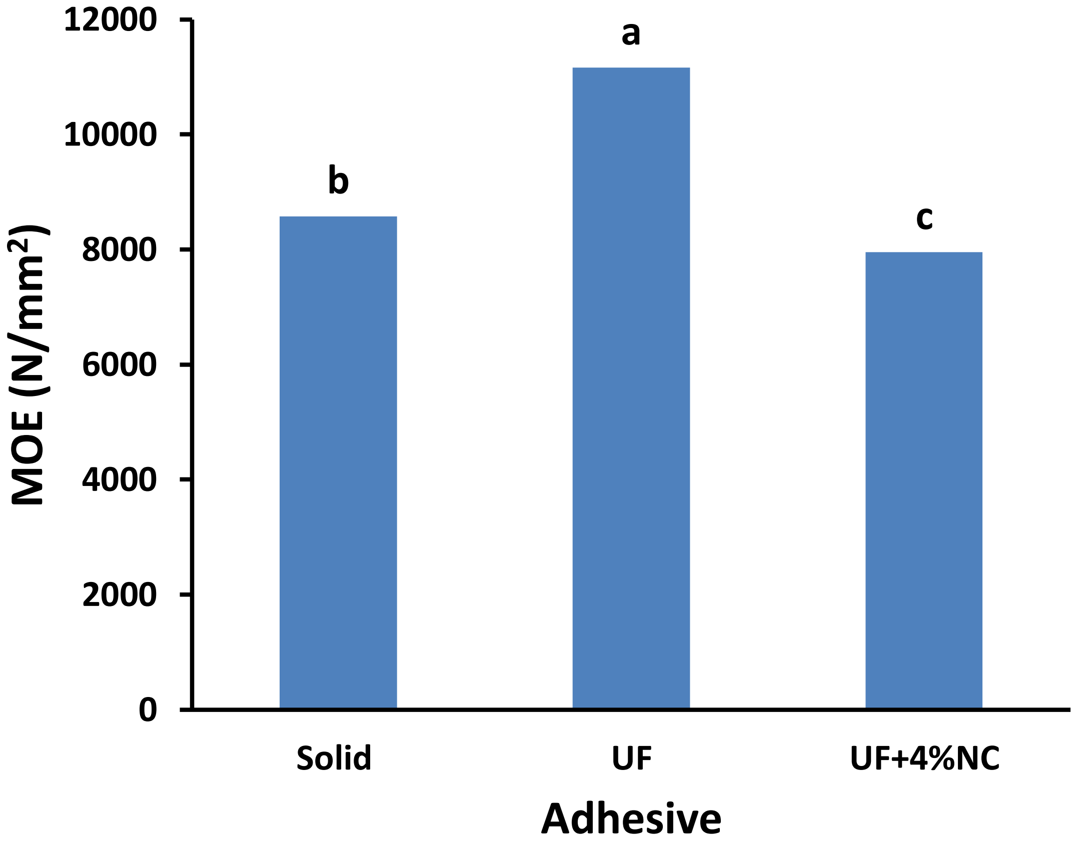

Figure 12. MOE of solid and finger jointed wood of Eucalyptus

Good retention of MOE of finger jointed African hardwood sections using resorcinol-formaldehyde adhesive up to about 83-98 % of the individual clear sections depending on the wood density and with a finger length of 18 mm also has also been reported (Ayarkwa et al. 2000a). They attributed this to the fact that stiffness being a more global phenomenon is not very sensitive to joint properties. Thus we find that though MoR did not improve, the MOE has not been substantially reduced in the joints.

5. Conclusions

- The finger jointed sections results in considerably lower bending strengths in the case of Eucalyptus when Urea Formaldehyde is used as the adhesive.
- The addition of 4 % Nano clay in UF has not affected the bending strength (MoR) of the jointed sections.
- The samples joined with UF show improved elasticity compared to solid wood.
- Nano clay addition in 4 % concentration has helped in retaining 92 % MOE in the jointed sections of Eucalyptus.

6. Acknowledgement

Every assignment big or small are successful largely due to the effort of a number of wonderful people who have always given their valuable advice or lent a helping hand. I sincerely appreciate the inspiration, support and guidance of all those people who have been instrumental in making my thesis a success.

I owe a great debt of gratitude to Dr. Kishan Kumar V.S, Scientist G of Forest Products Division for the confidence bestowed on me and entrusting my thesis titled "**Studies on Finger Jointing of Short Sections of Eucalyptus Timber**". I also feel deeply honored in expressing my sincere thanks to Dr. Sachin Gupta, Chief Technical Officer, WWF Discipline, Forest Products Division, FRI Dehradun, Mr.Ravindra Kumar and Mr.R.P. Bhatt at Wood Working & Finishing Discipline and Mr.Shikhar Skukla, (RA-I), Forest Products Division for his persistent support in making the resources available at the right time and providing valuable insights leading to the successful end of my thesis. I am extremely thanking to Sh. A.S. Rawat Director/ Vice Chancellor, Dr.H.S Ginwal, Dean (Academic), Dr.A.K Tripathi (Registrar) FRI Deemed to be University, Dehradun and Dr. Shailendra Kumar, (Programme Coordinator, WST) FRI, Deemed to be University. I am also thankful to Mr. A.K. Khanduri and his working staffs of the Timber Mechanics discipline for providing better facilities, guidance and assistance.

Another grateful list of my extremely thanking are Sir U Own Win (Minister for the Ministry of Natural Resources and Environmental Conservation), Dr.Nyi Nyi Kyaw (Director General, Forest Department, Ministry of Natural Resources and Environmental Conservation and Forestry, Myanmar) and Dr. Thaung Naing Oo (Director of Planning & Statistic Division, Forest Department, Ministry of Environmental Conservation and Forestry, Myanmar). And I would like to say thank you to our Director of Forest Research Institute, Yezin and all researchers, all staff and all friends who help me for my requirement document from the base of my mind. Last but not the least; I place a deep sense of gratitude to my father, my mother and my elder sisters and my colleague.

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