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Mechanical Properties of GFRP Wrapped Wooden Specimens with Various Wrapping Patterns

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Abstract

The Glass Fibre Reinforced Polymer (GFRP) composites has been widely preferred for its extensive applications in rehabilitation and retrofitting works with its high inelastic deformation capabilities, weight to thickness ra- tio and durability from the view point of anticorrosive nature. This research investigation focuses on the physical properties of wooden specimens wrapped with woven roving GFRP sheets. Four kinds of wooden specimens covering Pterocarpus Indicus, Hopea Parviflora, Ficus Benghalensis and Magnifera In- dica along with two "U" wrapping patterns involving two strip wraps and three strip wraps had been explored for tensile strength, compressive strength and flexural strength. The experimental investigation was executed with to- tal number of wooden specimens being 36. The research exposed that the Pterocarpus Indicus had highest enhanced compressive strength being 48.25% and 57.08% for two strip and followed by three strip GFRP wraps. The tim- ber made from Hopea Parviflora replicated enhancement of 27% and 33.4% for the above mentioned wrapping patterns. The same kind of behaviour was observed in flexure test. The tensile test projected Hopea Parviflora standing highest tensile strength followed by Ficus Benghalensis. The research projected the feasibility of using the Woven roving GFRP sheet as composite material for the South Indian traditional Madras terrace roofing adopted in old build- ing structures with wooden beams. This investigation further claims that the pattern wrapping would bring out economical ways for repair and retrofitting wooden structural elements or structures.

Keywords:* *Polymer composites, timber, flexural behaviour, GFRP wraps

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I. INTRODUCTION

Wood is widely used structural material for lightweight structures and bridges of shorter span. Glued laminated timber and sawn lumber are commonly used for engineering applications [1] . The wood could be reinforced or strength- ened using conventional methods like steel plates, bars, aluminium or timber patches. These may increase the dead loads, transportation expenses and installation costs. Conventional repair methods generally involve mechanical connections or fasteners, which may not be effective in deteriorated timber. Steel components are susceptible to corrosion and [2] aluminium plates may buckle when thermal loads are applied.

FRP materials are the only aliter and strengthening technique for timber structures, which increases the load carrying capacity and ensures necessary stiffness. The FRP composites provide favourable strength, stiffness – to weight ratios and being non – corrosive fits intensive usage along with concrete or tim- ber. The FRP composites may be bonded on the tensile soffit of timber beams to enhance the load carrying capacity and stiffness. Such strengthening work is conducted with externally bonded FRP strips or sheets and near surface mounted (NSM) FRP bars [3-5]. While epoxy adhesives are the dominant bonding agent for strengthening timbers, other types of attachments like mechanical shear spikes, fasteners and resorcinol formaldehyde may also used [6 -8]. The surface preparation, moisture content, and environmental exposure are the factors affecting the bond of FRP composites to timber elements. Adhesive bonding may change the failure mode of timber beams strengthened with FRP composites from brittle tension to ductile compression. FRP strengthening may increase the ductility of timber beams and usable strains of tension fibres by delaying the onset of tensile cracking of the fibres. Significantly, reduced creep has been reported [9]. The majority of strengthening techniques had been related to glulam timbers. Hence, there is a need for further research on the FRP repair of sawn timber beams. From various experimental investigations on mechanical properties of timber, it has been found that the tensile strength parallel to the grain is the highest strength property of the wood. Any irregularity in growth may affect the tensile strength. The high tensile strength wood can not be utilized in construction for several reasons. The shearing strength along the grain is (about 6 to 10%) extremely low when compared to tensile strength. It is difficult to characterize timbers of different species and even from the same log. It is needy to classify the timber species by investigating the mechanical properties of smaller species as indicated by past researches. The design criteria mostly depends on tensile strength of the structural timber and composite lumber. The strength and Young's modulus of the timber is affected by species of trees, degree of growth, moisture content specific gravity and so on and the deviation is larger.This research investigation focusses on four kinds of wood wrapped with woven roving GFRP sheets and tested for tension, compression and flexure.

Pterocarpus Indicus **Hopea Parviflora** **Ficus benhalanis** **Magnifera Indica**

Figure 1 Various Wooden Specimens

1.1.1 GLASS FIBRE REINFORCED POLYMER SHEET (GFRP):

The most extensively used class of fibres in composites are those manufactured from E-glass. E-glass is a low alkali borosilicate glass originally developed for electrical insulation applications. It was first produce commercially for composite manufacture in 1940's, and its use now approaches 2 MT per year worldwide. Many different countries manufacture E-glass and its exact composition varies according to the availability and composition of the local raw materials. It is manufactured as continuous filaments in bundles, or strands, each containing typically between 200 and 2000 individual filaments of 10-30μm diameters. These strands may be incorporated into larger bundles called roving and may be processed into a wide variety of mats, clothes, and performs and cut into short-fibre formats. Glass filaments have relatively low stiffness but very high tensile strength (~3GPa). In spite of their initial very high strength, glass filaments are relatively delicate and may become damaged by abrasion and by attack from moist air. It is therefore always necessary to protect the newly drawn strands with a coating or size (also referred to as a "finish"). This is usually applied as a solution or emulsion containing a polymer that coats the fibres and binds the fibres in the strand together (film former), a lubricant to reduce abrasion damage and improve handling, additives to control static electric charges on the filaments, and a coupling agent, usually a silane, that enhances the adhesion of the filaments to the matrix resin and reduces property loss on exposure to wet environments.

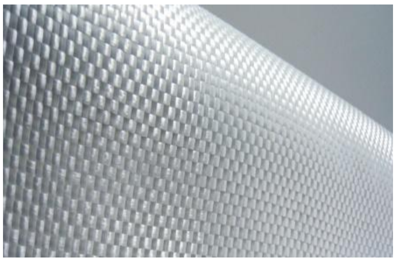


Figure 2 Woven Roving GFRP Sheet

1.1.2 ADVANTAGES OF GFRP:

- Non corrosive and forms permanent form work for concrete.
- High Fatigue endurance and Impact Resistance.
- GFRP has a very high strength to weight ratio.
- Low weights of 2 to 4 lbs. per square foot means faster installation, less structural framing, and lower shipping costs.
- Resists salt water, chemicals, and the environment - unaffected by acid rain, salts, and most chemicals.
- Domes and cupolas are resined together to form a one-piece, watertight structure.
- Virtually any shape or form can be molded.
- Research shows no loss of laminate properties after 30 years.
- Stromberg GFRP stood up to category 5 hurricane Floyd with no damage, while nearby structures were destroyed.

- Simple in construction.
- Non-conductive to heat and electricity.
- Non-magnetic (transparent to electrical fields).
- It reduces erection time.
- High durability and concrete confinement.

II. EXPERIMENTAL INVESTIGATION

2.1 SPECIMEN DIMENSIONS AND WRAPPING PATTERNS

Three strip wraps and two strip wraps at an interval of 220mm for wooden beam of 1.2m is projected in the following figure 3. The wooden beams had cross sectional area 70mm x 70mm and tested for flexure using two point loading.

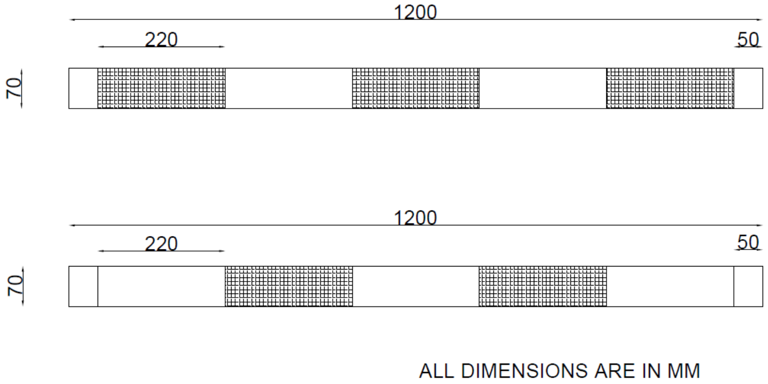


Figure 3

Wrapping Pattern

Figure 4 Experimental Setup for flexure test

Apart from flexure tests, tensile and compression tests were performed with two strip wraps and three strip wraps. The dimensions for the tests were adopted as per ASTM D4761.9105. The wooden specimens of compression tests were 80 x 80 x 200 mm. For tension tests, the dimension of the specimen were 25 x 25 x 508mm.

III. RESULTS AND DISCUSSIONS

3.1 INFLUENCE ON YOUNG'S MODULUS

Sl.no	WOOD	TABLE 1 Young's Modulus of Control Specimen		
		Compression Test MPa	**Flexure Test MPa**	**Tension Test MPa**
1	Pterocarpus Indicus	940.625	386346.9635	145678
2	Hopea Parviflora	765.62	479016.9728	176855
3	Ficus Benghalensis	884.38	289370.674	205654
4	Magnifera Indica	856.25	227326.247	112323

Sl.no	WOOD	TABLE 2 Young's Modulus of Two Strip Wrap Specimens		
		Compression Test MPa	**Flexure Test MPa**	**Tension Test MPa**
1	Pterocarpus Indicus	1003.125	220980.151	195678
2	Hopea Parviflora	678.125	216702.202	256355
3	Ficus Benghalensis	710.937	195567.433	223241
4	Magnifera Indica	664.062	195567.433	142123

Sl.no	WOOD	TABLE 3 Young's Modulus of Three Strip Wrap Specimens		
		Compression Test MPa	**Flexure Test MPa**	**Tension Test MPa**
1	Pterocarpus Indicus	989.06	233898.99	183678
2	Hopea Parviflora	801.56	301751.229	236322
3	Ficus Benghalensis	667.18	243106.497	213255
4	Magnifera Indica	639.06	202338.492	122188

Due to higher range of strain values, the Young's modulus showed a steady decline on two strip and three strip wrapped specimen when compared with the control specimen as observed from table 2,3 and 4. The Pterocarpus Indicus wooden specimen showed acceptable response in compression tests when compared with other wooden specimens and this composite specimen is suited for columns when wrapped with two strip or three strip pattern.

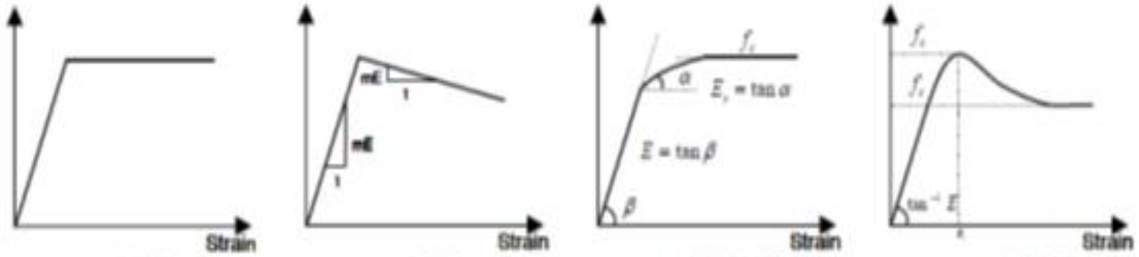
Hopea Parviflora is suited for flexural response as adopted for beams in south Indian roof terracing and also apt to act as tensile members in trusses made of timber.

3.2 LIMIT STATE DESIGN METHOD

In ultimate Strength Design or Limit state method of design the nature of constitutive relation among stresses and strains play significant role. The strength and Young's modulus of the timber is influenced by species of the trees, degree of growth, moisture content and specific gravity [1]. The timber when subjected to compression parallel to the grains is extensively studied which projected effect in maximum strength, Young's modulus and ultimate strain due to grade and numerous other factors.

3.3 STRESS STRAIN MODELS

The following are the stress strain models [10] suggested by Neely, Bazan, Malhotra and Glos

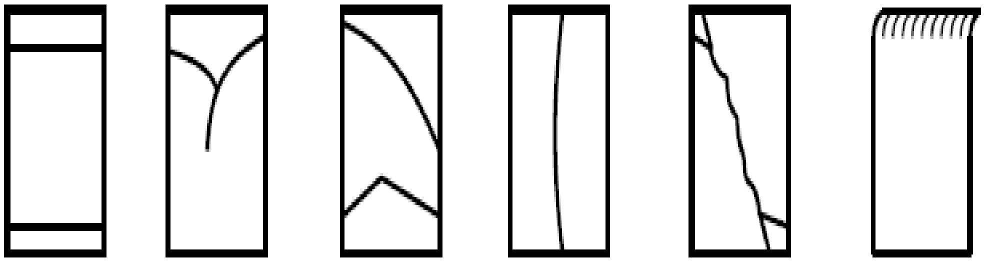


(a) Neely (b) Bazan (c) Malhotra (d) Glos

Figure 5 Stress Strain Model of Wooden specimens

3.4 TYPICAL MODES OF COMPRESSURE FAILURE PATTERN

The following are the typical failure pattern pronounced by ASTM classifications [1]

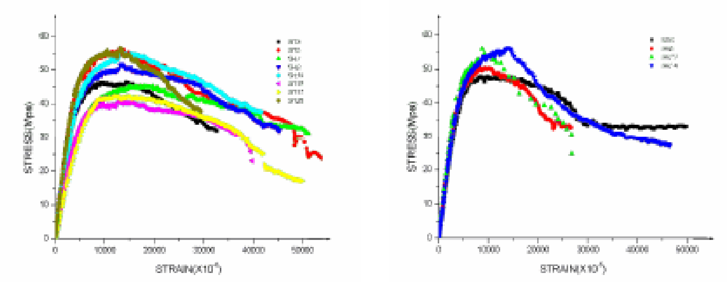


(a) Crushing (b) Wedge-splitting (c) Shearing (d) Splitting (e) Compression & Shearing (f) Brooming or End-Rolling

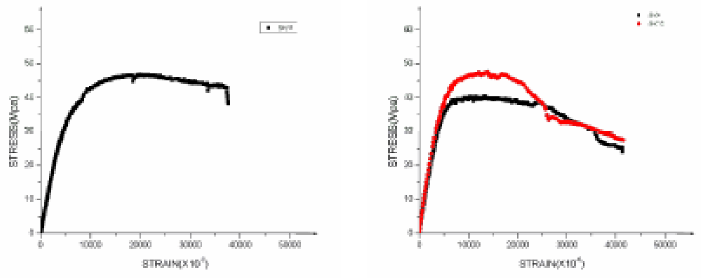
Figure 6 Compression Failure Pattern for Wood.

3.5 STRESS STRAIN CURVES FOR VARIOUS COMPRESSIVE FAILURE PATTERN:

The observed failure patterns and the corresponding stress strain curves [10] from the past research could be summarised in the following figures:



(a) Wedge-splitting (b) Shearing



(c) Crushing (d) Splitting-shearing

. Stress-strain relation associated with failure patterns

Figure 7 Constitutive models of wooden specimens in compression

3.6 STRESS STRAIN CURVES OF THE COMPRESSION TESTS ON WOODEN SPECIMENS:

The compression tests were conducted on four kinds of wooden specimens namely Pterocarpus Indicus (vengai), Hopea Parviflora (kongu), Ficus Benghalensis (Banyan) and Magnifera Indica (mamaram). Apart from control specimens, the wooden specimens were wrapped with two strips and three strips along their length and the influence of these GFRP wraps were observed. The figures from 3.6.1 to 3.7.8 leads to narration of section 3.7 about the compression tests on the wooden specimens and their response with FRP wrapping patterns.

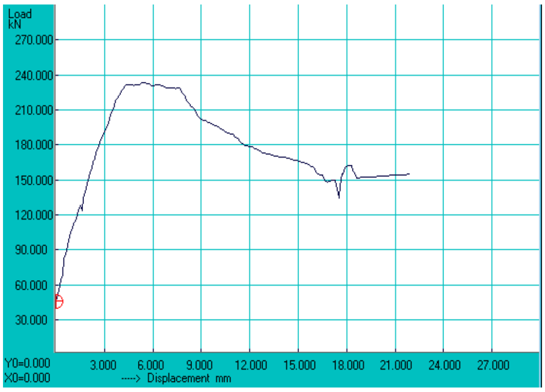


Fig 3.6.1 Pterocarpus Indicus (Control Specimen)

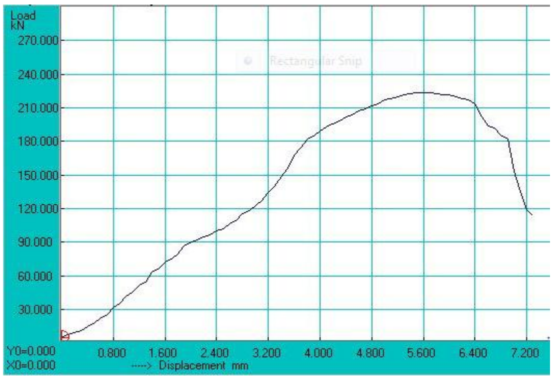
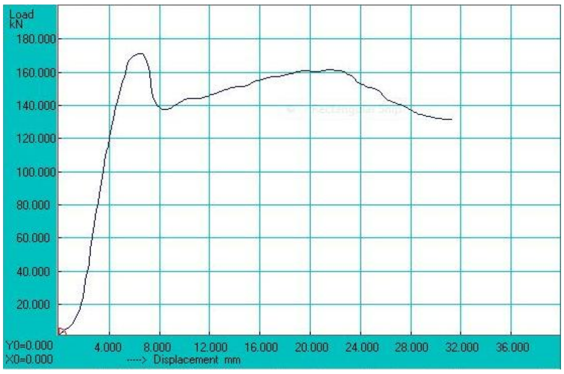


Fig 3.6.2 Hopea Parviflora(Control Specimen)



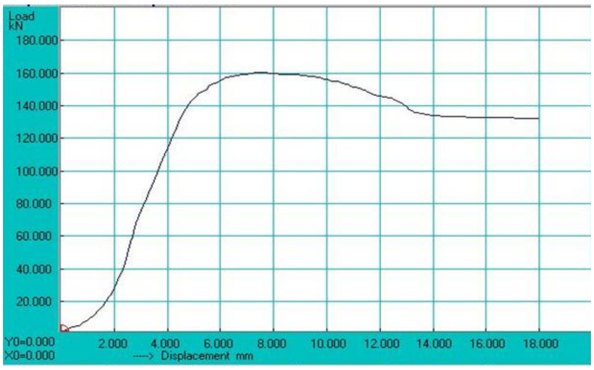


Fig 3.6.3 Ficus Benghalensis (Control Specimen)

Fig 3.6.4 Magnifera Indica (Control Specimen)

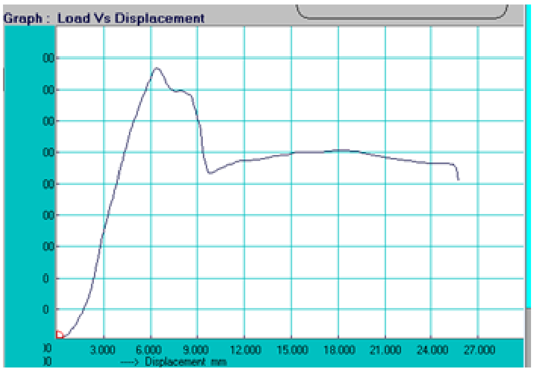


Fig 3.7.1Pterocarpus Indicus(2 strip Wrap)

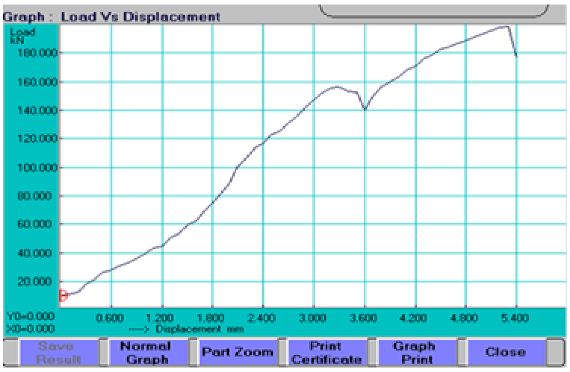


Fig 3.7.2Hopea Parviflora(2 strip Wrap)

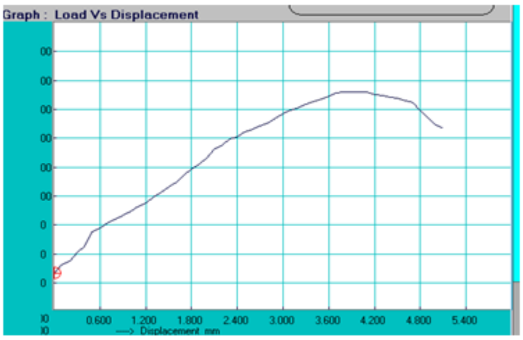


Fig 3.7.3 Ficus Benghalensis(2 strip Wrap)

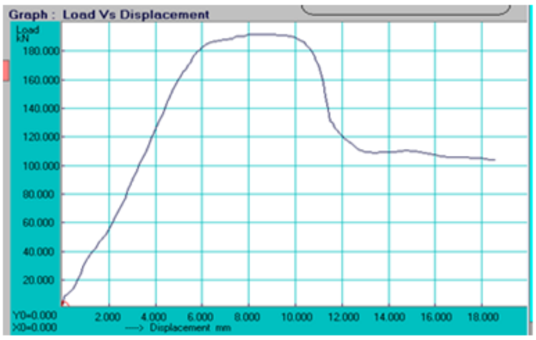
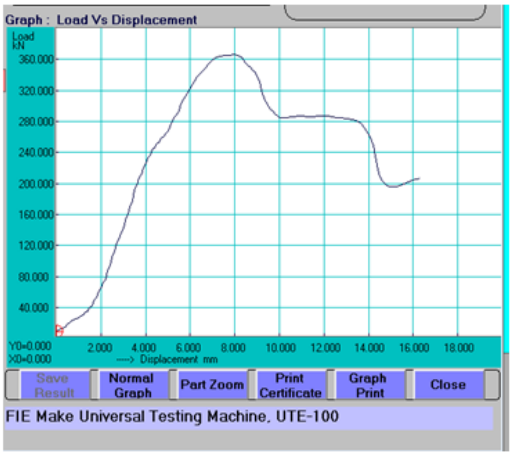


Fig 3.7.4 Magnifera Indica (2 strip Wrap)



FIE Make Universal Testing Machine, UTE-100

Fig 3.7.5 Pterocarpus Indicus (3 Strip Wrap)

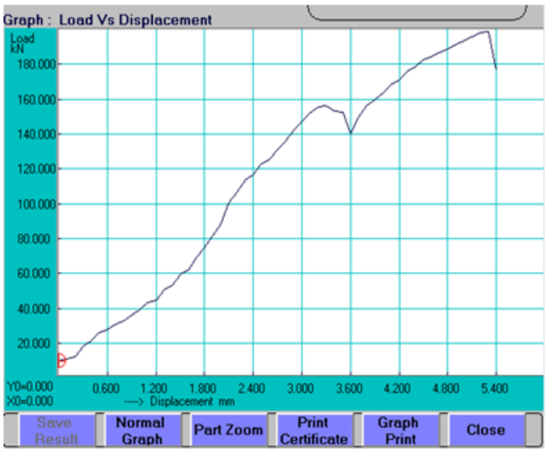


Fig 3.7.6 Hopea Parviflora(3 Strip Wrap)

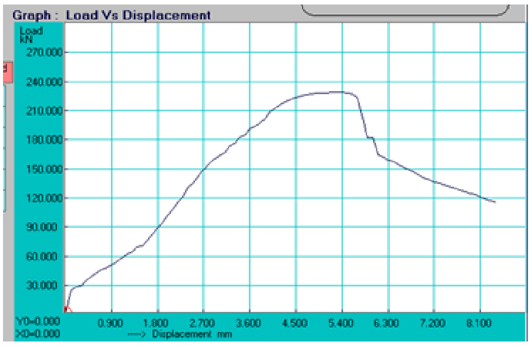


Fig 3.7.7 Ficus Benghalensis(3 Strip Wrap)

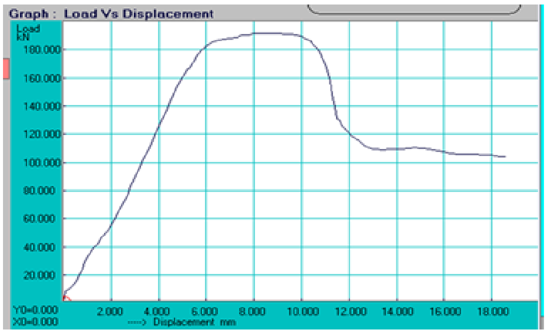


Fig 3.7.8 Magnifera Indica(3 Strip Wrap)

3.7 INFLUENCE OF WRAPPING PATTERN

3.7.1 PTEROCARPUS INDICUS

The stress strain curves of Pterocarpus Indicus (Vengai) , the control specimen had a flat plateau and failed by wedge splitting failure as observed from the figure 3.6.1. After wrapping with two stripped wrap, ultimate compressive load reached its peak followed by the densification of wood thereby lowering the strain values and finally had a flat plateau . The failure pattern observed was shearing failure. The shear failure was observed in three strip wrapped specimen, but loss of densification was reported.

3.7.2 HOPEA PARVIFLORA

Shearing failure was observed in the HOPEA PARVIFLORA as observed in the stress strain curve in figure 3.6.3 No densification was observed in the two stripped wrap specimens and three strip wrapped specimens.

3.7.3 MAGNIFERA INDICA

Splitting shearing failure was observed in this specimen which was then converted to shear failure when wrapped with two strip wrapping and finally with three strip wrapping, densification of wood was observed along with a flat plateau in the stress strain curve.

3.7.4 FICUS BENGHALENSIS

This wooden specimen reported shearing failure on control specimens with out strengthening with GFRP woven roving mats and the densification of wood was observed while testing. How ever the specimen with three stripped wrap failed to exposed densification and shear failure was observed in all the three specimens.

3.8 CONSTITUTIVE MODELS OF TENSILE TESTS ON THE WOODEN SPECIMENS

CONTROL SPECIMENS

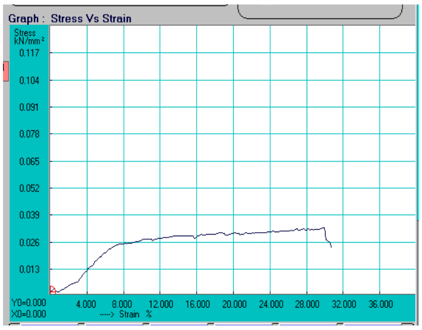


Fig 3.8.1 Pterocarpus Indicus (Control Specimen)

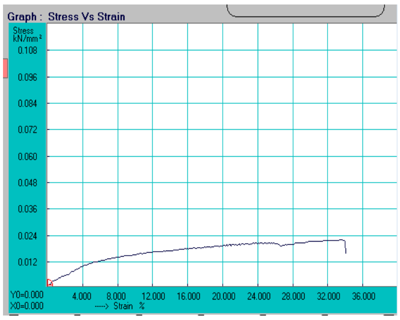


Fig 3.8.2Hopea Parviflora(Control Specimen)

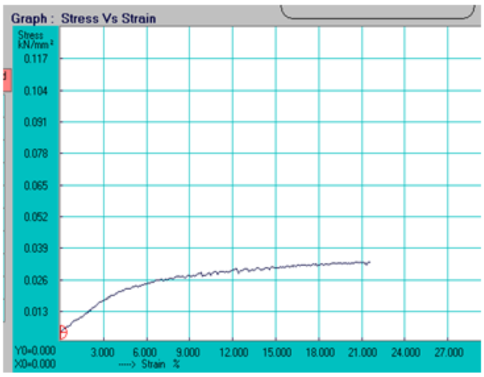


Fig 3.8.3 Ficus Benghalensis(Control Specimen)

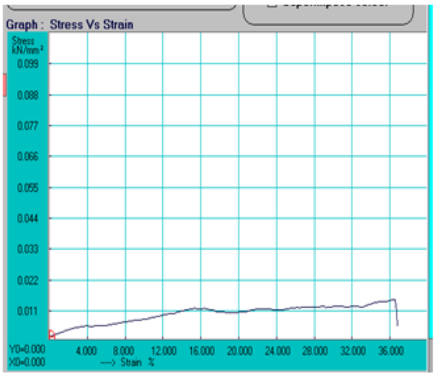


Fig 3.8.4 Magnifera Indica (Control Specimen)

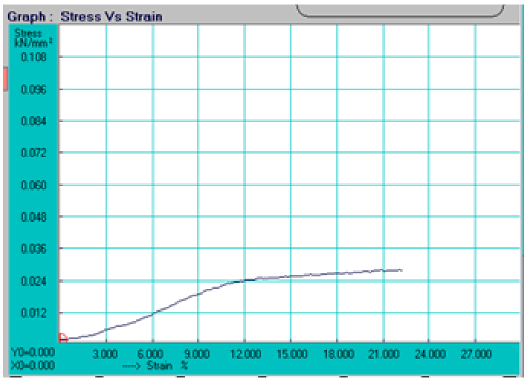


Fig 3.8.5 Pterocarpus Indicus (2 Strip Wrap)

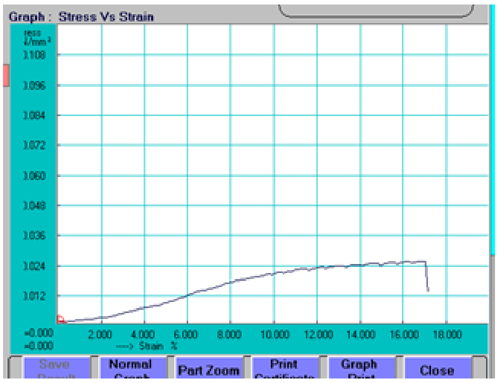


Fig 3.8.6 Hopea Parviflora(2 Strip Wrap)

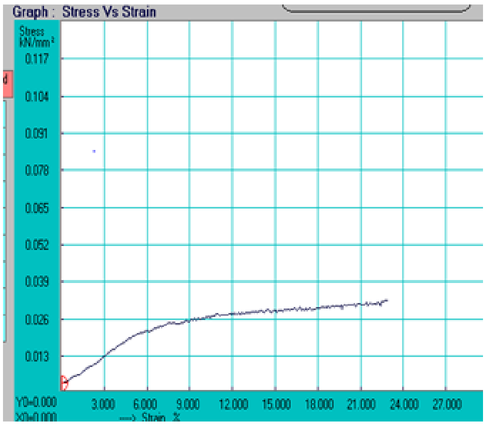


Fig 3.8.7 Ficus Benghalensis (2 Strip Wrap)

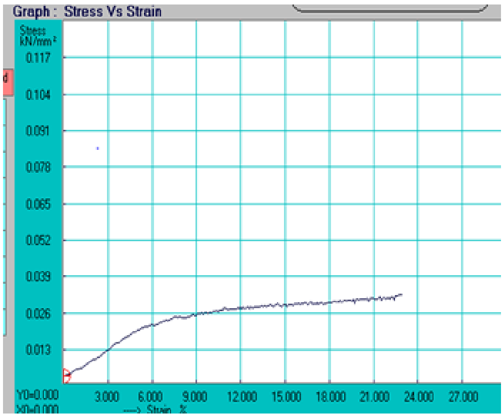


Fig 3.8.8 Magnifera Indica (2 strip wrap)

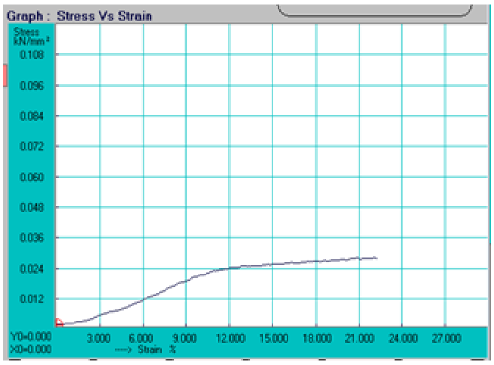


Fig 3.8.9 Pterocarpus Indicus(3 strip wrap)

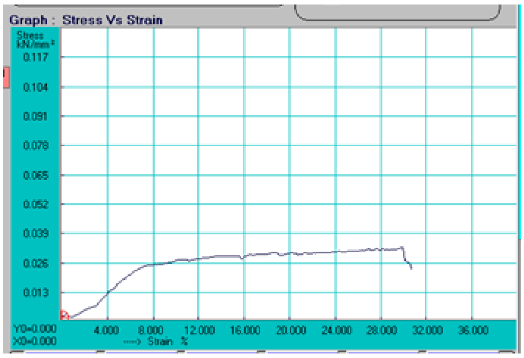


Fig 3.8.10 Hopea Parviflora (3 strip wrap)

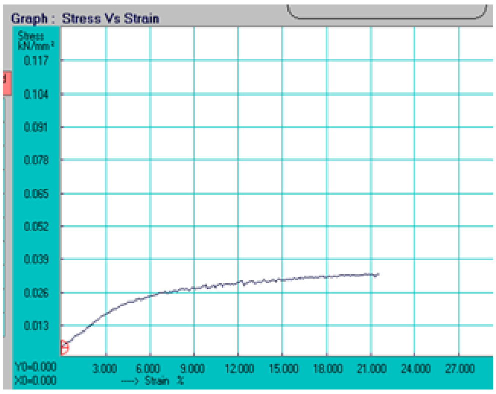


Fig 3.8.11 Ficus Benghalensis(3 strip wrap)

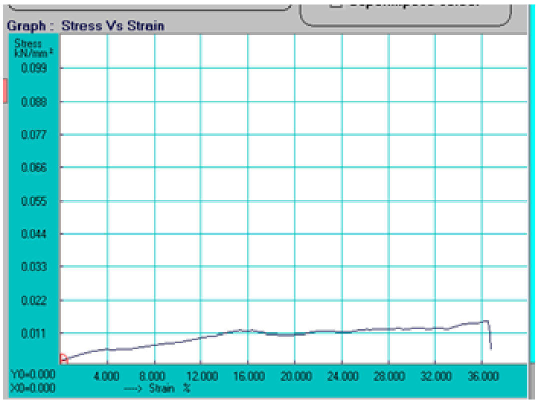


Fig 3.8.12 Magnifera Indica (3 strip wrap)

3.9 TENSILE FAILURE CHARACTERISTICS

The wooden specimens were tested for finding the Modulus of Elasticity as per ASTM D198 (Tension parallel to the grain) .The tensile strength is highest for the wood when tested for grains parallel to the tensile loads. The high tensile strength of wood can not be utilized in the construction industry. The shearing strength along the wood is extremely low when compared to the tensile strength along the grain. Hence wood may be regarded as tending towards shear failure or cleavage along the fastening or joints. The fabricated clamps were used in the tensile tests. Since the failure occurred at the fastenings of the clamps, the tests were confined to specimens with out using the fabricared clamps. The test was then conducted with having the tensile specimens by directly clamping to the Universal Testing Machine (UTM).

IV. INFLUENCE OF WRAPPING PATTERNS

4.1PTEROCARPUS INDICUS

The control specimen projected a nonlinear variation but the specimen encountered strain hardening as shown in figure 3.8.5. The specimen with two stripped wrap showed a loss of strain hardening, but linear variation projecting elastic limit up to failure was observed.

4.2 HOPEA PARVIFLORA

The tensile test revealed a linear stress strain curve followed by strain hardening effect. The ductility observed was lesser than that of Pterocarpus Indicus for the control specimen. The two strip wrapped specimen projected brittle failure where as the three strip wrapped specimen showed an enhanced ductility. The impact of wrapping could project a gain in ductility when three strips are wrapped around the specimen. The two strip wrapped encountered loss of ductility

4.3 MAGNIFERA INDICA

The control specimen responded with high ductility as observed from the graphical plot of figure 3.8.13. The specimen had the highest strain value when compared with other wooden species. How ever loss of ductility was observed in two stripped specimens.

4.4 FICUS BENGHALENSIS

The nonlinear curve was obtained in the control specimen as represented in figure 3.30 with a constant strain hardening. For the specimens with two strip and three strip wrap, no difference in the stress strain plot was observed. The tensile strength was the least when compared with other specimens.

V. FLEXURE TEST ON THE WOODEN BEAMS

5.1 PTEROCARPUS INDICUS

The specimen had huge response in the form of linear variation which is depicted from the load deflection curves with high energy absorption capacity. The specimens with two wraps responded with appreciable ductile behaviour when compared with the specimens with three wraps. This could impose the fact that the sufficient wraps should be provided at the point of application of the load. Adhesive bonding had changed the mode of failure from brittle tension to ductile compression.

5.2 HOPEA PARVIFLORA

This kind of species from wood had lesser ductility when compared with the Pterocarpus Indicus. The specimen with two stripped wrap could pronounce enhanced ductility when compared with the other specimens.

5.4 MAGNIFERA INDICA

The control specimen responded with linear graphical plot of stress strain curve. How ever the ultimate load carrying capacity was not appreciable when compared with other specimens except Benhalensis. The two strip wrapped specimen responded better when compared with the three strip wrapped specimen as observed earlier.

5.5 FICUS BENHALENSIS

The specimen responded with linearity in the load deflection pattern. The flexure test specimen with two stripped wraps exactly at the point of application of load responded with increased ductility and energy absorption capacity. How ever the three strip wrapped specimen offered better confinement and maintained linear load deflection response when conferred with the control beam specimen.

VI. CONCLUSIONS

1) The adhesive bonding may change the failure mode of the timber beams strengthened with FRP composites from brittle tension to ductile compression.

2) GFRP strengthening may increase the ductility of timber beams and usable strains of the tensile fibres by delaying the onset of the tensile cracking of the fibres.

3) The longitudinal Young's modulus of Elasticity (E_L) had significant influence in resisting the flexural load behaviour and energy absorption capability as observed from tables 2,3 and 4.

4) The properties of the timber specimen influenced the load carrying behaviour when compared with the GFRP composites. How ever the GFRP composites enhanced the flexural behaviour up to 38% which had been quoted in all researches confined to FRP composites.

5) The damage propagation was controlled and limited in the flexural response of all the beams wrapped with GFRP composites.

6) The failure modes observed exposed the fact that the longitudinal tensile fracture resulted in most of the timber species. Another kind of failure mode observed was fracture occuring at the end of the GFRP wrapped timber which resulted in failure of the beams to sustain further loading. These kind of failure mode was different from the delamination failure observed in concrete beams reported in earlier researches.

7) The strengthening schemes had a vital role in the flexural response. The wraps provided at the point of application of load was the ultimate scheme reported to conclude as the better confinement when compared with three strip GFRP wrapped timber species.

8) The Pterocarpus timber specimen repsonded densification and delayed failure in the compression tests when wrapped with three strips of GFRP wrap followed by Parviflora.

9) The tensile tests projected Parviflora (control Specimen) having highest yield strength compared to other specimens. How ever Magnifera Indica dominates the other timber species in composite behaviour when wrapped with GFRP wraps. The same trend was observed for Bengalensis which had appreciable influence when wrapped with two and three strip GFRP wraps.

10) The specimens with low load carrying capacity failed in brittle manner accompanied by decreased energy absorption capacity. How ever the GFRP strenghtening technique pronounced positivity in increasing the load carring capacity. The GFRP woven roving mat used for this research along with general purpose resin proved to be effective in all aspects covering tensile, compressive and flexure capacity of the timber .

11) Among the two patterns of GFRP wraps, the two strip wraps was the domineer in strength enhancement as observed from the flexural behaviour. This research was based on repairing/retrofitting Madras Terrace roofing used in South Indian locality. The research could be extended using other species of timber and other patterns of wrapping using CFRP, AFRP and changing the fibre orientation of the FRP composites.

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