BENDING BEHAVIOUR OF TIMBER BEAMS STRENGTHENED WITH GLASS FIBRE REINFORCED POLYMER (GFRP)

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ABSTRACT

This researched was conducted to investigate the bending behavior of the timber beams when strengthened with Glass Fiber Reinforced Polymer (GFRP) sheets. There are three timber beams of Keruing species with the dimensions of 100 x 100 x 1500 mm was tested. Two of the beams was strengthened before tested to failure under three point loading test, while one are used as a control beam (unstrengthen). The deflection was measured using Linear Variable Displacement Transducer (LVDT). The damaged beams was repaired by increasing the thickness of GFRP sheets to 10mm and tested using the same testing procedure. The failure modes also have been identified through the experiment. The beams are categorized as under-reinforced and over-reinforced based on the modes of failure in members. From the results, it shows that the beams strengthened with GFRP performed better result compared to control beam. The using of proposed experimental technique increased the ultimate load between 12 - 40% for the strengthened beams when compared to the control beam and decreased 10% of the specimen's deflection. Based on experimental results also, the repaired damaged beams can resist load up to 83% of the damaged beams. From the research findings, it shows that the use of GFRP sheets can decrease the effect of local defects in the timber and the bending strength of the members can be increased. The GFRP sheets are one of the reinforcement materials which have a good potential to be utilized in the new building structure or rehabilitation works of timber structures.

ABSTRAK

Kajian ini telah dijalankan untuk menyiasat tindakbalas lenturan rasuk kayu apabila diperkuatkan dengan kepingan Polimer Bertetulang Gentian Kaca (GFRP). Terdapat tiga rasuk kayu spesies Keruing dengan ukuran 100 x 100 x 1500 mm telah diuji. Dua daripada rasuk diperkuatkan sebelum diuji sehingga gagal di bawah pembebanan tiga titik, manakala satu telah digunakan sebagai rasuk kawalan (tidak diperkuatkan). Pesongan akan diukur dengan menggunakan Transduser Pesongan Pembolehubah Selari (LVDT). Rasuk yang telah rosak diperbaiki dengan meningkatkan ketebalan kepingan GFRP kepada 10mm dan diuji menggunakan cara yang sama. Jenis-jenis kegagalan juga telah dikenal pasti melalui eksperimen. Rasuk telah dikategorikan sebagai dibawah bertetulang, dan lebih bertetulang berdasarkan kelakuan kegagalan kayu tersebut. Keputusan menunjukkan rasuk yang diperkuat lebih kuat berbanding dengan rasuk kawalan. Penggunaan teknik eksperimen yang dicadangkan telah meningkatkan beban muktamad di antara 12 - 40% daripada rasuk yang diperkuat berbanding rasuk kawalan dan mengurangkan sebanyak 10% pesongan kayu tersebut. Berdasarkan kepada keputusan eksperimen juga, kayu yang telah diperbaiki boleh menanggung beban sehingga 83% daripada kayu yang rosak. Kajian menunjukkan penggunaan kepingan GFRP boleh mengelakkan kesan daripada kerosakan kayu dan sekaligus meningkatkan kekuatan lenturan pada kayu. Kepingan GFRP adalah salah satu sistem ikatan yang mempunyai potensi yang baik untuk digunakan dalam pembinaan atau proses pemulihan baru struktur kayu.

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LIST OF ABBREVIATIONS

FRP	Fibre Reinforced Polymer
GFRP	Glass Fibre Reinforced Polymer
CFRP	Carbon Fibre Reinforced Polymer
LVDT	Linear Variable Displacement Transducer
SG	Strength Group
MOR	Modulus of Rupture
MOE	Modulus of Elasticity
MS	Malaysian Standard
Pu	Ultimate Load
RC	Reinforced Concrete
CB	Control Beam
M	Moment

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Timber is one of the earliest materials used in construction. It has been used to construct structural building such as houses and bridges. Due to its high strength to weight proportion, it is the most popular building material before the existence of modern structural material such as concrete and steel. The timber is easy to mobilize and construct. In order words, it does not require any fabrication of formwork and curing time like concrete do. Therefore, using timber in the construction can reduce the use of heavy machinery, shorten the construction period and save up construction cost. Besides that, timber has the capability to resist oxidation, acid, saltwater and other corrosion agents.

Many opportunities exist for the use of Fibre Reinforced Polymer (FRP) in timber members for both new construction and rehabilitation of existing structures. While increasing the strength and create more efficient use of the timber structure, the effective strengthening techniques can be used in order to reduce the size of beams. For existing timber structures, strengthening techniques may save the cost of replacing the structure by allowing it to withstand higher load.

The strengthening process of the timber can increase the strength and stiffness of the members. The attachment of steel plate at tension side of the beam is one of the strengthening methods that can be applied in timber structure. By using this material, it can increase the bending strength of the timber, but it should be considered since steel has the ability to be rusty after a period of time.

1.2 PROBLEM STATEMENT

Timber is one of the building materials that have been used by mankind. It is different compare to the other materials like concrete and steel. Because of the timber's properties which are low strength and less durable compared to concrete and steel, the research about the timber beam needs to be explored. In order to increase its strength, the timber needs to be strengthened. Nowadays, Fibre Reinforced Polymer (FRP) is applied in timber in order to increase the load capacity of its structural elements. Since FRP is strong in tension, so it can fulfil the weakness of timber. In this research, Glass Fibre Reinforced Polymer (GFRP) is used as material to strengthen timber beams.

1.3 OBJECTIVE OF STUDY

i. To study the flexural strength of the timber beams strengthened with GFRP.
ii. To determine the deflection of the timber beams when load applied to the beams.
iii. To study the flexural strength and deflection behaviour between damaged beams with repaired damaged beam specimens.
iv. To investigate the failure mode of the strengthened beams with GFRP.

1.4 SCOPES OF STUDY

The main focus of this research is to analyse the bending behaviour of the timber beams strengthen with Glass Fibre Reinforced Polymer (GFRP) sheets. Therefore, timber beams and GFRP are the main materials being used. The timber type that will be used in this research is Keruing. For the adhesive, Epoxy Coating Resin is selected to bond the timber with GFRP. All beams will be tested under three-point loading.

1.5 RESEARCH SIGNIFICANCE

When the beam was strengthened at tension side, there will be the changes in term of modes of failure from tension to compression. It means that this strengthening method has increased the structure's tensile capacity. The compression capacity of the timber also has fully utilized.

As a result, it can be applied in new construction projects, as well as in the rehabilitation of existing timber structures. The load capacity of the rehabilitation and strengthening of the existing timber structures will definitely increasing. It may also save the cost of the replacement for timber structure. In addition, the size or depth of the timber beams that are required for construction can be reduced using the effective strengthening techniques.

Keruing timber is widely spread throughout the Indo-Malayan region. There were more than 70 sub species in this group and come in a wide scope of land and climatic conditions up to 4300ft about sea level from lowland forest. Keruing is widely distributed timber species in Malaysia. Because of its low strength and durability, it is not a high-performance material for the use of structural. Since Keruing is cheap and used in furniture industry, research will be conducted to study the feasibility of utilizing the low grade Keruing for structural usage by reinforcing it with Glass Fibre Reinforced Polymer.

1.6 CONCLUSION

In this chapter will discuss on the objectives and the scopes of the study. At the end of the study, it must be ensure that the objectives for this study are achieved. The strength of timber members can be enhanced through strengthening process. There are many methods to strengthen the timber structures such as the application of steel plate attached to the tension side of the beam. Although there are increments in the bending capacity of the beams, but due to some period of time, the steel plate tends to become rusty. Then, it contributes to the application of FRP in timber structure as the strengthening material.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter will discuss the literature review based on the previous researches. All of the topics reviewed have the relationship with the study on behaviour of timber beams strengthening with GFRP. As timber and GFRP were the main material that will be used in this study, the literature review was more detailed on these two materials. For example are the timber that will be used and its properties. Same as the strengthening material, this chapter will discuss on the type of FRP used and its mechanical properties. Other than that, there will be the reviewed on the adhesive that will be used to bond the timber and GFRP sheets.

In addition, the behaviour of beam about the bending test was studied in terms of flexural strength, deflection and modulus of rupture. The behaviour of timber beam repair also been reviewed in order to know the strengthening technique that have been used in the previous research.

2.2 TIMBER

Malaysia has more than 2500 species of wood, but only 10% are suitable to be used as construction material. Trees are either deciduous, having broad leaves or coniferous, having needles and cones containing seeds. The deciduous trees are hardwoods and the coniferous are softwoods. Timber consists of long, narrow, hollow cells called fibres. Normally the fibres are parallel to the length of the log.

The thin growing layer is called cambium as shown in Figure 2.1. The sapwood is within the cambium layer and its fibres are active. The heartwood at the centre of the tree consists of dead fibres. Heartwood and sapwood do not differ in mechanical properties (Theodore, 2005).

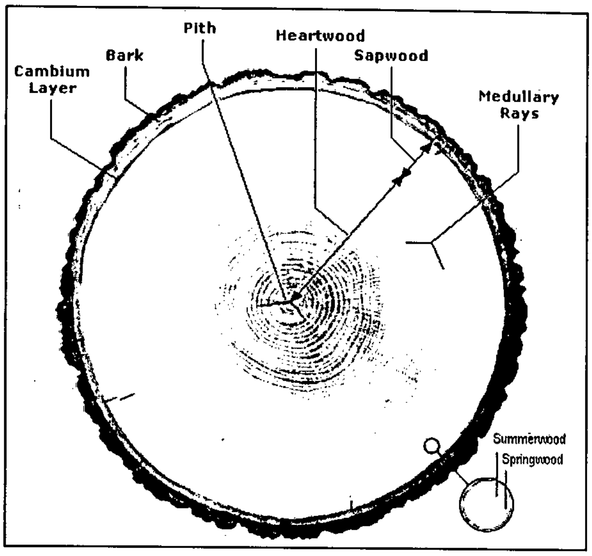

Figure 2.1 Cross section of timber log

Source: Theodore, 2005

2.2.1 Keruing

From more than 70 species of the genus Dipterocarpus, Keruing was name given to the timber yielded. This large hardwoods group is domestic to South East Asia, where the species are collected from the managed forests with renewal programs.

Across the entire species, a wide variety of heartwood hues are available, including deep-pink, orange-pink and purple-red. The most common heartwood is red-brown. Sapwood is usually lighter, sometimes with yellow or grey tinges. The wood has been darkens with age and attributes a generally straight or shallowly grains interlocked. It sometimes occur accordance to a stripe figure on the radial surface. Texture differs between species from fine to coarse, but it is always consistence.

Keruing timber is a low maintenance and hardwearing structure. Because of this characteristic, Keruing is suitable to be used as outdoor furniture. The wood is useful for construction purpose because it is strong and can be classified as durable. Another typical usage of the timber is internal used such as flooring, internal joinery and mouldings, lining, protected framing and board, panelling and framework. It is often used as a cheaper alternative to oak for heavy construction, decking, vehicle building and sleepers, and also in plywood.

Where other timbers may require curing, Keruing is completely cured and ready for immediate use with no risk of leaching, bleeding or leach sap. It contains oleo-resins and will exude it onto surfaces during drying or when exposed to heat or sunshine when in use; gums may also cause problems in machining.

2.2.2 Properties of Timber

Timber is suitable use for construction because of properties of their strength in support the load. This strength is different based on type of loading and can be classified into several type, which is tensile strength, compressive strength, bending strength, modulus of elasticity and shear strength.

Strength can be defined as the ability of material to withstand stress. The resistance may be greater as the material used are stronger. The resistance can be measured in several ways where the maximum stress that the material can resist before there is failure occurs, measure the deformation or strain that result from a given level of stress before the point of total failure and more. Table 2.1 shows the mechanical properties of the Keruing according to the Malaysian Timber Council.

Table 2.1 Mechanical Properties of Keruing

Modulus of Rupture - Unseasoned:	64-82
Modulus of Rupture - Seasoned:	110-137
Modulus of Elasticity - Unseasoned:	12-13
Modulus of Elasticity - Seasoned:	14-16
Maximum Crushing Strength - Unseasoned:	30-35
Maximum Crushing Strength - Seasoned:	59-60
Toughness - Unseasoned:	High - 25 Nm and above
Toughness - Seasoned:	High - 25 Nm and above
Hardness - Unseasoned:	3.2-3.6
Hardness - Seasoned:	4.6-5.3

Source: Malaysian Timber Council, 2006

2.2.2.1 Tensile and Compressive Strength

Timber has a good strength in the parallel direction to its grain which is about 40 times higher when compared to the direction perpendicular to the grain at air-dried. The compressive strength parallel to the grain for softwood is about 33% to 55% of the tensile strength parallel to the grain.

For hardwood, both compressive and tensile strength parallel to the grain are almost similar, whereas the compressive strength perpendicular to the grain is between 10% and 30% of its compressive strength parallel to the grain. Lorenzis (2005) said that for the most of the timber, the shear strength parallel to the grain is taken as the average strength of radial and tangential plane which is between 10% and 15% of tensile strength parallel to grain.

Timber shows different mechanical properties depending whether the timber is dry or wet. Dry timber is a stage when the vapour pressure within the wood equals the vapour pressure in the ambient space. For dry timber, the tensile bending capacity is usually lower than the compressive bending capacity. Thus, the strengthening should be done at the tension zone of timber beam. However, for wet timber its tensile bending capacity is higher than compressive bending capacity. In that case, strengthening should be done on compression zone (Premrov et al., 2004).

2.2.2.2 Modulus of Elasticity

For modulus of elasticity perpendicular to grain, a value of one-twentieth (i.e. 5%) of modulus of elasticity parallel to grain can be used. For shear modulus, a value of one-sixteenth (i.e. 6.25%) of modulus of elasticity can be used (MS 544:2001). For glulam, the compressive and tensile modulus of elasticity is almost same (Lorenzis et al., 2005).

2.2.2.3 Bending Strength

In the field of structural engineering, one of the most crucial concerns is to develop structural material with high strengths. Research shows that by using FRP to strengthen the timber beams substantially increase the strength of structures.

Bending strength is the ability of timber to sustain bending moment until it failed. Timber has very good bending strength, because of this and its lightness; it remains one of the important flexural materials in light construction. It is used for beams, joints, headers and other members that are subjected to bending moments. Wong (2006) said that the ultimate strength of a material is defined by the maximum load or stress that can be applied to break the material completely.

2.2.2.4 Shear Strength

A flexural member is always subjected to shear force. The resulting horizontal shear stress at the neutral axis of a wood beam may cause shear failure. The shear strength of wood is small, generally in the range 4.8 – 10 Mpa (Shan Somayaji, 2003). Most hardwoods have higher shear strength than most softwood.

2.2.2.5 Moisture Content

For beams strengthened using FRP, the fluctuations in the timber moisture content did not cause any problems to the FRP (Dagher and Altimore, 2005). However, to ensure good bonding between FRP and timber, the moisture content should be reduced to below than fibre saturation point at the time of bonding. This is of particular interest in the UK for the exploitation of green timber, which can have moisture content well in excess of 30%, which is greater that the fibre saturation point (Broughton and Hutchinson, 2003).

Wood is a hygroscopic material. It gains and loses moisture depending on the climatic conditions to which it is exposed. The loss and gain of moisture affects dimensional stability and strength, and the presence of water in combination with other conditions can cause decay (Stalnaker and Harries, 1999).

2.2.2.6 Density and Specific Gravity

Density is the best indicator of the property of a timber and is a major factor determining its strength. The density of wood is defines as the mass or weight per unit volume, measured in kilograms per cubic meter (kg/m^3). It also can be defined by the equation below:

$$\text{Wood density} = \frac{\text{Weight of dry timber}}{\text{Volume of timber}} \; x \; 100$$

Specific gravity of wood is defined as the ration of the density of wood to the density of water at a specific reference temperature where the density of water is 1000kg/m^3. Specific gravity is usually used as a standard reference basis, rather than density. Specific gravity or relative density is a measure of timber's solid substance. It is generally expressed as the ratio of the oven-dry weight to the weight of an equal volume of water.

To reduce the confusion introduced by the variation of moisture content, the specific gravity of wood usually is based on the oven-dry weight and the volume at some specified moisture content. Normally, specific gravity of wood is calculated using green wood condition. The specific gravity of wood is the ration between the density of wood and water such as below.

$$\text{Specific gravity} = \frac{\text{mass of wood (body)}}{\text{mass of an equal volume of water}}$$

2.2.3 Fire Resistance

When combustion occurs in a building, the temperature goes up to 1000°C within a short time. Large timbers do not support combustion except where there are corners or narrow opening, the square edges burn first. One log alone does not burn unless the fire is constantly fed by other fuel, but two or three logs close together support combustion in the spaces between them with no additional fuel. The sharp edges of a split log burn better than a rounded natural log. The charred exterior caused by the fire is a partially protective coating for the inner timber, cutting the rate of combustion (Theodore, 2005).

2.2.4 Stress-Strain Behaviour of Timber

In axial compression, when force is given, stress-strain curve will provide one linear line at curve is in elastic condition. This condition can reach up to eighty percent from the value of maximum load. After that, when the load is add until the sample was failed, the stress will decrease immediately. This condition is called plastic limit where the sample cannot going back to its original length or shape (Frederick, 2004).

2.3 FIBRE REINFORCED POLYMER (FRP)

Fibre reinforced plastics or sometimes called fibre reinforced polymers have been used for many years in the aerospace, automotive and many construction industries, where their high strength and low weight have shown distinct advantages over traditional strengthening materials such as aluminium and steel. This material has also been used for several decades for mainly architectural applications for example cladding.

FRP are becoming increasingly popular materials for strengthening of civil structures. This strengthening technique involves epoxy bonding FRP mostly to the tension face of the member, increasing both the strength and stiffness of the beam. With heat curing, epoxy can reach its design strength in a matter of hours, resulting in rapid bonding of FRP to the structure and consequently, minimum disruption to its use (Dutninh and Starnes, 2004).

FRP have a lot of advantages compared to steel as tendons or reinforcement material. High resistance to corrosion is one of their characteristics. As the solution to the problem of steel corrosion, the significant characteristics of FRP suggested. In addition to that, according to Patrick and Zou (2002) in their research, it is stated that FRP has high ratio of strength and stiffness to density yields to a strength/weight ratio of 10-15 times higher than that of steel.

2.3.1 Glass Fibre Reinforced Polymer (GFRP)

GFRP is a combination of polyester resin (thermosetting polymer) as a matrix and glass fibre as reinforcement, fillers and additives. Other names of GFRP are resin glass or fibreglass. The glass fibre can be arranged in one direction called unidirectional or two directions called bidirectional depending if design requirement. Generally, the glass used in plastic industry of 50% - 65% sand ($S_i\,O_2$).

Hence, it provides good resistance to chemical when compared to other fibres. In addition to that, the raw material for glass can be obtained easily at low cost. Shen (2005) in her research state that glass fibres have low water absorption and therefore it can be used for outdoor applications.

There are two major types of fibre glass, namely E-glass and S-glass. Both glass fibres are highly resistance to solvent, acid and alkali. S-glass is stronger and stiffer fibre with a greater resistance to corrosion and higher thermal stability. With the concern of high material cost for S-glass, it is solely used to produce high technology product such as manufacturing satellite. While for E-glass, it is widely used as the reinforcement in construction industry because the cost of E-glass is lower than S-glass (Giap, 2007).

Common uses of fiberglass include high performance aircraft (gliders), boats, automobiles, baths, hot tubs, septic tanks, water tanks, roofing, pipes, cladding, casts, surfboards and external door skins.

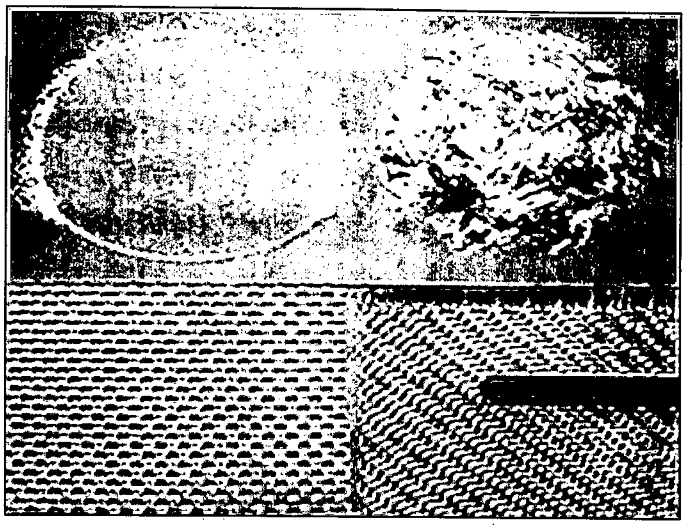

Figure 2.2 Glass reinforcements used for fiberglass

Unlike glass fibres used for insulation, for the final structure to be strong, the fibre's surfaces must be almost entirely free of defects, as these permits the fibres to reach tensile strengths. It is mostly inappropriate to produce bulk material in a defect-free state outside of laboratory conditions. It would be similarly as strong as glass fibres if a huge piece of glass were to be free from defect.

2.3.2 Production of GFRP

The fabrication process of glass fibres suitable for reinforcement uses large furnaces to gradually dissolve the silica sand, dolomite, limestone, kaolin clay, columnist and other minerals to liquid phase. Then it is extruded through bushings, which are bundles of very small orifices (typically 5–25 micrometres in diameter for E-Glass, 9 micrometres for S-Glass). Then, these strands are sized or coated with a chemical solution. The individual strands are now bunched together in large volume to provide a roving. The weight can be determined by the diameter of the strands and the number of the strands in the roving.

Then, the roving is used directly in a composite application. For example are pultrusion, filament winding (pipe) and gun roving. It is an automated gun which is cut the glass into shorter lengths and drops into a jet of resin. Then, it is forecast onto the mould surface. It also used in an intermediary step which is to fabricate the fabric such as Chopped Strand Mat (CSM), knit fabrics, woven fabrics or unidirectional fabrics. CSM are made of randomly from small cut lengths of fibre and it is bonded together.

2.3.3 Mechanical Properties of GFRP

The mechanical properties of glass fibre depend on fibre weight or volume content and fibre orientation. Glass fibres typically have a low modulus of elasticity (70 kN/mm^2 for E-glass) when compared to carbon fibres or steel (Shin, 2003). Unidirectional fibres provide the highest longitudinal tensile properties.

Jamaludin (2002) has tested GFRP composites (type E-glass/polyester), a product of Polymer Composite Asia Group, at Nilai, Negeri Sembilan and found that the tensile and compressive strength was 600 N/mm^2 and 414 N/mm^2, respectively whilst the modulus of elasticity under tensile test was 41 kN/mm^2. S-glass fibres exhibit a higher tensile strength than E-glass (Dagher and Altimore, 2005) and much higher when compared to steel. However, steel has higher strain at failure which exhibits high ductility. This ductility gives advantage to steel over FRP.

Fibreglass is applied in many products in industry. It is lightweight, extremely strong and also robust material. The raw materials are much less expensive compared to carbon fibre although the strength properties are lower. The material also less brittle and less stiff compared to others. Compared to metals, glass fibre can be easily formed using moulding processes. Other than that, its bulk strength and weight properties are also appropriate.