TIMBER REINFORCEMENT IN REINFORCED CONCRETE BEAM FOR LIGHT STRUCTURE

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ABSTRACT

Many researches and development of new reinforcement material for concrete structure as an alternative to the existing reinforcement material which is steel have been done nowadays. Timber looked like another alternative which possesses high strength ratio compare to its weight even basically; its strength is incompatible to steel. This study's focus on the flexural behaviour of beam reinforced with timber and also to make a comparison between the laboratory test and theory applying the Reinforced Concrete Design to EC2. In the result of flexural test, it showed that control beam which named STEEL carried the utmost loads compared to sample beam which reinforced with Balau and Meranti timber. Both of them are named as BALAU and MERANTI. Compared to the flexural strength of STEEL beam which is 73.18 kN, BALAU beam reached 69 % of the value meanwhile MERANTI is 66 % respectively. In comparison of deflection, BALAU beam reached 68 % of the control beam's value, which is convenient with the difference of flexural strength. For MERANTI, it showed the large different with only 26 % and it is not compatible with the value of flexural strength. This condition happened because of the stiffness of reinforcement. For the failure mode of the beam, it is closely related to the load-deflection behaviour. The larger the load-deflection value, the wider the range of cracking. Based on comparison of theoretical and experimental result, it can be concluded that the theoretical value of ultimate moment resistance is higher compared to experimental. This study concluded that, the Balau timber has a possibility to be an alternative to replace the steel in reinforced concrete structures because from the result of testing, the value is quite competitive compared to steel reinforcement.

ABSTRAK

Banyak kajian dan pembaharuan terhadap bahan tetulang baru untuk struktur konkrit sebagai alternatif kepada bahan tetulang sedia ada yang iaitu keluli telah dilakukan pada masa kini. Kayu dilihat sebagai salah satu alternatif yang mempunyai nisbah kekuatan yang tinggi jika dibandingkan dengan beratnya sendiri walaupun pada dasarnya; kekuatannya tidak serasi dengan keluli. Tumpuan kajian ini adalah mengenai kelakuan lenturan rasuk diperkuatkan dengan kayu dan juga untuk membuat perbandingan antara ujian makmal dan teori menggunakan Rekabentuk Konkrit Bertetulang untuk EC2. Dalam keputusan ujian lenturan, ia menunjukkan bahawa rasuk kawalan yang dinamakan STEEL membawa beban penuh berbanding dengan sampel rasuk yang diperkuatkan dengan kayu Balau dan Meranti. Kedua-dua mereka dinamakan sebagai BALAU dan MERANTI. Berbanding dengan kekuatan lenturan rasuk STEEL iaitu 73.18 kN, rasuk BALAU mencapai 69% daripada nilai tersebut sementara itu MERANTI 66%. Dalam perbandingan pesongan, rasuk BALAU mencapai 68% daripada nilai rasuk kawalan yang mana sesuai dengan perbezaan kekuatan lenturan. Untuk MERANTI, ia menunjukkan perbezaan yang besar dengan hanya 26% dan ia tidak serasi dengan nilai kekuatan lenturan. Keadaan ini berlaku kerana kekukuhan bar tetulang di dalam rasuk. Bagi mod kegagalan rasuk, ia berkait rapat dengan tingkah laku beban-pesongan. Semakin besar nilai beban-pesongan, lebih luas julat keretakan. Untuk perbandingan keputusan teori dan eksperimen, ia boleh disimpulkan bahawa nilai teori momen rintangan muktamad adalah lebih tinggi berbanding dengan nilai eksperimen. Kajian ini merumuskan bahawa, kayu Balau mempunyai kemungkinan untuk menjadi satu alternatif untuk menggantikan keluli dalam struktur konkrit bertetulang kerana dari hasil ujian, nilainya agak kompetitif berbanding dengan keluli tetulang.

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As	-	Area of tension reinforcement
b	-	Width or effective width of section
d	-	Effective depth of tension reinforcement
F_{ck}	-	Characteristic strength of concrete
F_{yk}	-	Characteristic strength of reinforcement
Fcc	-	Concrete compression force
Fst	-	Steel tension force
h	-	Height of the section
L	-	Effective length of section
M	-	Moment resistance
P	-	Point load
W	-	Uniform distribution load
z	-	Level arm

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Structure that based on timber has played an important role in construction industry nowadays especially in a country which have good resource of timber, such as Malaysia. Therefore, it will not be a problem if timber is widely used in local construction industry. Basically, timber is tough, strong and long lasting element. There are variety types of timber in Malaysia (see Malaysia Timber Industry Board). The usage of timber as a reinforcement material in concrete is rarely known.

This chapter will discuss the problem statement of the study which explains why the timber is chosen in this study to be used as the reinforcement in order to replace the steel. Besides, the objectives of study will be stated well so that it is easy to understand what the aim of this study is and it must be achieved at the end of this study through the testing of samples. This chapter also explains about the testing that will be used, type of timber to be used as reinforcement and appropriate dimension for all samples in the scope of study.

1.2 PROBLEM STATEMENT

This research is to investigate whether the timber can be an alternative to replace the steel reinforcement in reinforced concrete beam. However, using the timber as the reinforcement in reinforced concrete, rather than steel is not been applied yet in overall construction industry. For all known, steel reinforcement has been used in construction for centuries until now. But nowadays, the production of steels raised questions about the quality, strength and also the price. Besides that, the steel reinforcement also faced the several factors of damage such as an internal rust and inappropriate early design. So, by this research, an alternative construction method that is beneficial and economical can be identified for the industry.

1.3 OBJECTIVES OF STUDY

1. To determine the ultimate flexure load, and the deflection of beam samples.

2. Identify the mode of failure for each beam.

3. To make a comparison between the laboratory test and theory applying the *Reinforced Concrete Design to EC2*

1.4 SCOPES OF STUDY

The main purpose of this research is to describe the performance of timber as a reinforcement bar in reinforced concrete beam. In running the laboratory test, there are several tests will be included for this research such as Tensile Test, to get the ultimate tensile load of timber. Besides that, the Beam Strength Test which is three point loads will be held to identify the behavior of beam such as cracking, deflection and strain. In this research, three types of timbers that are usually known in Malaysia will be used. The purpose is to get the different result based on different type of timbers. Two types of timber chosen are Meranti and Balau. The overall samples for this research is three beams, two of them are using timber reinforcement from two types of timber as stated before and one beam using the steel reinforcement and act as the control beam for this research. The proposed size of beam is 1500 mm length, 150 mm width and 200 mm height. The theoretical calculation for deflection and ultimate flexure load will be compared with the laboratory test result.

1.5 RESEARCH SIGNIFICANCE

The proposed research is to serve the students as their reference or guide in creating their program. The students are rarely exposed to the engineering construction unless they have Industrial Training or site visit to the construction company. It will also help student taking engineering related courses to identify the real problems happened in construction industry. The proposed research also helps the instructors to have a deeper understanding about the problem statement and objectives of the research. The use of timber as an alternative to replace the steel reinforcement in reinforced concrete beam might sounds weird to some of them but when they properly understand, they will come up with another brilliant idea and their ideas might be used in construction industry nowadays. All engineers need a new challenge to expose their talent in engineering field. The proposed research will benefits and help the future researchers as their guide. The study can also open in development of this research.

1.6 CONCLUSION

At the end of this chapter, it shows the research significant which explained how this study will fulfill the engineering knowledge of certain people that need reformation in engineering industries. Chapter 1 explained the most important part which is problem statement and objectives of this study so that it is easy for the future researchers and student to understand why this study is held at the first place. Many people thought, timber is not compatible to steel because its strength is far too way compared to steel. The fact also cannot be denied about the strength of steel, furthermore it has been used widely in building construction centuries ago. In earlier decades, timber is just used to construct the houses, deck, and small structure or in minor construction such as finishing, roofing, and flooring.

The perception must be changed according to the development of technology in engineering field nowadays. The timber can be used in major construction and the strength of timber is according to the type of timber. By using the timber reinforcement in reinforced concrete beam, it is the alternative to replace steel reinforcement. The strength of beam reinforced with timber might be different compare to the beam that reinforced with steel and composite, but this study will find out whether the decision to make the timber as one of the alternative to replace steel is acceptable or not. For the next chapter, it will discuss about the previous researches that have been done about the replacement of steel reinforcement in reinforced concrete structure. There are variety types of reinforcement used besides the steel bar and all information about it will be gathered and discussed well in following chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the outcomes of research from the previous researchers are discussed. The results between them are discussed and compared to each other so that it can be a guide for this study. In the technology of construction industry nowadays, there are so many brilliant people come out with an interesting idea on how to improve the construction industry, how to save cost in structure construction or maybe to shorten the time of construction for any particular building but some ideas are acceptable and some of them are cannot be realized, especially in Malaysia.

In beam construction, there is so many reformations has been made by researchers for reinforcement such as using the composite materials which are Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP), steel strengthen with composite, timber beam strengthen with composite, bamboo reinforcement and also by using timber as reinforcement in concrete beam. Many researchers have replaced the steel reinforcement with other composite materials that have the lower cost, high workability and compatible strength. These replacements have been widely used in construction industry nowadays.

2.2 CONCRETE BEAM

Concrete beams are usually used in structural nowadays, for example to make bridges, and large buildings. It is easy to pour and level concrete in variety types of slab or spray it as a thick mixture to coat walls, but it is not easy to shape it into beams. According to Tyler Lacoma (2013), concrete cannot hold the direct weight or loads without any cracking and buckling, so, the manufacturers who make concrete beams use a number of techniques to both form the beams and make sure that they are strong enough to provide necessary support for the whole structure.

Beam is a structure element which carries lateral loads in form of shear force, bending moment and torsion moment. The beam must be safe to be imposed by load, so, it must comply with the ultimate and serviceability limit should be considered in the design process. In typical studies, Mohamad Salleh Yassin (2012) developed a very fine list steps in beam design:

- Determine the design life and fire resistance, including the consideration of durability
- Determine the preliminary size of beam
- Estimate the actions on beam
- Analysis structure to obtain critical moments and shear forces
- Design for flexural reinforcement and shear reinforcement
- Verify deflection
- Verify cracking

Generally, there are so many types of beam such as timber beam, composite beam and steel beam. Still, concrete beam is widely used for construction industry. Regarded as an economical and safe, conventional concrete beam is commonly can be prestressed concrete beam and reinforced concrete beam.

2.2.1 Prestressed Concrete Beam

The concept of prestressing was invented centuries ago when metal bands were wound around wooden pieces (staves) to form a barrel. The metal bands were tightening under tensile stress, which create the compression between the staves, allowing them to resist internal liquid pressure. The concept of prestressed concrete is also not new. In 1886, a patent was granted for tightening steel tie rods on concrete blocks. This is analogous to modern day segmental construction.

Prestressed concrete beam also known as precompressed structure. Also mean the compression force is imposed to the concrete beam before it is installed. The precompressed stress imposed onto the stress area of the beam because concrete can support compression but very weak when it is stressed. Yu Huang (2012) stated in his research, prestressed concrete is a method for overcoming concrete's natural weakness in tension. Prestressed concrete is essential in many applications in order to fully utilize concrete compressive strength, and through proper design, to control cracking and deflection. Generally, prestressed concrete can be applied in one of three ways: as pre-tensioned prestressed; as un-bonded post-tensioned concrete and as bonded post-tensioned prestressed concrete.

Although design methods have been developed over the decades, an understanding of ultimate mechanism in the prestressed concrete system is still greatly needed in many aspects. The principle goal of Yu Huang's studies is establishing finite element models of prestressed concrete systems subjected to particular problems. Jiangong Xu (2008) said in his research, prestressed members are critical to the integrity of a large share of existing building and bridges, so, an effective non-destructive testing technique is needed to evaluate the integrity of prestressed concrete beams. Prestressed concrete beams usually found in bridge structures and also the building structures that used the unique design.

2.2.2 Reinforced Concrete Beam

Reinforced concrete beam is usually a concrete structure which reinforced with steel bars. However, with the new application of current technology, there is also another material besides steel which can be used to reinforce concrete beam. Reinforced concrete beam should be designed based on Eurocode 2. Zakeriya (2013) explained, concrete beams may be reinforced with tension reinforcement only (singly reinforced beams) or both tension and compression steel (doubly reinforced beams). Hongge (2003) has done the review in his research about the stress distribution in a homogenous elastic beam of rectangular section, in order to gain an insight into the causes of the shear failure in reinforced concrete; he attached the free body diagram of reinforced concrete beam as below:

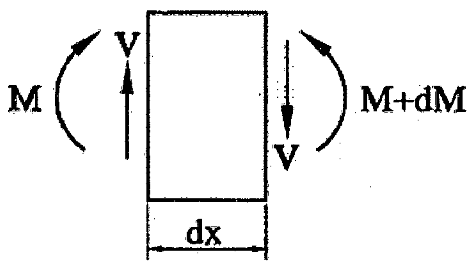

Figure 2.1 Internal forces in beam

$$\frac{dM}{dx} = V$$

where:

dM = the bending moment change from section to section

dx = the distance between sections

V = the shear force on the section

He also stated in his research, the behavior of beam with web reinforcement will express its failure in shear. It takes place under combined stresses resulting from an applied shear force, bending moment and, where applicable, axial loads and torsion as well. Moreover, Matthew R. Murray (2010) had observed that reinforced concrete beam without web reinforcement exhibit decreasing unit shear strength as beam size increases.

His study deals with the influence of beam size on the unit shear strength (the maximum shear force divided by the beam width times effective depth) of reinforced concrete beams without web reinforcement. Previous experimental studies examining beam size have indicated that with increasing depth, unit shear strength decreases. In current study, unit shear strength of beam is ignored because the shorter size of beam is used which is 1500 mm. The results that will be indicated from the experiment are tensile strength of the material, flexural strength and deflection of the beam.

Reinforced concrete beams are widely used in construction because it is economical and easy to construct but the side effects that cannot be seen such as corrosion must be considered. Corrosion is the continuing due to physicochemical deterioration of materials by the action of the surrounding environment. In previous research, Chenhui Ji (2003) stated that the corrosion of reinforcement due to chloride ingress is the most significant threat to an existing reinforced concrete structure. The concrete beams can got corroded to different corrosion levels. He also said that the mass loss of reinforcement is an important parameter, and it can help define the corrosion level and it also can be used to develop correlation between corrosion, cracking, bond strength at the steel-concrete interface and the ultimate strength of reinforced concrete elements.

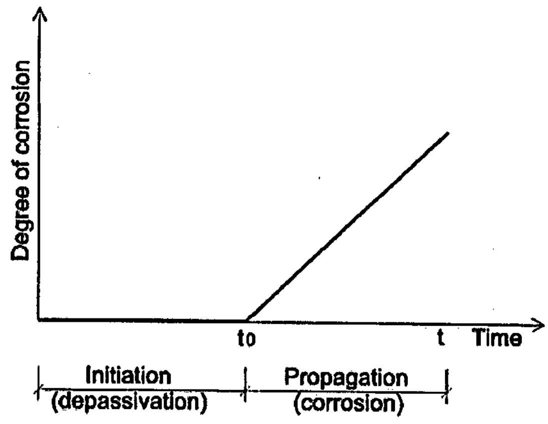

Figure 2.2: Process of depassivation

The initial stage is the process when steel becomes depassivated by penetration of chloride ions, while the propagation stage is the stage at which the corrosion reaction occurs and its rate can be controlled by availability of oxygen (O2), and the environment controlling parameters; temperature and relative humidity. The higher the value of corrosion, the lower the strength of steel and it will affect the strength of reinforced concrete structure.

2.3 CONCRETE

Concrete is a construction material that is widely used in many different structures including houses, commercial buildings, roadways, bridges, underground structures, and waterfront structures. These structures are dynamics system subjected to continuous changes in moisture content and temperature. Part of these structures are exposed to extreme environmental conditions and Brian Downie (2005) stated in his research, temperature and moisture variations affect the strains induced in concrete structures and mechanical properties of the concrete as well. Extensive research was accomplished testing concrete properties including but not limited to modulus of elasticity, compressive strength, tensile strength and Poisson's ratio using modulus of elasticity and strength testing.

Concrete is a constructional material which consists essentially of a binding agent and mineral filler. The binding agent is hydraulic cement which develops its strength when mixed with water and, by hydration, changes from a loose powder to a hard, brittle, stone-like material. A number of cements are in use, the most common being Ordinary Portland. Other cements in common use are blast-furnace slag, high alumina and super-sulfated cements. When cement reacts with water part of the water is chemically combined, but the remainder dries out, causing the set cement to shrink. To overcome the disadvantages of this shrinkage, inert filler is used. The filler, or aggregate, as it is termed, forms about 75% by volume of the whole. Various materials may be used as aggregate, the most common being naturally occurring sand and gravel. The main things in concrete mixes design are:

i. Cement
ii. Water
iii. Aggregates
iv. Admixtures

The experiment that always been used in laboratory to test the workability of concrete mixture is slump test and the testing that indicates the strength of concrete mix design is compression test. Slump test is the testing that will be made right after finish the concrete mixing and before start the concrete casting. The result of slump must be satisfied, follow the condition and instruction in code of practice. On the same day of concrete casting, the cube samples from the same concrete mix design must be done. The curing period of concrete cube samples take the same time with the main concrete sample in any particular experiment but the different is, concrete cube samples are cures in water for 7, 14 or 28 days.

2.4 MATERIAL STRENGTH

Mechanics of materials, also called strength of materials dealing with the behavior of solid objects, subject to stresses and strains. In material science, the strength of a material is its ability to withstand an applied stress without failure. For concrete strength, an attributes value of material strength is compressive strength. The concrete after 7, 14 and 28 days long of curing, normally graded about 25, 30, 35, 40 or 50 N/mm2. For steel, there are mild steel with strength 250 N/mm2 and high yield steel with strength 500 N/mm2 (see Eurocode 2). For timber, all strengths were stated in Malaysian Code of Practice (see MS 544: Part 2:2001).

2.5 REINFORCEMENT BAR

Conventional concrete structures are reinforced with steel bar or prestressed with steel tendons or wires. However, with the new research and technology in civil engineering field nowadays, the reinforcement bars are not just made from steel, but also from other materials such as timber and composites. The different materials will give different strength for concrete structures.

2.5.1 Ferrous Element

Steel is the only ferrous reinforcement in concrete beams; it is a combination of iron and carbon. The carbon content may range between 0.01-1 percent only. Carbon is added, not only hardens the metal but also imparts other distinct properties. Ferrous (Fe) is actually iron. Material with less than 50% iron is non-ferrous material and material with 50% or more iron is called ferrous material. Ferrous metals include steel and pig iron, stainless steel.

Usually, the steel reinforcement has been used as reinforcement bar in concrete structures. There are two types of reinforcement bar which is plain steel reinforcing bars in grade 250 up to 12mm in diameter and ribbed steel reinforcing bars in grade 500B and 500C. Plain steel reinforcing bars are steel with a smooth surface and usually used as link reinforcement in beam design.

Ribbed steel reinforcing bars are steel with at least two rows of transverse ribs, which are uniformly distributed over the entire length (see example in Construction Standard CS2:2012) and usually used as main reinforcement in beam design. The surface of rebar may be patterned to form a better bond with the concrete. Steel reinforcing bar is produced with a circular or practically circular cross-section which is suitable for the reinforcement in concrete. Steel bars are known for high tensile properties, high bend performance and long term quality level of production. The absolute maximum value of tensile properties for steel reinforcement grade 500 is 650 MPa (see example in Construction Standard CS2:2012).

2.5.1.1 Plain Steel Reinforcement

Plain bars are regularly encountered in historical structures and criteria for assessing their bond are necessary. Although the fundamental axial response of concrete elements reinforced with plain bars are known, the characteristic between the plain reinforcing bars and the surrounding concrete are not well understood. Lisa Robin Feldman (2006) reported, plain reinforcement does not possess lugs or other surface deformation and so cannot transfer bond forces by mechanical interlock. Bond is instead transferred using the following two mechanisms; adhesion between the concrete and reinforcing bar before slip occurs and wedging action of small particles that break free from the concrete upon slip. The effectiveness of these two mechanisms may be reduced because Poisson's effect causes the diameter of a tensioned bar to reduce slightly, lessening its area of contact with the surrounding concrete.

Lisa Feldman, in her research, she had been studied about the Centre Street Bridge, in Calgary that used plain steel reinforcement in most of their construction. She said, the lack of code criteria for the evaluation of structure built with plain bars, and the paucity of readily available and logical consistent information on the bond of plain steel bars in concrete revealed a gap in engineering knowledge. Bond strengths for plain reinforcing bars were typically measured from pullout tests. Typically, the specimen was loaded monotonically until failure. The highest strength achieved in her experiment is 40 MPa with concrete cover 92 mm, bar size 16 mm round, length 192 mm.