FLEXURAL STRENGTH OF TIMBER-LIGHTWEIGHT CONCRETE COMPOSITE BEAM

E.C. YEOH, DAVID[1], H.B. KOH[2], FAZALIANA ZAMZURI[3]

ABSTRACT

The purpose of this paper is to investigate the flexural strength performance of timber-lightweight concrete composite beam. The study involves the determination of maximum load by experimental test, modes of failure of the beam and factors influencing the strength of beam. The species of timber that were used are Kempas *(Koompassia Malaccensis)* and Kapur *(Dryobalanops spp)* while the type of lightweight concrete applied is foamed concrete of a certain targeted density. Three types of beam section configuration were produced where each of them was designed with different position of timber at the beam. The flexural test is done by using mid-point loading method based on ASTM C78 and the modes of failure of the beam are observed. Comparison between the maximum load of lightweight concrete beam being the control beam and timber-lightweight concrete composite beam are made. The test results indicated that the control beam yielded a maximum load of 11.55 kN, and compared to the Kempas -lightweight concrete composite beam 1 and Kapur -lightweight concrete composite beam 1, it is found that these two composite beams contributed a 49.74 % and 32.57 % strength increment respectively. By comparison also, Kempas -lightweight concrete composite beam 2 achieved 74.34 % strength increment and 69.27 % for Kapur -lightweight concrete composite beam 2. Meanwhile, Kempas -lightweight concrete and Kapur -lightweight concrete composite beam 3 achieved 85.54 % dan 85.42 % strength increment from the control beam. From the results, it is found that each composite section is unique in that the timber acting as a permanent form contributed to the overall strength of the beam in varying percentage and played a different function (ie. restraining tensile, shear or compressive force) in the beam reaction. Theoretical calculations were established based on first principles, but nevertheless it is inconclusive and requires further studies.

Keywords: Flexural strength, timber-lightweight concrete composite beam, Kempas, Kapur, foamed concrete.

1. Lecturer/Head of Timber Engineering Laboratory, Department of Structural and Materials Engineering, Civil and Environmental Engineering Faculty, Kolej Universiti Teknologi Tun Hussein Onn (KUiTTHO), 86400 Parit Raja, Batu Pahat, Johor, Malaysia.
   Tel: (607) 4546316, Fax: (607) 4546070, Email: david@kuittho.edu.my
2. Department Head, Department of Building and Construction Engineering, Civil and Environmental Engineering Faculty
   Tel: (607) 4546164, Fax: (607) 4546070, Email: koh@kuittho.edu.my
3. Undergraduate Student, Faculty of Civil and Environmental Engineering, KUiTTHO

INTRODUCTION

Timber – lightweight concrete composite is a new development in timber and concrete industry especially for building construction. It is an innovative composite to provide beam and column element. Besides, timber-concrete composite shows potential to promote the use of timber as construction material. Timber is one of the earliest materials to be used in building (Taylor, 2002). The uses of timber for structural purposes has been challenged significantly since the last few decades due to the fast development of new building materials such as steel, concrete and composites materials (Yeoh, 1999). Nevertheless almost every house uses at least some timber in its construction and about half the timber in the United States is used by the construction industry. Structural timber can stand heavy strain. It is used for posts, planks, joists, and beams.

Lightweight concrete is a concrete made lighter than conventional concrete. Lightweight concrete weighs less than other kinds of concrete. It has dry densities between 1400 kg/m^3 to 1600 kg/m^3 compared with 2000 to 2600 kg/m^3 for normal concrete (Taylor, 2002). Although its density is lower, lightweight concrete provides good thermal insulation and has a satisfactory durability. For many purposes the advantages of lightweight concrete outweigh its disadvantages and there is a continuing worldwide trend towards more lightweight concrete in applications such as prestressed concrete, high-rise buildings and even shell roofs (Neville, 1987).

The main purpose of timber – lightweight concrete composite is to enhance the strength of building elements such as beams, joist, and column. Furthermore, this is a preliminary study on timber – lightweight concrete composite that could help to develop this material to use in any local construction. Hence the objective of the study is to investigate the flexural strength of timber – lightweight concrete composite beam through the experimental test and characterize its flexural behaviour. Two species of Malaysian timber were selected i.e. Kempas (*Koompassia Malaccensis*) and Kapur (*Dryobalanops spp)* due to their common use in construction. The lightweight concrete applied for this experimental study is foamed concrete designed with density 1770 kg/m^3 with the mix proportion ratio of 1: 2: 0.32 (cement: fine aggregate: water). Four types of beam design were proposed i.e. Single Reinforced Lightweight Concrete Beam - Control specimen, Composite Beam 1 – Concrete with timber at the bottom of beam, Composite Beam 2 – Concrete with timber U-section, and Composite Beam 3 – Concrete with timber box section.

LITERATURE REVIEW

Strength of Timber

Kempas is categorized in Strength Group 2 (SG2) where the average density is 770 to 1250 kg/m^3 while Kapur is categorized in Strength Group 4 (SG4) where the average density is 575 to 815 kg/m^3 (Anon., 2001). Timber is an anisotropic material and therefore its strength properties are heavily dependent on the orientation of stress in relation to the grain direction (Taylor, 2002). According to Taylor (2002), bending stresses are very commonly applied to the timber in service and, as would expected, flexural strength, as measured by the modulus of rupture, is between tensile and compressive strength, values for dry softwoods being typically in the region of 70 N/mm^2 in the short term. In simple bending, the upper compression layers buckle, causing the neutral axis to move downwards during the test so that, ultimately, the lower part of the specimen fails in tension. The modulus of rupture is normally quoted, on the assumption that simple bending theory applies: if allowance were made for movement of the neutral axis, the magnitude of the modulus of rupture would be similar to the strength measured in pure tension. The tensile strength of timber is much higher than its compressive strength when measured parallel to the grain, since compression causes buckling of the fibres. Failure in tension is mainly due to shear failure between fibres or cells. The short-term tensile strength of most softwood is, for example, in the region of 100 N/mm^2 (tested dry) while compressive strength is about 40 N/mm^2. Failure in tension is mainly due to shear failure between fibres or cells (Taylor, 2002). Compression perpendicular to grain of timber is approximately 90 percent less than compression parallel to grain. In a moderately strong wood, the mean compression strength parallel to the grain is not more than 50 MPa (Hoyle, 1978). There are many factors that affect the strength of timber i.e. specific gravity, moisture content, knots, defects and slope of grain (Chu, 1997).

Lightweight Concrete

Concrete with density lower than the conventional normal weight concrete is defined as the lightweight concrete. The British Standard, BS 81110: Part 2: 1985 classified lightweight concrete as concrete having densities of 2000 kg/m^3 or lower while the Draft International Standard Model Code for Concrete Construction classifies lightweight concrete as having densities between 1200 and 2000 kg/m^3. However, according to Neville (1997), the practical range of densities of lightweight concrete is between about 300 and 1850 kg/m^3. Lightweight concrete is classified according to their method of production. There are essentially three methods of producing lightweight concrete, which are by omitting the fine aggregate, by introducing large voids in the concrete and by using lightweight aggregates (see Fig. 1).

Foamed Concrete

Foamed concrete is categorized as aerated concrete, produced by introducing large voids (0.1mm to 1.0mm diameter in sized) consist a fine aggregates, cement, water and foaming agents. The introduction of these voids is achieved by adding foam to the mix using foam generator. Foaming agents are made from liquid concentrates, consisting of hydrolyzed proteins or synthetic detergents, which are diluted with water and aerated to form the foam. A foam generator supplies foam at standard rate. Then, it is blended with slurry of cement and water to provide the finished product. Use of foamed concrete has become popularity not only because of the low density but also because of other properties mainly the thermal insulation and self compacting properties (Shetty, 1986). Foaming agent applied is a chemical admixture such as aluminium powder which reacts with the hydroxide produced in the hydration of cement to produce minute bubbles of hydrogen gas throughout the matrix. The extent of foam or gas produced is dependent upon the type and amount of aluminium powder, fineness and chemical composition of cement, temperature and mix proportions. The amount added are usually 0.005 to 0.02 per cent by weight of cement, which is about one tea-spoonful to a bag of cement. Larger amount are being used for the production of lightweight concrete. It is about 100 gms per bag of cement (Shetty, 1986).

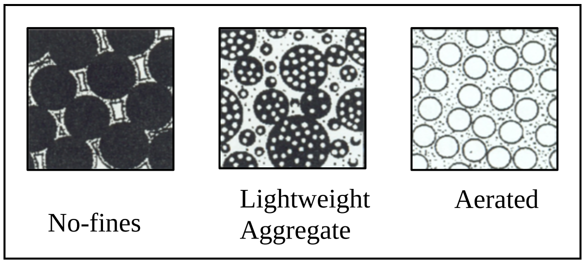

Figure 1 Three Basic Type of Lightweight Concrete [Neville, 1997]

Strength Properties of Foamed Concrete

The compressive and tensile strength of a foam concrete is affected by such factors as density, cement content, water cement ratio, properties of aggregates, methods of manufacture, curing and moisture content. Foamed concrete with densities from 400 to 1600 kg/m^3 cubed can be produced at strength in the range 1.0 - 10 N/mm^2. The density of the foam can have an influence on the ultimate strength, particularly for the lower density foamed concretes. Uniformly sized small bubbles appear to produce higher ultimate strengths at all densities. Besides that, the optimum water ratio for the base mix of foamed concrete between 0.5-0.6. The water should be kept fairly high to provide a base mix with a high workability (BCA, 1991). It is found that the flexural strength of structural lightweight concretes is only about 70 to 90 % of the flexural strength of normal concrete of the same compressive strength. The difference may be attributed to the difference in the total porosity of the concrete. It may also be due to the weakness of the aggregate particles and their differing modes of failure in flexure. Besides that, the flexural strength is affected by the concrete composition, namely by the type and fineness of the cement, water-cement ratio, air content and type of mineral aggregates. In addition, the effects of the size and shape of the specimen as well as the effects of testing may reduce the strength of specimen in flexural strength (Sandor, 1998).

EXPERIMENTAL METHODOLOGY

A total of 14 beams of nominal size 100 mm x 200 mm x 1000 mm were cast and tested to failure under flexural strength test after 28 days in accordance to ASTM C78-94 (ASTM, 1994). Compressive strength of 100 mm x 100 mm x 100 mm cubes was also tested at 7, 14 and 28 day. The beams comprised of four categories as given in Appendix 1. Timber of Kempas (*Koompassia Malaccensis*) and Kapur (*Dryobalanops spp)*species were selected from the same tree respectively and with minimum defects while foamed concrete with density of 1770 kg/m^3 was designed to a proportion of 1: 2: 0.32 and mixed to produce the composite beams. Fig. 2 shows a typical set up of the test while Fig. 3 provides the schematic diagram of the flexural test conducted on the beams.

Figure 2 Typical Setup of Flexural Strength Test

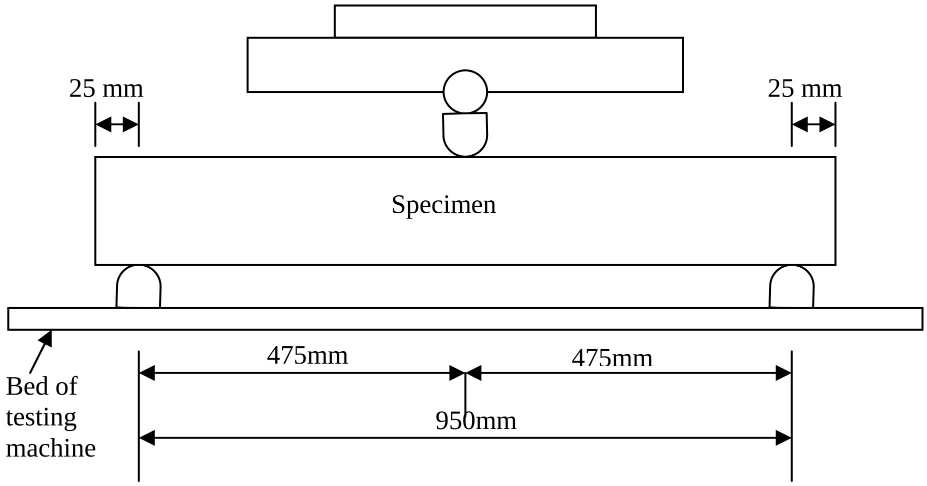

Figure 3 Schematic Diagram of Flexural Test

DATA ANALYSIS AND DISCUSSION

Compressive Strength

From Table 1 and Figure 4, it is found that the compressive strength for foam concrete increases proportionally with the age of hardening. The maximum compressive strength achieved at 28 days is 11.65 MPa. It is noted that 88 % of the total strength has been obtained at 7 days.

Table 1 Compressive strength test results for foamed concrete

Age of Hardening	Compressive Strength (MPa)
7-days	10.26
14-days	11.61
28-days	11.65

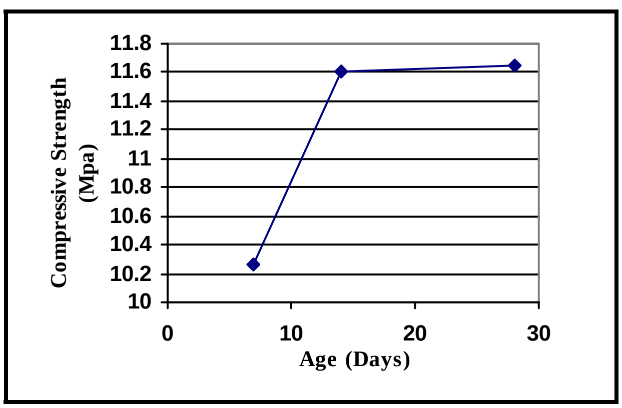

Figure 4 Compressive Strength Results

Flexural Strength (Experimental Approach)

Flexural strength test data from the 14 beams tested to failure were averaged and summarized in Fig. 5. The results verified that Kempas species is much superior in strength compared to Kapur species simply due to its density variation. It is also apparent here that lightweight concrete – timber composite beam sections enhances the flexural strength compared to the control beams with a similar increment pattern for both the timber species applied. Table 2 provides a summary of the strength improvement percentage for the experimental and theoretical evaluations.

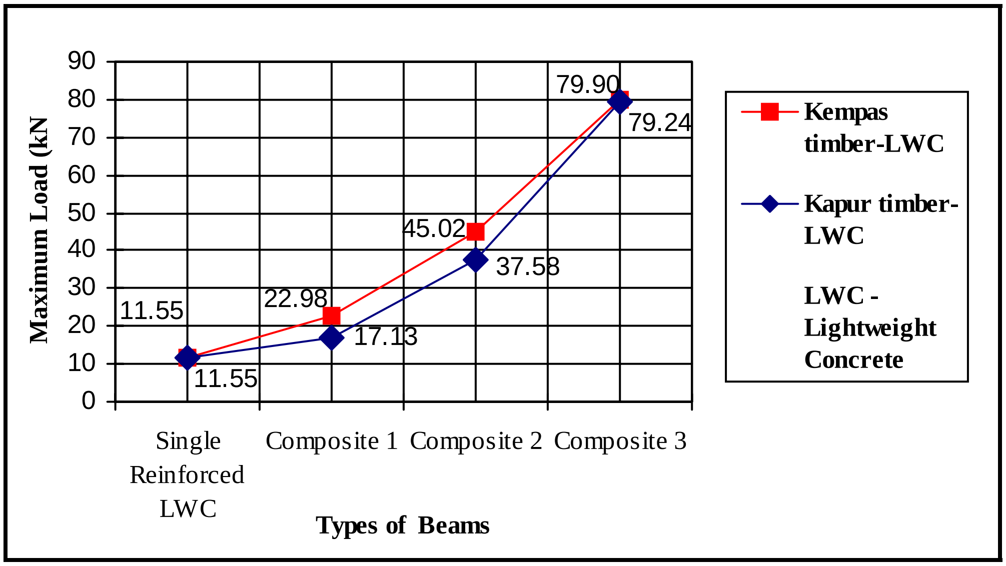

Figure 5 Comparisons of average maximum load for different types of beam

Table 2 Experimental and theoretical maximum load for different types of beam

Specimen Description	Types of Beams	Experimental Max. Load (kN)	Theoretical Max. Load (kN)	Improvement in Strength % *
LWC–Control Specimen	Single Reinforcement	11.55	8.42	-
Kempas-LWC	Composite 1	22.98	35.54	49.74
	Composite 2	45.02	53.81	74.34
	Composite 3	79.90	74.86	85.54
Kapur-LWC	Composite 1	17.13	34.48	32.57
	Composite 2	37.58	51.28	69.27
	Composite 3	79.24	71.16	85.42

Note: * Percentage Improved in Experimental Strength = $\frac{\text{Composite exp load–control exp load}}{\text{Composite exp load}} \times 100\%$

LWC – Lightweight Concrete

Theoretical Approach

Theoretical approach was taken to compare the maximum load values obtained from the experimental studies. The theoretical maximum load value for the four types of beams were derived in accordance to the first principal simplified stress block. Characteristic concrete strength was taken as 11 N/mm^2 acquired from the compressive strength test carried out while the characteristic strength of steel is taken as 250 N/mm^2 for mild steel diameter 6 mm. The strength of timber was assumed in bending under Selected Grade and taken from MS544: Part 2: 2001. Allowable stress approach were applied for calculations involving timber sections (i.e. Composite Beam 2 and 3) while assumptions of direct theoretical load summations for both materials were taken as a preliminary derivations although further verifications are required. A summary of the comparison for the experimental and theoretical maximum load values are provided in Table 3. It is seen in this table that the differences for the composite beams are not significant with differential coefficient ranging from 0.90 to 1.55 except for Composite 1 Kapur LWC with 2.07. This observation verifies the theoretical approach with the preliminary assumptions made and therefore can assist in future works to derive design formulas for such beams. As for the differential coefficient of 0.73 from control specimen, it is acceptable due to application of reduction factors in the theoretical approach.

Table 3 Comparison between experimental and theoretical maximum load and differential coefficient

Types of Beams	Specimen Description	Experimental Max. Load (kN)	Theoretical Max. Load (kN)	Differential Coefficient
Single Reinforcement	LWC – control specimen	11.55	8.42	0.73
Composite 1	Kempas - LWC	22.98	35.54	1.55
	Kapur - LWC	17.13	34.48	2.07
Composite 2	Kempas - LWC	45.02	53.81	1.20
	Kapur - LWC	37.58	51.28	1.36
Composite 3	Kempas - LWC	79.90	74.86	0.94
	Kapur - LWC	79.24	71.16	0.90

Note : Differential coefficient = $\frac{\text{Theoretical Maximum Load}}{\text{Experimental Maximum Load}}$

LWC = Lightweight Concrete

Behaviour of Composite Beam and Failure Mode

The behaviour of the timber lightweight concrete composite beam can be characterized indirectly by observing the mode of failures and their pattern under flexural load. Each plate element of the timbers on the beam plays a specific role in helping to enhance the composite beam compared to the control section. Timber is strongest in tension and therefore the bottom plate restrained the tensile stresses in the beam while the side plates are for shear stresses in the beam. The top plate is aimed to provide better restrain in compression. A diagonal crack pattern is exhibited in the control specimen compared to Composite Beam 1 with a bottom timber plate the crack pattern is close to vertical continuing to the plate (see Fig. 6). It is observed that the timber side plates for Composite Beam 2 and 3 exhibited vertical crack pattern lines under the maximum bending moment zone (see Fig. 7).

Figure 6 Crack Pattern for Control and Composite Beam 1

Figure 7 Crack Pattern in Composite Beam 2 and 3

CONCLUSION AND RECOMMENDATIONS OF FUTURE WORKS

According to the research undertaken, it shows that timber-lightweight concrete composite beam recorded a better performance as compared to lightweight concrete (LWC) beam (control beam) in flexural strength. The comparison of maximum load between LWC control beam and composite beam shows that composite beam is much stronger than the LWC control beam. As illustrated in Table 2, Kempas timber-lightweight concrete composite beam achieved about 49.74 % strength increment of LWC control beam for composite beam 1, 74.34 % strength increment of LWC control beam for composite beam 2 and 85.54 % strength increment of LWC control beam for composite beam 3. Meanwhile, Kapur timber--lightweight concrete composite beam achieved about 32.57 % strength increment of LWC control beam for composite beam 1, 69.27 % strength increment of LWC control beam for composite beam 2 and 84.42 % strength increment of LWC control beam for composite beam 3. Recommendations for future works to verify the current findings are as follows:

i. Similar testing conducted with wood composite of engineered instead of solid timber as they are more predictable.
ii. Further study of the theoretical derivation by determining the actual function of side timber plate.
iii. Investigate the width of loading applied to the timber-LWC composite beam, i.e. width of loading only on the concrete surface and inclusive of the timber surface.
iv. Finite element model for the composite beam.

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