Strength Behaviours Of Biomass Fiber-Reinforced Concrete Slab

CHAI TECK JUNG[1], Lee Yee Loon[2], Tang Hing Kwong[3] ,
Koh Heng Boon[4]

[1,3] Department of Civil Engineering, Politeknik Kuching
Sarawak, Km 22, Jalan Matang, 93050 Kuching, Sarawak.
tjchai@poliku.edu.my, hktang@poliku.edu.my

[2, 4] Department of Structure & Material Engineering, Faculty of
Civil and Environmental Engineering, Universiti Tun Hussein
Onn Malaysia, 86400 Parit Raja, Batu Pahat,Johor.
ahloon@uthm.edu.my, hbkoh@uthm.edu.my

Abstract

This paper investigates the compressive strength and flexural strength of biomass fibre-reinforced concrete slab. The main objective of this study is to examine the effect of biomass aggregate and fibre glass on the concrete slab strength. The biomass aggregate is used to replace the natural aggregates. A total of 36 slab samples (250 mm x 600 mm x 50mm thick) and 36 numbers of 150 mm cube samples containing 0%, 30%, 60% and 100% biomass aggregate were prepared. The E-class fibre and Supracoat SP800 were added to increase the strength and to achieve the required workability. All the samples were cured in water with room temperature and tested at the age of 7, 14 and 28 days respectively. The result showed that cube specimens containing 30% biomass aggregate achieved minimum strength for structural use of 15 MPa at 28 days. The flexural strength for slab specimens containing 30% biomass aggregate, Supracoat SP 800 and fibre glass gained higher strength compared with control specimens. The 100% biomass slab achieved 88% of the control specimen strength. The workability is between 150 mm to 170mm slump which can become self-compacting biomass aggregate concrete. The density of the specimens was reduced 20% for cube and 28% for slab compared with control specimens. From the finding, it can be concluded that the biomass aggregate has good potential as aggregate replacement in slab construction combine with the use of glass fibre and superplasticizer. However, more research needs to be carried out to verify it.

Keywords: Biomass aggregate, compressive strength, flexural strength, fibre- reinforced, self-compacting.

1. Introduction

Strength of concrete is commonly considered the most valuable property[1]. Strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. Moreover, the strength of concrete is almost invariably a vital element of structural design and is specified for compliance purpose. Strength is the most common concrete property tested due to three main reasons[2]. Firstly, the strength of the concrete gives a direct indication of its capacity to resist loads in structural applications. Secondly, strength tests are relatively easy to conduct. Finally, correlations can be developed relating concrete strength to certain other concrete properties that involve much more complicated tests. The two principal reasons for determining the strength of a concrete are to measure the quality or uniformity of the concrete produced and provide a measure of load-carrying capacity in structures[3]. Among concrete strength properties, compressive strength of concrete is one of the most important technical properties. This is because in most structural applications, concrete is employed primarily to resist compressive stresses. In those cases where other stresses are of primary importance, the compressive strength is still frequently used as a measure of the resistance because it is the most convenient way to measure[4]. This is also highlighted in British Code of Practice, BS8110 :1997 [5] where most of the stresses checking are related to compressive strength. For example, BS8110: Part 1, clauses 3.4.5.2 and 3.4.5.8 state that the nominal shear stress of beam must not exceed $0.8f_{cu}^{1/2}$ or 5 N/mm^2 where f_{cu} is the characteristic compressive strength on 28 days. Compressive strength is one of the important mechanical properties of concrete. In structural concrete design, the characteristics strength of concrete refers to the 28 days compressive strength [5], [6], [7]. The compressive strength of concrete or mortar is usually determined by submitting a specimen of constant cross section to a uniformly distributed increasing axial compression load in a suitable testing machine until failure occurs [4]. Compressive test is the most common test carried out on concrete. This is because of four reasons [8] : (1) concrete has low tensile strength compared to its compressive strength, thus it is used primarily in compressive mode; (2) it is assumed that most of the important properties of concrete are directly related to the compressive strength; (3) the structural design codes are mainly based on the compressive strength of concrete; and (4) the test is easy and economical. The shape of the specimens for compressive strength testing can be cubes [9] or cylinders [10]. However, the compressive strength obtained from cylinders is lower than cubes specimens [4]. The compressive strength determined by cylinders is around 80% to 96% [6] of the compressive strength determined by cubes. Generally, cube test is widely used at the construction sites in Malaysia [11]. A minimum of six numbers 150 mm concrete cubes are prepared during the concreting work. These cubes are used to determine the compressive strength at 7, 14 and 28 days. Flexural strength or modulus of rapture (MOR) is a mechanical parameter for brittle material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a beam specimen in rectangular cross section is bent until fracture using a two point flexural test technique [12]. The flexural strength represents the ultimate strength of materials in bending is taken corresponding to the ultimate moment by the elastic relationship[13]. It is measured in terms of stress. The proposed flexural strength where at the time of delivery to the work site, the average flexural strength in the test specimens shall be 4.5 MPa, with no individual unit less than 4 MPa[14]. According to J. Newman and S. C. Ban, (2003), the requirements for lightweight aggregate for structural use are that it has strength sufficient for a reasonable crushing resistance based on BS EN 13055, concrete strengths excess 20 MPa and produces compacted concrete with an oven-dry density in the range 1500–2000 kg/m^3. Lightweight-concrete is defined by BS EN 206-1 as having an oven-dry density of not less than 800 kg/m^3 and not more than 2000 kg/m^3 by replacing dense natural aggregates either wholly or partially with lightweight aggregates. Lightweight aggregate is defined in BS EN 13055 as any aggregate with a particle density of less than 2.0 Mg/m^3 or a dry loose bulk density of less than 1200 kg/m^3. These properties mainly derive from encapsulated pores within the structure of the particles and surface vesicles. For structural concrete suitable aggregates should require a low cement paste content and have low water absorption [15], [16]. For slab construction, the flexural strength must be identified because the design of slab or pavement is based on the theory of flexural strength. Therefore, laboratory mix design based on flexural test may be required. What is flexural strength? Flexural strength is one of the tests to measure the tensile strength of concrete to resist failure in bending such as beam and slab. According to T. H. G. Megson, (2007), the materials ultimate strength in bending is defined by the modulus of rapture (MOR). This is taken to be the maximum direct stress in bending ($\sigma_{x,u}$) which corresponding to the ultimate moment (M_u) and is assumed to be related to ultimate moment by elastic relationship in equation 1[17].

$$\sigma_{x,u} = [M_u/I]\, y_{max} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 1}$$

where, Mu = Moment of resistance at the section
I = Second moment of area of the section
Y_{max} = Distance of the layer under stress from the neutral axis
σ = Stress

2. Experiment Program

2.1 Materials Preparation

The raw materials for the preparation of concrete mix are ordinary Portland cement, natural fine aggregate, biomass aggregate (fine and coarse) and water. The biomass aggregate used for this research was collected from the plywood factory (Linshanhao Plywood Sarawak Sdn Bhd) located at Demak Laut Industrial Park, Jalan Bako, Kuching. The bulk density of the biomass aggregate was determined for the classification as lightweight aggregate. The biomass aggregate was sieved manually using 5 mm sieve to separate it as fine and 10 mm sieve for coarse aggregate before it was used to replace the natural aggregate in this study. The purpose of replace fine and coarse aggregate in the study will lead to the solution for disposal problem in plywood industry. Chemical compound of biomass aggregate was determined using X-ray fluorescence (XRF). The results are shown in **Table 1**. The mechanical properties of glass fiber Class-E are shown in **Table 2**.

Table 1 : Chemical Compound of Biomass Aggregate

Chemical Name	Formula	Concentration
Carbon dioxide	CO_2	0.10%
Silicon dioxide	SiO_2	29.10%
Calcium oxide	CaO	18.40%
Barium oxide	BaO	14.40%
Aluminium oxide	Al_2O_3	13.10%
Sodium oxide	Na_2O	5.88%
Iron oxide	Fe_2O_3	5.75%
Magnesium oxide	MgO	4.78%
Potassium oxide	K_2O	4.38%
Sulfur Trioxide	SO_3	1.28%
Nitrogen Dioxide	P_2O_5	1.23%
Manganese oxide	MnO	0.62%
Titanium oxide	TiO_2	0.57%
Strontium oxide	SrO	0.34%
Vanadium	V	$0 <$ LLD

Table 2 : The Mechanical Properties of Class-E Glass Fiber

Parameters	Values
Tensile Strength (MPa)	3500-3600
Modulus Elastic (GPa)	74-75
Expansion (%)	4.8
Density (kg/m^3)	2600
Perimeter (µm)	8-12

2.2 Mix Proportions

There is one series of concrete mix for the experimental work in the present study. The concrete mix consists of four types of mix proportion with the replacement of natural fine and coarse aggregate with fine and coarse biomass aggregate ranging from 0%, 30%, 60% and 100%. Class-E Glass fiber with the amount of 1kg glass fiber /400 kg cement was added to identify the effect to the biomass concrete strength. The compressive strength and flexural strength is determined by the same concrete mix. The mix proportions for the present study are tabulated in **Table 3**.

Table 3: Mix Proportions for Concrete Mix

Mix ID	Mix Proportion							Replacement of Biomass Aggregate	
	Cement (kg/m^3)	Water (kg/m^3)	Natural Fine Aggregate (kg/m^3)	Natural Coarse Aggregate (kg/m^3)	Water / Cement Ratio	ClassE-Glass Fiber (kg)	Supra coat SP800 (ml)	Coarse (kg/m^3)	Fine (kg/m^3)
C 0	568	250	720	812	0.44	0	0	0	0
C 30	568	250	504	568.35	0.44	0.12	482.8	243.65	216
C 60	568	391.18	288	324.82	0.69	0.12	482.8	487.18	432
C 100	568	414.71	0	0	0.73	0.12	482.8	812	720

2.3 Specimens and Tests

The 150 mm cubes and slab size is 600 mm x 250 mm x 75 mm were used for the compressive strength and flexural strength study. The specimens were de-mould after 24 hours and then subjected to water-curing at room temperatures varied from 24 to 34^{O}C. Density of each specimen was recorded during testing. Three 150 mm cubes were used for the compressive strength test and three slabs size 600 mm x 250 mm x 75 mm were used for flexural strength at each age according to BS 1881 [9], [12]. Both compressive strength and flexural strength are tested at the age of 7, 14 and 28 days.

3.0 Result Analysis And Discussion

3.1 Properties of Raw Materials

The bulk densities of fine and coarse biomass aggregate, natural fine and coarse aggregate and cement are summarized in **Table 4**.

Table 4: Bulk Densities of Raw Materials

Materials	**Loose Bulk Density (kg/m^3)**	**Compacted BulkDensity (kg/m^3)**
Cement	1195	-
Natural Fine Sand	1244	1320
Natural Coarse Aggregate	1458	1665
Fine Timber Ash Aggregate	432	485
Coarse Timber Ash Aggregate	840	975

Based on the bulk density, fine and coarse biomass aggregate have fulfilled the requirement as lightweight aggregate according to BS 3797. The density of the lightweight aggregate must not more than 1200 kg/m^3 for fine aggregate and 1000 kg/m^3 for coarse aggregate [18].

3.2 Concrete Density and Slump

The dry densities and slump test of the specimens are shown in **Table 5**. The replacement of natural aggregate with biomass aggregate had reduced the density of concrete. A weight reduction of 20% for cube specimens and 28% for slab specimens at the age of 28 days was achieved when 30% to100% of natural fine and coarse aggregate was replaced by fine and coarse biomass aggregate. The reduction in weight of the biomass aggregate concrete compared to the control specimen is due to the higher porosity of biomass aggregate with a lower bulk density compared to natural aggregate. The weight reduction of biomass aggregate concrete is significant especially for 100% biomass aggregate concrete with a reduction up to 20 % for cubes and 28 % for slab compared to natural aggregate concrete. The slump for concrete mix were achieved between the range of 150 mm to 170 mm. According to BS EN 206-1: 2000, the slump class is S3 (100 mm – 150 mm) for mix C100 and S4 (160 mm – 210 mm) for mixes C0, C30 and C60. This shown that the concrete workability is high and towards self-compacting biomass concrete purpose.

Table 5: Concrete Density and Slump

Mix ID	Dry density (kg/m^3)			Slump (mm)	Remark
	7 Days	14 Days	28 Days		
C 0	2363	2326	2318	160	**Cube Specimens**
C 30	2148	2133	2111	165	
C 60	1990	1950	1895	170	
C 100	1963	1874	1859	150	
C 0	2393	2333	2220	160	**Slab Specimens**
C 30	2260	2260	1967	165	
C 60	2113	2047	1753	170	
C 100	1947	1887	1593	150	

3.3 Compressive Strength

The compressive strength developments for cube specimens are shown in **Figure 1**. The results showed that all biomass aggregate concrete (C30, C60 and C100) achieved lower compressive strength compared to the natural aggregate concrete (C0).

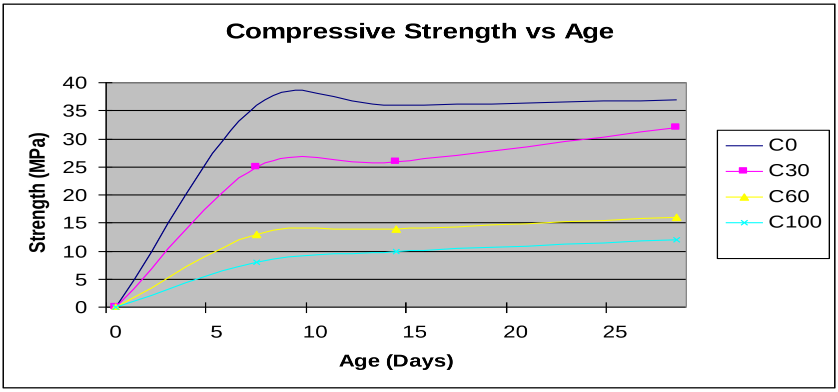

Figure 1 : Compressive Strength for Cube Specimens

Referring to **Figure 1**, the replacement of 30 % biomass aggregate achieved 32 MPa at the age of 28 days. According to J. Newman and S. C. Ban (2003), the compressive strength development excess 20 MPa can be used for structural purposes. The others mixes C60 and C100 gain a lower compressive strength which achieved 16 MPa and 12 MPa respectively. The strength development for C30 is 3 MPa lower than the targeted one which is 35 MPa. This is maybe due to the mechanical properties of the biomass aggregate even admixture (Supracoat SP 800) was added.

3.4 Flexural Strength

The flexural strength developments for the slab specimens are shown in **Figure 2**.

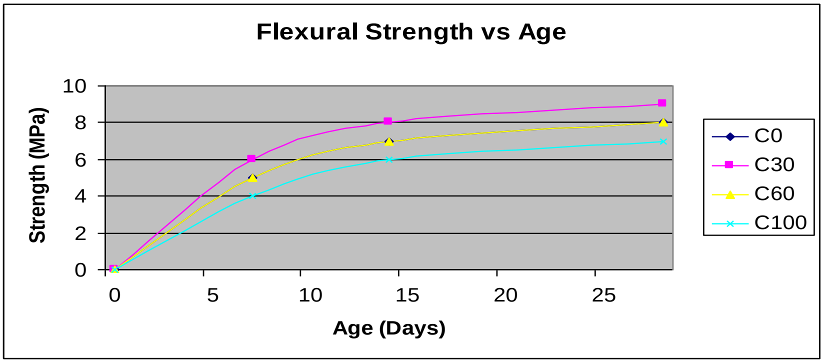

Figure 2 : Flexural Strength for Slab Specimens

Referring to **Figure 2**, the results showed that biomass aggregate slab with glass fiber produced higher flexural strength (C30) compared with control specimen (C0). The flexural strength for 30 % biomass aggregate with glass fiber is 9 MPa while the control specimen (natural aggregate) without glass fiber and Supracoat SP 800 is 8 MPa at the age of 28 days. The result also showed that C60 have the same flexural strength with control specimen. This result showed that the mixes with fiber glass and Supracoat SP 800 can develope the same strength even though the aggregate is not from the natural resources. The mechanical properties of fiber glass class E also indicate that it behavior is more benefit to flexural strength where the Modulus Elastic is 74 – 75 GPa.

4.0 Conclusion

This paper investigated the strength behaviours of biomass aggregate fiber-reinforced concrete slab. Biomass aggregate concrete achieved lower compressive strength may be due to the lower mechanical strength of biomass aggregate. The 30% biomass aggregate concrete were able to achieve the compressive strength of 32 MPa for structural use. According to BS 8110, the strength requirement is 15 MPa which C30 and C60 were fullfilled the British Standard requirement. However, J. Newman and S. C. Ban, (2003) stated that for structural use, the strength must exceed 20 MPa. For flexural strength, the strength development is higher than control specimen for 30 % biomass aggregate added with fiber glass and supracoat SP 800. From the preliminary experimental results obtained in this study, biomass aggregate possesses the potential to be used in construction for materials replacement and willing to save the construction industry cost for one way slab. However, more research needs to be done before the findings can be considered conclusive.

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