Impact resistance performance of green construction material using light weight oil palm shells reinforced bamboo concrete slab

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Abstract. This paper investigate the performance of lightweight oil palm shells (OPS) concrete with varied bamboo reinforcement content for the concrete slab of 300mm x 300mm size subjected to low impact projectile test. A self-fabricated drop-weight impact test rig with a steel ball weight of 1.2 kg drop at 1 m height has been used in this research work. The main variables for the study is to find the relationship of the impact resistance against the amount of bamboo reinforcement and slab thickness. A linear relationship has been established between first and ultimate crack resistance against bamboo diameters and slab thickness by the experiment. The linear relationship has also been established between the service (first) crack and ultimate crack resistance against the bamboo reinforcement diameter for a constant spacing for various slab thickness using 0.45 OPS and 0.6 OPS bamboo reinforced concrete. The increment in bamboo diameter has more effect on the first crack resistance than the ultimate crack resistance. The linear relationship has also been established between the service (first) crack and ultimate crack resistance against the various slab thickness. Increment in slab thickness of the slab has more effect on the crack resistance as compare to the increment in the diameter of the bamboo reinforcement.

1. Introduction

The search of sustainable green materials for the construction industry has reached its critical time to mitigate the negative impact of the climatic change. It is critical to study the impact strength characteristics and assess its performance for eco-green construction materials for various potential use in the building industry.

There is lack of research investigation been carried out on impact resistance of light weight bamboo reinforced concrete. Impact resistance represents the ability of concrete to withstand repeated blows and absorb energy without adverse effect to cracking and spalling. Impact scenario can also be classified into low velocity impact and high velocity impact. According to Dancygier [1], the nuclear structures are designed to resist impact loading caused by projectile or missiles travelling up to 1000 m/s. The response of reinforced concrete structures under impact loading is different from the static loading especially in the case of high velocity impact of rigid projectile. For impact velocities up to 10 ms⁻¹, the failure modes are generally the same as the static failure, except there is increased tendency for local damage or shear failure to occur. The review paper on impact resistance on
concrete target has been published by Z Che Muda et al [3]. Impact resistance of oil palm shells lightweight concrete slab with bamboo fibers has been studied by Z Che Muda et al. The results indicate that 2% volume fraction of bamboo fibers has an optimal performance in first crack resistance and ultimate crack resistance regardless of its fiber length with a potential to be used as an impact resistance composite structures in the future [4]. Z Che Muda et al has also studied the impact resistance of the OPS reinforced with geogrid. Type 80/80 geogrid increased the impact resistance under service (first) crack up to 3.2 times and ultimate crack up to 8.3 times than the control specimen [5].

2. Materials
Oil palm shells (OPS) has unique physical properties, which make it a suitable replacement for conventional aggregate. OPS are naturally sized, hard and lighter than the conventional aggregates. The lightness in mass of oil palm shells makes them a good substitute in the production of lightweight concrete. In the mix design, OPS to cement ratio by weight of 0.45, 0.50 and 0.60 are used.

Bamboo Reinforcement
Buloh kuning (Bambusa vulgaris Schrad) is used to prepare the bamboo reinforcement material. The bamboo are splice and cut into the required diameters of 2.5 mm, 5 mm and 7.5 mm diameter and tied to form a mesh at 50 mm spacing.

Ordinary Portland cement complying to ASTM Type I cement are used with a water cement ratio of 0.45 for all experimental design of concrete. Silica fume used in the design mix is 5% of cement weight to achieve an optimum concrete grade. Two percentage (2%) of super plasticizer is used in the design mix to achieved the desired workability.

3. Methodology
The potential energy due to the drop body is absorbed as strain energy, generating stresses that causes cracks in the target element. The width, depth, length of the crack developed and its failure mode is associated with the intensity of the energy, the amount of energy absorbed and the properties of concrete. It is assumed that the total computed energy imparted is fully absorbed by the specimens. The relationship of potential energy of a drop-weight projectile and the strain energy dissipated in cracks development is expressed as following formula as proposed by Kankam [6];

\[ N^*e = R_u^* l_c^* d_c^* w_c \]  \hspace{1cm} (3.1)

Where, \( N \) = No. of Blows, \( e \) = Energy per blow (Joules), \( l_c \) = Total length of all cracks, \( d_c \) = Maximum crack depth, \( w_c \) = Maximum crack width, \( R_u \) = Ultimate crack resistance

Another dimensionless factor “impact crack resistance ratio” was also defined:

\[ C_r = R_u^* f_{cu} \]  \hspace{1cm} (3.2)

Where, \( C_r \) = Impact crack resistance ratio, \( f_{cu} \) = Cube compressive strength

Residual impact strength ratio as defined in Equation 3.3 helps to evaluate the ‘post – crack’ behavior and use to measure the ductility of the bamboo reinforcement composite imparted in the OPS cement matrix.

\[ \text{Residual impact strength ratio (IRS)} = \frac{\text{Energy absorbed at ultimate failure}}{\text{Energy absorbed at initiation of first crack}} \]  \hspace{1cm} (3.3)

A total of 36 sample slabs of size 300mm x 300mm with 30 mm, 40mm and 50mm thickness were casted and tested with 0.45 OPS and 0.60 OPS.

The study used a self-fabricated low velocity drop-weight impact test using a steel ball weighing 1.25 kg with drop height of 1000mm impacting the specimen mounted on the steel rack frame. The test sample is 2 way simply supported. At the first crack and ultimate (failure) crack, the total crack length, the crack width and the crack depth measured by filler gauge with its total numbers of blows recorded.
4. Results and Discussion

4.1 Relationship between Crack Resistance and Bamboo diameter
There is a strong linear correlation between impact resistance against bamboo diameter as shown in Figure 1 and Figure 2. Generally the first and ultimate crack resistance increases with increasing diameter. For 0.45 OPS, crack resistance increase by up to 21% for first crack and 10% for ultimate crack as the bamboo diameter increases whilst the effect is only marginal for the 50mm thick slab. For 0.60 OPS, crack resistance increase by up to 32% for first crack and 19% for ultimate crack as the bamboo diameter increases.

The increment in bamboo diameter has more effect on the first crack resistance than the ultimate crack resistance.

4.2 Relationship between Crack Resistance and Slab Thickness
There is a linear relationship between the crack resistance and slab thickness. Increase in crack resistance is more substantial. For 0.45 OPS, the first crack resistance increase up to 85% and 31% for ultimate crack resistance as the slab thickness increases. For 0.60 OPS, the first crack resistance increase up to 47% and 37% for ultimate crack resistance. Thickness of the slab has more effect on the crack resistance as compare to the diameter of the bamboo reinforcement.
5. Conclusions

The correlation for the first and ultimate crack resistances are presented and discussed. OPS percentage effect impact resistance, bamboo diameter outcome on the impact resistance and also slab thickness effect on the impact resistance have different contribution on impact resistance.

The linear relationship has also been established between the service (first) crack and ultimate crack resistance against the bamboo reinforcement diameter for a constant spacing for various slab thickness using 0.45 OPS and 0.6 OPS bamboo reinforced concrete. The increment in bamboo diameter has more effect on the first crack resistance than the ultimate crack resistance.

The linear relationship has also been established between the service (first) crack and ultimate crack resistance against the various slab thickness using 0.45 OPS and 0.6 OPS bamboo reinforced concrete. For 0.45 OPS, the first crack resistance increase up to 85% and 31% for ultimate crack resistance as the slab thickness increases.

Increment in slab thickness of the slab has more effect on the crack resistance as compare to the increment in the diameter of the bamboo reinforcement.

References

[1] Dancygier A N 1997 Effect of reinforcement ratio on the resistance of reinforced concrete to hard projectile impact Nuclear Engineering and Design 172 233-245
[2] Muda Z C, Ying K S, Sharif S F, Sidek L M and Farhan N S 2013 A Review - Local Failure On Concrete Target Due To Projectile Impact International J. of Science and Engineering Research (IJSER) 4(1)
[3] Muda Z C, Sharif S F, Sidek L M and Farhan N S 2013 Impact Resistance Of Oil Palm Shells Lightweight Concrete Slab With Bamboo Fibers International Journal of Science and Engineering Research (IJSER) 4(1)
[4] Muda Z C and Sharif S F 2012 Impact Behavior of Lightweight Oil Palm Shells Concrete Slab by Geogrid Reinforcement International J. of Scientific and Engineering Research (IJSER) 3(11)
[5] Kankam CK 1999 Impact Resistance of palm kernel fibre-reinforced concrete pavement slab J Ferrocement 29(4) 279-86