Impact resistance of high strength chopped basalt fibre-reinforced concrete

Resistencia al impacto de hormigón armado con fibra de basalto de alta resistencia

Sathes Kumar Sateshkumar (Main Author)
Department of Civil Engineering, Jayshriram Group of Institutions
Tiruppur 638660 (India)
sathescivil@gmail.com

Paul Oluwaseun Awoyera (Corresponding author)
Department of Civil Engineering, Covenant University
PMB 1023 Ota (Nigeria)
Paul.awoyera@covenantuniversity.edu.ng

Tamilarasan Kandasamy
Department of Civil Engineering, Jayshriram Group of Institutions
Tiruppur 638660 (India)
tamilarasan5670@gmail.com

Sathishkumar Nagaraj
Department of Civil Engineering, Jayshriram Group of Institutions
Tiruppur 638660 (India)
sathishcivil412@gmail.com

Praveenkumar Murugesan
Department of Civil Engineering, Jayshriram Group of Institutions
Tiruppur 638660 (India)
Praveenkumar10995@gmail.com

Boopathirasan Ponnusamy
Department of Civil Engineering, Jayshriram Group of Institutions
Tiruppur 638660 (India)
boopathyrasan@gmail.com

Manuscript Code: 913
Date of Acceptance/Reception: 10.07.2018/27.05.2017
DOI: 10.7764/RDLC.17.2.240

Abstract
There is an increasing quest for sustainable development in the built environmental through the use of alternative construction materials. Basalt fibre is one of those materials that is currently gaining interest in concrete production, because it is environmentally friendly, and also has good mechanical features. The current study evaluates the workability, strength properties, impact resistance and hydration characteristics of high strength chopped basalt fibre-reinforced concrete. Basalt fibre was used in varying proportions, and manufactured sand was used as a total replacement of natural fine aggregate, while other natural materials were kept constant, when casting concrete specimens. The results showed that increasing the cut length of basalt fibre could enhance the strength characteristics and impact resistance of concrete. Overall, the study revealed an improved impact resistance in the tested concrete, which could be traced to be a result of rapid hydration.

Key words: Chopped basalt fibre, crack; impact resistance, manufactured sand, strength properties, thermogravimetric analysis.

Resumen
Hay una creciente búsqueda de desarrollo sostenible en el medio ambiente mediante el uso de materiales de construcción alternativos. Fibra de basalto es uno de los materiales que actualmente está ganando interés en la producción de hormigón, ya que con el medio ambiente y también tiene buenas características mecánicas. El presente estudio evalúa la trabajabilidad, resistencia, características de hidratación y resistencia de impacto de alta resistencia picado basalto reforzado con fibra de hormigón. Fibra de basalto fue utilizado en proporciones variables, y arena fabricado fue utilizado como un reemplazo total de agregado fino natural, mientras que otros materiales naturales se mantienen constantes, cuando especímenes de concreto. Los resultados demostraron que aumentando la longitud de corte de fibra de basalto podría mejorar las características de fuerza y resistencia del concreto al impacto. Había una resistencia al impacto mejorada en concreto como resultado de la rápida hidratación.

Palabras clave: Fibra de basalto picado, grieta, resistencia al impacto, arena manufacturada, características de la fuerza, análisis termogravimétrico.

Introduction

It is becoming important to determine the impact load resistance and strength properties of cement based materials at experimental level before they can be considered for use in construction. This is mainly because, around the world, there are increasing instances of bomb blasts in buildings, due to terrorist attacks, or seismic hazard due to earthquake loading(Awoyera, Ogundeji, & Aderonmu, 2016). The effects of different loading conditions varies in structural elements, depending on the material properties and the structural integrity of the composite member.

A significant number of studies (Fujukake, Li, & Soeun, 2009; Khalil, Abd-Elmohsen, & Anwar, 2014; Pham & Hao, 2017; Zhanga, Shimb, Lua, & Chewa, 2005) have evaluated the effect of impact loading on concrete containing conventional materials, or modified concrete having secondary materials. From those studies, it was inferred that the impact resistance of concrete is totally dependent on its material composition.

There is an increasing attempt to assess the suitability of locally sourced materials for production of concrete. The research efforts are focusing on minimization of the environmental degradation resulting from disposal of such materials, or even to reduce construction cost incurred on materials by utilizing wastes. The use of artificial fibres as reinforcement, and recycled aggregates as substitute to natural aggregates, and cementitious materials as replacement of cement in concrete, is currently gaining huge attention. Several positive recommendations have been made on some alternative materials; fibres (Awoyera, Ijalana, & Babalola, 2015; Cordero, García, & Overend, 2015), recycled ceramics (Awoyera, Dawson, Thom, & Akinmusuru, 2017; Awoyera, Akinmusuru, & Ndambuki, 2016; Cabrera, Gómez, Almaral, Arredondo, & Corral, 2015), hydraulic concrete waste (Gutiérrez, Mungaray, & Hallack, 2015), and plastics (Sanchez, Oshiro, & Positieri, 2014), for use in mortar and concrete.

The current study investigates the impact resistance and strength characteristics of chopped basalt fire-reinforced concrete. Basalt, a natural material mostly found in volcanic rocks originating from frozen lava, has been found to exhibit similar characteristics as other fibres (steel, glass, polystyrene, and carbon). Basalt fibre has been well researched as an ingredient for improving properties of concrete as demonstrated in the following studies (Ayub, Shafiq, Fadhil Nuruddin, & Ullah Khan, 2014; Borhan & Bailey, 2014; Shaikh & Haque, 2018).

The mechanical properties of recycled aggregate concrete was found to be enhanced by using basalt fibre reinforcement (Dong, Wang, & Guan, 2017), ductility (Alnahhal & Aljidda, 2018), and also, concrete pre-cracking strength has been improved by using basalt fibre (Branston, Das, Kenno, & Taylor, 2016). However, despite the significant efforts that have been made in previous studies to determine the mechanical properties of basalt fibre reinforced concrete, the behavior of such concrete under impact loading phenomenon has not been overly explored. Therefore, it is intended in the current study to evaluate strength characteristics of basalt-fibre reinforced concrete containing manufactured sand as fine aggregate replacement. Also, the study determines the impact resistance of concrete slab at macro-level.

Methodology

Materials

A grade 32.5 Ordinary Portland Cement conforming to the Indian Standard (IS 4031, 1996) was used in this study. The physical properties and the chemical composition of the cement are shown in Tables 1 and 2 respectively. The fine aggregates used comprised of river sand and manufactured sand. The particle size distribution of the fine aggregates was determined in another study (Karthik, Rao, & Awoyera, 2017), following Indian Standard (part 1 IS 2386, 2002). The result is presented in Figure 1. The river sand and the manufactured sand are well-graded.

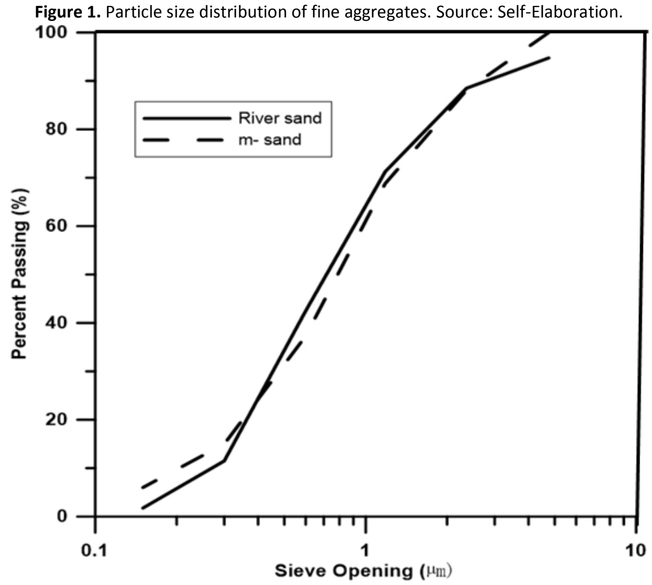
Table 1. Physical properties of cement. Source: Self-Elaboration.

S/N	Physical Property	Value
1	Specific Gravity	3.15
2	Standard Consistency	30%
3	Setting Time 1)Initial 2)Final	 30 min 5 hours
4	Soundness Test	1mm
5	Fineness	1g

Table 2. Chemical composition of cement. Source: Self-Elaboration.

Oxides	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3
Concentration (%)	1.743	3.19	19.475	24.094	1.138	0.847	74.211	0.619	6.273

Figure 1. Particle size distribution of fine aggregates. Source: Self-Elaboration.



The coarse aggregate used comprised of crushed granite stone of 12 mm size and angular in shape. The physical properties of the aggregates were determined according to IS 2386 (2002), the results are shown in Table 3. Two cut lengths categories of the basalt fibre were considered, 12 mm and 18 mm, while the diameter of the fibres was 13 µm. The mechanical properties of the basalt fibre is presented in Table 4.

Basalt fibre was added to the concrete at 0.5 and 1% by weight of concrete. The manufactured sand (M-sand) was used as fine aggregate in making another set of samples.

Table 3. Physical properties of the aggregates. (Source: Self-Elaboration.

Aggregates	Specific gravity	Water absorption (%)	Fineness modulus	Aggregate crushing value (%)	Aggregate impact value (%)
River sand	2.6	6.5	2.89	-	-
m-sand	2.84	5.6	2.84	-	-
Granite	6.5	2.5	-	27.07	34

Table 4. Properties of basalt fiber. Source: Self-Elaboration.

Property	Value
Tensile strength (GPa)	4.84
Elastic modulus (GPa)	89
Elongation at break (%)	3.15
Density (g/cm^3)	2.7

Concrete mix design, sampling and testing

An M25 grade of concrete was designed according to the procedure of IS 10262 (2009). The concrete samples were cast using a mix ratio of 1: 1.7: 2.7 (by weight of cement, fine aggregate, and coarse aggregate), and water/cement ratio of 0.5. This approach of concrete mix design is applicable only to ordinary and standard concrete grades, where mostly the air content of the concrete is not considered.

Table 5 shows the mix proportion for the concrete samples. Samples were prepared in two batches, one batch for 12 mm fibre length and another batch for 18 mm fibre lengths. A potable water was used for the concrete mixing, and slump was measured before placing the concrete in moulds. Sample preparation includes 150 mm dimension cubes, 150 x 300 mm cylinders, 100 x 100 x 500 mm prisms, and 600 x 600 x 50 mm slabs, for determination of compressive strength, split-tensile strength, flexural strength, and impact resistance respectively. The reference prisms were reinforced with 12 mm steel reinforcement main bars and 6 mm stirrups, while the modified samples were only reinforced with basalt fibres. The reference slab was reinforced with wire mesh, while the modified slabs were only reinforced with basalt fibres.

The average strength of triplicate test samples was recorded for compressive strength and split tensile strength, while average of duplicate samples flexural strength was recorded during the bending test.

Table 5. Mix proportion for concrete. Source: Self-Elaboration.

Mix ID	Cement (Kg/m^3)	River sand (Kg/m^3)	M-sand (Kg/m^3)	Granite (Kg/m^3)	Water (lit/m^3)	Fibre content (%)
Ref.	413	720	-	1126.5	186	-
BS- 0.5%	413	720	-	1126.5	186	0.5
BS- 1.0%	413	720	-	1126.5	186	1.0
BM-0	413	-	720	1126.5	186	-
BM- 0.5%	413	-	720	1126.5	186	0.5
BM- 1.0%	413	-	720	1126.5	186	1.0

The compressive strength of cubes was determined by dividing the ultimate load by the cross sectional area of the concrete cube, while the split-tensile strength was calculated using:

Split-tensile strength = $\frac{2P}{\Pi dl}$ in N/mm^2 Equation 1

where:
P is the crushing load in N
d is the diameter of the specimen in mm
l is the length of the specimen in mm,
and the flexural strength was determined using;

Flexural strength = $\frac{Pl}{bd^2}$ in N/mm^2 Equation 2

where: P is the ultimate load applied to the specimen in N

l is the length of specimen between supports in mm
b is the breadth of the specimen in mm

For the impact resistance tests, the slabs were mounted on a frame with hinged support conditions as shown in Figure 2. A drop hammer of 8.5 kg weight was used for the impact test. There was a dial gauge set to measure the deflection as the hammer punches the slab, until the first visible crack occurs. Thus, the free fall of the hammer impact at the center of the slab simulates the impact load as well as the deflection.

Figure 2. Typical slab during impact load loading. Source: Self-Elaboration**.**

Results and discussion

Workability of concrete mixtures

The workability of the concrete mixes was assessed through slump test using the guidelines of IS 1199 (1959). For all the samples, slump values were in range 39 – 49 mm, which falls within the categories of low slump, in line with IS 1199 classification. It is possible for these concrete mixtures with low slump to suit applications involving mass concreting or lightly reinforced structural members. The effect of the basalt fibre addition on the slump was barely noticeable, concrete containing basalt fibre measured slump of about 6 - 7 mm than the reference mixture. It was obvious that part of the mixing water was absorbed by basalt fibers. So, as the basalt fiber absorbs the water, there was improvement in the friction between the fibers and the bulk cement paste. This result agrees with a related studies performed by Sathanandam, Awoyera, Vijayan, & Sathishkumar (2017) and Katkhuda and Shatarat (2017). From this study, it was discovered that slump can be decreased by increasing the volume of basalt fiber content.

Strength properties

The effects of basalt fibre content and manufactured sand on the strength characteristics of the concrete are described as follows. The compressive strength result of the concrete is shown in Figure 4, for concrete containing 12 mm length of basalt fibre (Figure 3a), and 18 mm basalt fibre length (Figure 3b). As can be seen in Figures 3 and 4, the compressive strength and the split-tensile strength of the concrete, respectively increased with increasing curing age. This shows that there was rapid hydration of the concrete matrix, and more to this could be as a result of linking crack boundaries by basalt fibres (Anandaraj, Rooby, Awoyera, & Gobinath, 2018), which enhances the ductility of the concrete. The concrete strength development was totally influenced by the hydration rate and fibre linkages.

For concrete cubes and cylinders cast with river sand and M-sand, the compressive strength and the split-tensile strength increased with increasing basalt fibre content. After 28 days curing, the highest compressive and split-tensile strength was achieved by sample containing river sand and 1% basalt fibre. However, the strength of the concrete varied with the cut length of basalt fibre. Samples containing 18 mm length of basalt fibre had better strength than those of 12 mm fibre length. This suggest that increasing the length of basalt fibre will also improve the strength properties of concrete. A similar assertion was made by Branston et al. (2016) in a study involving effect of basalt fibre length in mechanical properties of concrete. In addition, the reason for this could be that there was improved rigidity and compactness along the lengths of the embedded fibre in the concrete matrix. On a general note, there was improved strength properties in the samples made with river sand than in the m-sand concrete.

The flexural strength of the concrete prisms obtained after 28 days curing is shown in Figure 5. Again, the samples containing river sand as fine aggregate and 18 mm basalt fibre yielded higher flexural strength than other samples. Also, the modified samples containing secondary materials performed better than the samples containing natural materials. Therefore, this performance suggests that the inclusion of basalt fibre create a ductile failure process as a result of strain hardening behavior of the materials. It can also be inferred that the basalt fibres were well placed around the tension zone of the prisms, and this also controlled the crack width and pattern along the prism length.

Figure 3. Compressive strength developed with age (a) 12 mm fibre length (b) 18 mm fibre length. Source: Self-Elaboration.

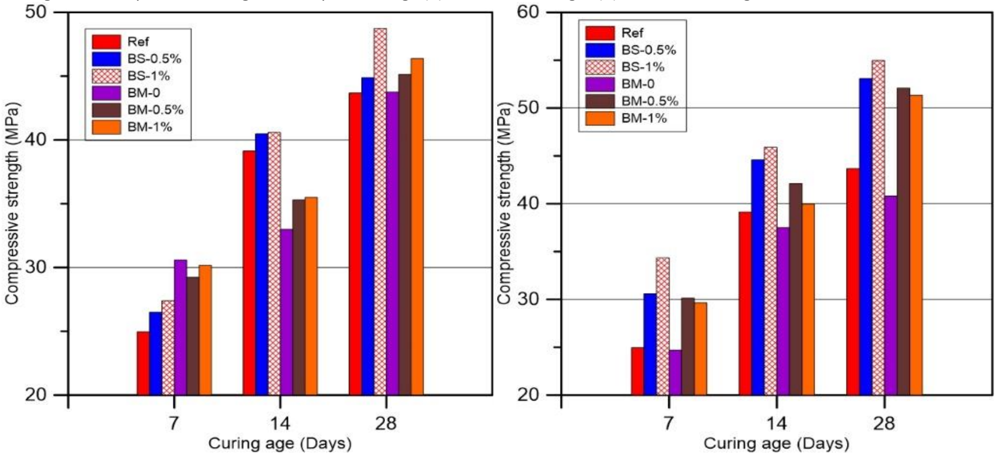


Figure 4. Split-tensile strength developed with age (a) 12 mm fibre length (b) 18 mm fibre length. Source: Self-Elaboration.

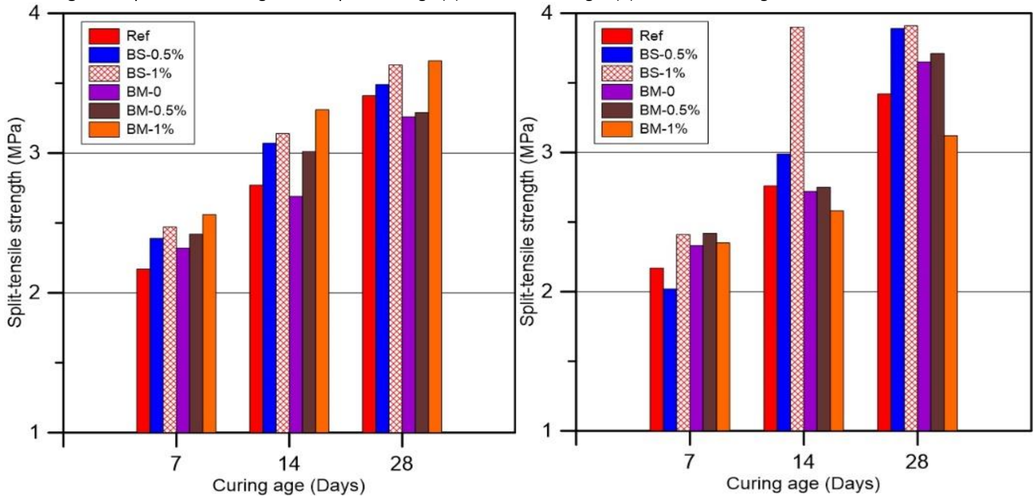
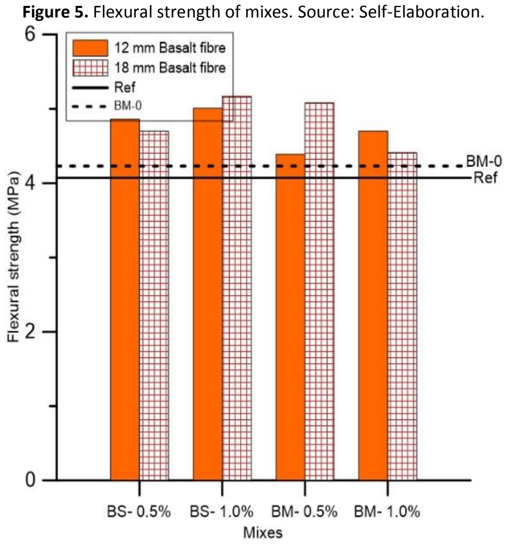


Figure 5. Flexural strength of mixes. Source: Self-Elaboration.



Impact resistance

The impact resistance test was used to evaluate the behaviour of basalt fiber reinforced concrete slab under a repeated low velocity impact loading. The procedure adopted for the test followed the ACI Committee 544 (1988) recommendation, and also the insight on this procedure given by Badr and Ashour (2005). Thus, during testing, the number of blows from the 8.5 kg punching hammer, falling through a drop height of 450 mm that causes a visible crack on concrete surface, was noted as well as the corresponding deflection as obtained on the dial gauge for each specimen.

In this study, aside the reference slabs samples, slabs were cast using strictly 1% dosage of the 18 mm basalt fibre cut length since this has shown better improvement on strength properties of the concrete than the 12 mm fibre length. A slab was considered failed as soon as the impact piston was fully embedded in the slab.

Figures 6, and 7 show the blows – deflection curves and the failed slabs for all the selected test specimens. As can be seen, there was a similar performance between samples without basalt fibre, and samples containing basalt fibre, they failed at about 5 and 7 blows of the punching hammer respectively. It was obvious that the basalt fibre addition or its dosage has no definite impact on the post-cracking behaviour of the slabs. This is behavior was also reported in related studies (Duic, Kenno, & Das, 2018), where cracking moments in basalt fibre reinforced concrete beam was found to be minimal.

Figure 6. Reference slab containing river sand (a) blows versus deflection (b) failed slab. Source: Self-Elaboration.

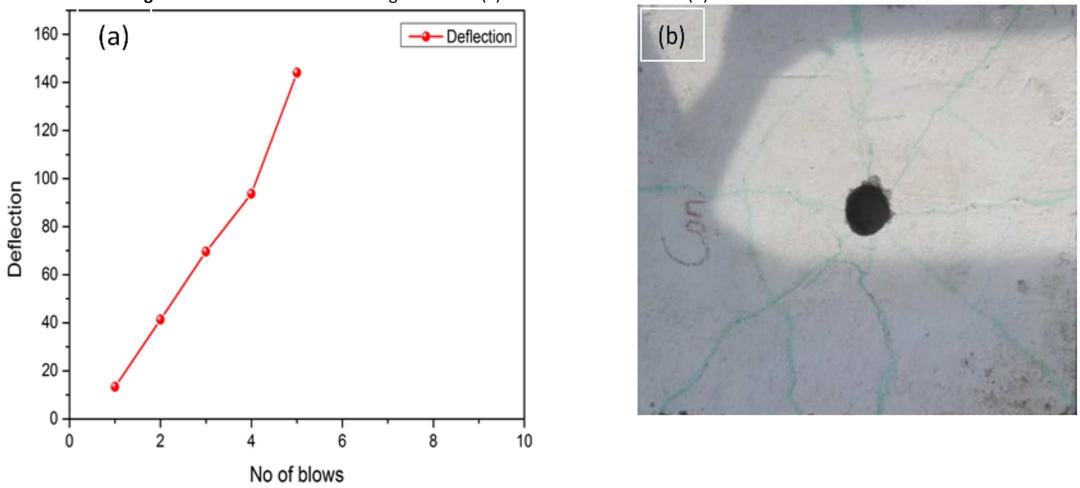
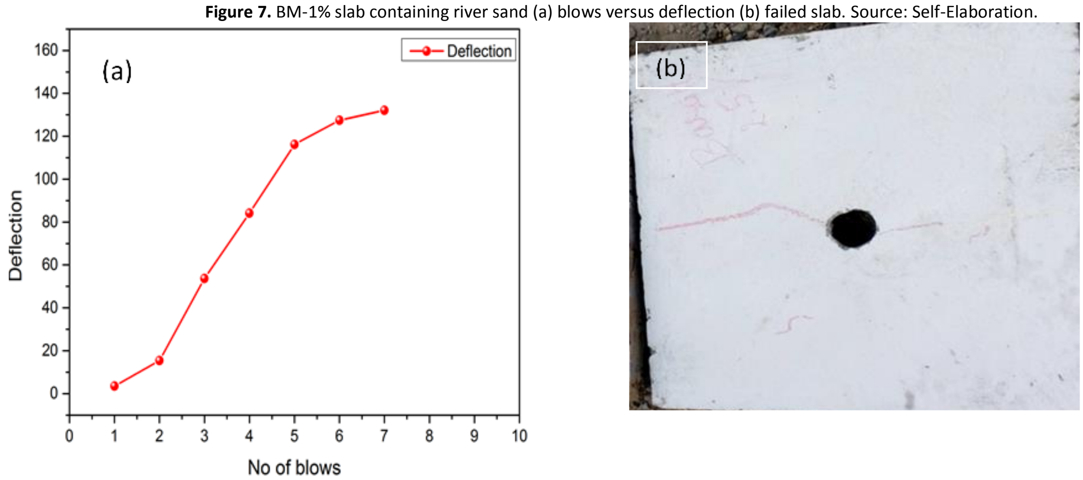


Figure 7. BM-1% slab containing river sand (a) blows versus deflection (b) failed slab. Source: Self-Elaboration.



Conclusion

This study has evaluated the strength properties and the impact resistance of chopped basalt fibre-reinforced concrete. Based on the results obtained, the following conclusions are drawn:

i. it has been observed that the workability of concrete decreased with increasing addition of basalt fiber. However, on a general note, there was low workability in all the mixtures including the reference mixes.

ii. the strength of concrete increased with increasing basalt fibre content up to 1%. The 18 mm basalt fibre length, when added to mixtures containing river sand, produced greater strength characteristics than other mixtures.

iii. The impact resistance of slab was improved by the addition of basalt fibre. There was increase in the number blows before first visible crack were seen, and at the same time the deflection decreased.

Acknowledgement

The authors are grateful to the Jasiri Group of Schools Tiruppur 638660, India for supporting this research.

References

ACI Committee 544. (1988). Measurement of properties of fiber reinforced concrete. *ACI Materials Journal*, *85*(6).

Alnahhal, W., & Aljidda, O. (2018). Flexural behavior of basalt fiber reinforced concrete beams with recycled concrete coarse aggregates. *Construction and Building Materials*, *169*, 165–178. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2018.02.135

Anandaraj, S., Rooby, J., Awoyera, P. O., & Gobinath, R. (2018). Structural distress in glass fibre-reinforced concrete under loading and exposure to aggressive environments. *Construction and Building Materials*. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2018.06.090

Awoyera, P. O., Akinmusuru, J. O., & Ndambuki, J. M. (2016). Green concrete production with ceramic wastes and laterite. *Construction and Building Materials*, *117*, 29–36. https://doi.org/10.1016/j.conbuildmat.2016.04.108

Awoyera, P. O., Dawson, A. R., Thom, N. H., & Akinmusuru, J. O. (2017). Suitability of mortars produced using laterite and ceramic wastes: Mechanical and microscale analysis. *Construction and Building Materials*, *148*, 195–203. https://doi.org/10.1016/j.conbuildmat.2017.05.031

Awoyera, P. O., Ijalana, J. K., & Babalola, O. E. (2015). Influence of Steel and Bamboo Fibres on Mechanical Properties of High Strength Concrete, *6*(12), 3634–3642.

Awoyera, P. O., Ogundeji, J. F., & Aderonmu, P. A. (2016). Simulated combined earthquake and dead load lateral resistance building systems using Nigeria seismic data. *Journal of Materials and Environmental Science*, *7*(3).

Ayub, T., Shafiq, N., Fadhil Nuruddin, M., & Ullah Khan, S. (2014). Mechanical Properties of High-Strength Concrete Reinforced with PVA and Basalt Fibres. In R. Hassan, M. Yusoff, Z. Ismail, N. M. Amin, & M. A. Fadzil (Eds.), *InCIEC 2013* (pp. 567–575). Singapore: Springer Singapore.

Badr, A., & Ashour, A. (2005). Modified ACI drop-weight impact test for concrete. *ACI Materials Journal*, *102*(4), 249–255.

Borhan, T. M., & Bailey, C. G. (2014). Structural behaviour of basalt fibre reinforced glass concrete slabs. *Materials and Structures*, *47*(1), 77–87. https://doi.org/10.1617/s11527-013-0046-0

Branston, J., Das, S., Kenno, S. Y., & Taylor, C. (2016). Mechanical behaviour of basalt fibre reinforced concrete. *Construction and Building Materials*, *124*, 878–886. https://doi.org/10.1016/j.conbuildmat.2016.08.009

Cabrera, F., Gómez, J., Almaral, J., Arredondo, S., & Corral, R. (2015). Mechanical properties of mortars containing recycled ceramic as a fine aggregate replacement. *Revista de La Construcción*, *14*(3), 22–29.

Cordero, B., García, A., & Overend, M. (2015). Thermal performance of novel frame-integrated unitised curtain wall. *Revista de la Construcción*, *14*(1), 23–28.

Dong, J. F., Wang, Q. Y., & Guan, Z. W. (2017). Material properties of basalt fibre reinforced concrete made with recycled earthquake waste. *Construction and Building Materials*, *130*, 241–251. https://doi.org/10.1016/j.conbuildmat.2016.08.118

Duic, J., Kenno, S., & Das, S. (2018). Performance of concrete beams reinforced with basalt fibre composite rebar. *Construction and Building Materials*, *176*, 470–481. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2018.04.208

Fujukake, K., Li, B., & Soeun, S. (2009). Impact Response of Reinforced Concrete Beam and Its Analytical Evaluation. *Journal of Structural Engineering*, *135*(8).

Gutiérrez, J., Mungaray, A., & Hallack, M. (2015). Reuse of Hydraulic Concrete Waste as a New Material in Construction Procedures: a Sustainable Alternative in Northwest Mexico. *Revista de La Construcción*, *14*(2), 51–57.

IS 10262. (2009). Guidelines for concrete mix design proportioning. *Indian Standard*.

IS 1199. (1959). Methods of sampling and analysis of concrete. *Indian Standard*.

IS 2386. (2002a). Method of test for aggregate for concrete. *Indian Standard*.

IS 2386, part 1. (2002b). Methods of test for aggregates for concrete: Particle size and shape. *Indian Standard*.

IS 4031. (1996). Methods of physical tests for hydraulic cement. *Indian Standard*.

Karthik, S., Rao, P. R. M., & Awoyera, P. O. (2017). Strength properties of bamboo and steel reinforced concrete containing manufactured sand and mineral admixtures. *Journal of King Saud University - Engineering Sciences*. https://doi.org/10.1016/j.jksues.2016.12.003

Katkhuda, H., & Shatarat, N. (2017). Improving the mechanical properties of recycled concrete aggregate using chopped basalt fibers and acid treatment. *Construction and Building Materials*, *140*, 328–335. https://doi.org/10.1016/j.conbuildmat.2017.02.128

Khalil, E., Abd-Elmohsen, M., & Anwar, A. (2014). Impact Resistance of Rubberized Self-Compacting Concrete. *Water Science*, *29*(1), 45–53.

Pham, T., & Hao, H. (2017). Axial Impact Resistance of FRP-Confined Concrete. *Journal of Composites for Construction*, *21*(2).

Sanchez, I., Oshiro, A., & Positieri, M. (2014). The use of recycled plastic in concrete. An alternative to reduce the ecological footprint. *Revista de La Construcción*, *13*(3), 19–26.

Sathanandam, T., Awoyera, P. O., Vijayan, V., & Sathishkumar, K. (2017). Low carbon building: Experimental insight on the use of fly ash and glass fibre for making geopolymer concrete. *Sustainable Environment Research*, *27*(3), 146–153. https://doi.org/10.1016/j.serj.2017.03.005

Shaikh, F., & Haque, S. (2018). Behaviour of Carbon and Basalt Fibres Reinforced Fly Ash Geopolymer at Elevated Temperatures. *International Journal of Concrete Structures and Materials*, *12*(1), 35. https://doi.org/10.1186/s40069-018-0267-2

Zhanga, M., Shimb, V., Lua, G., & Chewa, C. (2005). Resistance of high-strength concrete to projectile impact. *International Journal of Impact Engineering*, *31*(7), 825–841.