Advances in Concrete Construction, *Vol. 8, No. 4 (2019) 305-309*
DOI: https://doi.org/10.12989/acc.2019.8.4.305

Porous concrete with optimum fine aggregate and fibre for improved strength

Savithri S. Karanth*, U. Lohith Kumar[a] and Naveen Danigond[a]

Department of Civil Engineering, Global Academy of Technology, Bangalore, India

(*Received July 15, 2019, Revised September 21, 2019, Accepted October 11, 2019*)

Abstract. Pervious concrete pavements are the need of the day to avoid urban flooding and to facilitate ground water recharge. However, the strength of pervious or porous concrete is considerably less compared to conventional concrete. In this experimental investigation, an effort is made to improve the strength of pervious concrete by adopting fibres and a small amount of fine aggregate. A porous concrete with cement to aggregate ratio of 1:5 and a water-powder ratio of 0.4 is adopted. 30% of the cement is replaced by cementitious material ground granulated blast furnace slag (GGBS) for better strength and workability. Recron fibres at a dosage of 0.5, 1.0 and 1.5% by weight of cement were included to improve the impact strength. Since concrete pavements are subjected to impact loads, the impact strength was also calculated by "Drop ball method" in addition to compressive strength. The effect of fine aggregate and recron fibres on workability, porosity, compressive and impact strength was studied. The investigations have shown that 20% inclusion of fine aggregate and 1.5% recron fibres by weight of cement give better strength with an acceptable range of porosity.

Keywords: porosity; pervious concrete; drop ball method; impact strength; compressive strength; fibrecrete

1. Introduction

Industrialization and urbanization has led to climate change resulting in scanty rain or heavy flooding. Porous or pervious concrete is a mixture of cement, water and coarse aggregate. Since fine aggregate is not used as an ingredient, the resulting concrete has a lot of pores and allows water to percolate through it. The voids range between 10 to 35% of volume of concrete with sizes of the pores ranging between 2 to 8 mm and the density of concrete ranging between 1600 to 2000 kg/m^3. The pores allow the rainwater to percolate into the soil beneath aiding the recharge of groundwater which is the need of the day. Pervious concrete pavements reduce the risk of flash flooding as the surface run off is reduced and also acts as a natural filter preventing contaminants such as chemicals and heavy metals from reaching into ground water. The increase in porosity can be achieved by decreasing the paste and fixing the dosage of coarse aggregate (Zhang 2018). Hatanaka (2012) indicated that the strength of pervious concrete increases with strength of binder paste and the size of the aggregate. Lot of research works have been taking place to improve the strength properties of porous concrete. Li (2019) used metal tailings to improve the mechanical properties of porous concrete and also as a green building initiative to reduce the environmental pollution. The results were encouraging with increased strength in both tension and compression. Recycled materials such as crushed glass, steel slag, steel fibres, plastic and tires were used to produce porous concrete by Toghroli (2018) in their investigations with cement being partially replaced by industrial waste. It was found that the mechanical properties and porosity is dependent on properties of waste materials used. Polymer, silica fumes and crushed rubber were also used by Diyuan (2019) for the production of pervious concrete as a replacement for coarse aggregate which also proved to be beneficial with remarkable improvements in strength. Similar experiments using recycled coarse aggregate and recycled asphalt pavement by Nasim (2018) have also proved to enhance the properties of porous concrete. Sarwono (2016), in an attempt to improve the strength of porous concrete pavements used soil and sand. Fine aggregate at a proportion of 30% of coarse aggregate and soil and volcanic ash to fill the remaining voids were adopted. The results showed a high compressive strength of 5.71 MPa when concrete was filled with volcanic ash. However, higher permeability values were obtained with the replacement of sand alone. The research work recommended this type of pavements for light traffic only. Xu (2017) studied the mechanical properties of porous concrete with the inclusion of fine aggregate and fly ash. Addition of fine aggregate has the advantage of shrinkage resistance and volume stability and fly-ash improves the strength. Fine aggregate improves the distribution of cement paste, thus enhancing the mechanical strength. Drop ball method with high speed photography technique for accurate measurement of crack pattern was adopted by Safak (2018) to measure the impact strength of porous concrete. Due to the highly porous nature and heterogeneity of materials, thermal properties of porous concrete also vary (Chan 2018). The porosity increases as the thermal conductivity decreases. Eco friendly porous concrete made by industrial by-products such as coal ash as coarse aggregate and geo polymer as a binder have proved beneficial in preventing

*Corresponding author, Associate Professor
E-mail: savithri_karanth@yahoo.co.in
[a]Ph.D. Student

http://www.techno-press.org/?journal=acc&subpage=7
ISSN: 2287-5301 (Print), 2287-531X (Online)

leaching of heavy metals into the ground. It was observed that this type of porous concrete can immobilize heavy metal as stabilized products. The compressive strength also was found to be better than conventional porous concrete. (Jang 2015). Porous concrete with 20% fine aggregates was found to be more suitable for parking areas and low traffic roads in a study conducted for roads in Muscat with very high porosity and strength sufficient to sustain medium traffic. (Sulaiman 2014). Strength increases with the increase in contact area between the aggregate and binding material. Hence, smaller sized aggregates exhibit better mechanical strength though it reduces the porosity. (Uma 2013). The introduction of mineral admixtures has given better strength. However, the inclusion of silica fumes has resulted in reduced strength of pervious concrete. (Vikram 2015). Porous pavements need to have strength as well as permeability. Strength is indirectly proportional to permeability, porosity and void contents. Experiments conducted by Kishore (2017) showed that adding 50% of crushed stone gave better strength and reasonable permeability for rural pavements. The effect of the size of aggregate and w/c ratio on strength, permeability, density and porosity was studied by Tejas (2016) who showed that a *w/c* ratio of 0.3 and combination of different sized aggregate gives better results in pervious concrete. A small amount of air entrainment agents will improve the permeability of concrete. Use of latex additives and fibres will improve bonding. The ideal water binder ratio ranges between 0.27 and 0.43. (Sonebi) (2016). A mix Design based on specific surface areas of aggregates is the most suitable method with minimum errors (Xiao 2017).

2. Experimental work

2.1 Materials

The materials used in the present investigations are
i. Cement of 43 grade with specific gravity 3.15
ii. Ground Granulated Blast Furnace Slag (GGBS) of specific gravity 2.9, an industrial waste possessing cementitious properties known to improve strength of concrete.
iii. Crushed stone as fine aggregate belonging to zone II and specific gravity 2.6
iv. Coarse aggregate of size 16-12mm and specific gravity 2.64
v. Recron 3S modified polyester fibres of length 12mm and diameter 35-40 micron to improve the resistance against impact and abrasion

2.2 Mix design

Mix with a proportion of 1:5 to cement to coarse aggregate is adopted in the present investigation. 30% by weight of cement is replaced by GGBS to improve the workability and mechanical properties of concrete. Fine aggregate is used as replacement for coarse aggregate at 5, 10, 15, 20 and 25% by weight to determine the optimum percentage of replacement for strength. Recron fibres are used at 0.5, 1.0 and 1.5% by weight of cementitious

(a) (b)

Fig. 1 Prepared cube and plate specimens kept for air curing for 24 hours and water curing for 28 days

material to improve the strength in impact and to check the optimum dosage. Cubes of size 100mmx100mmx100mm are cast to check the compressive strength and flat plates of size 300mmx300mm and thickness 50mm are adopted for checking the impact strength by drop ball method. A water to powder ratio of 0.4 was adopted throughout and change in workability values with the addition of fibres and inclusion of sand is obtained by compaction factor tests. Specimens are prepared, air cured for 24 hours and cured in water for 28 days. The specimens are tested for compressive strength and impact strength after the specified duration of curing.

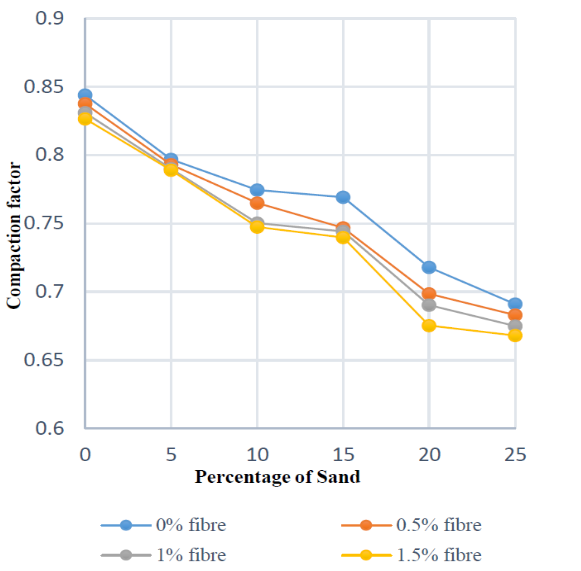
3. Results and discussions

3.1 Workability studies

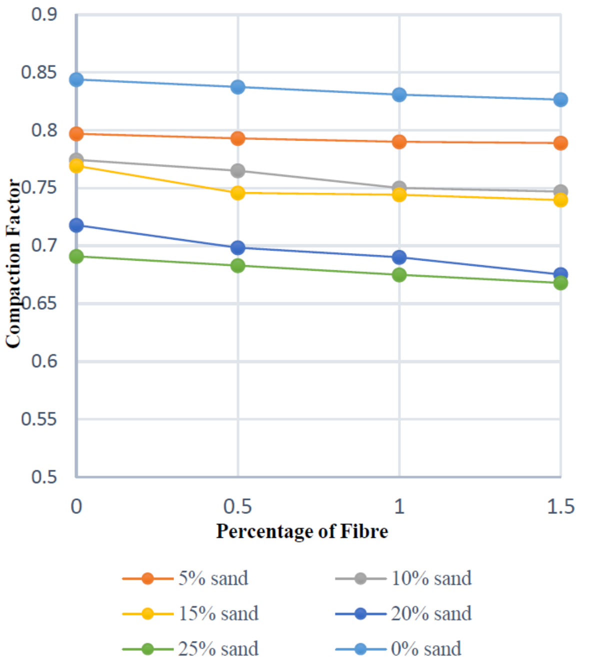
Concrete with water powder ratio of 0.4 tends to be stiff and slump test will not be suitable to check the workability characteristics. Hence compaction factor tests are conducted to check the variation of workability values with the inclusion of fibres and fine aggregate. As expected workability decreases with the inclusion of fibres and fine aggregate gradually. The concrete was more flowable in the reference concrete with no fibre and fine aggregate having a compaction factor of 0.844 which reduced to 0.668 with 25% fine aggregate and 1.5% of fibres in concrete. The reduced workability resulted in an uneven surface which required a layer of capping before testing. Fig. 2(a) and 2(b) show the variation of workability values with the inclusion of fibres and fine aggregate in the porous concrete. However, porous concrete is generally stiff in nature and does not hamper the placing much in case of road pavements. The graphs indicate that the inclusion of small percentage of fibres has not affected the flowability as much as fine aggregate.

3.2 Compressive strength

The basic objective of this work is to determine the optimum percentage of fine aggregate for better strength and porosity keeping in mind constant grades of coarse aggregates. Two fundamental strength tests were conducted for various percentages of sand and fibre to determine the optimum percentage of fine aggregate for better strength



(a) Variation of workability with inclusion of fine aggregate



(b) Variation of workability with inclusion of fibre and fine aggregate

Fig. 2 Variation of workability

and porosity. Cube compression test was carried out as per IS 516-1959.

The graphs indicate that that the compressive strength of porous concrete increases with the inclusion of fine aggregate. The increase in strength is gradual up to 20% of sand with a decrease in strength beyond that. The average strength obtained in the reference block was 13.25 MPa which increased to 29.45 MPa at 20% replacement of coarse aggregate with fine aggregate without the inclusion of fibres. The strength also increased with the inclusion of fibres with every increment in the percentage of fibres. The maximum strength obtained was 42.22 MPa, an increase of 143% with 20% replacement of Coarse aggregate with fine aggregate and 1.5% inclusion of fibres. The dip in the

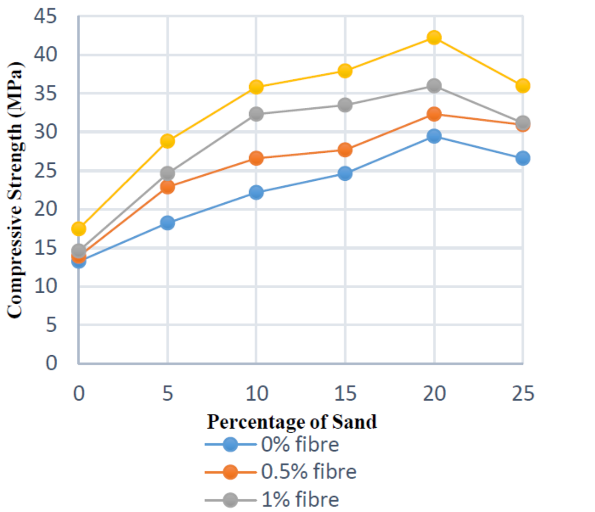


Fig. 3 Variation of compressive strength with percentage of sand

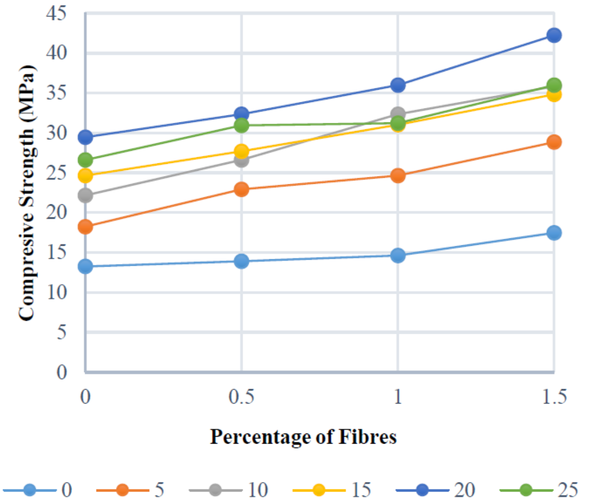


Fig. 4 Variation of compressive strength with addition of fibres

graphs beyond 20% indicate that it is the optimum percentage of replacement for compressive strength. A very important observation is that the fibres have helped in increase of strength without affecting the workability (Fig 2(b) and Fig. 4)

3.3 Impact strength (ACI 544.2R-89)

Drop ball method of testing impact strength adopts the principle of “number of blows” or “repeated impact”. The test determines the number of blows required to cause prescribed level of distress in the specimen which in turn tells about the energy absorbed till the prescribed level of distress. An impact test measures how much of energy is absorbed before the object fails or breaks due to sudden load. A known weight is dropped from a known height on the object. The impact energy is the kinetic energy of the mass at impact.

$E=N*m*g*h$

Where E=Impact energy

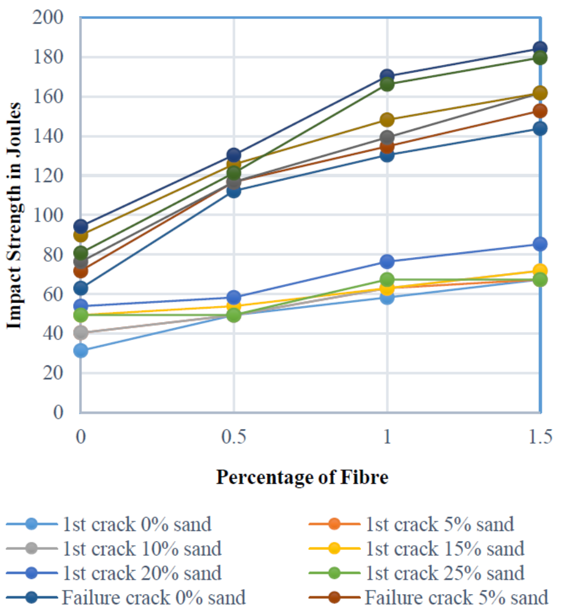


Fig 5 Variation of impact energy with percentage of fibre

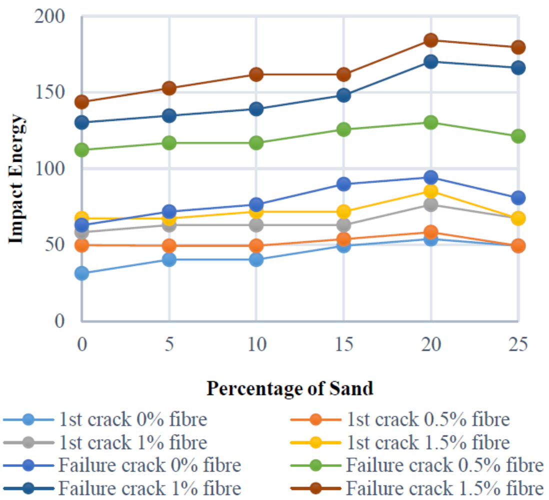


Fig. 6 Variation impact energy with percentage of sand

N=Number of blows

m=Mass of the drop ball in Kg

g=acceleration due to gravity in m/s^2

h=Height of drop

A ball of 1.5 kg weight was allowed to fall freely from a height of 1metere such that it falls exactly at the centre of the plate and the no of falls required to cause the first crack and failure was counted. Impact energy absorbed was calculated using the formula. The results are shown in Fig. 5 and Fig. 6.

As can be seen in the graphs, there is a rise in the impact strength with the addition of fine aggregate up to 20%, beyond which there is a drop in strength indicating that 20% is the optimum replacement. However, Fig 5 indicates a tremendous increase of impact strength with inclusion of fibres. The increase in impact strength is as much as 2.85 times with 1.5% fibres and 25% of fine aggregate for final failure and 2.15times for first crack. Flat plates without fibres have very less impact strength compared to the one with fibres. The results are in concurrence in any type of concrete with inclusion of fibres.

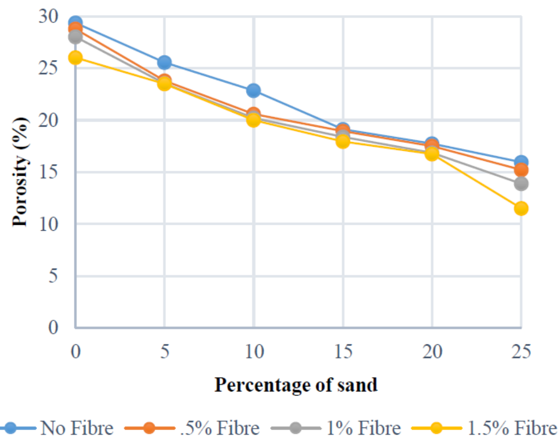


Fig. 7 Variation of porosity with % replacement of sand

3.4 Porosity test

Concrete is said to be porous when it has a void ratio ranging between 10 to 35%. The porosity is calculated theoretically by absolute volume method i.e.,

Void volume=volume of specimen-volume of ingredients.

The volume of ingredients are calculated based on the weight and specific gravity of material used for preparation of specimen. The variation of porosity with different percentages of sand is shown in Fig. 7

The graph indicates a reduction in the porosity with the inclusion of fine aggregate gradually. However, in every case the void ratio is above 10% which permits it to be called as porous concrete.

4. Conclusions

- Workability decreases with the addition of fine aggregate. This is normal as the surface area of aggregate is increased more area needs to get wet for paste to coat around.
- Maximum increase in compressive strength was observed at 20% replacement of fine aggregate. The strength was in par with M20 concrete. The inclusion of fine aggregate resulted in porosity which reduced to more than 50%. However it was still in the range to be considered as porous concrete. This is an expected outcome and the quantity of fine aggregate should be adjusted to achieve the required strength and porosity.
- The impact strength increased with inclusion of fibre as well as fine aggregate. As the road pavements are subjected to impact load more often, this is an important observation from the present study. The increase in impact strength was as much as 2.15 times for first crack and 2.85 times for final failure with the inclusion of 1.5% of recron fibres. Hence with the strength equal to M20 concrete, 16.8% porosity and impact strength of 85 joules, the porous concrete is very much suitable for

pavements.

• Porosity reduced from 28.77% at plain concrete to 16.8% at 1.5% fibre at 20 % replacement by sand which is an acceptable range for moderate rain fall regions.

The study shows the effective ness of fine aggregate and fibres in improving the compressive and impact of porous concrete and 1.5% fibres and 20% sand can be adopted without much compromise in the strength and porosity of the concrete.

References

ACI Committee 544.2R-89 (1999), Measurement of Properties of Fiber Reinforced Concrete, American Concrete Institute, Detroit, U.S.A.

Al Maawali, M.S.N., Reddy, N.S. and Al-Hatali, E.M.A. (2017), "A study on mechanical properties of porous concrete for its use in low traffic volume roads and parking area in Muscat", *SSRG Int. J. Civil Eng.*, **4**(5), 27-33.

Chen, J., Wang, H., Xie, P. and Najm, H. (2019), "Analysis of thermal conductivity of porous concrete using laboratory measurements and microstructure models", *Constr. Build. Mater.*, **218**, 90-98.

Hatanaka, S., Mishima, N., Nakagawa, T., Morihana, H. and Chindaprasirt, P. (2012), "Finishing Methods and compressive strength-void ratio relationships of in-situ porous concrete pavement", *Comput. Concrete*, **10**(3), 231-240.

IS 10262-2009, Concrete Mix Proportioning-Guidelines, Bureau of Indian Standards.

IS 516-1959, Indian Standard Methods of Tests for Strength of Concrete, Bureau of Indian Standards.

Jang, J.G., Ahn, Y.B., Souri, H. and Lee, H.K. (2015), "A novel ecofriendly porous concrete fabricated with coal ash and geopolymer binder: Heavy metal leaching characteristics and compressive strength", *Constr. Build. Mater.*, **79**, 173-181.

Joshi, T. and Dave, U. (2016), "Evaluation of strength, permeability and void ratio of pervious concrete with changed w/c ratio and aggregate size", *Int. J. Civil Eng. Technol.*, **7**(4), 276-284.

Kishore, R. and Guntakal, S.N. (2017), "Experimental investigations on properties of pervious concrete for its application in rural pavements", *Int. J. Civil Eng.*, **8**(4), 111-120.

Li, D., Toghroli, A., Shariati, M., Sajedi, F., Bui, D.T., Kianmehr, P., ... and Khorami, M. (2019), "Application of polymer, silica fume and crushed rubber in the production of pervious concrete", *Smart Struct. Syst.*, **23**(2), 207-214.

Li, H.N., Liu, P.F., Li, C., Li, G. and Zhang, H. (2019), "Experimental research on dynamic mechanical properties of metal tailing porous concrete", *Constr. Build. Mater.*, **213**, 20-31.

Maguesvari, M.U. and Narasimha, V.L. (2013), "Studies on characterization of pervious concrete for pavement application", *Procedia-Soc. Behav. Sci.*, **104**, 198-207.

Ozbek, A.S.A., Weerheijm, J., andvan Breugel, K. (2018), "High speed photography technique for measuring impact strength of porous concrete", *Constr. Build. Mater.*, **186**, 1092-1104.

Sarwono, D. and Setyawan, A. (2017), "The application of porous concrete filled with soil and sands for low volume traffic roads", *Sci. Direct, Procedia Eng.*, **171**, 1429-1434.

Shatarat, N.K., Katkhuda, H.N., Hyari, K.H. and Asi, I. (2018), "Effect of using recycled aggregate and recycled asphalt pavement on the properties of pervious concrete", *Struct. Eng. Mech.*, **67**(3), 283-290.

Sonebi, M., Bassuoni, M. and Yahia, A. (2016), "Pervious concrete: mix design, properties and applications", *RILEM Tech. Lett.*, **1**, 109-115.

Toghroli, A., Shariati, M., Sajedi, F., Ibrahim, Z., Koting, S., Mohamad, E.T. and Khorami, M. (2018), "A review on pavement porous concrete using recycled waste material", *Smart Struct. Syst.*, **22**(4), 433-440.

Vikram, M.R.P. (2015), "Experimental study on pervious concrete pavement", *IJRASET*, **3**(7), 40-48

Xiao, L. and Jiang, D. (2017), "The study of Pervious concrete mix design by method of surface area aggregate", *IOP Conference Series: Materials Science and Engineering*, **231**, Conference 1.

Xu, G., Shen, W., Huo, X., Yang, Z., Wang, J., Zhang, W. and Ji, X. (2017), "Investigation on the properties of porous concrete as road base material", *Constr. Build. Mater.*, **158**, 141-148.

Zhang, W., Li, H. and Zhang, Y. (2018), "Effect of porosity on frost resistance of portland cement pervious concrete", *Adv. Concrete Constr.*, **6**(4), 363-373.

CC