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Development of ultra-high performance fiber Reinforced Ductile concrete

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ABSTRACT

Concrete is a versatile construction material that is capable of being moulded into virtually any shape. This property is valuable as it allows engineering design to suit the aesthetics of modern and ever evolving architecture in addition to optimization of material and geometries. However, the downfall of concrete is its brittle characteristic. The brittle behavior of concrete is due to the fast growing of a single crack that leads to the uncontrollable failure of the specimen.

In order to improve the behavior of concrete, fibre reinforced concrete (FRC) is made by adding discrete short fibres into the concrete matrix. PVA fibre that has in the recent years attracted much interest in the research and development sector of fibre reinforced concrete. This is due to its high tensile strength, similar Young's modulus with concrete, small diameters and relatively cost effective price. When the cementitious matrix is placed under stress, cracking of the cementitious matrix begins to occur at which point the randomly dispersed short fibre within the matrix begin to bridge the matrix cracks and take up the tensile load.

This study will undertake the effect of hollow microsphere addition to the PVA-ECC. With the addition of PVA fibre, this research aims at further developing an ultra-high performance reinforced ductile concrete by replacing a fraction volume of cement with a lightweight hollow glass microsphere additive. The research shall also investigate the behavior and characteristics of the ultra-high performance PVA-ECC when exposed to different loading conditions. FRCs with 6 mm fibres and volume fractions ranging 1.5% with hollow microspheres ranging from 0-15% are investigated to find out mechanical properties i.e. compressive strength of small and large cubes and flexural strength.

The study will also do a cost analysis to check if the ultra-high performance Poly Vinyl Alcohol-Engineered Cementitious Composite is a cost effective and viable option to be used in the construction.

Introduction

Concrete is a versatile construction material that is capable of being moulded into virtually any shape. This property is valuable as it allows engineering design to suit the aesthetics of

modern and ever evolving architecture in addition to optimisation of material and geometries. However, the downfall of concrete is its brittle characteristic. The brittle behaviour of concrete is due to the fast growing of a single crack that leads to the uncontrollable failure of the specimen. This kind of failure mode results in a low ultimate strain around 0.01% and a sudden failure without warning. . Concrete adheres

exceptional strength when under compression, however when exposed to tensile loading, the brittle behaviour governs its failure that results in a very weak material. The addition of steel reinforced within concrete provides tensile strength to the material,

by means of the steel reinforcement taking up the tensile stresses within the load carrying member. In order to improve the behaviour of concrete, fibre reinforced concrete (FRC) is made by adding discrete short fibres into the concrete matrix. Fibres used currently include steel, glass, carbon and polymer fibres. These fibres act as bridges across the cracks to delay their propagation.Tensile strength of concrete can also be improved by the addition of randomly dispersed short fibres within the concrete matrix. Fibre material may include steel fibre, glass fibre, carbon fibre, polyethylene (PE) fibre, polypropylene fibre (PP), and polyvinyl alcohol (PVA) fibre. The tensile strength inherited by the concrete with the addition these fibres is not as high as the conventionally reinforced concrete. However due to the randomly dispersed fibres throughout the entire concrete matrix, the composite begins to behave in a similar manner as an isotropic material. Though, this is not the case for all fibre additions. Through the process of micromechanics, a connection has been made between the microstructure of the materials used for concrete composites and the composites mechanical performance. This has allowed for tailoring of the fibres, matrix and their interface that has led to the development of Engineered Cementitious Composites (ECC's) or ultra-high performance reinforced ductile concrete.

Design & Methodology

The purpose of this research is to develop the ultra-high performance, fibre reinforced ductile concrete. The fibres which are used for research are PVA fibre. Hollow microspheres are also used to develop a new type of concrete. The compressive strength and flexural strength of the new developed concrete has been investigated in concrete lab. Further to the literature review on fibre reinforced concretes, engineered cementations composites, polyvinyl alcohol fibres and glass hollow microspheres; physical samples of Lightweight PVA-ECC's with hollow glass microsphere additives have been created and tested under external loading conditions. In order to achieve the objectives, hollow microspheres are added to the PVA fiber to eliminate the need of coating the surface of PVA fiber with oily substance. These hollow microspheres may decrease chemical bond as of surface coating. Samples were produced by mixing all the components together. The first stage involved the preparation of mix designs. The second stage attempted to make beams, small and large cubes and kept for curing. The third stage looked into characterization of design such as flexural strength and compression strength by performing test in the lab. The last stage evaluated the properties such as stress, strain and putting all the data on the graphs and did comparison of the graphs. The results analyzed and reported on in order to determine the characteristics and behavior and of lightweight PVA-ECC when exposed to these loadings. Below is the methodology of carrying out these tests and analysis of results.

Mix Design

The mix proportions as mentioned in Section 2.2.1 will be used for the mix design for this study. The PVA fiber was received in the form of 6mm long fibers. For each mix design, a total of two (2) cube specimens of 100 mm x 100 mm x 100 mm, two cube specimens of 150 mm x 150 mm x 150 mm are to be created and three (3) rectangular cross sectioned beams of 350 mm long x 50 mm wide x 50 mm deep . A total concrete volume of 0.087 m3, which includes 10% surplus as in accordance with Indian Standard IS 456:2000, is required in order to create these samples. The specific gravity of cement and silica sand is taken as 3.15 and 2.65, respectively. A total of 8 mix designs

For 4 mix designs 75-250 μm sand have been used. A sieve was used to separate the desired sand size from normal sand. Sieving is easy and convenient method for separating the particles of different sizes. The separation of sand was done using round vibratory sieves for 75-250 μm.

Figure shows the round vibratory sieves and sieves of desired size. It took long time to get 5.15 Kg sand for one mix design.

The PVA fibre in figure 10 fraction volume included in this mix design will be 1.5% throughout all mixes, expect for mix design MD1 which is plain concrete and will serve as a plain concrete control sample. The PVA fibres utilized in this research are Nylon monofilament PVA RECS15 fibres manufactured as in accordance with American Standard ASTM C-1116, Section 4.1.3 and AC-Each individual fibre is 8 mm long with a diameter of 38 mm

Due to the lack of fly ash in the current mix designs that result in poor workability, a super plasticizer showing in figure 11 proportions of 2% by weight is used for the mixes with little or no microsphere additive. Super plasticizers are known as high range water reducers. These are used to keep well dispersed particle suspended. According to Verback 1968, Super plasticizers are linear polymers with sulfonic acid group's component of polymer backbone at regular intervals. It improves the workability of concrete.

The hollow glass microspheres utilized in this study are Spherical 110P8 products shown in figure 10. These engineered microspheres represent single cells manufactured to controlled dimensions. Each cell has thin glass walls relative to its nominal diameter whereby the cell is filled with air and thus provides a hollow space. For this reason the microsphere product have reduced densities when replacing solid cementitious products of same volumes. In other words, microspheres simultaneously add volume and reduce density.

(Potters Hollow Spheres - The lightweight additive for peak performance).When viewing a collection of microspheres (cells) to the naked eye, the microspheres take on the form of fine powder, however when viewed through a microscope they take on the form of tiny ping-pong balls. It is this ping-pong ball resemblance that will also improve workability to the concrete mix due to their behavior similar to that of ball bearings thus allowing ease of ow between lubricated particles.

The glass bubbles and polymeric micro-hollow bubbles used by all had average sizes below 100µm diameter. Two variations of glass bubbles were used; a S38 and S60 Glass Bubble with a mean size of 30µm and 60µm and a density of 380 kg/m3 and 600 kg/m3, respectively.

The density for Spherical 110P8 is below the density of S60, however slightly higher than S38. Furthermore, S38 glass bubbles have a mean diameter greater than Q-Cel 5070S only. It is therefore expected that Spherical 110P8 may outperform S38 due to the smaller mean diameter of the product; however it will more than likely exhibit a greater composite density. It must be noted however that these assumptions are based on particle mean size and bulk density only as the working pressures of S38 and S60 from previous studies are unknown. Table 4 tabulates the properties of hollow glass microspheres.

Mixing Procedure

The samples moulds are first lined with a de-bonding agent, such as oil, to all internal surfaces. With the use of a vibrating plate, the sand is separated through a series of sieves whereby the 75µm – 250 µm particles are collected for mix design D1, D2, D3 and MD3. For MD1, MD2, MD4, MD5 normal size sand have been used. The cement, sand, water, superplasticizer, PVA fibres and microspheres are proportion by weight as stated in Section 4.1 for each mix design and to the accuracy of 0.2%. There is no Indian Standard for preparing fibre reinforced composite samples; however the Indian Standard AS1012.2 for the preparation of mixes in the laboratory was used with minor modifications to suit this study. The cement and sand, in addition to the PVA fibre and hollow glass microspheres where required, are first dry mixed in a motorised drum mixer for a minimum of 3 minutes. This is to ensure a good dispersion of PVA fibre and microsphere is achieved. A cover shall be placed over the drum mixer in order to assist with any loss of powder form materials. The water and superplasticizer will then be combined and added to the dry mix. This shall then be further mixed for a period of 3 minutes and then allowed to rest for 2 minutes. Then concrete was put in to the cubes and beam moulds. After 24 hours the specimens were demoulded and placed in curing room for minimum 28 days. AS 1012.8 has been followed for preparing and curing of all concrete samples.

Uni-axial Compression Test

Compressive strength test is very common test among all tests on the concrete.it is very easy to perform. Instead of that, compressive strength exhibited many needed characteristics of concrete. However, the main reason for compressive test popularity is the intrinsic importance of the compressive strength in concrete structural design (Neville 1991). In Indian Standard, method of testing concrete, only specimens which are prepared in accordance with IS 10086-1982 are accepted to be tested to determine the concrete compressive strength. Therefore, all compressive tests are performed on cylindrical specimens of 100 mm diameter with 200 mm length following IS 10086-1982 procedural requirements. A minimum of two (2) samples as dimensioned in Section 3.1 are to be created for each mix design. The specimens were covered with capped before testing to comply with the standards, The samples will then be tested via a uni-axial compression load by placing the specimens in a universal testing machine under a controlled loading rate of 20 ± 2 KN per minute. The loading shall be recorded in order to assess the compressive strength in addition to the failure behaviour of each specimen.

Stress-strain tables:

During the experiment, load is starting to apply on concrete specimen. At peak volume where concrete reaches its max ability to carry loads and cracks, for this load volume stress is equal to fc. At this point, strain is equal to εc, it's the strain that corresponds to the strain at the moment of peak volume.

However, when concrete gets out of the elastic zone, and after it's cracking point it has the ability to continue to carry loads, ability that we want to increase. During this discharge zone, although load and stress decrease, strain can continue to increase since concrete hasn't lost completely its consistency.

Permanent deformation exist in this zone and we measure the max strain εmax before concrete finally dissolves. εmax is obviously an indicator that shows a concrete's mix ability to carry loads even after reaching its cracking point.

According to that, despite showing a graph with the εmax comparison between mixes we will show the increase of ε as given by: (εmax-εc)/εc , because as the percentage of the increase is regarded to be a more crucial indicator than the absolute value of max.

However, for small cubes this kind of graph is not presented, as for many mixes we reached the max load without breaking the cubes ε=εmax .

All mixes Compression Small Cubes.

, the conclusion can be drawn that PVA fibers (D2) lead to a 10.17% increase of f_c compared to plain concrete (D1). Moreover, the addition of Hollow microspheres can lead to an extra 23.82% increase of f_c.

it suggested that a significant increase of f_c for MD1, MD2, and MD3 mixes. Fc is equal to 140MPa and the cubes were practically unable to break for the max applied load (99kN). This graph leads also to the conclusion that addition of hollow microspheres amount to the mixture (MD4, MD5) has a positive effect in ε_{max} (almost 60.0% comparing MD5 with plain concrete MD1), as long as it has the opposite effect in f_c (more than 40% decrease comparing MD4 with plain concrete MD1).

4.6 Cost Analysis

In construction projects cost remains by far the most important factor after strength and durability that decides the use of a material in that project. So to make the use of Ultra High Performance Fibre reinforced ductile concrete in construction it should be cost effective. Let us analyse the cost of PVA Fibre Reinforced Concrete to that of steel reinforced concrete. We know that the reinforcement required for columns 2-3% for beams 1-1.5% and for piles 2-5% of concrete volume.

Example

Lets take example of RCC Column, where reinforcement required is 2.5 % of concrete volume, weight of steel required in 1 meter cube will be:

$\frac{2.5}{100\times1}\times7850$ =196.25 kg. (Density of Steel =7850kg/m3)

So 196.25 kg steel reinforcement will be required in 1 cubic meter of concrete. Now as we know that 12mm steel in India costs around 45-50 Rs per Kg. So the total cost would be

196*45= Rs 8820

As per Standard Schedule of Rates and Analysis of Rates, one bar bender is required for 100 kg of steel as for 1 day, with the equipment and other miscellaneous cost of around 7.5%

So adding bar bender cost of Rs 1000 approx. and the miscellaneous cost of Rs 736.5. The total reinforcement cost would sum up to Rs 10,556.5 for 1 cubic meter of concrete.

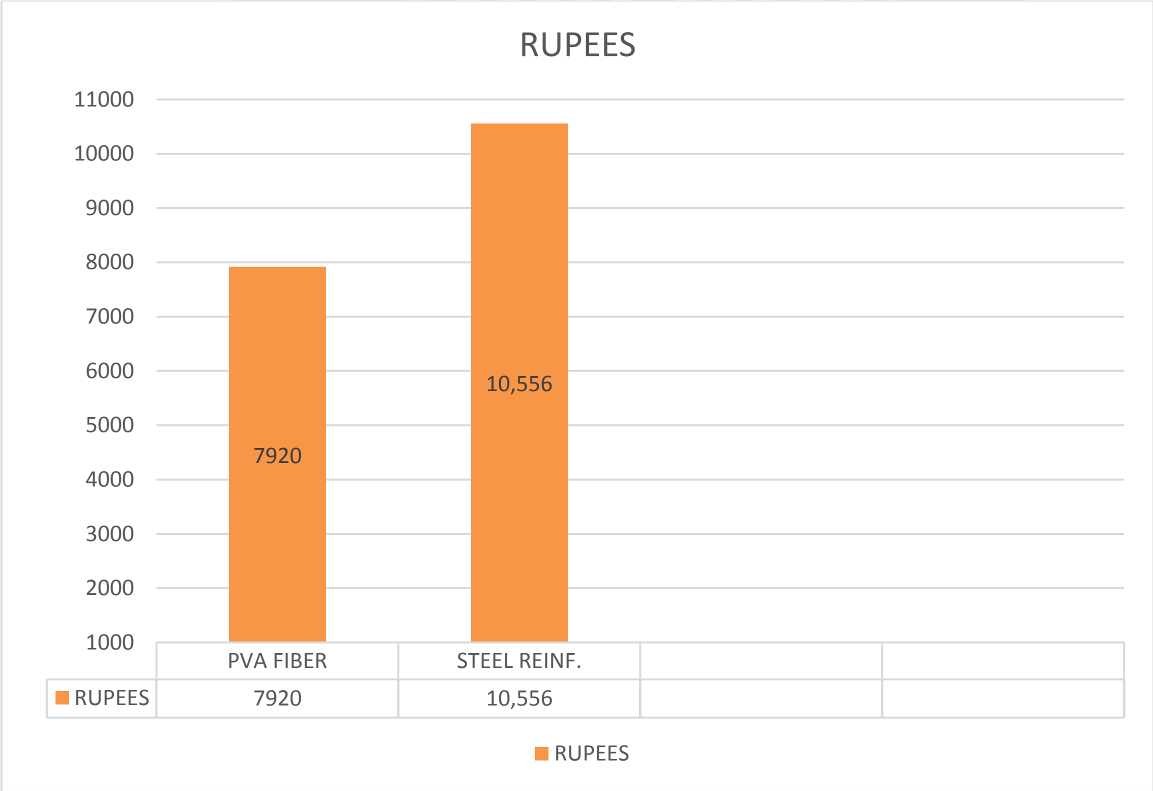
For the same volume of concrete the amount of PVA Fibre reinforcement required will be:

2/(100*1)*2400=48 kg

So 48 kg PVA Fibre reinforcement is required in 1 cubic meter of concrete. Now we know that 1 kg of PVA Fibre costs around Rs 140-180.

48*165= Rs 7920

Thus the total reinforcement cost of PVA fibre in concrete would sum up to Rs 7,920 for 1 cubic meter of concrete.



Cost Analysis of PVA Fibre

Thus it is clear by the cost analysis that by the use of Ultra High Performance Fibre reinforced ductile concrete in construction is cost effective as compared to that of steel reinforced concrete. So to make the use of PVA-ECC more effective a bit of research needs to be done to make the necessary changes as to make it more common to save both time and money.

Future Work

- In order to utilize the maximum achievable capacity of FRC composites, the fibre matrix interaction plays an important role. Therefore, testing with coated PVA fibre and microsphere is greatly emphasized. With this testing and study required FRC composite behavior may be accomplished.

- In order to get exact result for compressive strength for large cubes, test should be performed on 28 days.

- To reduce the cost issues came up from the use of cement in concrete, another available cementitious material such as fly ash and slag should be used.