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Hysteresis Behaviour of Mass Concrete Mixed with Plastic Fibre under Compression

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Abstract**—**Unreinforced concrete is a comparatively brittle substance when exposed to tensile stresses, the required tensile strength is provided by the introduction of steel which is used as reinforcement. The strength of concrete may be improved tremendously by the addition of fibre. This study focused on investigating the compressive strength of mass concrete mixed with different percentage of plastic fibre. Twelve samples of concrete cubes with varied percentage of plastic fibre at 7, 14 and 28 days of water submerged curing were tested under compression loading. The result shows that the compressive strength of plastic fibre reinforced concrete increased with rise in curing age. The strength increases for all percentage dosage of fibre used for the concrete. The density of the Plastic Fibre Reinforced Concrete (PFRC) also increases with curing age, which implies that during curing, concrete absorbs water which aids its hydration. The least compressive strength obtained with the introduction of plastic fibre is more than the targeted 20 N/mm^2 recommended for construction work showing that PFRC can be used where significant loading is expected.

Keywords**—**Compressive strength, plastic fibre, concrete, curing, density.

I. Introduction

CONCRETE is a composite material composed of water, coarse granular material (the fine and coarse aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together. One of the main advantages of conventional concrete is its self-weight. Hence, concrete can be classified into three categories namely, light weight concrete, normal, and heavy weight concrete depending on their density.

Light Weight Concrete (LWC) has a density which varies between 300 to 1850 kg/m^3, it is made by inclusion of air which is achieved by (a) replacing original mineral aggregate by light weight aggregate, (b) Introducing gas or air bubble in mortar (c) Omitting sand fraction from concrete to make "fine concrete" [1]. The relatively low density of LWC makes it have a lower dead load in comparison to other concrete types.

The density of normal concrete is of the order of 2200 to 2600 kg/m^3 while the density of heavy weight concrete varies from 3360 to 3840 kg/m^3 depending on the nature and type of natural aggregate used [2].

Concrete may also be classified according to inner structure, bulk unit weight (average density), heavy and light concrete. It can also be classified based on the type of binding agent (cement, lime,) etc. [3]

A. Mass Concrete

The generation of high heat of hydration distinguishes mass concrete from other forms of concrete [4]. Any concrete volume with a large size such that extra attention is given to the heat of hydration to minimize crack is referred to as mass concrete. Significant tensile stresses and strains may result from the restrained volume change associated with a decline in temperature as heat of hydration is dissipated [5]. Measures should be taken where cracking due to thermal behaviour may cause a loss of structural integrity and monolithic action, excessive seepage and shortening of the service life of the structure, or be aesthetically objectionable.

Mass concrete is used for thick-sectioned structures such as dams, mat foundations, pile caps and other structures whose minimum dimension exceeds 3 feet [6]. The output of any system is a function of both its previous and current input, this study therefore is carried out to understand and improve upon the previous studies done on the behaviour of mass concrete mixed with plastic fibre.

B. Fibre Reinforced Concrete

Concrete, being a homogenous mixture of different materials, possesses different mechanical strength and behaves like a brittle material under the application of normal stress and impact load, its tensile strength increases tremendously when reinforced with steel. The addition of steel reinforcement however needs to be carefully monitored to control the development of micro cracks. A potentially superior solution is the use of discontinuous, randomly distributed fibres in place of steel reinforcement, fibres combine well with constituents that make up a concrete matrix and improve the flexural and tensile strength of concrete. There are different types of fibre reinforced concretes depending on the material used in making the fibre. The common ones are steel fibre reinforced concrete, glass fibre reinforced concrete, synthetic fibre reinforced concrete and natural fibre reinforced concrete [7].

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Open Science Index, Civil and Environmental Engineering Vol:10, No:7, 2016 publications.waset.org/10006136/pdf

C. Structural Importance of Fibre Reinforced Concrete

The ductility of concrete after cracking has been found to improve with the addition of fibres [8]. The addition of fibres thus delay sudden crack appearance in concrete. The ability of fibres to control cracks in concrete affects post cracking behaviour of providing the much needed ductility for the concrete. [9]. The stretching ability under load of reinforcing fibre is greater than that of mass concrete; initially, the composite system will function as an un-reinforced concrete. However, with additional loading, the fibre reinforcing will be activated to hold the concrete mix together. The characteristics of fibre reinforced concrete depend upon the type of fibre utilized, volume proportion of the fibre, ratio of length of the fibre to the diameter of the fibre, dispersal, direction and concentration of fibres. These conditions will improve the mechanical properties, including toughness, ductility, tensile strength, shear resistance and loading limit of the fibre reinforced concrete. The composite system of fibre reinforced concrete is assumed to work as if it were non-reinforced until it reaches its "first crack strength". It is from this point that fibre reinforcement takes over and holds the concrete together. Different materials are used for fibre reinforcement such as Plastic, Nylon, Asbestos and Carbon fibres.

The total volume of the composite material required determines the amount of fibre to be added. The ratio of cement to fibre is the volume fraction while the ratio of fibre length to diameter is called the Aspect ratio. If the fibre's modulus of elasticity is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increasing the aspect ratio of the fibre usually segments the flexural strength and toughness of the matrix. However, fibres that are too long tend to "ball" in the mix and create workability problems.

II. Materials and Methodology

A. Materials

Cement, river sand, crushed granite aggregates passing IS 20 mm sieve and retained on 4.75 mm sieve, Potable water of pH value 6.72, and plastic fibre (Straw).

B. Methodology

Cement, sand and gravel were mixed in the ratio 1:2:4 with water cement ratio of 0.7. The slump achieved was 162 mm. locally sourced plastic straw with an average length of 29 cm was used as the fibre. The straw was cut into small chips of about 3 cm and then mixed with concrete in a standard concrete mixer which was then poured into 24 Standard cubes of dimensions 100 mm x 100 mm x 100 mm. The moulds were tightly fitted such that no space exists between the plates. Also, mass concrete was poured in a different mould without plastic straw to serve as control in order to compare the compressive strength of the one mixed with plastic fibre and the one without plastic fibre. The concrete cubes were cured using Water Submerged Curing (WSC) for 7, 14 and 28 days before they were crushed to determine the corresponding compressive strengths. Other laboratory tests that were carried out include:

a. Sieve Analysis
b. Specific gravity
c. Water Absorption Capacity
d. Slump Test

III. Laboratory Tests

A. Sieve Analysis

These are preliminary tests carried out to ascertain the fitness of materials used. The grain size particle test and the specific gravity test were the preliminary test done. Grain size analysis of samples is of paramount importance in selecting suitable type of soil to be used in construction. The test was carried out in accordance with ASTM D422 62 in order to select the grain size of sand and granite [10].

B. Specific Gravity Test

The ratio of the weight of sample to the weight of equal volume of water is termed specific gravity. The specific gravity of cement in accordance to ASTM C1884 can be used to determine the weight of sample to equal weight of water and was adopted in determining the volume of the samples that was used in the mixing of the concrete.

C. Water Absorption Capacity of Coarse Aggregate

The water absorption capacity of the aggregates plays a fundamental role in the quality of concrete. Water is required by cement to complete its hydration and achieve its strength. However, the amount of water to be added must be carefully controlled as it is a function of the weight of other constituents that makes up the concrete. Addition of excess water increases the porosity of concrete and reduces its strength and durability whereas shortage of water decreases the workability of concrete and leads to incomplete hydration which also affects the strength of concrete. Therefore, the water absorption capacity of coarse aggregate is

$$\text{Water absorption capacity } (\%) = \frac{W_s - W_B}{W_B} \times 100\% \qquad (1)$$

W_B = Weight of sample; W_s= Weight of saturated surface dry sample

$$\text{Water absorption capacity } (\%) = \frac{550-500}{500} \text{ X } 100 = 10\%$$

D. Concrete Slump

TABLE I
SLUMP TEST FOR MIX RATIO 1:2:4

No	W / C RATIO	SLUMP (mm)
1	0.3	150
2	0.4	152
3	0.5	158
4	0.6	160
5	0.7	162

Workability is the ease with which the ingredients can be mixed and the resulting mix handled, transported and placed with little loss in homogeneity. The slump test is very useful in

Open Science Index, Civil and Environmental Engineering Vol:10, No:7, 2016 publications.waset.org/10006136/pdf

detecting variations in the uniformity of a mix. The slump (in mm) can be adjusted by varying the water cement ratio.

E. Compressive Strength Test

The standard method of specifying concrete strength for structural applications is by determining characteristic compressive strength, which is the maximum compressive stress a concrete material, is capable of withstanding. The compressive strength of each PFRC was tested using the compressive testing machine. Cubes for each age and each percentage were crushed. The Weight, Density, Crushing load, Compressive Strength, for the different % of fibre included with their respective curing ages are shown in Table II. Also, the relationship between % plastic fibre and compressive strength for each curing age is shown in Tables II-IV.

$$\text{Compressive Strength} = \frac{\text{Crushing load (KN)}}{\text{Area of cube}(mm^2)} \quad (2)$$

Compressive Strength of a material can also be obtained from Stress-Strain graph where

$$\text{Stress} = \frac{\text{Load Applied (kN)}}{\text{Oringinal Area of Specimen}(mm^2)} \quad (3)$$

$$\text{Strain} = \frac{L - L_0}{L_o} \quad (4)$$

where L is the Current Specimen length and L_o is the original length of specimen. The difference in value is due to the fact that the specimen will shorten and tend to spread in the lateral direction.

TABLE II
AVERAGE WEIGHT, DENSITY AND COMPRESSIVE STRENGTH OF CONCRETE

S/N	%PFRC	AGE (days)	Average Weight (g)	Density (kg/m^3)	Crushing load (kN)	Compressive strength (N/mm^2)
1	0	7	2473	2473	256.0	25.60
2	0	14	2495	2495	318.9	31.89
3	0	28	2525	2525	334.3	33.43
4	0.1	7	2479	2479	265.8	26.58
5	0.1	14	2493	2493	323.0	32.30
6	0.1	28	2528	2528	344.0	34.40
7	0.2	7	2485	2485	280.2	28.02
8	0.2	14	2498	2498	328.9	32.89
9	0.2	28	2530	2530	350.6	35.06
10	0.3	7	2490	2490	294.0	29.40
11	0.3	14	2514	2514	337.0	33.70
12	0.3	28	2532	2532	361.3	36.13

TABLE III
RELATIONSHIP BETWEEN % PLASTIC FIBRE AND COMPRESSIVE STRENGTH AT 7 DAYS

S/N	AGE(DAYS)	%PF	Compressive strength (N/mm^2)
1	7	0	25.60
2	7	0.1	26.58
3	7	0.2	28.02
4	7	0.3	29.40

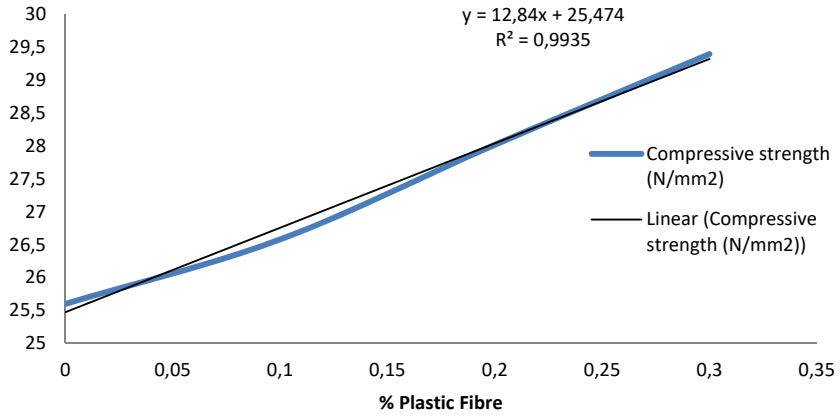


Fig. 1 Compressive strength (N/mm^2) against % Plastic fibre at 7 days

TABLE IV
RELATIONSHIP BETWEEN % PLASTIC FIBRE AND COMPRESSIVE STRENGTH AT 14 DAYS

S/N	AGE(DAYS)	%PF	Compressive strength (N/mm^2)
1	14	0	31.89
2	14	0.1	32.30
3	14	0.2	32.89
4	14	0.3	33.70

TABLE V
RELATIONSHIP BETWEEN % PLASTIC FIBRE AND COMPRESSIVE STRENGTH AT 28 DAYS

S/N	AGE (Days)	%PF	Compressive strength (N/mm^2)
1	28	0	33.43
2	28	0.1	34.40
3	28	0.2	35.06
4	28	0.3	36.13

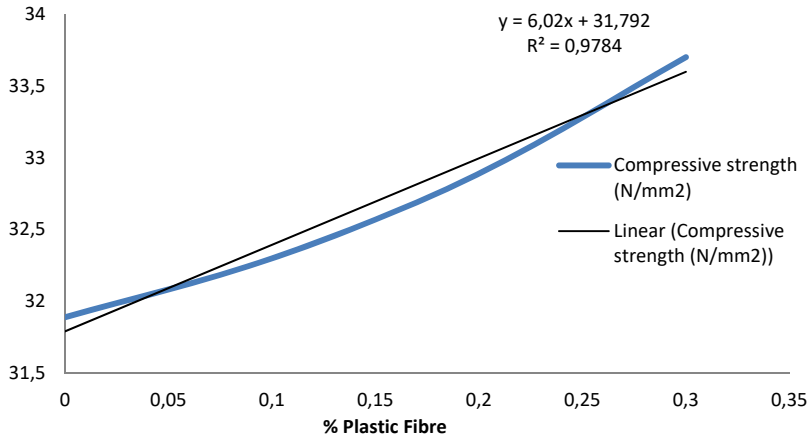


Fig. 2 Compressive strength (N/mm^2) against % Plastic fibre at 14 days

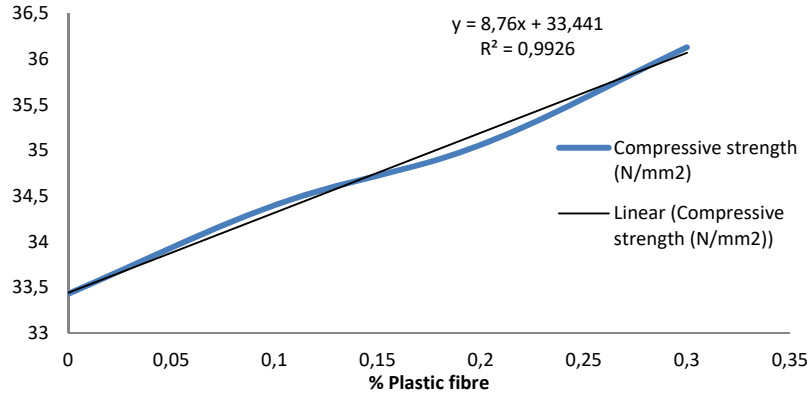


Fig. 3 Compressive strength (N/mm^2) against % Plastic fibre at 28 days

Based on the compressive strength obtained at 7, 14 and 28 days of curing as presented in Tables III-V, regression analysis for compressive strength against % plastic fibre was carried out and the following regression equations were obtained:

- At 7 days $Y = 12.84x + 25.474$, $R^2 = 0.9935$
- At 14 days $Y = 6.02x + 31.792$, $R^2 = 0.9784$
- At 28 days $Y = 8.76x + 33.441$, $R^2 = 0.9926$

where R^2 is the coefficient of determination that shows how well the regression line approximate the real data values. The average R^2 value of 0.9882 is very close to 1 indicating the regression line perfectly fits the plotted data, implying high accuracy.

IV. Results and Discussion

A. Laboratory Experiments

As expected, from the sieve analysis, the percentage cumulative weight retained increases as the sieve sizes decrease. The water absorption capacity of the coarse aggregate was found to be 10%. This value was considered in the design of mix in other to achieve the appropriate nominal mix to avoid excess use of water in concrete mixes. Slump tests results shows that the slump of PFRC increased with increase in water cement ratio. That is, the nominal mix exhibited the least slump of 150 mm which falls on 0.3 w/c ratio, while the highest slump is 162 mm obtained for w/c ratio of 0.7. The density of the PFRC also increases with curing age, which implies that during curing, concrete absorbed water which aids the hydration. The density of the specimens ranged from 2473 to 2532 Kg/m^3. This lies within the range of 2200 to 2600 Kg/m^3 specified as the density of normal weight concrete [11].

B. Compressive Strength of PFRC

Compressive strength of PFRC increased with rise in curing age. Compressive strength increases for all dosage of fibres, this is due to increase in confinement provided by bonding characteristics of the fibre, and hence compressive strength increases with the increases in the fibre content and the targeted mean compressive strength of 20 N/mm^2 was achieved as the minimum compressive strength was 25.6 N/mm^2 at 7 days, which is more than the target mean compressive strength of concrete.

V. Conclusion

Plastic fibres do not disperse properly in the mixing water. Addition of fibres to dry mix was found to be more practical. Compressive strength of concrete mixed with fibre increases with increasing fibre content. This which can be seen in

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previous researches relating to Fibre Reinforced Concrete. The compressive strength of concrete used in construction for general use in construction must be at least 20 N/mm^2, the Plastic fibre concrete can thus be used since the minimum compressive strength obtained is 25.6 N/mm^2. Furthermore, the range of compressive strength obtained is between 25.6 - 36.3 N/mm^2 thus the concrete can be used for applications where surface spalling is not acceptable, and significant loading is expected. One example is paving curbs, where heavy traffic may drive on the surface. Other uses include building footings, bond beams, grade beams, and floor slabs where heavy loads may be moved or stored

VI. Recommendation

- Plastic fibre waste can be put into more productive use in order to reduce environmental pollution.
- Concrete mixed with plastic fibre should be used where high compressive concrete strength is required
- Further research to test for the tensile and compressive strength of fibre concrete by the addition of steel fibre as it the latest fibre used recently should be considered so as to compare the outcome with the strength of plain concrete.

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