Seventh International Conference on Construction in the 21st Century (CITC-VII)
"Challenges in Innovation, Integration and Collaboration in Construction & Engineering"
December 19-21, 2013, Bangkok, Thailand

Effectiveness of Polypropylene Fibre in Improving the Flexural Capabilities of Light Weight Aggregate Concrete

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Abstract

The presented study examined the flexural behavior of lightweight aggregate concrete modified with Polypropylene (PP) fibres through testing of six (06) beam specimens casted, cured and tested after 28 days for the purpose. The experimental design included mix design of concrete at a target strength of 21 MPa for control sample Natural aggregate (NC) as well as for synthetic aggregate (Light Weight Aggregate) modified with PP Fibers (LFC). Compressive strengths of both categories of concrete were also evaluated by crushing the cylindrical samples at the age of 7, 14, 21 and 28 days. The casted beams were later subjected to application of two point loading test till failure. It was found that the LFC was better resistant to cracks as compared to NC both in terms of number and crack width. It can be concluded on the basis of results that the light weight aggregate if modified with PP fibres could revolutionize the concept of using lightweight aggregates in regular structures consequently saving the environment from ill effects due to production of natural aggregates. Also since the LFC is light weight concrete, this advantage will result in reduced quantity of steel required which in turns could affect the overall cost of structure.

Keywords

Light Weight Aggregate polypropylene Fibre Concrete (LFC), polypropylene (PP), Natural aggregate concrete (NC), flexural behaviour, compressive strength.

1. Introduction

Concrete constitutes of a mixture of sand, aggregates, cement, water and admixtures, which when set and hardened resembles a stone. The heterogeneity of materials in concrete greatly affects the strength, workability and its durability. Concrete is known to have very good compressive strength but is weak in tension, to overcome this drawback one more constituent is added to it which is steel. The introduction of steel brings forth some extraordinary flexural strength because of its own force resisting properties and also because of its ability to make perfect bonding with concrete.

In the production of concrete, aggregates contribute 70-75 % by volume. As such the weight of concrete is highly dependent upon the weight of aggregate used. This in turn increases the steel requirement in the concrete consequently increasing its cost. The use of synthetic aggregate commonly known as lightweight aggregate is being experimented by the engineers and scientists to reduce the weight of concrete through replacement of natural aggregates. These light weight aggregates reduce the dead weight of structure which consequently helps in reducing the percentage of steel required thereby reducing the cost of RCC structure. Also it is estimated that production of 1 metric ton of natural aggregates from the quarry requires energy of order of 1.650 kWh, which in today's world of sustainability is little too high to swallow. Moreover the bulk production of aggregates from rocks is a burden to existing natural resources. As such there is a need for replacing the conventional aggregates with light weight aggregates in a more consistent manner than ever before. Light weight aggregates despite being known for their existence for several years have not yet replaced the conventional aggregates in a normally designed structure due to its weakness in flexure that results in large number of cracks.

The addition of polymer is being investigated by the researchers of late to bring more durability to the concrete and make concrete less dependent upon steel for driving its flexural strength. One such polymer is PP is chemically inert and which once mixed with concrete gives exceptional results in controlling cracks and increasing the ductility of the members incorporating such materials.

This study has investigated the use of PP in combination with light weight aggregate to come up with a concrete (LFC) and comparing its properties with normal weight aggregate concrete (NC) in order to know whether the introduction of PP will make light weight aggregate concrete equally trustable to be used in important structural members in a typical concrete built structure or not.

1.1 Objective and Scope

The presented study set forth the following objectives:

- PP modification of concrete incorporated with locally manufactured synthetic light weight aggregates (LFC)
- Evaluation of Compressive and flexural strength through laboratory testing
- Comparison of LFC concrete with NC in terms of strength, load bearing capacity and cost incurred.

The scope of this project contains fabrication of beam specimen for control (NC) and modified concrete (LFC) for testing under two concentrated point forces. Both configuration of concrete were mixed according to the mix design performed to achieve targeted compressive strength of 21MPa, evaluated from testing of standard cylinder prepared. The result thus obtained during the testing will be compared and discussed.

1.2 Literature Investigation

This section presents the literature survey carried out in this study to set the experimental program. The European used lightweight aggregate in 2000 BC during Roman period to build Pantheon, the aqua duct and the coliseum in Rome. It is envisaged that light weight aggregates were also used in the construction of Pyramids in Mexico during Myan Period (Chandra S and Berntsson L, 2003). Investigation of the behavior of light weight aggregate concrete (Shafigh et al., 2011) and examined flexural behavior during the beam test, they conclude that light weight aggregate concrete should not be prepared for high target compressive strength member. A research endeavor (Kiliç et al., 2003) for determination of compressive, flexural strength and unit weight requirement of lightweight aggregate was executed. They found satisfactory values for their use in light weight concrete. Also they concluded that the light weight aggregates from different sources will yield different results, which would mean that the production of strength of light weight concrete is also influenced by the source from which light weight aggregate is derived. The investigation (Muyasser et al., 2011) showed that the elastic stage of normal weight concrete is lesser than other stages i.e. appearance of first crack and stress redistribution. They concluded that the steel in light weight concrete yield much before normal weight concrete. Toughness index of concrete were found to have increased with Polymer and carbon addition. Fibrillated PP Fiber was used to cast cylindrical cubical specimens at target strength of 3000 Psi (20MPa). The fibres were mixed in different proportion and of different length. The result in comparison to control specimen showed that the addition of PP fiber increased the average split tensile strength by at least 40%.

The literature review concludes that the concrete produced by using light weight aggregates are dependent upon the source, has limited flexural strength but that strength can be improved by addition of polymers.

2. Research methodology and Materials in the Study

The research methodology included Collection and determination of properties of natural aggregate, synthetic light weight aggregate, Ordinary Portland Cement and PP fibre, performance of mix design through trial preparation of cylinder, fabrication and casting of prismatic beam section, testing of cylinder and beams, result analysis and discussion.

Normal weight aggregates were collected form outskirts of Karachi city and their important properties were determined in the laboratory. Table 1 summarized the properties of these aggregates, these properties confirms to the requirements of ASTM C33-01.

Table 1: Properties of Normal and Light Weight Aggregates

	Normal Weight Aggregate		Light Weight Aggregate	
Property	Coarse	Fine	Coarse	Fine
Absorption,%	0.90	NA	4.50	1.20
Compacted density, Kg/m^3	1540	1781	757	1060
Loose density, Kg/m^3	1393	1679	656	996
Moisture content,%	0.30	0.60	0.70	0.60
Specific gravity	2.5	2.6	1.7	1.9
Fineness modulus	NA	3.05	NA	3.46

For preparation of lightweight aggregates concrete, the light weight aggregates were donated by the Council for Works and Housing Research (CWHR). These aggregates were prepared by burning hard grey shale stone in a rotary kiln at specified temperature of around 1200ºC. The grey shale stone were extracted from the coastal line of Baluchistan province in Pakistan. The CWHR supplied the required material in the required size and weight for this study.

PP fibres are available in different forms, sizes and groups, one that used in this study were fibrillated, having length of 13 mm. Other important properties related to PP fiber used were supplied by the local manufacturer. The properties are shown in table 2 of this manuscript. Further to that, the amount of fiber incorporated is again by trial and error and usually the range is between 0.1%-5percent (Vikrant et al., 2012), in this study 0.1% PP was added to the concrete.

Table 2: PP Fiber Used in the Study

Property	Value
Density, Kg/m^3	897
Specific gravity	0.91
Young's modulus of elasticity, MPa	3450.4830
Tensile strength, MPa	485-760
Elongation at break, percent	10-15

2.1 Mix Design

Once the material was procured the next task was to perform mix design for production of NC and LFC. Since the objective of this study was to cast beam members therefore a targeted compressive strength of 21 MPa was selected for determining the proportions of ingredient in the respective concrete. The mix design was accomplished by preparing trial cylindrical specimen and water cement ratio. The summarized mixed design is illustrated in Table 3. The targeted strength of 21 MPa was achieved by preparation of trial batches of concrete in the form of cylinders (16 each).

Table 3: Mix Design

Description	NC	LFC
Max aggregate size, mm	12.7	12.7
W/c ratio	0.68	0.5
Mix proportions`	1:2.5:4.5	1:3.4:1.8
Designed slump, mm	50.8	50.8
Target strength (fc'), MPa	21	21
Modulus of elasticity, GPa	21.5	21.5
PP fiber, g	NA	56

Once achieving the desired strength, six (06) reinforced beams were casted as per experimental design of this study. In order to obtain a failure in the beams, all the beam sections were designed as under reinforced. Table 4 presents the summarized detail of the beam casted in this study. RCC beams of dimensions 1800 x 200 x 152 mm was casted for both aggregate types with 2-13 mm bottom bars and 2-10 mm compression bars having shear reinforcement of10 mm bars spaced at 90 mm c/c.

2.2 Testing of Cylinders and Beams

Forney compressive testing machine was used to test the cylinder casted for trial mixes and their compressive strength was determined at 3, 7, 21 and 28 day respectively. Moreover, 12 cylinders were poured alongside the beam to verify the design compressive strength, were also tested in the same machine after 28 days. All the beams were tested in a Universal Testing Machine (UTM) for two point loading; the machine has a capacity of applying load up to 500 KN. The arrangement for two point loadings were accomplished with the help of two steel plates placed at 610 mm from both ends of the beam. A steel girder was placed over the steel plates which transfers the load exerted by the machine. Mid-span deflections were measured at 5 KN intervals alongside surface strains at deformation rate of 1 mm/sec.

2.3 Surface Strains and Crack Width

Surface strains were measured through ‘Demec’ buttons that were fixed to the beam profile with the help of epoxy solution under the loading points. Figure 1 illustrates the position of Demec gauges fixed to the beam. The crack widths were measured using filler gauges at the ultimate load. All the cracks were identified by markers to infer and comprehend their pattern.

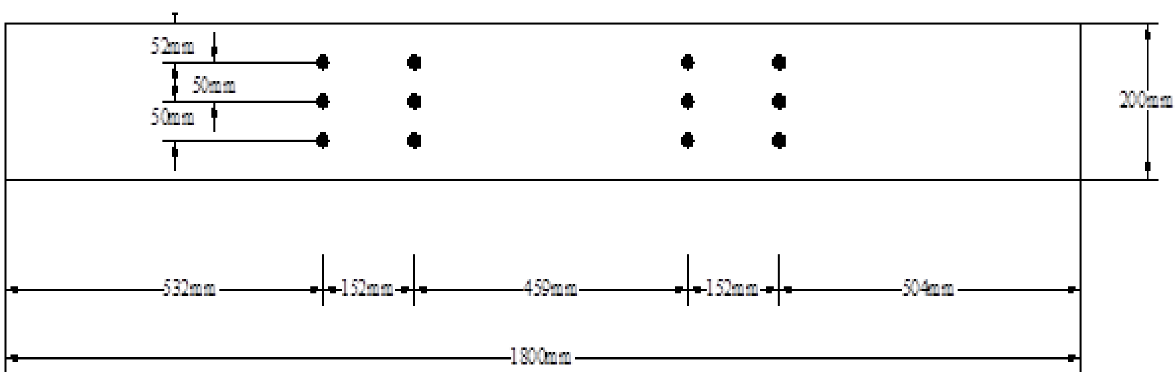

Figure 1: Placement of Demec Buttons in Beam

3. Results and Discussions

This section is dedicated on the observed results and discusses the reason of such observation at length to draw a comparison between different configurations of concrete in this study. The main focus of discussion includes the compressive strengths, Load-deflection behavior of beams, crack width measurement and ductility index.

3.1. Compressive strength

The compressive strength were determined by testing all (32) cylinders, made of NC and LFC using Forney Apparatus. The measured strength is being illustrated in the form of bar charts in Figure 2. The results verified that the targeted mix design strength of 21 MPa was achieved by the mix incorporated for both types of concretes.

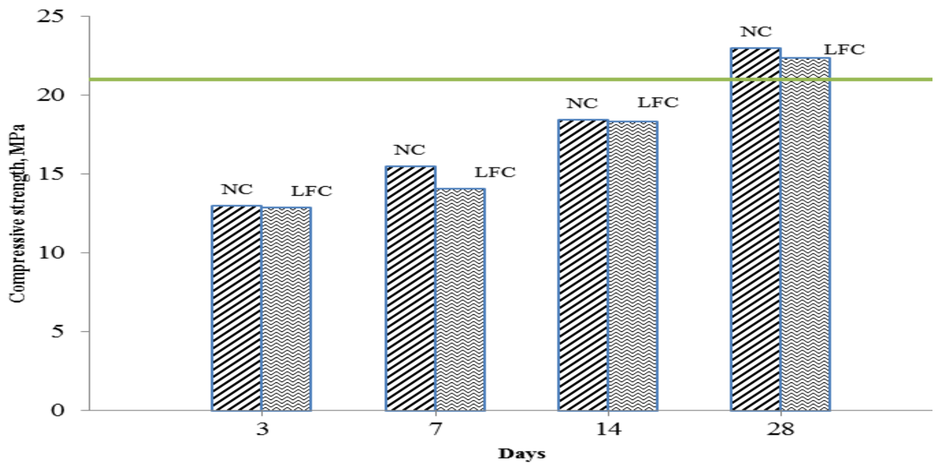

Figure 2: Compressive Strength of NC and LFC

The result also demonstrated that the compressive strength of LFC is less as compared to NC, which makes sense since the normal weight concrete derives its strength from the aggregate which of course are superior to those from light weight aggregate used in this study. However the incorporation of fibres in light weight mixes have been able to improve the compressive strength of light weight aggregate concrete making it equally good to NC, mathematically upto the extent of 97% which is noteworthy.

3.2. Load-deflection behaviour of beams

All six (6) beams, casted as NC and LFC, concretes were tested till failure. The values of loads and their corresponding deflection were measured at every 5 KN load increment. The behavior of load and deflection in all samples of concrete tested in this study is shown in Figure 5. The results are very inspiring as it shows that the addition of fibres have increased the ductility of the concrete and ultimately resulted in more load carrying capacity of the light weight concrete. Moreover the ultimate load capacity of LFC has increased by approximately 9% as compared to NC which is very much conveyed from the illustrated Figure 3.

3.3. Crack Patterns and Crack width

The cracks patterns in all the beams tested in this study shows similar behavior in terms of their origination and propagation. All cracks are hairline emerging from the bottom and extending vertically upwards. This shows that the mode of failure of all the beams were due to the yielding of steel reinforcement as expected. Detailed crack patterns of each beam are shown in Figure 4 and Figure 5 respectively.

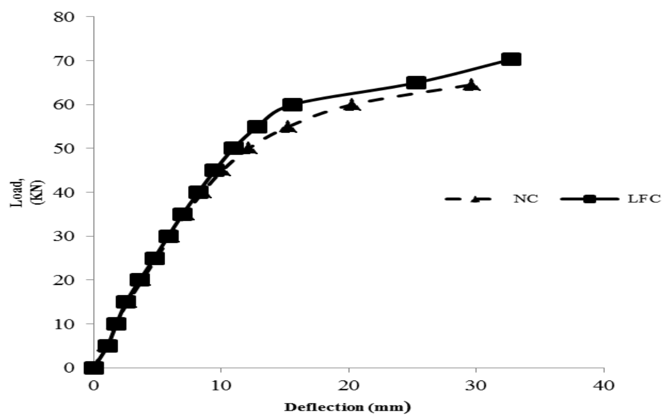

Figure 3: Load Deflection Behavior NC and LFC

Figure 4: NC Beam after Failure **Figure 5: LFC Beam after Failure**

Crack widths in the beams measured with filler gauge measured in all samples of concrete are being represented in Figure 6. The Figure illustrates that there is an efficient decline in crack widths in LFC concrete as compared to NC. The possible reason for such declination of width is due to the fibers that act as a crack arrester.

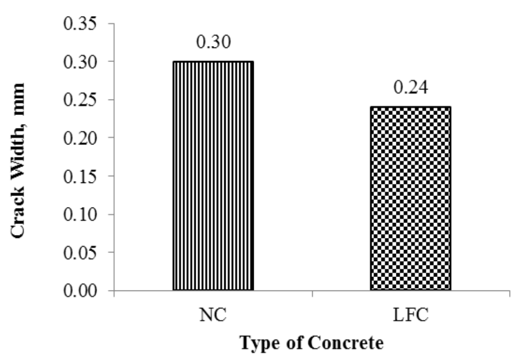

Figure 6: Average Crack Width (mm)

3.4. Ductility Index

The deflection data were collected at different stages of loading to calculate the deflection ductility index of the different concretes in this study. The ductility indices are the indication of the lateral load sustainability of structure such as those experienced during the earthquake.

$$\mu_\Delta = \frac{\Delta_u}{\Delta_{cr}} \qquad (1)$$

Generally it is believed that the ductility index should be greater than 3 to have a stable structure. The deflection ductility of LFC was found out to be 2.62 which are 10% more than NC. From the figure 7, it is noticeable that the fiber incorporated concrete (LFC) has higher deflection ductility index as compared to that of concrete made with NC making fiber addition ideal for increasing the ductility index in a typical concrete structure suggesting that it would provide sufficient warning before its complete failure.

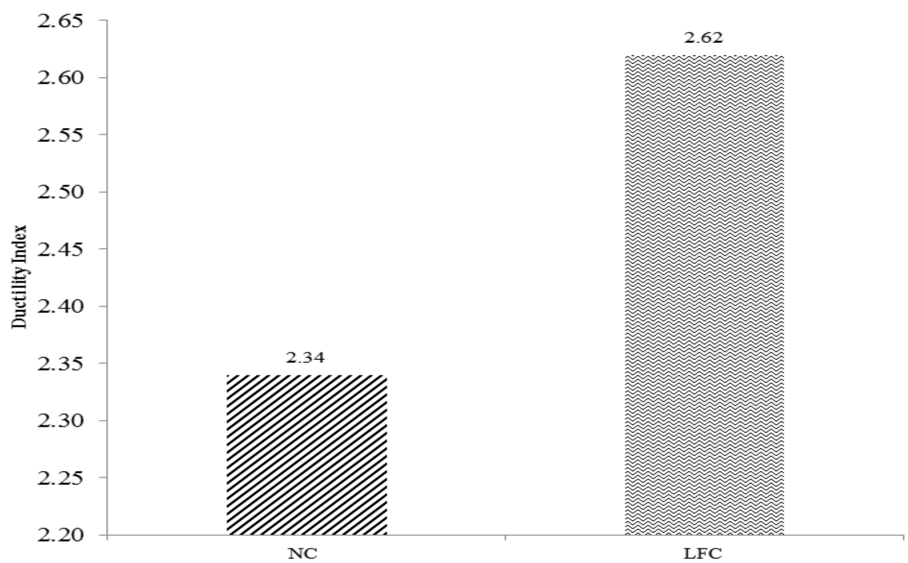

Figure 7: Ductility Index

3.5 Cost Estimation

Two identical room structures were assumed comprising of a 3m x 3m RC slab transferring load on the beams beneath. One structure being made of NC while the other being LFC. Thus a design of beams was carried out incorporating the dead load of the slab. It was found that the steel required in LFC beam was reduced by 21% as compared to NC due to the decline in the dead load of the structure when it is built with LFC. Further to that if the cost estimation were also executed to infer the variation in cost for each beam element of reinforced concrete prepared in this study. The results suggest that LFC beams are 14% costly than NC beam.

4. Conclusions

The following conclusion can be summarized from this study

- Both type of concrete displayed designed compressive strength at 28 days
- The ultimate load capacity of LFC has increased by approximately 9% as compared to NC
- The LFC specimen showed more resistant to crack occurrence as compared to NC specimen both in terms of occurrence and crack width
- The unit weight of lightweight aggregate helps in 21 % reduction in the quantity of steel required. The decrease value of steel requirement would mean that the cost of preparing LFC is 14% more than NC since the manufacturing of lightweight aggregates is not on mass basis, but it may serve as an efficient alternative for NC.

5. Recommendations

The following recommendations are being proposed regarding the LFC in order to enable its use in the construction industry:

- Since the beams were tested in flexure hence it is important to determine the shear response of the LFC mixes that may be explored in future studies
- Though the LFC has a higher value of ductility index, its seismic behaviour is still questionable and must be investigated.
- There is always a question of economy in such modified mixes hence a detail comparative cost analysis is essential to be carried out to make it candidate in the construction industry
- Last but not least is to make lightweight aggregates manufacturing more cost effective.

6. Acknowledgements

- The author(s) would like to acknowledge the efforts made by the undergraduate students for carrying out the tasks with full dedication
- The cooperation of CWHR for providing light weight aggregate free of cost and for their continuous support.

7. References

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