A review on strength characteristics of GGBS based fiber-reinforced lightweight aggregate concrete

S Sindhuja, K Saketh Raman and P Bhuvaneswari*
School of civil engineering, SASTRA Deemed University, Thanjavur – 613401, India.
Email: *bhuvaneswari@civil.sastra.edu

Abstract: This study is a review on the strength characteristics of Lightweight concrete (LWC) using lightweight expanded clay aggregate (LECA), supplementary cementing material (GGBS) and micro-steel fibers at its optimum percentages. Based on the review of literatures, preliminary experiment is conducted to determine the effect of partial replacement of conventional coarse aggregate with lightweight expanded clay aggregate (LECA) on its strength characteristics. Comparison is made with conventional concrete to check the suitability of structural lightweight concrete for various construction purposes. A total of 14 cubes of size 100 mm x 100 mm x 100 mm are cast by varying the percentages of LECA as 30%, 50% and 100%. On comparison, it is noted that the density of concrete decreased in the range of (6.2%–38%) with increase of LECA content, meanwhile strength characteristics were reduced. So in order to achieve enhanced strength characteristics by retaining the benefits of LECA, cement was partially replaced with Ground granulated blast furnace slag (GGBS) at its optimum percentage (40%) and Micro steel fibers are also added to improve tensile characteristics and to prevent micro cracks in the Lightweight concrete specimens.

1. INTRODUCTION

1.1. General
In the construction industry, concrete is one the most important materials and has been extensively used in all major constructions. As we know, concrete consists of cement, water and aggregates (coarse and fine aggregate), where aggregates consume a major volume of about 70% in which the characteristics of concrete and strength attainment depend on the coarse aggregates whereas the workability of concrete depends on the fine aggregates. This results in high density concrete leading to heavy self-weight. LWC is the concrete which is produced using lightweight aggregates. Light weight aggregates contribute to low density concrete which aids in the reduction of dead load. Thus it is gaining popularity in the recent years as it aims to reduce the self-weight mainly in case of weak soil and tall structures.

LWC cannot be said as stronger than conventional concrete so it can be utilized in the structures where lightness of the concrete is given more priority than its high quality. Structural light weight aggregates find its application in elevated structures and other important constructions due to its favorable properties like (i) Higher strength/weight ratio (ii) lower density (ii) Reduced self-weight (iii) lower transport and handling costs (iv) Faster rate of construction and (v) Better insulation against sound and heat (vi) Lower coefficient of thermal expansion. The structural LWC is mainly used to reduce the dead load of the construction which thereby reduces the cross section of structural members and reinforcing steel, resulting in lesser overall cost of construction.
Generally, in case of structural applications, strength of concrete must be greater than 17 MPa. The structural LWC has density in the range of 1440-1840 kg/m$^3$ when compared with the normal concrete having density in the range of 2240-2400 kg/m$^3$. Some LWC are well suitable to be utilized for the structural purposes and this type of concrete has an extraordinary future in the coming years. Light weight expanded clay aggregate is one of those effective alternative materials for coarse aggregate which can be incorporated in structural lightweight concrete owing to their numerous advantages like reduced density and thereby reducing the dead weight of the structure, provides high sound and heat insulation due to its porous structure, improves fire resistance and modify workability of the mixture. LECA being a multipurpose material it can effectively utilized in many construction fields ranging from structural to non-structural members. On contrary using LECA in mixture, reduces the strength characteristics of concrete. So to overcome this effect by maintaining the benefits of LECA various types of additives can be added to the mixture, which improves the strength of concrete.

Ariozet. al.[1] focused on the microstructural properties of LECA produced by different clays using different firing temperatures and it was observed that the type of clay and the firing temperature plays an important role in deciding the properties of lightweight expanded clay aggregate (LECA). It was suggested that LECA could be used in lightweight blocks and lightweight concrete in buildings as it is readily available or could be produced which helps in reducing the dead weight. Mahmoud Hassanpouret. al.[2] used steel fibers of low volume to understand the mechanical properties of LWC and concluded that the usage steel fibers helps in improving the mechanical properties of LWC. Since steel fibers have high specific gravity they could increase the overall density of LWC. It was suggested to use a low volume fraction of steel fibers (i.e., ≤1%) to prevent the increase in the density of LWC.

Roohollah Bagherzadeh et. al.[3] investigated the influence of polypropylene fibers in improving the performance characteristics of structural LWC composites. It is observed that the increase in the fiber availability in LWC specimens, in addition with the long Polypropylene fibers to pile the micro cracks, could be the reasons for the betterment of mechanical properties. Payam Shafighetet. al.[4] presented the behavior of LWC beams under flexure and concluded that the ultimate moments and deflections of lightweight specimens were found satisfactory by the equations provided in the ACI building codes. It was suggested to prefer a lighter concrete, to make the flexural elements using LWAC. Muhammad Riaz Ahmad et. al.[5] focussed on the formulation of efficient lightweight aggregate foamed concrete using LECA and silica fumes. To enhance the compressive and tensile strength of the lightweight concrete, the cement was partially replaced with supplementary cementing material silica fume by 5% and 10%. It has been noted that there was an enhancement in the compressive and tensile strength of concrete mix from 6.5 MPa to 24.30 MPa and 0.52 MPa to 1.63 MPa respectively.

Danièle Waldmannet. al.[6] used lightweight woodchip concrete in preparing composite slab specimens and found that dense LWC was transferring enough longitudinal shear forces to the composite joints. Thelightweight woodchip concrete ensured self-weight deduction upto 50% compared to normal concrete. Xin Li et. al.[7] produced new type of LWC using shale ceramicsite lightweight aggregate as a replacement of coarse aggregates in the laminated fiber reinforced composite slab specimens. A comparison was made to observe the variation in the behaviours of LWC and Fiber-reinforced LWC composite slabs. It was concluded that the addition of fibers in LWC could help in restraining the generation and extension of concrete cracks apart from enhancing the mechanical interlocking and friction. Mouli and kelfi[8] used the light weight aggregate (natural pozzolan) as infill in the concrete filled steel columns and verified the performance of light weight aggregate concrete-filled steel tube specimens in comparison with normal concrete. The axial capacity and bond strength of concrete-filled steel columns using light weight aggregates were determined. It was concluded that the LWC offered higher strength than normal concrete and showed higher results.
to pushout loads. Its contribution to squash load was also considerable, thus it was concluded that the LWA has sufficient bond strength and adequate density. Abilash et al. [9] conducted study on calcite powder pellets as semi lightweight aggregates, filled in CFST columns. It was concluded that with an increase in wall thickness of steel tube, the strength behavior of core semi-LWC filled steel tube was improved due to its confinement effect. Thus the effective confinement enhanced the overall performance of semi LWC and improved the load carrying capacity with reduced self-weight of the CFST columns. From the previous research works it was observed that LECA could be effectively used to replace the conventional coarse aggregates. The optimum percentage of replacement of LECA for coarse aggregate with effective usage of ground granulated blast slag (GGBS) needs more investigation.

1.2. Research significance
The main objective of this study is to determine the strength characteristics of LWC by using ground granulated blast furnace slag (as a supplementary cementing material) at its optimum percentage and also partly replacing the conventional coarse aggregate with LECA, along with brass coated micro fibres. The behaviour of LWC mixture is to be observed by varying the percentages of LECA as (0%, 30%, 50%, 100%) to replace the coarse aggregate.

2. MATERIALS AND ITS PROPERTIES

2.1. Cement
Standard OPC cement of grade-53, procured from the local suppliers was used for the investigation. Specific gravity of the cement was found to be 3.15, consistency of about 27% and initial setting time was observed as 32 minutes.

2.2. Ground Granulated Blast Furnace Slag
The usage of lightweight aggregate reduces overall density of concrete which thereby reduces the strength. In order to enhance the overall strength of concrete, GGBS was used to replace cement at its optimum percentage of 40%.

2.3. Fine aggregates
Manufactured-Sand was used as fine aggregate in this study. The fineness modulus was observed to be 4 and specific gravity was around 2.63, falling in zone II as per IS:383-1970 [10].

2.4. Coarse aggregates
Crushed gravel of sizes 20mm and 12.5mm were used in this study. 50% of 20mm aggregates and 50% of 12.5mm aggregates of total volume were taken for better core confinement. The aggregates have been tested as per IS:2386-1963 (Part I) [11] and specific gravity was found to be 2.74. The fineness modulus of coarse aggregate was found to be 6.24.

2.5. Lightweight Expanded Clay Aggregates
The lightweight aggregate used for study was LECA (Lightweight expanded clay aggregate) as shown in Figure 1. Aggregate was produced from clay fired in rotary kilns and of size 8-15mm. The fineness modulus of LECA was found to be 5.9. The properties of LECA are as shown in Table 1. The conventional coarse aggregates were replaced by varying the percentages of 30%, 50%, 100% with LECA aggregates.

| S.No. | Property       | Value  |
|-------|----------------|--------|
| 1     | Specific gravity | 0.56   |
| 2     | Water absorption | 16%    |
| 3     | Impact value    | 48.78% |
2.6. Steel Fibers
Brass coated micro fibers used in study are as shown in Figure 2. It was of length 13mm, diameter 0.2mm, tensile strength 2850MPa and density 7890 kg/m$^3$. These fibers were used to improve mechanical properties of LWC.

3. MIX DESIGN
In the present study, M25 grade concrete is used and mix design for conventional concrete is done by confirming to IS10262:2009 [12] and for lightweight aggregate concrete using LECA, by ACI 211.2-98 [13] as there is no standard mix design procedure for lightweight concrete in Indian standards. Table 2 and 3 shows the mix proportions adopted for the conventional M25 grade concrete and for the lightweight aggregate concrete using LECA.

### Table 2. Mix design and mix proportioning for M25 grade concrete as per IS10262:2009 [12]

| S.No. | Materials       | Mass (kg/m$^3$) | Proportion |
|-------|-----------------|-----------------|------------|
| 1     | Cement          | 426.66          | 1          |
| 2     | Fine aggregate  | 654.89          | 1.53       |
| 3     | Coarse Aggregate| 1161.73         | 2.722      |
| 4     | Water           | 191.5           | 0.45       |

### Table 3. Mix design and proportioning for lightweight concretes using LECA as per ACI 211.2-98 [13]

| S.No. | Materials         | Mass (kg/m$^3$) | Proportion |
|-------|-------------------|-----------------|------------|
| 1     | Cement            | 442.38          | 1          |
| 2     | Fine aggregate    | 643.77          | 1.53       |
| 3     | Lightweight aggregate | 303.552  | 0.706      |
| 4     | Water             | 211.2           | 0.48       |

4. METHODOLOGY
A total of 24 specimens (100 mm X 100 mm X 100 mm) were cast, by varying the percentages of LECA as 0% (NC), 30% (LCL30-F1), 50% (LCL50-F1), and 100% (LWC100-F1) and using a constant percentage of steel micro-fibers (1%) in all the specimens. Since the replacement of coarse
aggregate would bring own the strength of LWC, another 18 specimens were cast by replacing cement with constant 40% of GGBS (LCL30-G40-F1), (LCL50-G40-F1) and (LWG100-G40-F1). The densities of fresh and hardened concrete are measured for all the specimens. Around 30% additional water is used for pre-wetting of LECA aggregates before 30 minutes of mixing concrete for showing a better performance.

The cast specimens Figure 3 were kept in water curing for a period of 7 days and 28 days. The cured specimens were tested up to failure in Compression Testing Machine of 3000 kN capacity to check for compressive strength as shown in Figure 4.

5. RESULTS AND DISCUSSION

LWC cubes were cast without and with partially replacing supplementary cementitious material (GGBS). Both fresh and hardened properties were tested and compared with that of NC.

5.1. Fresh properties of concrete
The weight density for the different specimens are shown in Table 4. The test results revealed that with the incorporation of 30%-100% of LECA (size 8-15 mm), higher workable mixture was achieved. The average slump of LWC was 33.3% higher than that of the slump for conventional concrete mixture. The density of fresh concrete for LCL30-F1 and LCL30-G40-F1 are 6.4% and 8.6% lesser than that of NC. For LCL50-F1 and LCL50-G40-F1, the density reduction was in the range of 24.9% and 25.7% respectively. The declination of density for fresh concretes LCL100-F1 and LCL100-G1-F1 are 38% and 36.4% respectively.

5.2. Hardened properties of concrete
5.2.1 Dry density of concrete
The density of hardened concrete for LCL30-F1 and LCL30-G40-F1 were 6.28% and 8.66% lesser than that of NC respectively. Compare to NC, the reduction of density for LCL50-F1 and LCL50-G40-F1 was in the range of 24.08% and 24.4% respectively. Whereas the declination of density for hardened concretes LCL100-F1 and LCL100-G1-F1 were 36.73% and 35.94% respectively.

| Table 4. Densities under fresh and hardened conditions |
|-----------------|-----------------|-----------------|
|                 | Density of Fresh concrete (g/cc) | Density of Hardened concrete (g/cc) |
| NC              | 2.517            | 2.529            |
| LCL30-F1        | 2.356            | 2.37             |
| LCL30-G40-F1    | 2.30             | 2.31             |
| LCL50-F1        | 1.89             | 1.92             |
| LCL50-G40-F1    | 1.87             | 1.91             |
| LWC100-F1       | 1.56             | 1.60             |
| LWG100-G40-F1   | 1.6              | 1.62             |
5.2.2 Compression strength of cubes
The characteristic compressive strength of cubes for the specimens are as shown in Table 5. The values are compared in Figure 5.

Table 5: Compressive strength of cubes specimens

| Type of concrete | 7-days compressive strength in N/mm$^2$ | 28-days compressive strength in N/mm$^2$ |
|------------------|----------------------------------------|----------------------------------------|
| NC               | 19.50                                  | 30.145                                 |
| LCL30-F1         | 13.11                                  | 17.12                                  |
| LCL30-G40-F1     | 14.22                                  | 19.20                                  |
| LCL50-F1         | 10.24                                  | 13.21                                  |
| LCL50-G40-F1     | 12.38                                  | 18.10                                  |
| LCL100-F1        | 4.24                                   | 5.72                                   |
| LCL100-G40-F1    | 5.58                                   | 7.41                                   |

Comparison of results shows that the conventional concrete (NC) for 7 and 28 days compressive strength are 19.5 N/mm$^2$ and 30.145 N/mm$^2$ respectively for M25 grade of concrete. The LWC mix with 30% replacement of LECA added with optimum 1% of steel micro fiber without the cementitious material (GGBS), (LCL30-F1) showed compressive strength of 13.11 N/mm$^2$ and 17.2 N/mm$^2$ for 7 and 28 days respectively, which are comparatively lesser than NC. This reduction of compressive strength can be counteracted with and the partial replacement of GGBS at its optimum percentage (40%) for cement in the concrete. Thus the compressive strength at the age of 7 and 28 days were enhanced by 7.8% and 10.8% respectively, compared with LCL30-F1. For 50% replacement of LECA without GGBS (LCL50-F1) the compressive strength for 7 and 28 days were found to be 10.24 N/mm$^2$ and 13.21 N/mm$^2$ respectively, which were 47% and 56% lesser compared to NC. The addition of GGBS to the mix with 50% of LECA has yielded the 7 and 28 days compressive strength as 12.38 N/mm$^2$ and 18.10 N/mm$^2$ respectively, thus making it efficient to be utilized as structural lightweight concrete. The strength characteristics for LCL50-G40-F1 have been enhanced by 17% and 27.45% when compared to LCL50-F1. For concrete mix with 100% replacement of LECA without and with GGBS (LCL100-F1 and LCL100-G40-F1) showed very much reduced strength compared to NC.
6. CONCLUSIONS

Strength characteristics are determined for the concrete cubes in which coarse aggregates are partially replaced by light weight expanded clay aggregates in varying percentages (0%, 30%, 50% and 100%) along with and without the usage of optimum 40% of GGBS and constant 1% of steel fibers.

From the above test results the following conclusions have been made:
1. LWC (LCL30-G40-F1, LCL50-G40-F1an LCL100-G40-F1)showed reduction in weight density of about 6% - 36% compared to NC.
2. The cube compressive strength for 30% replacement of LECA and GGBS (LCL30-G40-F1) was about 13% higher than that of LCL30-F1.It can be concluded that the usage of GGBS at its optimum 40% enhanced the overall compressive strength of concrete.
3. The compressive strength values for cubes with 50% replacement of LECA both (LCL50-F1 and LCL50-G40-F1) were comparatively lesser than that of LCL30-F1 and LCL30-G40-F1.
4. The ultimate strength for the cubes with 100% replacement of LECA (LCL100-F1 and LCL100-G40-F1) showed much reduction compared LCL30-G40-F1 and LCL50-G40-F1.
5. The cube strengths for 30% replacement of LECA, with and without the addition of GGBS, have gained enough strength to be effectively used for structural purposes (as we know the compressive strength for structural LWC is 17MPa as per ACI norms) and also 50% replacement of LECA with GGBS could be used as structural LWC.
6. It could be concluded that percentage of replacement of LECA for coarse aggregate could be up to 50% along with partially replacing cement with GGBS for enhanced strength properties of LWC.

SCOPE FOR FURTHER STUDY

As the results obtained for LWC using LECA is satisfactory at 30 and 50% using GGBS, similar concrete can be used in the construction field for structural purposes. Composite sections like concrete filled steel tube columns and composite deck slabs have gained lot of importance in the recent years. Structural LWC could be an alternative for the traditional NC, as it helps in reducing the overall weight and makes it easier for transportation and casting in large scale projects.

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