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# Lightweight Aggregate Concrete: Strength Analysis

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

The lightweight concrete (LWC) has been successfully employed, by the ancient Romans and its popularity has grown for its reduced density and higher thermal insulation capabilities. Compared to ordinary mix concrete (OMC), LWC can substantially lessen the dead load of high-rise structures. The density of LWC is comparatively low i.e. 300 to 1850 kg/m3, whereas conventional concrete has a unit weight of 2200kg/m3 to 2600kg/m3. Many pieces of research on adding disposable industrial wastes LWC focus on "semi-lightweight" or concrete built of lightweight materials which have provided both structural, financial, and environmental achievements.

Synthetic lightweight aggregate derived from industries/environmental waste is not possible for reuse openly dumped and makes it environmental abuse. The lowering self-load of a structure made of lightweight concrete makes it easy the handling heavier pre-cast pieces. Present research involves of amalgamation of low specific weight "cinder" as coarse and fine aggregate replacements at various percentages and comparing the physical and mechanical characteristics of concrete made from it with orthodox concrete. The replacement was 10%, which will boost the flexural, tensile, and compressive strength if replaced as a fine Aggregate. The compressive strength, flexural splitting, and tensile strength of SF were raised by 20%. Will be cut back. Cinder added as coarse and fine aggregate in concrete, makes the LWC that enhances workability, foaminess, and up to 20% replacement as CA behaves as the ordinary normal concrete.

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## 1. INTRODUCTION

Lightweight concrete (LWC) is in use for the past 3000 years and traced to 3,000 BC, during Mohenjo-Daro and Harappa civilizations. Although lime was the cementitious component with washed grits, LWC has been employed. In past civilizations of Romans in St. Siphia Cathedral and Turkey in Hagia Sofia, in Turkey, [1,2]. Compared to regular concrete, rigid LWC systems are very occasionally used for pavements, partition walls, and roof casting. LWC reduces the dead load of the building. LWC has the advantage of being easy to handle. less cost of transportation, durable, Improved workability, low thermal conductivity (α) value to a tune (thermal R-value of R-30), and freezing & thawing resistance in comparison to usual cement concrete. Even fly ash added cellular-based Cellular Lightweight Concrete (CLC) has been emerging concrete technology which is light in weight, cost-effective, and eco-friendly, [3,4].

LWC should be quite helpful because it alters the structure significantly. Instead of using typical natural coarse aggregate like hard granite pieces, lightweight concrete (LWC) uses specialized lightweight aggregate. The low density and good heat conductivity of lightweight concrete are its major properties. The in-situ density of LWC is structurally between 1440 and 1800 kg/m3. Decrease of self-weight by adding light aggregates, which lower the self-load, as well as inertial mass, can help to reduce the size of the member, and load on the foundation is counted among its benefits. According to their production method and intended purpose, the LWC is divided into various forms. The great building constructed with LWC is the Bank of America in Charlotte, N.C. in which the dead load is conveyed floor to floor at a reduced rate without overloading the foundation.

The present investigation is to find the physicochemical and mechanical properties of LWC made up of various % replacements of coarse and fine aggregate and find its suitability for structures.

## 2. LITERATURE REVIEW

The pollution and scarcity in aggregates (agt.) resources warranted replacing, the naturally available coarse aggregates (CA), fine aggregate (FA), and partially or total blending by cinder for making cement concrete (CC). The wastes from industrialized units like Pulverized fly ash (PFA), ground granulated blast furnace slags (GGBS), red mud, cinder, and Ferro chrome slags, were investigated to supplant the black HG (hard granite) CA in normal CC (approx. 40% to 60%), [5-11]. In addition, industrial trashes like red mud (alumina plants), Poly-siloxanes basalt fibers (BF), PFA (Pulverized fuel ash), and GGBS obtained from ferrous smelters enhance the strength of CC when it partly substitutes BHG aggregates. The addition is to be done judiciously as the unit weight of the additional materials contributes to the dead-load (DL) of buildings, and may deviate from the thermal compatibility as cinders have porosity, light in weight, [12-16].

LWC is prepared by substituting CA and FA with industrial waste materials, based on the size in a definite proportion, even nanomaterials, in normal concrete, [19-22] About 60% replacement by cinder ( in volume) to normal BHG aggregates and cement is substituted by about 1/10th silica fume (weight basis), retains the strengths intact, specifically in M20 & M25 grade CC, [23-26]. Concrete made of Light Weight Aggregates (LWAC) can have acoustic and thermal properties of better quality in comparison to LWC, [27,28]. Absorptivity, contact angle, open porosity, cementitious properties, surface free energy (SFE), mechanical strength(compressive, flexural, split tensile), resistance to sulfate and chloride attack properties, along with protecting freezing-thawing sustains the physical and mechanical strength when cinder CA and FA’s are used, [29-32].

At various percentages, the cinder has been replaced with coarse aggregate, and in some cases fly ash replaces cement. The various strengths and mechanical properties have been compared. The final concrete produced is lightweight (1980Kg/m$^3$ - 2000Kg/m$^3$) whereas it is about 2440kg/m$^3$ for the conventional cement concrete (CC). Maximum replacement of cinder keeps the mechanical properties of lightweight CC is about 30%-60% and 15%replacement of cement by fly ash with 15% and silica flume of 15% with water curing for 28days, [6,22,33-36].

### 2.1 Significance

Large numbers of concrete composite experiments are done either to replace the fine aggregate, coarse aggregate by the industrial wastes like GGBS, cinder, copper trailings, Ferrochrome slag, fine aggregate by silica flumes or powder cinders or crusher dust, *etc.,* [37,14,17,15,38,39]. The present search is to determine the consequences of the composite lightweight aggregate from the byproducts of steel factories. The compressive, split tensile, Flexural, density and shear stress, *etc.* are found by replacing cinder with black hard granite chips at 0% to 100% at an interval of 20%.

## 3. EXPERIMENTAL METHODOLOGY

The ingredients after collection were thoroughly cleaned, soaked with dry cotton, and dried in sunlight so that the cinder and coarse and fine aggregates are well cleaned and free from silt, clay and other impurities. The properties of various materials are tested in the civil Engineering laboratory of GITA and CUTM and the following results are obtained.

Cinder is the unused waste kills space for disposal, and lightweight concrete is the need of the hour for safe and secured disposal of industrial trailing. The LWC can be No-fines, LWC, or AFC Foam concrete. The ingredients are cement, aggregates, admixtures, and other lightweight materials used for gaining required properties [40].

### 3.1 Ordinary Portland Cement (OPC)

This cement of grade- 53 with a specific gravity (Sp. Gr.) of 3.13 is used. The setting times (initial and final) were 34 minutes and 505 minutes respectively. The other properties of the OPC cement were normal consistency of 36% and compressive strength of the std. mortar cubes = 55.4 MPa [41]

### 3.2 Cinder

The lightweight rock of igneous origin is the cinder. The Sp. Gr. of C.A. is 2.00 and the fineness modulus is 2.82 (IS 2269-1987) [41]. Cinder occurs naturally or as an industrial end product from iron/steel plants. It is pyroclastic and light in weight as having cavities. The cinder (called scoria can have black (ordinarily), brown, or red according to its chemical structure. The cinder used, is collected from the Rourkela Steel Plant, (RSP), Odisha (Fig. 1). The RSP produces about 1570 Th.MT of cinder annually. The cinder, both in FA particle size and CA particle size has been picked to replace black hard granite (HG) chips and river sand. The surficial properties of cinder are rough and porous and have required angularity with water absorption of ≈1.5%.

### 3.3 Sand

It is locally accessible the Kuakhai river sand from Trisulia quarry, the nearest bank available. The sand is of medium quality sand with Sp. Gr. 2.77 and FM (fineness modulus), 4.82 passes through IS 4.75 mm sieve. Water absorption (WA) was 0.94%, loose bulk density (BD) was 1.62, and show the distribution of its particle size was as per Zone III (IS 373-2016) [42].


**Fig. 1. Cinder from steel plants waste used as FA and CA for CC**

**Image 1. The specimen testing of the flexural test in the laboratory**

**Table 1. The physical characteristics of CA, HG Aggregate & Cinder**

| The ingredients | Specific Gravity | Fineness Modulus | Water Absorption (%) | Qty of Material (Kg) | Properties |
|---|---|---|---|---|---|
| Cement | 3.13 | 2.75 | - | 378kg//m3 | Ordinary Portland cement grade- 53 |
| Sand | 2.64 | 2.74 | 1.1 | 691kg/m3 | River sand from river Kathajodi |
| HG Chips | 2.77 | 4.82 | 0.6 | | IS383-2016,IS2386;(Part-III)-1963;2 016 (Re) |
| Cinder | 2.00 | 2.82 | 1.3 | | Maximum nominal size 20mm |
| Water | 1.0 | - | - | 174ltr/ m3 | Standard drinking water (Tap) |

## 3.4 HG Chips

The Black HG chips used from a nearby quarry are being collected from the Tapanga quarry at Narangada, near Khurdha of Odisha. The size of the chips, loose bulk density, sp. gr., and FM are 12-20 mm range, 2.64, 1.6 gm/cm3, is 2.74 respectively and flakiness and elongation maintained as <15% (IS 383-2016] [42].

## 3.5 Design Mix Calculations

The physicochemical characteristics of the ingredients of the search were conducted in the CUTM and GITA civil engineering laboratories as per the available standard procedure. The CC mix was designed for M25 grade following the standards stipulated code IS10262 of 2019 [43]. The targeted average mean strength (TMS), the formulae used is $F'_{CK} = 25 + 1.65 * 4 = 31.6\ N/mm^2$ (IS 456- 2000) σ (Std Dev.) = $4N/mm^2$, F'ck= TMS. The CC Specimens are submerged in water for curing. The results after 7 and 14 days were not taken. Since COVID -19 was in full swing during the experiment execution period, the strength results were taken only after 28days submerged in water in a vat in the laboratory. After 28 days of curing the comp. strength of the cube is $F_{ck}$. The water vs.

cement (WC) ratio was 0.46 (IS 456/2000). The normal laboratory procedures of the concrete lab, the amount of ingredients mixed for the CC are OPC= 378 kg /m3, Water= 174 ltr / m3, river sand (fine aggregate) = 691kg/m3, HG chips (coarse aggregate) = 1230kg\m3 for CC. The final design mix proportion keep up by weight was 0.46:1:1.83:3.25 (IS 10262-1982 [42].

Maintaining the design mix proportions for M25 amount by weight, the specimen's cubes (150 x150x 150mm), cylinders (150 (L)x300 (b)mm), and beams (100(length)mm x 100 (breadth)mm x 500 (height) mm) cast in the formwork and after removal of forms, cured for 7, 14, and 28days for various tests like Compressive Strength Test (CST), Split Tensile Test (STT) and Flexural Test (FT) using CTM or UTM (IS 456-2000) [44]. Three specimens for each test were cast and the test results were averaged and individual results were not reflected.

### 3.6 Design Provisions

The comp. strength (characteristics) of M-25, after 28 days curing should be 25 N/mm2. The size of aggregates should have a range of 12mm to 20mm, workability = 0.9 (medium), and the good type of exposure for the water-cement ratio of 0.46 should be moderate. The method of concrete is manual placing. The Design Mix quantities by proportion maintained 0.46:1:1.83:3.25.

Cement, fine aggregates (sand), coarse aggregates (BHG, maximum 20 mm), cinder (12mm to 20mm range), and water is the essential constituents of blended concrete mixes. The local portable tap water is used for mixing concrete. Concrete is cast in three equal layers in regular pre-mentioned molds, and the tamping is done by the rod, compact each layer, and vibrated on the vibrating table for 15 seconds for appropriate compaction. For smooth surfaces finally, the top surfaces of concrete specimens were completed. The replacement @ 0%, 20%, 40%, 60%, 80% and 100% mixes are designated as M-X-I, M-X-II, M-X- III to … M- X-VI.

Split Tensile strength results indicate that the strength values reduce gradually (Table 2 and Fig 3).

The density of the coarse aggregate gradually reduces where the highest density is 2614kb/$m^3$ with no addition of cinder. The characteristics and strength of the amalgamated coarse agt have shown 31.6N/$mm^2$ when the mix addition is 60% Hard Granite chips and 40 %cinder. This shows higher the percentage of addition cinder lower is the compressive strength (Table 2 and Fig 2).

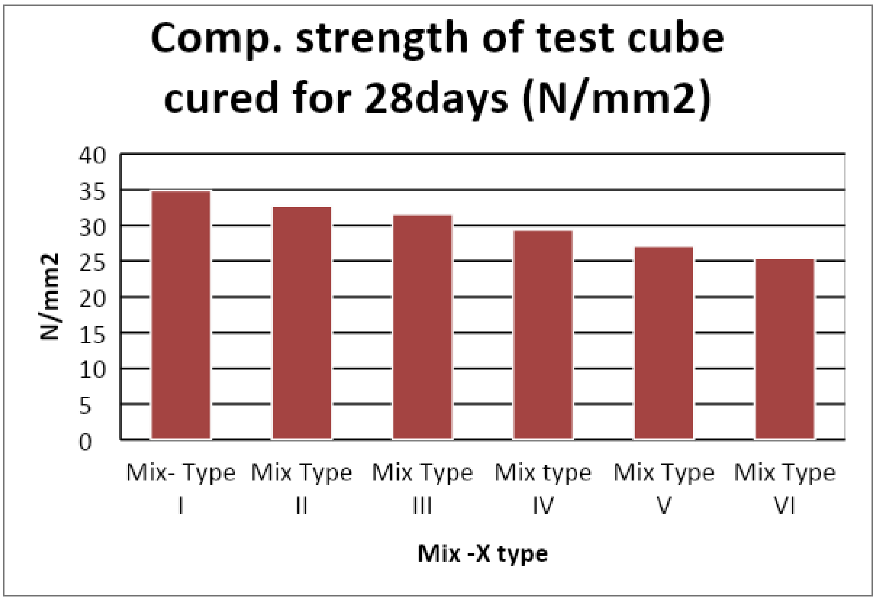


**Fig. 2. Comp. strength of test cube cured for 28 days(N/mm2)**

**Table 2. Density and compressive strength of test cubes, with % replacement by weight**

| Description | Percentage replacement by weight | | Density (kg/m3) | Comp. strength of specimen cube after 28days curing |
|---|---|---|---|---|
| | HG chips. | Cinder (%) | | (N/mm2) |
| M- X-I | 100(%) | 0(%) | 2614 | 34.9 |
| M- X-II | 80(%) | 20(%) | 2553 | 32.72 |
| M- X- III | 60(%) | 40(%) | 2428 | 31.64 |
| M -X - IV | 40% | 60% | 2277 | 29.43 |
| M- X- V | 20% | 80% | 2195 | 27.12 |
| M- X- VI | 0% | 100% | 2102 | 25.41 |

**Table 3. The split tensile strength of the various mix of HG chips and cinder**

| Mix Description | % substitute | by weight | Split tensile strength (STS) |
|---|---|---|---|
| | Coarse Agt. (%) | Cinder blending | (N/mm2) |
| M- X-I | 100% | 0% | 03.84 |
| M- X-II | 80% | 20% | 03.61 |
| M- X- III | 60% | 40% | 03.52 |
| M -X - IV | 40% | 60% | 03.31 |
| M- X- V | 20% | 80% | 03.02 |
| M- X- VI | 0% | 100% | 02.81 |

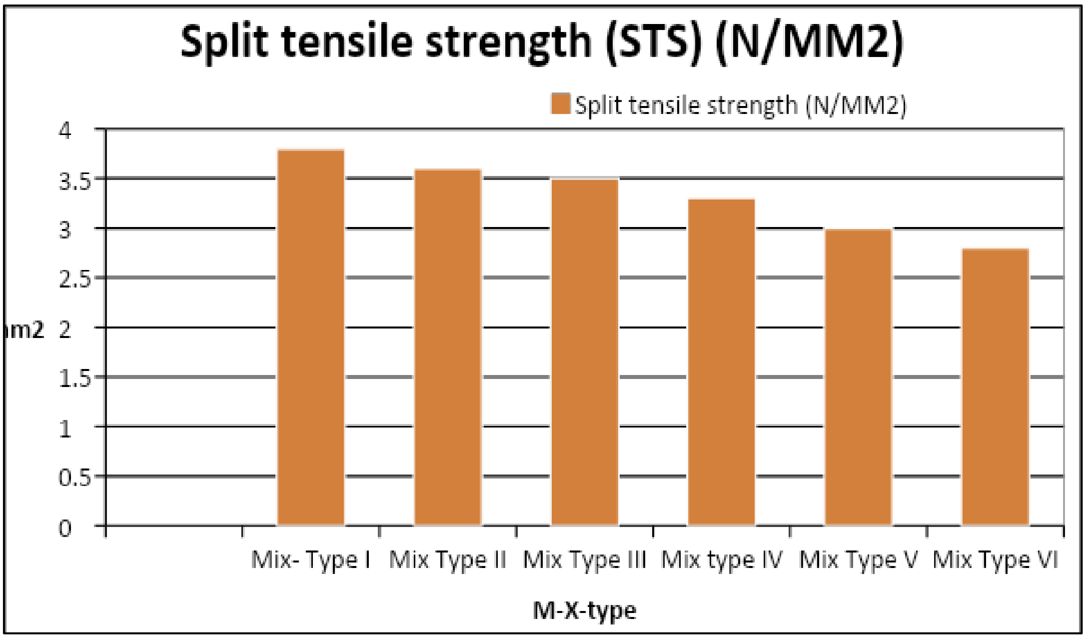


**Fig. 3. The split tensile strength of the cured concrete at various mixes**

**Table 4. The flexural strength of the cured concrete at various mixes**

| Mix Description | (%) replacement by weight | | Flexural strength |
|---|---|---|---|
| | Coarse Agt. (%) | Cinder (%) | (N/mm2) |
| M- X-I | 100% | 0% | 3.84 |
| M- X-II | 80% | 20% | 3.63 |
| M- X- III | 60% | 40% | 3.42 |
| M -X - IV | 40% | 60% | 3.21 |
| M- X- V | 20% | 80% | 2.92 |
| M- X- VI | 0% | 100% | 2.73 |

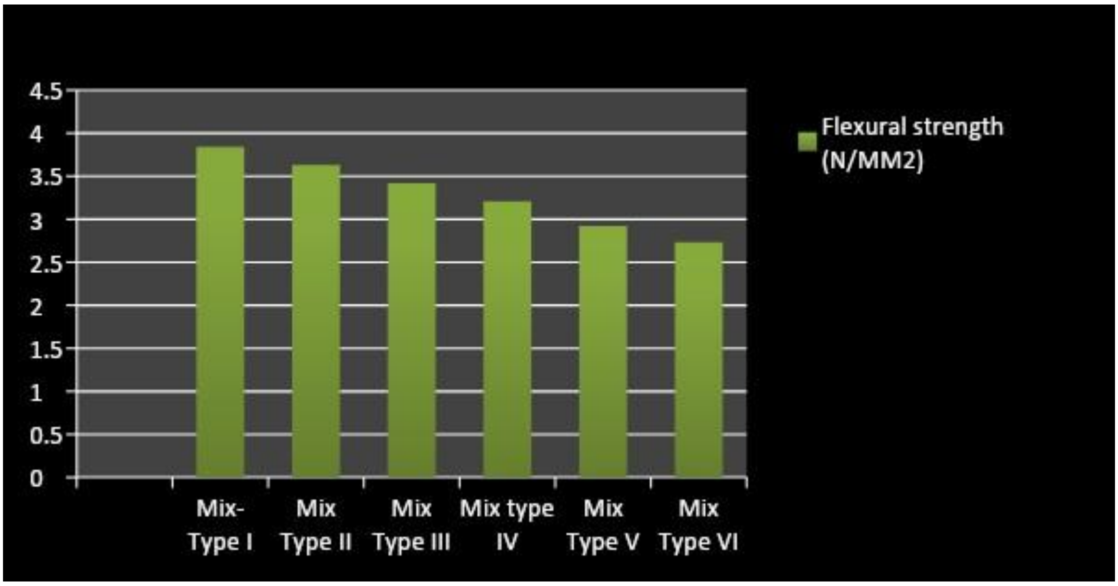


**Fig. 4. The flexural strength of the cured concrete at various mixes**

**Table 5. Comparison of LWC's unit cost with that of traditional concrete at various alternatives**

| Mix Designation | Percentage (%) replacement by weight | | Cost per cum LWC in rupees |
|---|---|---|---|
| | **Coarse Agt. (%)** | **Cinder (%)** | |
| Mix X-I | 100% | 0% | □ 7164.50/Cum |
| Mix X-II | 80% | 20% | □6972/Cum |
| Mix X- III | 60% | 40% | □ 6792/Cum |
| Mix -X IV | 40% | 60% | □ 6603/Cum |
| Mix X- V | 20% | 80% | □6412/Cum |
| Mix X- VI | 0% | 100% | □6223/Cum |

The flexural strength results indicate that the strength values reduce gradually (Table 4 and Fig 4).

The cost of the blended concrete for various mixes was calculated and found to be gradually decreasing. This indicates the cost is steadily decreasing showing replacement of cinder of HGchips is cost-effective.

## 4. RESULTS AND DISCUSSION

It is well known that silica fume (SF) and fly ash (FA) generally increase a material's flexural strength, splitting tensile strength, and compressive strength concrete. When hard granite chips, sand is replaced by cinder, fly ash and silica fume, *etc.* added can reduce the unit weight of concrete retaining the strength properties. Three categories of LWC are used, i.e. (i) Lightweight aggregate concrete, (2) Aerated concrete, and (3) No fines concrete.

The conclusions drawn from the experimental study are as follows:

1. As the percentage of cinder is increased, the compressive strength of blended cubes gradually decreases but eventually reaches the desired mean strength.
2. As the percentage of cinder has increased, the split tensile strength has steadily decreased.
3. As the percentage of cinder has increased, the cube densities have steadily decreased, making the concrete lighter.
4. It is discovered that by increasing the percentage of cinder, the cost of LWC concrete is dropping while keeping its strength properties, allowing the cinder to be substituted by natural concrete aggregate.
5. The density of LWC ranged from 1950 to 2100 kg/mm3, which was smaller than the density of regular concrete, which are 2637 kg/mm3.
6. Concrete's unit weight decreases when using cinder as coarse aggregate when compared to regular aggregate. Several

houses and pavement shoulders are constructed using lightweight concrete.

In course of time with the implementation of sustainable development goals (SDGs), the thermal power plants shall close and the PFA shall not be available. The blended materials to cement or aggregate should have properties like cost-effectiveness, and workability but at a low water-cement ratio, lower drying, creep, bleeding, and shrinkage properties, and less potential for Alkali aggregate reaction, sulfate, and chloride attack. Though GGBS blended concrete has very high ultimate strength, have the disadvantage of slow setting time, which prohibits its use underwater in swampy places. The use of silica flumes though provides high strength, it is uneconomical, and creates environmental issues. Whereas the blending with cinder it is observed that the CC shall be cost-effective, low-weight concrete, and used for green concreting. Cinder added as coarse and fine aggregate in concrete, makes the LWC that enhances workability, foaminess, and up to 20% replacement as CA behaves as the ordinary normal concrete.

## 5. CONCLUSION

From the experimental results at various substitutional mixes of HG chips with cinder, it can be concluded that the LWC is porous, low compression, and can replace natural Black HG up to 20% to get compatible strength of orthodox normal concrete, continuous diminution of the flexural and split tensile strength with increase of cinder percentage. The GGBS, PFA, silica flume, *etc*. can be blended with CC satisfying the industrial waste disposal. But blending the CA with cinder has the advantages of cost-effectiveness. The cinder has its uniqueness of use as LWC by replacing the normal CA.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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