# STRUCTURAL PROPERTIES OF LIGHTWEIGHT SELF-COMPACTING CONCRETE MADE WITH PUMICE STONE AND MINERAL ADMIXTURES

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***This study investigates the structural properties of lightweight self-compacting concrete produced using mineral admixtures and pumice stone as aggregate. Lightweight self-compacting concrete (LWSCC) mixes were prepared using pumice stone as replacement for natural coarse aggregate, and ground granulated blast furnace slag and rice husk ash were added as mineral admixtures. The flowability of the concrete mixtures was achieved by using gelinium B223 super plasticizer. Structural properties such as: density, compressive strength, flexural strength, and split-tensile strength of the concrete samples were determined for different mix proportions. Test results revealed that 30-40% replacement of coarse aggregate by pumice stone is considerable for improved density, compressive strength, split tensile strength and flexural strength development in LWSCC.***

***Keywords:*** *self-compacting concrete, pumice stone, Lightweight concrete, mineral admixture, Super plasticizer*

## 1. Introduction

The density of concrete is a major factor of concern in monitoring the dead load of concrete structures, in fact it is problematic during construction of some high-rise structures. As a result, lightweight concrete has been in use instead of normal weight concrete in some modern-day structures. Normally, a concrete is referred to as lightweight when its in-place density falls between 1440 to 1840 kg/m$^3$ [1]. The production of lightweight concrete entails the use of low density aggregates, which is mostly achieved through the use of new materials. It is noteworthy that local and waste materials [2-6], are also being considered for production of lightweight and non-structural concrete. Various lightweight aggregates such as expanded clay shale, paper waste, vermiculite, rice husk, perlite, pumice stone, stuff, scoria, and cinders are used in preparation of lightweight concrete.

On the other hand, durability of concrete structures is another major factor engineers consider at both design and construction stages of building. Adequate compaction is required to make durable concrete. However, the introduction of self-compacting concrete (SCC) technology has helped in controlling issues relating to both fresh and hardened state of concrete during construction [7], because SCC flows under its own weight without any external vibration for compaction or consolidation. In addition, SCC also solves the problem of segregation and bleeding of concrete [8], and its fresh and hardened properties are influenced by aggregates composition of 60 -70% in concrete [9].

Studies [10-12] have shown that the use of different mineral admixture increases the workability of concrete, and this also improves the properties of fresh and hardened SCC. The use of mineral admixtures in SCC gives a good mechanical properties advantage like thermal features [13], and also improve the economic feasibility of SCC production [14].

Lightweight concrete, however, is selected for structural purpose because its use can reduce the dead load of buildings and consequently foundation costs will be less than those of normal weight concrete. Consequently, the reduction of dead load on structural supports, trusses, girders and slabs can allow extra storeys on buildings where dead load is a governing factor [15, 16]. A study [17] revealed that lightweight pumice and mineral aggregates cause reduction in specific weight of concrete up to 14% and 28 day cylindrical strength gain up to 287 kg/cm$^2$. However, Kockal and Ozturan [18] and Libre et al. [19] opined that the strength and elastic properties of concrete slightly decreased by the use of lightweight aggregate instead of normal weight aggregate.

Further, efforts made in recent researches have been to combine lightweight and SCC features to produce light-weight self-compacting concrete (LWSCC) [20]. Although these two concrete types have separate application with standard codes of practice about their usage. It is disadvantageous that there is no reference and technical draft about LWSCC mix design and its application. A mix design

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of LWSCC has been proposed [5]. Investigations [21, 22] showed that the compressive strength of LWSCC is influenced by the aggregate type and water-to-binder ratio. In addition to past studies, the aim of this investigation is to determine the structural properties of LWSCC produced with artificial pozzolans (ground granulated blast furnace slag and rice husk ash) as admixtures, and pumice stone as lightweight aggregate. Pumice is a natural sponge-like material from the volcanic origin composed of molten lava rapidly cooling and trapping millions of tiny air bubbles. Pumice can float on water and after becoming waterlogged, it sinks. This study evaluated the appropriate partial replacement percentage of pumice stone in SCC mix, effect of mineral admixture on LWSCC mix, and finally explore the rheological and strength characteristics of light weight self- compacting concrete.

## 2. Experimental

### 2.1. Materials

In this study, materials used includes: grade 42.5 Ordinary Portland Cement, river sand as fine aggregate, gravel as coarse aggregate, 12 mm main bars and 6 mm stirrups, ground granulated blast furnace slag (GGBS), rice husk ash (RHA), pumice stone, gelinium B223 as super plasticizer, and potable water. The specific gravity and fineness modulus of the binders are respectively: 3.15 and 4 for cement, 2.15 and 3.9 for GGBS, 2.1 and 7.2 for RHA. The superplasticizer and water contents were kept constant at 4.64 litre/m$^3$ and 190.4 litre/m$^3$, respectively. The oxide composition of the binders used in this study is presented in Table 1. The specific gravity of gelinium B233 superplasticizer used was 1.22. The plasticizer was obtained from BASF Company in India. GGBS was obtained from by-product of iron and steel-making company in India. GGBS are formed as a result of blast furnace in water to produce a granular material. Both GGBS and RHA were chosen as pozzolans to partially replace cement in the LWSCC mixes.

RHA is a waste material which is produced by rice - mill industry while processing rice from paddy. Large amount of rice husk is generated in Tirrupu, India, but it is currently not gainfully utilized. In this study, the ash content of the rice husk was used, it was obtained by incinerating rice husk at 500-700$^o$C for short duration of 15-360 minutes. This burning criteria was adopted from related studies [23, 24]. The RHA contains 80% of amorphous silica (Table 1), which is a significant indicator of its pozzolanic feature.

The properties of the aggregates are presented in Table 2. Both the sand and gravel conformed to IS 2386 [25]. Pumice stone was used as lightweight aggregate. Pumice stone is from a volcanic rock that consisted of highly vesicular rough textured volcanic glass, which may or may not contain crystals. Just as known with natural aggregates, size of pumice stone also play important role in LWSCC and size used was 8 -10 mm. From other studies, pumice is a highly porous volcanic aggregate with low bulk density (300 kg/m$^3$ - 800 kg/m$^3$) and high water absorption capacity (30% - 80%, by weight) [26, 27]. The pumice used in this study possessed properties similar to the aforementioned results.

### *2.2. Methodology*

### *2.2.1 Mix proportion*

The summary of the mix proportion adopted for this study is presented in Table 3. The mix proportion was prepared based on the European Federation National Associates Representing for Concrete (EFNARC) [28] provision. Binder material and aggregates are mixed for few minutes. At first, during trial mix, 70% of required water was mixed for couple of minutes. Then the remaining water with super plasticizer (9% by cement weight) were added to the concrete mix and mixed for 5 minutes using concrete mixer. After that, the mixing was stopped and discharged for SCC tests. As shown in Table 3, mix proportion was developed by partial replacement of pumice stone at 10%, 20%, 30% and 40% for coarse aggregate, with constant mineral admixture contents of 9.05% of GGBS and RHA..

**Table 1**

Oxide composition of binders

| **Oxides** | **CaO** | **SiO$_2$** | **Al$_2$O$_3$** | **Fe$_2$O$_3$** | **Na$_2$O** | **K$_2$O** | **MgO** | **LOI** |
|---|---|---|---|---|---|---|---|---|
| Cement | 62.6 | 22.3 | 3.1 | 4.2 | 0.02 | 0.01 | 0.08 | 7.69 |
| GGBS | 36.4 | 42.1 | 9.4 | 1.2 | 1.9 | 1.3 | 4.6 | 3.1 |
| RHA | 3.84 | 80 | 3.93 | 0.41 | 0.67 | 1.45 | 0.25 | 8.56 |

**Table 2**

Properties of fine and coarse aggregate

| **Properties** | **Aggregates** | | |
|---|---|---|---|
| | **sand** | **Gravel** | **Pumice stone** |
| Fineness Modulus (%) | 2.18 | 6.36 | 5 |
| Specific gravity | 2.61 | 2.73 | 1.84 |
| Bulk density (kg/m$^3$) | 1635 | 1571 | 460 |
| Water Absorption (%) | 0.52 | 0.45 | 2.8 |

**Table 3**

Mix proportion for tested LWSCC

| Mix ID | Cement ($Kg/m^3$) | GGBS ($Kg/m^3$) | RHA ($Kg/m^3$) | Sand ($Kg/m^3$) | Gravel ($Kg/m^3$) | Pumice Stone ($Kg/m^3$) |
|---|---|---|---|---|---|---|
| Mix 1 | 466.6 | - | - | 899.2 | 500.5 | - |
| Mix 2 | 424.4 | 42.2 | - | 999.1 | 450.45 | 50.05 |
| Mix 3 | 424.4 | 42.2 | - | 999.1 | 400.4 | 100.1 |
| Mix 4 | 424.4 | 42.2 | - | 999.1 | 350.35 | 150.15 |
| Mix 5 | 424.4 | 42.2 | - | 999.1 | 299.8 | 200.2 |
| Mix 6 | 424.4 | - | 42.2 | 999.1 | 450.45 | 50.05 |
| Mix 7 | 424.4 | - | 42.2 | 999.1 | 400.4 | 100.1 |
| Mix 8 | 424.4 | - | 42.2 | 999.1 | 350.35 | 150.15 |
| Mix 9 | 424.4 | - | 42.2 | 999.1 | 299.8 | 200.2 |

### *2.2.2. LWSCC sample preparation and testing*

After mixing the concrete, workability properties of the LWSCC mixes was determined by slump flow, J-ring, L-box, V-funnel tests tests based on provision of EFNARC [28].

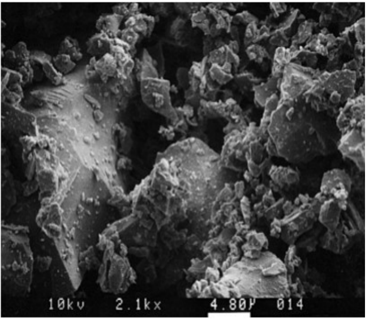
Slump flow test was done to determine the free flowability and deformability of LWSCC. A slump flow cone of height 300 mm, base diameter 200 mm and top diameter 100 mm was used for the test. The J-ring test was conducted to determine the passing ability of LWSCC. The equipment consists of an open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. The dimension of the ring vertical bar 300 mm diameter and height 100 mm. After pouring of concrete, the difference in concrete between the concrete inside and that just outside the J-ring was measured. V-Funnel Flow Time Test was done to determine the deformity through restricted area. The LWSCC fresh mix was filled with a trap door. After filling, the trap door is opened and the time taken to flow of concrete was measured. Lastly, L-Box test was done to assess the effect of reinforcement on free flow of concrete constrained by form work. The flowability, blocking and segregation of the concrete were measured for the LWSCC mixes. Thus, concrete samples were cast for compression tests (150 mm cubes), split-tensile tests (100 mm × 200 mm cylinders), and for flexural tests (100 mm × 100 mm × 500 mm beams). For each mix, samples were tested in triplicates for compression and split-tensile tests, whereas two (2) samples were tested for flexural strengths. Beams were reinforced with 12 mm main bars and 6 mm stirrups. The hardened concrete was tested in alignment with the provision of IS: 516 [29].

After placing concrete in the moulds, it was left for 24hrs to properly set, before the samples were demoulded and were cured in water for 7, 14 and 28 days periods. This procedure allows the samples to be partially hardened before curing process begins. Compressive strength, split-tensile strength and flexural strength of the samples were determined after 7, 14 and 28 days curing period.

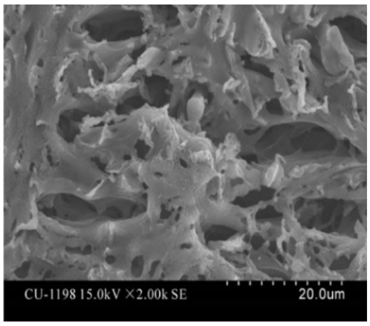
## 3. Results and discussions

### *3.1 Microstructural analysis of materials*

The scanning electron micrograph (SEM) images of GGBS and RHA are shown in Figures 1a

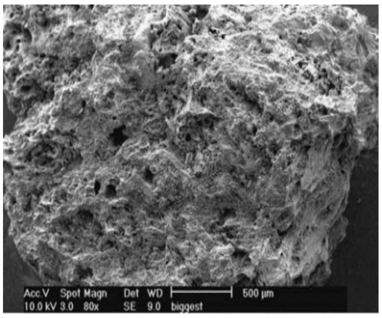


(a) GGBS

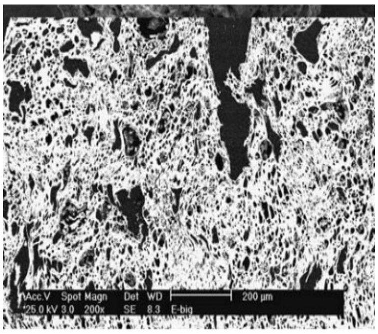


(b) RHA

Fig. 1 - Scanning electron microscope image of (a) GGBS (b) RHA



(a) Pumice stone at 500 µm size



(b) Pumice stone at 200 µm size

Fig. 2 - Scanning electron microscope image of pumice stone at (a) 500 µm size (b) 200 µm size.

Table 4

Fresh Concrete Properties

| Mix Id | Slump value (mm) | T50 slump value (sec) | J-ring value (mm) | V-funnel value (sec) | L-box value (mm) | U-box value (mm) |
|---|---|---|---|---|---|---|
| Specification | 600 - 800 | 5 | 10 | 12 | 1 | 30 |
| Mix 1 | 695 | 3 | 8 | 7 | 1 | 26 |
| Mix 2 | 785 | 5 | 7 | 9 | 0.8 | 24 |
| Mix 3 | 760 | 4 | 9 | 8 | 0.8 | 27 |
| Mix 4 | 730 | 4 | 9 | 7 | 0.9 | 29 |
| Mix 5 | 775 | 5 | 8 | 7 | 1 | 29 |
| Mix 6 | 785 | 5 | 7 | 9 | 0.8 | 24 |
| Mix 7 | 760 | 4 | 9 | 8 | 0.8 | 27 |
| Mix 8 | 730 | 4 | 9 | 7 | 0.9 | 29 |
| Mix 9 | 775 | 5 | 8 | 7 | 1 | 29 |

and 1b, respectively. The structure of GGBS (Figure 1a) appears to be well compacted, with variation in the particle sizes and larger particles are spherical. The sphericity of the particle shape could be during crushing, in the process of interaction between interaction between steel cylinder and ring, and that between a steel ring and vessel wall [30]. Probably, the increasing rubbing action creates smooth edges and angles in the particles.

Also, it can be seen that the RHA structure (Figure 1b) contains large pores and it is interlayered, which appeared to have many crystal-like interlaced such like thin walled hollow spheres. According to Bie et al. [24], this kind of structure is known as a reticular porous or honeycombed structure. From the EDX analysis (Table 1), silica ($SiO_2$) is dominantly represented. Pumice stone on the other hand has numerous pores (Figure 2a and 2 b). These pores significantly contribute to less weight characteristic of pumice stone.

### *3.2. Workability of fresh LWSCC tested*

Table 4 presents the results of the workability tests conducted on fresh concrete which includes: slump flow, J-ring test, V-funnel test, T-50 slump, L-box test, U-box test results.

The slump flow range was between 600 to 800 mm for all the mixes, which was similar to the range recommend for self-compacting concrete [31]. As can be seen from Table 4, every mix considered was within the range of workability properties examined.

### 3.3. Hardened LWSCC properties

Density of the concrete cubes produced from all the LWSCC mixes were determined, and the results are presented in Figure 3. Mix 4 and Mix 8, having 30%PS, and Mix 5 and Mix 9, with 40% pumice aggregate, fell within the limits of lightweight concrete as recommended in CIP 36 [1] provision. Thus, it can be deduced that increasing pumice aggregate considerably reduces the density of concrete. As density is concerned, the influence of other mineral admixtures was not as significant as pumice aggregate.

The compressive strength of the samples contained is shown in Figure 4. Compressive strength increased with increasing curing period, which is also a common phenomenon in normal weight and SCC concretes [32]. The highest compressive strength, in the range of 45 – 50 N/mm$^2$ were obtained for mix 1 and mix 6 which both contained GGBS and RHA, respectively. However, the mixes 1 and 6 are categorically normal weight concrete, owing to their increased densities. As for a LWSCC, mixes containing 30-40% pumice aggregate yielded an appreciable compressive strength. It is noteworthy that compressive strength increased with increasing GGBS, but in contrast, the former decreased with increasing PS. Results showed that 30-40% PS and 9.05% GGBS are adequate for production of LWSCC. The result of split-tensile strength shown in Figure 5 was synonymous with that of compressive strength. The highest split-tensile strength, in the range of 3.5 – 4 N/mm$^2$, was obtained with type 1 and type 6 mixes. Similarly, it can be observed that mixes having 30-40%PS yielded the optimum tensile strength for LWSCC.

The flexural strengths of LWSCC followed similar trend as its compressive and split-tensile strengths. The flexural results for all the mixes are shown in Figure 6. Flexural strength also increased with increasing curing age and GGBS content but with decreasing PS. As can be seen: Mix 1, Mix2, Mix 6 and mix 7 of the LWSCC yielded the appreciable flexural strengths. These mixes displayed flexural strengths between 7-9 N/mm$^2$.

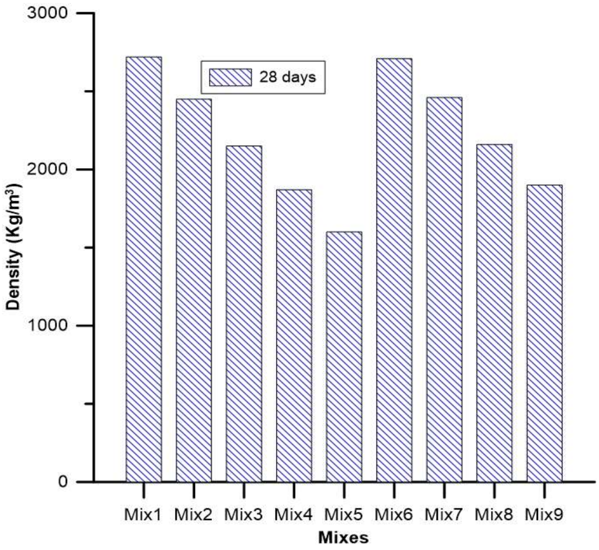


Fig. 3 - Density of SCC with Lightweight Aggregate.

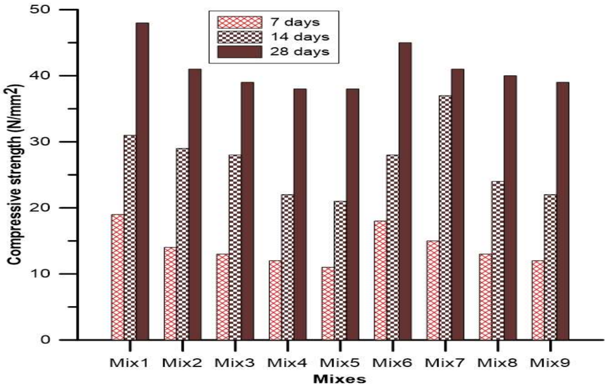


Fig. 4 - Compressive Strength.

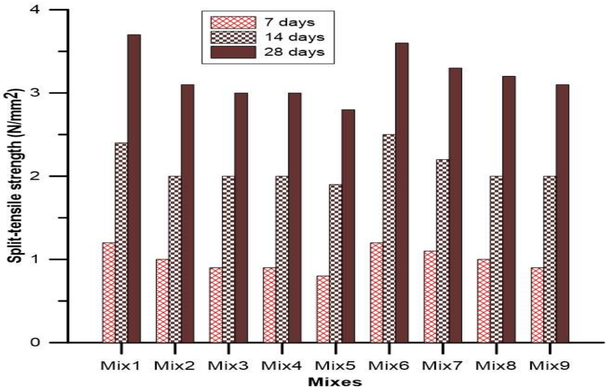


Fig. 5. Split-tensile Strength

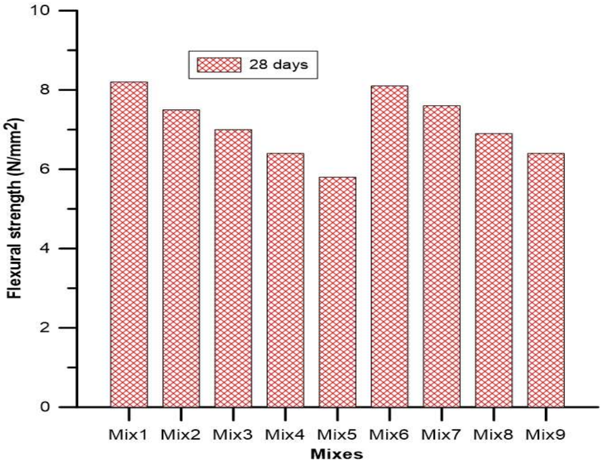


Fig. 6 - Flexural strength.

## 4. Conclusion

The structural properties of LWSCC made with mineral admixtures and pumice stone have been investigated and the following conclusions were drawn:

1. The workability of all the LWSCC mixes considered were within the specified standard limits; an indication that the use of mineral admixtures in addition to superplasticizer also enhance the workability of LWSCC. Thus, this concrete technology will reduce the noise pollution from vibrators used for compaction of normal weight concrete.

2. It has been observed that, between 30-40% PS replacement of coarse aggregate significantly reduces the density of concrete and overall, contribute to the making of a durable LWSCC.

In summary, it is very evident that pumice stone, even though are slightly weaker in compression can be used for structure purpose in addition with other pozzolanic material such as GGBS and RHA. Through the study it is found that for better density and strength not more than 30-40% replacement of coarse aggregate by pumice stone is suggested, when can be used with GGBS, RHA. If PS and RHA are used at the same proportion, then it can be more effective. For any admixture concerned with the durability factor, the predefined proportion provides better durability and structural strength.

Thus, a proper choice of aggregates has significant influence on the fresh and hardened properties of SCC and moreover, it leads to a better quality concrete and an efficient construction process. Therefore, meaning that a successful development of SCC ensure a good balance between deformability and stability.

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