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NEW TYPE OF LIGHTWEIGHT AGGREGATE FOR USE IN STRUCTURAL CONCRETE

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Abstract

This research studied the utilization of municipal solid waste incineration bottom ash (MSWI-BA) in lightweight coarse aggregate (LWC) production. A special method was followed to prepare the new aggregate to fully replace the normal aggregates (NWA) in concrete. The mechanical properties such as compressive strength, tensile strength, and elasticity modulus were investigated for the LWC concrete. Then, two beams were prepared; one from LWC and the other from NWC. The structural performance of beams made up of lightweight aggregates compared to normal aggregates was investigated. The results showed that this type of aggregates led to a 20% reduction in concrete density. There was a decrease in compressive strength, tensile strength, and elasticity modulus when using lightweight aggregates. In addition, there was a reduction in the structural performance of the NWC beam was better than the LWC beam

Keywords

Bottom ash, Concrete, Lightweight Aggregate, Sustainability, Structural Performance

1. INTRODUCTION

Environmental issues have always been one of the first priorities of researchers in various scientific fields due to the various repercussions of environmental pollution in recent times. Among these fields is construction materials, where many researchers have made great efforts to utilize different waste materials in the manufacture of concrete and various Cementous materials (Jahami *et al.* 2019[a], Jahami *et al.* 2019[b], Khatib *et al.* 2019, Bawab *et al.* 2020, Khatib *et al.* 2020[a], Khatib *et al.* 2020[b], Bawab *et al.* 2021, Khatib *et al.* 2021[a], Khatib *et al.* 2021[b]). On the other hand, this research complements other work on producing lightweight concrete in order to reduce the dead load of the structure; thereby, leading to a reduction in the dimensions of the load-bearing structural elements and the total structure cost.

Tamil Selvi *et al.* (2021) conducted a study on mechanical and durability properties of concrete containing High-density Polyethylene Granules (HDPE) as partial replacement of coarse aggregate. Five concrete mixes were prepared with HDPE percentage ranging from 1% to 5%. Different mechanical and durability tests were considered including; compressive strength test, split tensile test, bending test, acid test, rapid chloride permeability test and alkaline test. Results showed that concrete specimens with HDPE aggregates performed better than the control specimens. This was proved for both mechanical and durability properties.

Adhikary and Rudzionis (2019) studied the efficiency of Expanded glass aggregate in producing lightweight concrete. Two different groups of lightweight concrete mixes were prepared by using different sizes of expanded glass aggregates. The first group contained combinations of different sizes of expanded glass aggregates with 787.5 kg/m^3 binding material volume, while the second group contained smaller size expanded glass aggregates with 500 kg/m^3 binding material volume. Results showed that aggregate properties and size had a significant effect on compressive strength, where concrete samples with smaller size expanded glass aggregates showed higher strength properties. In addition, concrete with smaller size lightweight expanded glass aggregates showed lower flowability due to higher specific surface area and water absorption properties.

Khatib *et al.* (2015) studied the structural performance of RC beams containing expanded glass as light weight aggregates. Fine aggregates were replaced with expanded glass at ratios ranging from 25% to 100%. Results showed that the compressive strength of concrete decreased as the ratio of expanded glass increased. However, the ductility of RC beams increased as the percentage of expanded glass increased. Furthermore, it was shown that for concrete with 50% expanded glass had a better workability than the other mixes with expanded glass.

Dinakar (2012) conducted a study on fly-ash lightweight aggregate concretes with various water/cement ratios ranging from 0.30 to 0.50. Coarse aggregates were completely replaced with sintered fly-ash aggregates. Results showed that using this type of aggregates helped in reducing the concrete density by 20% compared to control specimens. As for mechanical properties, they were comparable to the control specimens expect for elasticity modulus. In addition, it was shown that the best water cement ratio to be adopted ranged from 0.45 to 0.5.

Gao *et al.* (1997) investigated the mechanical properties of high strength lightweight concrete with steel fibers. Compressive strength, tensile strength, and elasticity modulus were investigated in this study. Results showed that the compressive strength was slightly improved, while there was a noticeable increase in tensile in the presence of steel fibers. In addition, aspect ratio "L_f/d_f" and Fiber volume fraction "V_f" had great effect on fracture toughness and flexural strength.

The aim of this study was to utilize the MSWI-BA in creating lightweight aggregates which will reduce the density of structural concrete. Two concrete mixes were considered for this purpose: a normal weight concrete (NWC) mix as reference and a lightweight concrete mix made from lightweight aggregates. Different mechanical properties were determined for each concrete mix such as compressive strength, tensile strength, and elasticity modulus. In addition, a reinforced concrete beam was cast from each mix to investigate the structural performance of beams containing LWC compared to NWC.

2. METHODOLOGY

2.1 Lightweight Aggregate Manufacturing

The lightweight aggregates were produced mainly using MSWI-BA. First of all, the MSWI-BA was dried in an oven at 100 C. Then, the bottom ash was sieved using 9.5 mm diameter sieve to remove any unwanted objects that may affect the properties of aggregates.

After that, the MSWI-BA, cement, water, and admixture were mixed together in the concrete mixer (Fig. 1). The mixer was rotated to a specific angle to allow the particles (lightweight aggregate) to take the required spherical shape. As for the admixture, it was added to improve the mix's workability without the need of excess water which can affect the aggregate strength. The last step in the process was to place the lightweight aggregates on a plastic clean sheet (Fig. 2) and spray them with water daily for 28 days.

Fig.1: Lightweight aggregate under Manufacturing.

Fig.2: Fresh sample of lightweight aggregates.

2.2 Mix Design

Two mixes were prepared in order to be used in this project. The first mix was a normal weight concrete mix (NWC) with mix proportions of (1 Cement : 2 Sand : 4 Coarse Aggregate), and the second mix had a mix proportions of (1 Cement : 1.25 Sand : 1.65 Lightweight Coarse Aggregate). The lightweight aggregates prepared from MSWI-BA which was brought from a local waste incinerator. These proportions of materials were selected based on initial trial mixes to achieve adequate workability. The details for all mixes are presented in Table 1.

Table 1: Mix Design Details

Mix	Cement (kg)	Water (kg)	Sand (kg)	Gravel (kg)	Admixture (kg)
NWC	317	185	634	1268	3.2
LWC	427	170	540	712	4.4

2.3 Mixing Procedure

After preparing all the required quantities, they were mixed in a drum-type mixer as per ASTM standards 31/C 31M. First, sand and cement were added and mixed together for 2 minutes. Then the gravel/lightweight aggregates were added to the mixture and the whole mix was mixed for 2 minutes. After that, two thirds of the water quantity was added to the mixer while the remaining quantity was used to mix it with the chemical admixture before adding it to the mixture. Finally, the whole mixture was mixed for 5 minutes until reaching a homogeneous texture.

Three (15 cm x 15 cm x15 cm) cubes (Fig. 3) in addition to three (15 cm diameter x 30 cm height) cylinders (Fig. 4) were cast from each mix to determine the mechanical properties of NWC and LWC. The slump value for the lightweight concrete (LWC) sample was 16 cm, while for normal weight concrete (NWC) sample it was 12 cm. Finally, all specimens were cured for 28 days by submerging them in a water tank.

Fig.3: Concrete cubes after curing.

Fig.4: Cylindrical specimens after casting.

Two reinforced concrete (RC) beams were cast in order to test the structural performance. One beam was cast with NWC mix and the other from the LWC mix. Each beam had dimensions of 100 mm width, 200 mm height, and 1000 mm length. The beams were reinforced with two 8 mm diameter rebars at the bottom and two 6 mm diameter rebars at the top and 6 mm diameter stirrups spaced at 50 mm. The design was made such that beams would fail in flexural mode. Fig. 5 shows the dimensions and reinforcement of the beams.

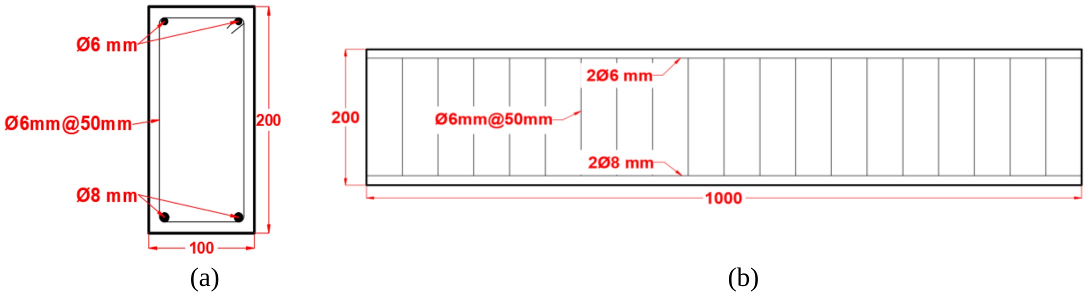


Fig.5: RC beam details

2.4 Experimental Tests

Four tests were considered in this study to determine the mechanical properties of LWC and NWC mixes. The dry density, compressive strength, splitting tensile and the elastic modulus tests were determined according to ASTM C138 / C138M - 17a, ASTM C496 / C496M – 17, ASTM C39 / C39M – 18 and ASTM C469 / C469M - 14e1 respectively. In addition, three-point bending test was conducted on the RC beams as per (ASTM C78 / C78M – 21) to study the structural response of beams with LWC compared to NWC. The failure loads, ductility factor and crack patterns were determined. Fig. 6 shows more details about the three – point bending test setup.

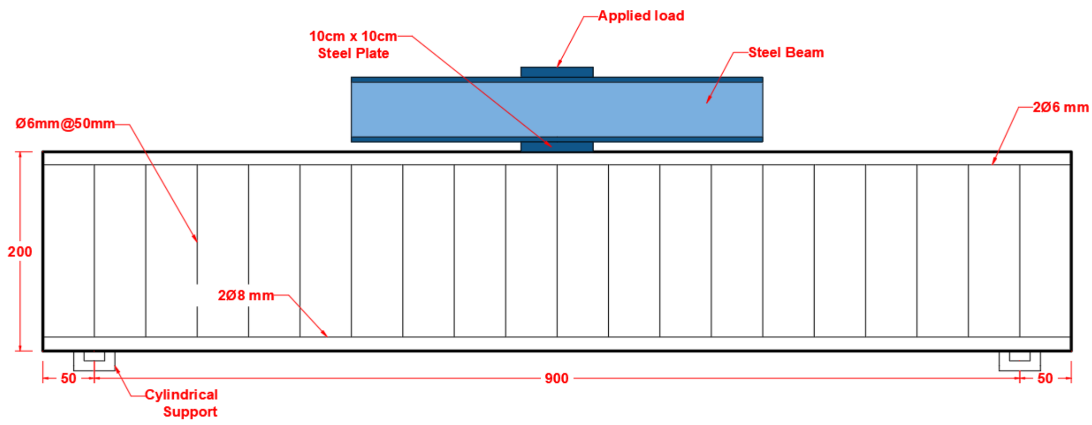


Fig.6: Three – point bending test details.

3. EXPERIMENTAL RESULTS

3.1 Density and Elasticity Modulus

The concrete density of NWC and LWC is in Fig. 7. Using light weight aggregates in concrete as a replacement of conventional coarse aggregates led to a decrease in concrete density by 20%. This is important since it will lead to a decrease the dead load which would lead in reduced dimensions of structural elements. The elasticity modulus decreased when using lightweight aggregates as depicted in Fig. 8. The elasticity modulus decreased from 29760 MPa for NWC to 20074 MPa for LWC which is around 32% reduction.

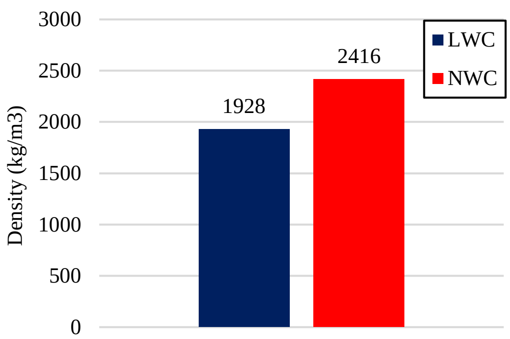


Fig.7: Density of LWC and NWC specimens

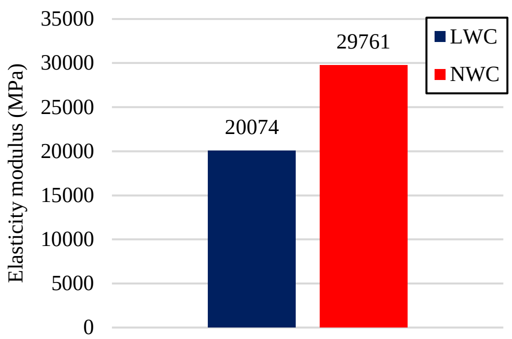


Fig.8: Elasticity modulus for LWC and NWC specimens.

3.2 Compressive and Tensile Strength

The presence of lightweight aggregate led to a reduction in compressive strength compared NWC mix as shown in Fig. 9. The compressive strength at 1 day was 7.6 MPa and 10.3 MPa for LWC and NWC specimens respectively. At 7 days, the strength was increased to 15.1 MPa and 19.1 MPa for LWC and NWC specimens respectively, while at 28 days, the final compressive strength reached 21.5 MPa and 30.5 MPa for LWC and NWC specimens respectively. A 28-day compressive strength of 21.5 MPa is suitable for structural applications.

Similar trend was realized for tensile strength at 1, 7, and 28 days, where LWC specimens had around 10% less tensile strength than NWC specimens as shown in Fig. 10. However, by comparing the ratio of tensile strength to compressive strength, it can be seen that it was increased from 0.1 for NWC specimens to 0.13 for LWC specimens at 28 days (Fig. 11).

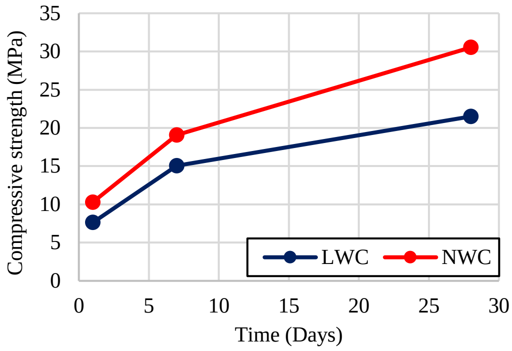


Fig.9: Compressive strength for LWC and NWC.

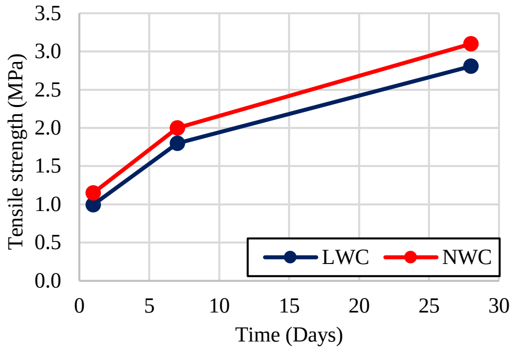


Fig.10: tensile strength for LWC and NWC.

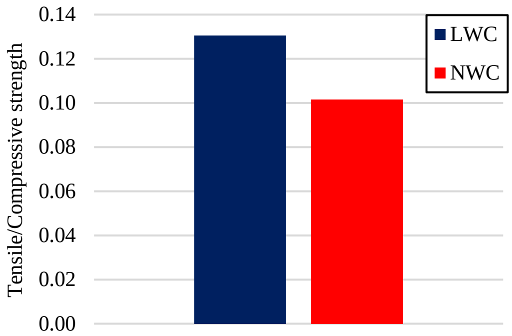


Fig.11: Tensile/Compressive strength ratio for LWC and NWC.

3.3 Three – Point Bending Test

The load – displacement curve for each beam is depicted in Fig. 12. The NWC beam had a failure load of 42.3 kN while for the LWC beam the load was 33.3 kN. This is a reduction of 21% which is partly due to the higher compressive strength and elasticity modulus for NWC beam compared to LWC beam. In addition, the ductility of NWC beam was much better than LWC beam. This can be shown from the failure displacement for both beams, where NWC beam had 17.6 mm displacement at failure while LWC beam had 9.1 mm displacement only. This could be due to the higher elasticity modulus for NWC compared to LWC which led to higher ductility for NWC beam compared to LWC beam.

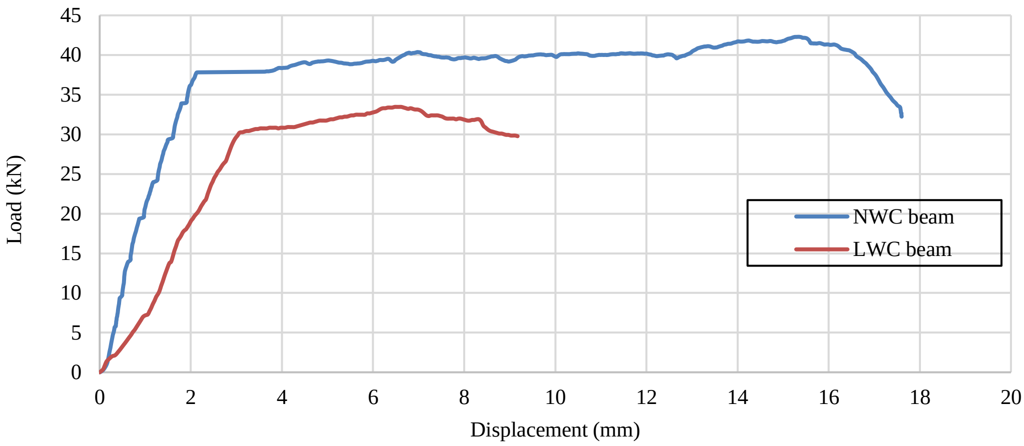
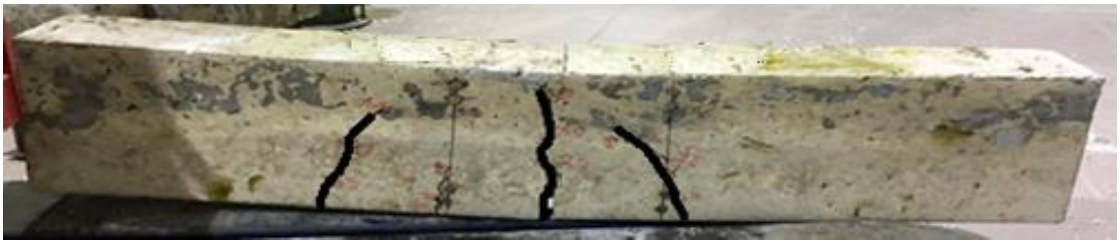


Fig.12: Load – displacement curves for NWC and LWC beams.

Fig. 13 shows the damage pattern of NWC and LWC beams. They both failed in flexural mode. This can be seen from the crack pattern at failure which started from the bottom face of the beam and extended upward until reaching the upper face (compression face). One difference between the damage pattern of beams is that LWC beam had more visible cracked that NWC beam, which can be justified by the difference in strength between both beams.



(a)

(b)

Fig.13: Crack pattern for:
a) NWC beam. b) LWC beam.

4. CONCLUSION

The following conclusions can be made:

1- Concrete specimens made from MSWI-BA lightweight aggregates showed to have 20% less density than the normal weight concrete. This will help in reducing the self-weight of concrete structures and eventually reducing reinforcement quantities.

2- Normal weight concrete showed to have better mechanical properties than LWC. The compressive strength and elasticity modulus at 28 days for LWC specimens were less than NWC specimens by 30% and 33% respectively. As for tensile strength, LWC specimens showed 10% less tensile strength than NWC specimens. However, a 28-day concrete compressive strength of 21.5 MPa was achieved with using lightweight aggregate which is considered suitable for structural applications.

3- Lightweight concrete (LWC) beams showed to have 21% less ultimate load capacity than normal weight concrete (NWC) beams. In addition, the ductility of LWC beams were reduced compared to NWC beams. More research is recommended to enhance strength and ductility of RC beams made out from bottom ash lightweight aggregates.

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