Lightweight Concrete Using Local Industrial By-product

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Abstract: Construction is one of the largest users of energy, material resources and water and it is a formidable polluter. One of the major materials used in construction is concrete and ordinary concrete contains about 12% cement which is a major producer of greenhouse gas in the world. The use of waste materials as partial replacement of cement in concrete reduces greenhouse gases, frees up land fill space, and reduces raw materials consumption. This contributes towards sustainable development, as in a sustainable society, nature is not subject to systematically increasing concentrations of substances extracted from the earth's crust. This research work explores the possibility of replacing some percentage of cement in concrete with marble sludge powder to produce lightweight concrete. This was achieved by determining the compressive strength and some hardened properties of concrete like sorptivity and carbonation with marble sludge. The results so far have been able to prove that lightweight concrete can be produced when some percentage of cement is replaced with this waste.

Key words: Lightweight concrete, marble sludge, filler, carbonation, permeation.

1. Introduction

Industrial by-products are waste materials produced by industries as a result of production. More production equals more waste, and more waste creates environmental concerns of toxic threat. An economically viable solution to this problem should include utilization of these waste materials for new products especially in construction applications which in turn minimizes the heavy burden on the nation's landfills, saves natural resources, energy, reduces air and water pollution and also reduces the emission of green house gases. Examples of these wastes that can be used in construction works which include cement kiln dust, foundry sand, fly ash, silica fume, slag, marble sludge, and so on [1].

By virtue of its size, construction is one of the largest users of energy, material resources and water, and it is a formidable polluter [2]. There is increasing concern now that the choice of construction materials must also be governed by ecological considerations.

Concrete is the major construction material in the world with 11.5 billion tons of concrete as world demand per year and the demand for concrete is expected to grow to approximately 18 billion tons a year by 2050 [3].

Ordinary concrete, typically, contains about 12% cement, 8% mixing water, and 80% aggregate by mass [3]. This means that, in addition to 1.5 billion tons of cement, the concrete industry is consuming annually 9 billion tons of sand and rock together with one billion ton of mixing water. The 11.5 billion tons a year concrete industry is, thus the largest user of natural resources in the world which if continue unchecked will result in depletion of natural resources. Greenhouse gas is also generated which is responsible for 5% CO₂ production in the world. The mining, processing and transport of huge quantities of aggregate, in addition to billions of tons of raw materials needed for the cement manufacture consume considerable energy and adversely affect the ecology of virgin lands. If the waste product of one industry is recycled as a substitute for virgin raw material of another industry, it will thereby reduce the

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environmental impact of both. Any efforts to reduce such dependence of virgin materials will, therefore, be a contribution towards sustainable development.

Marble sludge powder is an industrial waste containing heavy metals in its constituent and it is produced from cutting of marble stone for usage in various construction applications in Nigeria. The amount of industrial waste generated due to the cutting is increasing every day; this put pressure on the limited number of land fill and suggests more sustainable use of such in construction development and in production of new products like concrete. The use of marble sludge as filler material in cement reduces the amount of natural resources required. This displaces some cement production, an energetically expensive and environmentally problematic process, while reducing both the need for land area for extracting resources and amount of industrial waste that must be disposed of.

In recent times, marble dusts have found some use in the construction industry and research has been conducted to examine their applications. An exclusive work has been done on the feasibility of the usage of quarry rock dust and marble sludge powder as hundred percent substitutes for natural sand in concrete [4]. From the study, it is found that the compressive, split tensile strength and durability studies of concrete made of quarry dust and marble sludge powder are nearly 14% more than the conventional concrete. The concrete resistance to sulphate attack was enhanced greatly, according to the experiment performed on the hardened properties of bituminous concrete with marble dust as filler [5]. Fillers are fine aggregate material that passes 0.063 mm sieve [6]. The behaviour of bituminous concrete with marble dust compared very well with bituminous concrete with lime and stone dust.

Marble powder has a very high Blaine finess value of about $1.5 \text{ m}^2/\text{g}$ with 90% of particles, passing 50 μm sieves and 50% under 7 μm [7]. The maximum compressive and flexural strengths were observed for

specimens containing 6% waste sludge when compared with control and it was also found that waste sludge up to 9% could effectively be used as an additive material in cement [8]. The result of an investigation on the abrasion resistance of concrete made by percentage substitution of sand by marble waste powder compared very well with that of conventional concrete [9]. In the same study, increment in percentage of substitution of sand caused a significant increment in the sodium sulphate resistance of concrete; whereas water penetration depth of concrete with marble powder at 15% substitution was found considerably less than that of concrete with 0 marble powder. Marble dust can also be used as filler and helps to reduce the total voids content in concrete [9]. Consequently, this contributes to improvement of strength of concrete.

The durability of concrete is a function of permeability [10], hence concrete can be made durable by reducing the extent of voids. Permeability is the movement of fluids across a porous medium as a result of pressure gradient. Thus, concrete permeability refers to its ability to transmit fluids through it caused by pressure head; this applies to the transport of both gases and liquid [11]. More research is still needed to see its wider application in concrete especially as partial replacement of cement. The objective of this study to provide more scientific evidence to support the re use of accumulated marble wastes in Nigeria; by investigating into the following hardened properties of concrete with marble sludge powders, compressive strength, permeability, sorptivity and carbonation. If this is successful there will be less demand on cement, thus providing possible solutions to environmental concerns of green house gas (CO_2) pollution, waste production and depletion of natural resources. The paper is organized as follows: Section 2 shows the characterization of materials; Section 3 explains the materials and experimental methods used in the study; Section 4 presents results and discussions; and Section 5

2. Characterization of Materials

3. Materials and Experimental Methods

Ordinary Portland cement that conforms to ASTM C150—standard specification for Portland cement obtained from a local commercial manufacturer in Nigeria precisely (Dangote cement) was used throughout the experiment.

Marble dust samples from Coker, Lagos State, Nigeria were crushed and grinded using laboratory crusher and ball mill and passes 0.063 mm sieve size.

The coarse aggregate used was crushed granite chippings with a size of 12 mm at the average.

Medium size fine aggregate from Ebute River in Ikorodu with clean tap water available in the concrete laboratory was used in manufacturing the concrete. The qualities of water samples are uniform and potable.

The batching of concrete was done by weighing the different constituent materials based on the adopted

The water cement ratio for both two mixes was 0.65% by weight. The freshly mixed concrete was then filled in 150 mm by 150 mm moulds in approximately 50 mm layers with each layer given 35 strokes of the tamping rod. Samples were held in the laboratory at an atmosphere of more than 95% relative humidity and ambient temperature, i.e., 25 °C. The moulds were opened after 24 h and the specimens were stored in the humid bath for 28 days curing age.

The 150 mm size concrete cubes were used as test specimens to determine the compressive strength. The test specimen at the end of 28 curing days were subjected to compressive load from a 214 × 250 shambhavi compression testing machine until failure.

The object of this durability study is to investigate the permeability through sorptivity test and resistance to carbon attack for both conventional concrete and concrete with % replacement of cement. Sorptivity test was conducted over six hours. The water sorptivity test measures the rate of movement of water front through the concrete under capillary suction. The specimens after dried were saw-cut in

Material	Moisture content (%)	Bulk density (kg/m ³)	Fineness modulus	Effective size (mm)	Coefficient of uniformity	Coefficient of gradation	Wet dry
Marble powder	23.35	1.59	1,118	2.04	0.17	1.58	1.37

[illegible]

Marble	11.99	0.08	2.08	8.74	2.33	4.45	1.58	64.86
Portland cement	2.27	0.045	0.75	2.24	0.70	5.86	64.07	20.15

pieces ($75 \times 150 \text{ mm}^2$). The surfaces of the concrete samples were then placed in water. For each mass determination, the test specimens were removed from water and the surfaces cleaned with a dampened paper towel to remove water droplets. The mass of the samples were then measured and were replaced to continue the test. The cumulative change in mass 1, 2, 3, 4, 5 and 6 hours were used to obtain the respective cumulative absorption values (i) expressed as Eq (1):

$$i = \Delta m / A \ell \quad (1)$$

where, Δm = cumulative change in mass due to water absorption, A = cross-sectional area of test specimen (mm^2) and ℓ = density of water (10^3 kg/m^3)

As soon as concrete is formed, the carbon dioxide in the air reacts with the calcium hydroxide, forming calcium carbonate, a process known as carbonation. For the carbonation test of the samples, phenolphthalein indicator solution was applied to fresh fractured surface of concrete. The indicator turns purple at PH above 8.6 and remains colourless when the PH of the concrete is below 8.6, suggesting carbonation. A fully carbonated paste has a PH of about 8.4. In practice, strong immediate colour change to purple suggest a PH that is rather higher, perhaps PH 9.0 or 10.0.

4. Results and Discussion

4.1 Compressive Strength Development

Compressive strength tests were conducted in accordance with BS EN12390-3:2009 [12] on all cubes of the two mixed ratios at 28 curing days. Compressive strength test results are shown in Table 3 and Fig.1. MDC (marble dust concrete) showed a reduction in compressive strength compared to the control PC concrete. This confirms that different mixes of concrete ingredients produce different strengths which are measured in MPa [13]. Different strengths of concrete are used for different purposes;

very low-strength (14 MPa or less) concrete maybe used when the concrete must be lightweight [13].

Table 3 Average compressive strength in N/mm^2 at 28 days.

MIX	% Marble concentration			
	0	5	10	20
MIX A	29.3	20.5	19.6	19.1
MIX B	24	15.3	15.1	9.6

4.2 Applications of Lightweight Concrete in Construction

- Curtain walls for high-rise construction;
- Highway sound barriers;
- Low cost insulated walls for residential buildings;
- Tilt up panels;
- Façade tiles for an architectural application;
- Repairs on a bridge;
- Slope protection;
- Aircraft arresting beds;
- Foundations for roads and sidewalks;
- Subsurface for sport arenas, e.g., tennis courts;
- Explosion-resistant structures.

4.3 Permeation Test

Sorptivity test was conducted over six hours and the cumulative change in mass at specific intervals was determined. The results in Fig. 2 show decrease in sorptivity as the level of replacement of cement increases. This means marble dust can be used as filler and helps to reduce the total voids content in concrete. This result is in line with Ref. [9].

4.4 Carbonation Test

Phenolphthalein indicator solution was used to achieve the carbonation test. There was strong immediate colour change to purple in all the samples which suggest a PH that is rather higher perhaps PH 9.0 or 10.0, but within 24 hours, the specimen begin to turn colourless. The result of carbonation test of MDC

compares very well with control concrete. The penetration rate of carbonation increases with increase in exposure time for all samples with faster rate in

MDC. This improves the compressive and tensile

Fig. 1 Compressive strength of concrete samples.

Fig. 2 Sorptivity and concrete type.

strength of concrete by reducing the porosity of dense and compact concrete, protecting it against water and chloride ion infiltration. Chloride ions can corrode the steel placed in reinforced concrete. It is important to

keep these advantages in mind because the carbonation is an inevitable process for concrete to undergo.

5. Conclusions

From the above study, it is concluded that the marble sludge powder may be used as a partial replacement material for cement in producing lightweight concrete. The investigation was primarily to find solution to the disposal problem of marble dust. The disposal of this waste material can lead to the following environmental problems:

- If the waste is disposed on soils, the porosity and permeability of top soil will be reduced, the fine marble dust reduces the fertility of the soil by increasing its alkalinity;
- When dumped, marble powder suspends in the air and slowly spread out through wind to the nearby area;
- When dumped along a catchment area of natural rainwater, it results in contamination of over ground water reservoir and also causes drainage problem.

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