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LIGHTWEIGHT CEMENTETIOUS (GEM-TECH) STRUCTURAL MATERIAL

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SUMMARY
The growing need for a better and effective way of reducing structural weight and high cost in productivity of concrete products has led to a great innovation in the use of lightweight concrete such as foam concrete which is known to be in use for about thirty to forty years, but its low quality characteristics has in no small measure hinder its wide industrial application.
This paper presents a novel material the GEM-Tech product which early results from laboratory compressing testing of samples suggest that it has formidable characteristics and the potential to result in lightweight elements and huge savings in the construction of structures.

Keywords: Lightweight, material, compressive, strength, experimental, GEM-Tech.

1. INTRODUCTION

Over the years, concrete has been the dominant structural construction material and has a very wide range of applications with billions of tonnes produced every year. Its excessive weight on foundations has been a major flaw, especially when used to construct high rise buildings and this is a serious problem in areas prone to earthquake forces. The keenness to come up with a more effective lightweight structural material (not just void fillers and partition walls) that will in turn lessen the entire weight of structures on their foundation has resulted in tremendous evolution in concrete research.

Cellular concrete is a class of lightweight concrete that has received extensive interest by researchers but also the construction industry. It is defined as " cement-bonded material that is manufactured by blending a very fluid cement paste(slurry) or mortar with a separated manufactured foam (resembling shaving leather) in to a grey mousse with high fluidity.

It is defined by (Tikalsky, 2004) as a concrete composed of cementitious mortar surrounding disconnected random air bubbles, with the air typically occupying more than 50% of the volume. The air bubbles are a result of gas formed within the mortar or foam introduced into the mortar mixture. Specifically, the volume between the slurry and the foam determines the density of the foam concrete. The presence of the cement causes the material to be cohesive (strength/stiffness) after hydration of the cement. Its overall matrix can be described as a pore structure surrounded by cement slurry" (Foam Concrete Limited, 2008).

Cellular concrete can be describe as a type of concrete whose components includes an expanding agent that increases the volume of the mixture while giving additional qualities such as reduced dead weight. As defined by (American Concrete Institute, 2003): "*cellular concrete is referred as a low density, product consisting of Portland cement- pozzolan, or lime silica pastes containing blinds of these ingredients and having a homogeneous void or cell structure, attained with gas-forming chemicals or foaming agents"*.

Cellular concrete is lighter than conventional concrete, with a dry density of 300 kg/m^3 up to 1840 kg/m^3 (87 to 23% lighter). It was first introduced by the Romans in the second century where 'The Pantheon' has been constructed using pumice, the most common type of aggregate used in that particular year (Mohd Roji,1997). From there on, the use of lightweight concrete has been widely spread across other countries such as USA, United Kingdom and Sweden.

The main characteristics of cellular concrete are its low density and thermal Insulation properties. Comparatively, the advantages are apparent as uses of cellular concrete leads to reduction of dead load, faster building rates in construction and lower haulage and handling costs. The building of 'The Pantheon' of lightweight concrete material is still standing eminently in Rome until now for about 18 centuries as shown in figure 1. It confirms that the lighter materials can be used in concrete construction and has an economical advantage.

Figure 1: The Pantheon (Andrew and William, 1978)

In accordance to (Orchard, 1979) cellular concrete could be produced in the following ways:

1. By mixing normal air entraining agents with cement or cement and sand in special high speed or whisking mixers.
2. By mechanically entraining foam in a plastic mortar.
3. By making foam separately and subsequently adding a given quantity to a known density plastic mortar.
4. The formation of air bubbles through the addition of calcium carbide (CaC_2)
5. By adding hydrogen peroxide (H_2O_2) to a base mix.
6. By adding aluminium powder or zinc powder to the cement mortar

1.1 Types of cellular concrete

Cellular concrete can be prepared either by injecting air in its composition or by aerating a plastic mortar. The former and latter are said to have been prepared by two major method of preparing cellular concrete. They are; preformed foam method and autoclave or mixed method, details of the said methods will be discussed later in this chapter. Particularly, cellular concrete can be categorized into five groups:

- Foam concrete
- Gas concrete
- Aerated concrete

- No-fines concrete
- Lightweight aggregate concrete

1.1.1 Foam concrete

Generally, foam concrete is defined as concrete created by uniform distribution of air bubbles throughout the mass of concrete'' (htt://www.ibeton). It is produced by mechanically mixing of foam prepared in advance with concrete mixture and not with help of chemical reactions.

Intrinsically, foam concrete could be describe as free flowing, self- levelling , material that does not require compaction. Its main advantage over more traditional fill or sub base material is ability to flow around pipes and cables in situation where crowded excavation would make it difficult to adequately compact other materials. It is also a useful material to apply where the side stability of trenches is poor or where there is undercutting of the adjacent carriage. The lack of compaction also helps towards the reduction of white knuckle syndrome (htt://www.ibeton).

The foam concrete is a low density cementitious material, due to replacement of aggregate by air voids from air entraining or foaming agent.

The mix of this material is restricted to comply with the 28 days compressive strength. Thus the maximum permitted strength for all foam concrete mixes is 10N/mm^2. Therefore care should be taken not to exceed the maximum values for two reasons, firstly above 14N/mm^2 it starts to behave more like structural concrete and may crack and produce reflective cracking.

1.1.2 Gas concrete

This is another form of lightweight concrete, which is produced from different mixture of silica, sand, cement, lime, water and aluminium cake which produces gas. However, it is said to be produced by a chemical process of the above constituent material mix. The gas concrete is five times lower than the usual concrete material. In addition, the heat transfer that exists in gas concrete is reduced fivefold by the bubbles inside. It is sometimes called autoclaved aerated concrete '(AAC)', this is due to air bubbles arising in the chemical reaction. More so, according to research, the gas concrete exhibits an extraordinary properties of the heat insulation at high or low outside temperature. In accordance to (Autoclave aerated concrete, 1993), gas concrete is a form of aerated concrete produced by the formation of microscopic air gas bubbles within the mass during the liquid or plastic phase. The said air bubbles are uniformly distributed and are retained in the matrix on setting and later hardening to produce a cellular structure.

1.1.3 Aerated Concrete

Aerated concrete is a form of cellular concrete without a coarse aggregate, and can be regarded as an aerated mortar. Typically, aerated concrete is made by introducing air or other gas into a cement slurry and fine sand. In commercial practice, the sand is replaced by pulverized fuel ash or other siliceous material, and lime maybe used instead of cement (Mohd Roji, 1997).

Particularly, there are two methods to prepare the aerated concrete. The first method is to inject the gas into a plastic mortar by means of a chemical reaction. The second method, air is introduced either by mixing-in stable foam or by whipping-in air, using an air-entraining agent. The first method is usually used in precast concrete factories where the precast units are subsequently autoclaved in order to produce concrete with a reasonable high strength and low drying shrinkage. The second method is mainly used for in-situ concrete, suitable for insulation roof screeds or pipe lagging. Figure 2 shows the aerated concrete.

Figure 2: Aerated Concrete (Mohd Roji, 1997)

1.1.4 No-Fines Concrete

This is another form of cellular concrete composed of cement, fine aggregate and uniformly distributed voids formed throughout its mass. Besides the main characteristics of this type of lightweight concrete is it maintains large voids and not forming laitance layers or cement film when placed on the wall. Figure 3 shows an example of No-fines concrete.

Figure 3: No-Fines Concrete (Ghafoori and Dutta, 1995)

1.1.5 Lightweight Aggregate Concrete

The lightweight aggregate can be natural aggregate such as pumice, scoria and all of those of volcanic origin and the artificial aggregate such as expanded blast-furnace slag, vermiculite and clinker aggregate.

The main characteristic of this lightweight aggregate is its high porosity, which results in a low specific gravity (Ghafoori and Dutta, 1995).
The lightweight aggregate concrete can be divided into two types according to its application: one is partially compacted lightweight aggregate concrete and the other is the structural lightweight aggregate concrete.

The partially compacted lightweight aggregate concrete is mainly used for two purposes that is for precast concrete blocks or panels and cast in-situ roofs and walls. The main requirement for this type of concrete is that it should have adequate strength and a low density to obtain the best thermal insulation and a low drying shrinkage to avoid cracking (Mohd Roji, 1997).

Structurally lightweight aggregate concrete is fully compacted similar to that of the normal reinforced concrete of dense aggregate. It can be used with steel reinforcement as to have a good bond between the steel and the concrete. The concrete should provide adequate protection against the corrosion of the steel. The shape and the texture of the aggregate particles and the coarse nature of the fine aggregate tend to produce harsh concrete mixes. Only the denser varieties of lightweight aggregate are suitable for use in structural concrete (Mohd Roji, 1997). Figure 4 shows the feature of lightweight aggregate concrete.

Figure 4: Lightweight Concrete (Mohd Roji, 1997)

In recent years, research had been done on some lightweight materials. Nambiar and Ramamurthy (2006) had developed empirical models for predicting strength and densities of foam concrete, Jones and McCarthy (2005) gave an introductory study on the potential of foamed concrete to be used as structural (load carrying) material. Others have explored the use of some lightweight aggregate such as scoria (Yasar et al., 2003), expanded clay (Li et al., 2011), oil palm shell (Shafigh et al., 2014) etc.

The GEM-TECH technology offers a highly workable material that does not contain coarse aggregate (same principle as foamed concrete) and yet gives a good strength to weight ratio with its consistent liquid nature when freshly mixed, allowing for pumping with no need for vibrating or tamping, hence reducing labour cost (see Figure 5).

Figure 5: GEM-TECH material pumped into slab and beam moulds

1.2 The GEM-TECH Material

The GEM-TECH material is a unique product of GEM-TECH Technology made up of cement, sand, water and the GEM-SOL catalyst and results in an outstanding consistent distribution of air cells that are non-collapsible, forming a very consistent structure with low density characteristics and good compressive strength values. The GEM-SOL catalyst acts as glue that holds the air cells in place in their distinct position so that they do not collapse throughout the curing stage like the other foam concretes, thereby forming a consistent mix with good strength.

1.3 The GEM-TECH Machine

The GEM-TECH machine (see Figure) is a patented machine that employs precision engineering to achieve a consistent mix with uniform mixing of the constituent materials (sand, cement, water and the GEM-SOL catalyst). Dan-jumbo (2015) in a maiden research on the material had described the operation of the machine in details.

Figure 6: the GEM-TECH machine for mixing the material

2. EXPERIMENTAL PROGRAMME

Material and mixture composition

The constituent material used to produce Gem-tech materials were comprised of: Pro-chem cement conforming to BS12, pulverized river sand finer than 300µ (specific gravity 2.5) and foam produced by GEMating, a foaming agent (GEM-Sol) (dilution ratio 1:5 by weight) using an indigenously GEM-Tech machine calibrated to a density of 1810kg/m^3. For this experiment three different types of mixes were used:

(1) several specimens were composed of Pro-chem cement, pulverized river sand, distil water and foam;

(2) a good number of specimens were composed of Pro-chem cement, pulverized river sand, distilled water, foam and a plasticizer;

(3) the third types of specimens are composed of Pro-chem cement, water, foam and fibre mesh.

Different mixes of the GEM- Tech materials were made varying the filler- cement ratio of 4.78:1 and 5.83:1 design mixes.

The mixing sequence consisted of a well calibrated GEM-Tech machine, which passes the constituent material from its internally built-in conveyor to a mixing chamber, which is designed like a mini batch plant. This process continues until a uniform homogeneous base mix was achieved.

The high air content eliminates any tendency to bleed and with good insulation properties, as the mix temperature increases during setting, the air expands slightly which ensures good filling and contact in confined voids.

Test Procedure

With a clear objective of assessing the compressive strength performance of GEM-Tech, the author had considered the use of cubes and mini beams as specimens for testing. The base mix from the GEM-Tech machine is poured into cube moulds and mini beam moulds. The samples are then levelled to achieve good finished surface, left for 24 hours, after which the moulds are uncoupled and carefully placed for air curing in accordance to BS1881 testing procedures. The air-curing period are 7 days, 14 days, 28 days, 56 days and 6 months period as the case maybe. On completion of air-curing period in compliance with test requirements, a compressive strength test is carried out to ascertain the GEM- Tech resistance capability.
In order to study the behaviour of GEM-Tech materials, normal concrete testing was carried out to determine the material and structural properties of each type of GEM-Tech and how these properties differ according to different types of mix design.
Once the concrete has hardened, it is subjected to a wide range of tests to prove its ability to perform as planned and to determine its characteristics. In the next section are given the results of compressive strength tests carried out on GEM-Tech specimens.

3. RESULTS AND ANALYSIS

Tables 1 to 5 show the results of compressive strength for a number of specimens with different densities and different water content ratios, with or without plasticizer.
As may be seen, the compressive strength increases with increased density of the material. For a given mix, overall the density of the material is seen to reduce with time (age). This is due to water evaporation with time. Also, the introduction of 1% plasticizer is seen to reduce the compressive strength by more than 50% for the lower density specimens.

Table 1: 5.83:1mix

Specimens	Density	Compressive Strength	Age (days)
CU320	1993	13.14	7
CU325	1964	16.93	14
CU322	1945	20.24	28
CU321	1925	21.65	56

Table 2: 5.83:1 with 1% plasticizers

Specimens	Density	Compressive Strength	Age (days)
CU420	1993	6.7	7
CU426	2010	13.9	14
CU429	1943	15.14	28
CU428	2003	14.55	56

Table 3: 4.78:1 mix with 20% water reduction

Specimens	Density	Compressive Strength	Age (days)
CU331	1816	16.43	7
CU337	1830	26.56	14
CU330	1805	27.30	28
CU336	1858	28.30	56

Table 4. 4.78:1 20% water reduction and 1% plasticizer

Specimens	Density	Compressive Strength	Age (days)
CU455	1729	13.6	7
CU457	1722	15.19	14
CU456	1692	13.4	28
CU453	1747	18.83	56

Table 5: Other effects on compressive strength

There seem to be some signs of inconsistency of the results using the plasticiser additive. This is probably due to a chemical reaction with the foaming agent. This an example of this research being so important, as it is part of the research programme to investigate material behaviour with various additives, but also to effectively calibrate the GEM-Tech machine more finely and to produce consistent materials and results in the future.

The reduction of mixing water by 20%, with no additives added, has produced the highest compressive strengths of GEM-Tech materials.

The use of fibermesh added to the mix shows that more mixing water is required to achieve higher compressive strengths.

The compressive strength of GEM-Tech material is determined by carrying out 7, 14, 28 and 56 days testing for specimen taken after a complete air-curing. These specimens are then placed under an axial max load of 2000 kN. Essentially, this research had produced extensive number of samples, for a proper analysis. The results of density and strength values were taken based on average results given. On the whole, fewer variables had been set for different ultimate mixtures as mentioned earlier. These variables will change while others were fixed in order to investigate their effects on the mixture. Thus, the varying percentage of foam agent, water, fibermesh, plasticisers, cement and sand ratio were variables made during mixing process. For example Table 5 shows that a particular mix of 4.78:1 can be displayed in variable content of water, plasticisers and fibermesh. It shows an extraordinary performance of GEM-Tech, as it confirms that at lower water-cement ratio and presence of high % of fibermesh, a clear indication of high strength is observed. This is achieved due to the even distribution of fibermesh, which is fed into the mixing screw to overcome any clogging up problems in GEM-Tech machine.

On a broad view, it may be observed that a percentage reduction in water volume gives a corresponding increase in compressive strength, appreciably 20% water reduction shows higher strength value as against 12%, 8% and 5% reduction of water in a 4.78:1 mix for the same duration. Interestingly, it is clear that higher % reduction of water content for this mix ratio, led to a higher compressive strength due to the cement paste forming a stronger bond and setting quickly.

The results as presented in Table 1 show that the compressive strengths for GEM-Tech material are lower. This is because the ratio of the mix used was 5.83 parts sand to one part cement. The density is higher due to the increase in the sand proportion in the mix. As a result, compressive strength decreases with the increase in the voids ratio.

4. CONCLUSIONS

Considering the important factors influencing strength and density of GEM-Tech materials, it is clear that the percentage of foam in GEM-Tech base mix is a determining factor. The test results have also shown that the adjustment of the GEM-Tech machine is an important parameter of the research programme and can have a big influence of the results and their consistency. All of these will be part of the further research programme to be carried out in the future.

The research has also shown that reasonable amount of strength is gained using admixtures like fibermesh by using more mixing water. A higher reduction of water content in GEM-Tech mixes with no additives leads to higher strength gains.

5. FUTURE

This is an ongoing research programme into a novel and very promising area. There are still unanswered questions that the research will be aiming to address through the ongoing PhD research programme. For instance, structural tests and finite element modelling are planned.

6. ACKNOWLEDGEMENT

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