Advances in Research
3(6): 548-557, 2015, Article no.AIR.2015.050
ISSN: 2348-0394

SCIENCEDOMAIN *international*
www.sciencedomain.org

SCIENCEDOMAIN

The Effects of Curing Methods on Early-age Strength of Sustainable Foamed Concrete

Alonge O. Richard[1*] and Mahyuddin B. Ramli[1]

[1]School of Housing, Building and Planning, Universiti Sains Malaysia, Penang, Malaysia.

Authors' contributions

This work was carried out in collaboration between both authors. Author AOR designed the study, wrote the protocol, and wrote the first draft of the manuscript. He also managed the literature searches, analyses of the study and the experimental process while author MBR proofreads the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2015/13373
Editor(s):
(1) Francisco Marquez-Linares, Full Professor of Chemistry Nanomaterials Research Group School of Science and Technology University of Turabo, USA.
(2) Enrico Franceschi, Department of Chemistry and Industrial Chemistry - University of Genoa Via Dodecanese 31-16146 Genoa, Italy.
Reviewers:
(1) Anonymous, Belarusian National Technical University, Belarus.
(2) Kofi Agyekum, Department Of Building Technology, Kwame Nkrumah University Of Science And Technology (Knust), Ghana.
(3) Anonymous, Linköping University, Sweden.
(4) Anonymous, Chungnam National University, Korea.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=758&id=31&aid=7113

Original Research Article

Received 14th August 2014
Accepted 28th October 2014
Published 8th December 2014

ABSTRACT

Curing is a process aimed at keeping concrete saturated or nearly saturated, so as to ensure complete hydration process of cement. For curing to be done properly, the temperature, duration and condition remain key factors. The rate of hydration is usually controlled by the quality and quantities of the cementitious materials present in the mix as well as the moisture availability and environmental temperature. Lightweight foamed concrete is regarded as a sustainable construction material in the construction industry. Some well known major setbacks such as low tensile and compressive strength, low flexural strength, fractural toughness and increase shrinkage as the ages grows, have been reported with this type of concrete. This work is directed at potential ways of increasing the compressive strength of this material by varying the curing method. Therefore, observing the effects of these variables on the eventual compressive strength of the samples in the early-ages of the concrete. The study was conducted using foamed concrete of 1200kg/m^3- 1600kg/m^3 density and at the water cement ratio of 0.45. No additives or admixtures

**Corresponding author: E-mail: olarichy07@yahoo.com;*

were used in this study. The samples were cured using three methods i. e. Water, air and moisture. At the end of the study, the compressive strength of the samples was analysed and the result shows that the samples cured by moisture has the highest compressive strength at 28 days.

Keywords: Sustainable construction materials; lightweight foamed concrete; curing method; early-age compressive strength.

1. INTRODUCTION

Sustainable building materials can be defined as materials that has an overall superior performance in terms of some specified criteria such as locally produced and sourced materials, transportation costs and environmental impact, thermal efficiency, health consideration and occupant needs, financial viability, recyclability, waste and pollution, energy efficiency and maintenance cost. The well known global warming has placed an insatiable demand in the construction industry relative to sustainable materials and energy savings. The sustainable principle covers four areas which are social, economic, technical and biophysical. According to Hossain and Inoue [1], sustainable construction has emerged as a paradigm to create a new kind of built environment: "one that meets the needs of humans in the present without limiting the ability of future generations to meet their own needs". In the word of Mohamad et al. [2], sustainability is the enablement to maintain a state or nature as it is now in the present and without any negative effect or hazard to the unborn generation potentials.The main aim of sustainability is to minimize the environmental and ecological impacts, caused by man on earth's surface resulting in cordial interrelationship of environment, economy and society. This practice has given rise to green buildings and hence green materials from which they are made.

Curing can best be described as the process of maintaining a satisfactory moisture content and temperature suitable for complete early hydration process in concrete. This is vital for the concrete strength development. It also has strong effects on properties such as durability, abrasion resistance, volume stability, strength, resistance to freeze and thaws as well as water tightness. When the temperature and moisture content are favourable, relatively rapid hydration is normally recorded within the first few days after placement of the fresh concrete. This is contrary to hydration process that may arise as a result of the evaporation process. Hence, curing regime can be referred to as the period of subjecting concrete surface for special treatment of continuous wetting or comfortable temperature and moisture contents. It can have a dominant effect on the strength, quality control and comparative purpose of foamed concrete. It is essential to established a clear cut curing regime for foamed concrete, a subject area that Brady et al. [3] considered as deserving further studies. This curing system has been adjudged to be a source of strength gain through research studies.

Foamed concrete can be considered as a free flowing, self compacting and versatile material that consist of foam produced under pressure from surfactants, fine aggregates as filler or some other cementitious materials and cement with water for proper hydration process. It is classified as a lightweight material in which air void are entrapped in cement sand mortar. Foamed concrete production can be done in two ways, it can either be by prefoaming method or mixed foaming method. The preform method involves the process of preparing a stable foam solution separately and then blends with base mix that has been prepared separately. While the process of mixed foaming method involves the mixing of the foaming agent along the base mix constituents till there is proper mixing and then resulted in cellular concrete structure [3].

The dry density of foamed concrete is usually between 400 and 1600 kg/m^3 and its compressive strength, which varies with density, can typically range between 1 N/mm^2 and 25N/mm^2 at 28 days [3]. Foam concrete has a satisfactory resistance to freeze/thaw effect and sulphate attack.

Many research works have been carried out on the physical, mechanical and chemical properties of foamed concrete. Mechanical properties was dealt with by Kearsley [4], Liang and Chen [5], Chen [6], Visagie and Kearsely [7] and Jones and McCarthy [8]. Durability properties by Brady et al. [3], Nambiar and Ramamurthy [9], Kearsley and Wainwright [10], Giannakou and Jones [11] and Davalos et al [12]. Functional properties has been studied by Jones et al. [13], Böttcher and Lange [14], Serrano-Perez et al.

[15], Kearsley and Mostert [16] and Ramamurthy et al. [17].

In these past studies, the issue of low compressive strength of lightweight foamed concrete was essentially mentioned and curing effects was analysed but in all, the effect of curing regime at the early ages of foamed concrete produced without any additives or admixtures was very handy hence this research study.
There are some handful research studies on the curing methods of foamed concrete at maturity age. Kearsley [4], in his study, concluded that water-cured specimens gave low strengths due to the build-up of pore water pressure in the saturated microstructure of the foamed concrete. In another research study [18], it was found that air-cured specimens at 40°C had higher strengths than those cured in water.

Arif et al. [19] in their study, concluded that specimens cured in air had a higher strength than those sealed-cured, but stated that the differences was specifically marked by the content of PC and PFA mixes. Liang and Cheng [5] concluded that autoclaving increases the compressive strength and declared that, the compressive strength of water-cured foamed concrete is higher than that of air cured specimens. All these studies were carried out at mature ages of concrete while this present study focuses on the early ages of foamed concrete and also without addition of any admixtures or additives.

Compressive strength of concrete can be described as the ability of the concrete to resist any axially directed stress or forces. The compressive strength of foamed concrete at 28 days is believed to be as a result of its air void content, which is the foam, their composition is the base mix and density. Some studies revealed that there are some other parameters that determines the compressive strength of foamed concrete. [5,6], mentioned, in their studies, that cement-sand and water-cement ratios, curing regime, type and particle size distribution of sand and type of foaming agent used, determined compressive strength of foamed concrete.

1.1 Significance of Study

Although, lightweight foamed concrete cannot be said to be relatively new, it has not been generally accepted for structural applications in most buildings and civil construction works.This, perhaps, is as a result of its low compressive strength development of both early and maturity ages in comparison with conventional concrete. For instance, in building, the strength, load carrying capacity and fire resistance are most important features to be considered. For effective prediction of the performance of foamed concrete under certain load and ambient temperature, there must be a determination of the compressive strength at the early-age without any material strength aids like the addition of admixtures under different atmospheric temperature to be depicted by curing method. The findings may give room for the determination of effective or appropriate admixture that can best suit the material.

2. MATERIALS AND METHODS

2.1 Materials

The constituent materials used in the production of the lightweight foamed concrete, used for this study comprises of Ordinary Portland Cement, fine aggregates, portable water and stable foam from a protein based surfactant. The summary of the materials is given in table 1 and 2. The research was aimed at determining the effects of curing method on the early-age of foamed concrete so as to determine or predict the ambient temperature that produces the highest compressive strength for probable use in structural applications. The cement-sand ratio was kept at ratio 1:2 while the water cement ratio was kept at 0.45 throughout the experiment. The reason for chosing high cement-water ratio was to be able to achieve a better strength since there is no addition of any admixtures. This was also found acceptable in order to achieve adequate workability as established in previous study [20]. Figs. 1a and 1b shows the portafoam TM2 Foam generator and samples of materials used in the study.

Lightweight foamed concrete of density ranging between 1200kg/m^3 to 1600kg/m^3 was used. This is because the variance from lower grades to structural grades cadre will gives better result and considerations that varies for analysis. This can be recommended for structural analysis too.

2.2 Mix proportioning and curing

Table 3 presents the mix designs for all the samples except for the density that varies. The sand, cement ratio used, was 1:2 and the water cement ratio was 0.45.

Table 1. Materials constituents used

Constituents	Details
Cement	Ordinary Portland Cement type 1 [21]
Fine aggregates	Local fine sands, sieved to eliminate particles. Sizes that pass through sieve size 2.3mm.
Foam	Noraite PA-1. Mix in the ratio of 1:30 of water to surfactant and produced a foam of 80kg/m^3 Density.

Table 2. Chemical and mechanical properties of OPC type 1. (as provided by the manufacturer)

Chemical composition (%)	
CaO	64.01
SiO2	20.01
Al_2O_3	5.28
Fe_2O_3	3.65
MgO	1.21
SO_3	2.47
Cl	0.033
Na_2O/K_2O	0.25/0.81
Loss on ignition	2.27
Insoluble residue (max)	0.32
Specific gravity (g/cm^3)	3.14
Blaine fineness (cm^2/g)	3570
Setting time Initial-	145
Final-	180

Mechanical properties in N/mm^2 (as provided by the manufacturer)

Days	Flexural strength	Compressive strength
7 days	6.3	33.9
28 days	9.3	50.1

Fig.1a

Fig. 1b

Fig. 1. a) Portafoam TM2 Foam generating machine and b) the materials

This same mixing procedure was followed in the mixing and production of the foamed concrete, only that the density was different according to each target. Stable foamed was generated from Portafoam TM2 System, which was acquired from a local manufacturer in Malaysia. It is a system that make use of an air compressor, a main generating unit, a lance unit and foaming unit. Protein based Noraite PA-1 was used in this study and it is suitable for densities of lightweight concrete ranging from 600kg/m^3 to 1600kg/m^3 [22].

The mixing was done using a laboratory size incline rotating drum mixer of 7cubic meter capacity according to mix proportioning guideline of ASTM C796 [23]. Based mixed was produced by mixing the fine sand and cement thoroughly, conducting the density test and workability by slump test. The target slump of 22cm was targeted for the experiment. Thereafter, the preformed foam was introduced into the base mix as per calculated volume per seconds taken by a stop watch and the flow rate of the portal foam nozzle. The density of the produced foamed density was then taken after the foam has been allowed to mix thoroughly with the base mix for some few minutes without any agitations that can result to the breaking of the bubbles. This was then cast immediately into already prepared 100mm x 100mm square size cubes and 100mm x 100mm x 500mm prisms. This procedure was repeated for all the samples. Fig. 2 shows the mixing procedure. All the experiment was conducted under a measured relative humidity ranging from 57.30% and 72.80% and a temperature of 30.5ºC and 34.4ºC. After casting, the specimens were always covered with black polyethylene plastic to prevent evaporation and after 24hours they were all demoulded. The hardened density determined and transferred to the curing system selected for this study, air, water and moisture cured. The specimens for moisture cure were wrapped in wet transparent polyethylene plastic and kept on a curing shelve under a controlled room temperature.

All specimens were left in theses various curing condition till the test dates. It should be noted that this experimental work concentrates on the early ages of the specimens and pure foamed concrete without any admixtures. After this, the specimens were tested at each targeted age of 7 days, 14 days and 28 days.

Table 3. Mix proportion

Samples	Cement (by weight)	Aggregate (by weight)	w/c (by weight)
1200-1600Kg/m^3	1	2	0.45

2.3 Specimen Preparation and Testing Methods

During mixing, the consistency and fresh density of the foamed concrete were tested in compliance with BS EN 12350 part 6. The slump of the based mix was measure in compliance with BS EN 12350 part 1. The Compressive strength and flexural strength were determined at ages of 7, 14 and 28 days after exposure to three different curing methods. The Compressive strength test was carried out on three samples of sizes 100mm x 100mm per each day and per each curing, making a total of nine samples for each density targeted according to ASTM [24]. The prism samples of sizes 100mm x 100mm x 500mm were used for the flexural test in accordance with ASTM [25]. Fresh properties, compressive strength and flexural strength at early ages were majorly focused in this experiment, hence each specimen was removed from their curing locations and tested for flexural and compressive strength. Water cured and moisture cured specimens were removed 24 hrs before the test and stored in an oven at a temperature of 105±2°C. This is done so as to reduce build-up of pore water pressure in the saturated microstructure of the foamed concrete as earlier study has shown. A modern compressive ELLE machine was used for the compressive strength testing in the Concrete and Structure laboratory of University of Science, Malaysia, where the experiment was conducted. Figs. 2a, 2b and 2c shows the set up of the tests.

Fig. 2. Mixing procedure of the foamed concrete

3. RESULTS AND DISCUSSION

3.1 Fresh Properties

The results of the fresh properties of the foamed concrete in terms of the consistency reveal that the consistency of the fresh mixed foamed concrete, which was represented by a measure of fresh density to the designed density ratio was kept to near unity, that is 1. This was achieved by eliminating segregation and bleeding during mixing. Table 4 shows the consistency, stability and slump value of the samples.

The slump value clearly shows that the fluidity of the lightweight foamed concrete depends on the amount of water in the mix and the closeness in values reveal that the same water binder ratio was used for all the samples during mixing. The more the cementitious material, the lower the slump value. This goes to prove that water absorbed by the cementitious material, metakaolin particles did not contribute to the flowability of the foamed concrete but rather reduced their flowability. Metakaolin gave a lower level of water absorption and the value increased with an increase in the content. The pore structures could likely be the reason for this as metakaolin gives homogenous distribution of pore structures. The closely packed cell structure between each particle will resist the movement of water inside the foamed concrete and resulted in lower water absorption. This result also complements the studies done by Nambiar and Ramamurthy [11], whereby it was established that the flowability and self compatibility of foamed concrete are evaluated in terms of stability and consistency and these two properties are basically affected by the water content of the base mix and amount of foam added along with the solid ingredients in the mix. In another study by Ramamurthy et al. [17], it was established that consistency and rheology is attributed to differences in particles shape and size of fine aggregates.

3.2 Flexural Strength

The result of the flexural strength which was determined in compliance with BS 1881: Part 118: 1983 revealed that the samples cured using water and moisture had an increase of between 0.9 to 1.6 MPa and the ratio of flexural to compression strength ranges from 0.19 to 0.21 for these specimens. Fig. 3 shows the line graph of the 28days flexural strength. Specimen cured by water has the highest strength with 1.6 and closely followed by moisture cured specimens. In all the specimens, air cured specimens have the lowest value. ASTM C869-91 recommends that foamed concrete should have a minimum tensile strength of 0.17N/mm^2 when it is subjected to bending load. The low strength value recorded by the specimen RTM1200-NF-0.45 and RTM 1300-NF-0.45 may likely be due to the lower density of the samples as foamed concrete of low density tends to reduce with increasing water cement ratio.

Fig. 2a. Slump test

Fig. 2b. Compressive strength test setup

Fig. 2c. The flexural test setup

3.3 Compressive Strength

The result of the compressive strength at each age is presented in Figs. 4–6 below. In this result, the 7 days compressive strength for samples cured by moisture were having the highest strength of 10.3N/mm^2 followed by that of water cured with 9.7N/mm^2 and that of Air cured was the least. All these were achieved by the samples with the highest density of 1600kg/m^3. While the lower and lowest density samples have lower compressive strengths, ranges between the ranges of 3.0 to 7.2 MPa.

For 14days, it shows that moisture cured specimens achieved higher strength more than that of water cured, this may be due to the effect of higher density and more presence of microstructure particles. It is almost 10% difference. At 28 days, it was obvious that Moisture cured specimens recorded more strengths than that of other specimens cured by other means. This signifies that as the ages grows, foamed concrete cured by moisture, gains more strength than those cured by water, although the range depends on the density of the specimens, and this may be probably due to consistent saturation of the microstructure as against that of water cured which may attain a permanent value at a certain age when all the microstructure have been duly saturated to the optimum. This also goes to reveal that with moisture cured, higher compressive strength can be attained at the age of 28days hence the more the ages, the higher the compressive strength of foamed concrete cured by moisture. In all, the specimens cured by moisture has a significant value over other specimens cured by other means.

Also, judging from the percentage of strength developed at 7 days compared to 28 days, it is revealed through the result that at 7days, the strength achieved is 87%, using moisture cured specimen as parameter, this signifies that the higher the density, the higher the compressive strength attained at an early age and with minimal increase as the ages grows. This can be compared to the normal weight concrete, which is generally believed to have achieved 70% to 80% of 28 days strength in the first 7 days.

Table 4. Properties of the fresh concrete

Sample Code	Consistency	Stability	Slump value(mm)
RTM1600-A	1.02	1.00	200
RTM1600-W	1.02	1.00	200
RTM1600-M	1.02	1.00	200

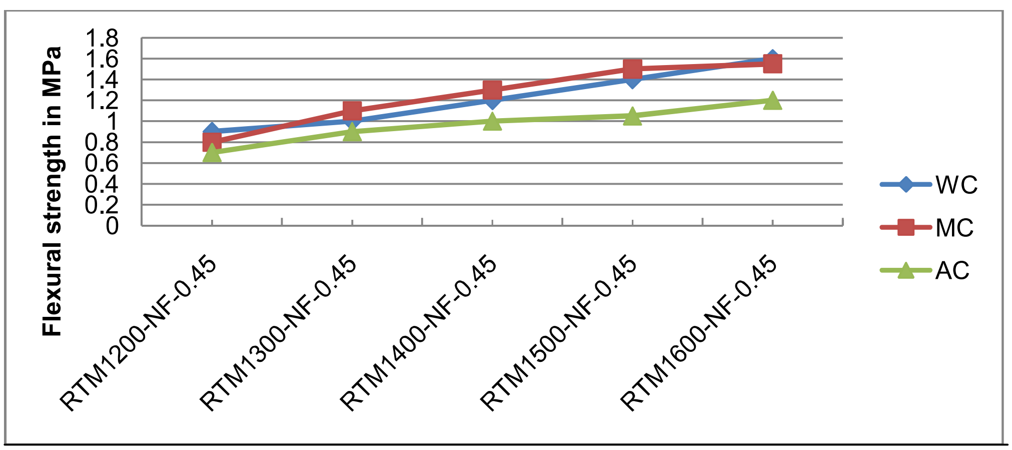

Fig. 3. Flexural strength of the specimens at 28 days RTM-Research trial mix; WC–Water cured; Mc–Moisture cured; Ac–Air cured

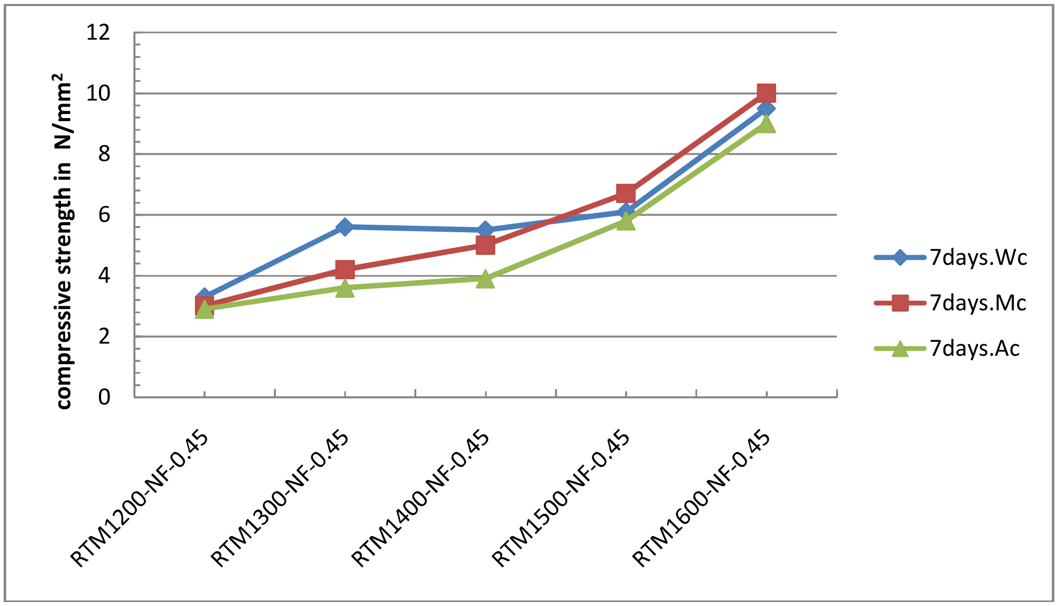

Fig. 4. Compressive strengths of the samples at different curing regime for 7days
RTM–Research trial mix; WC–Water cured; Mc–Moisture cured; Ac–Air cured

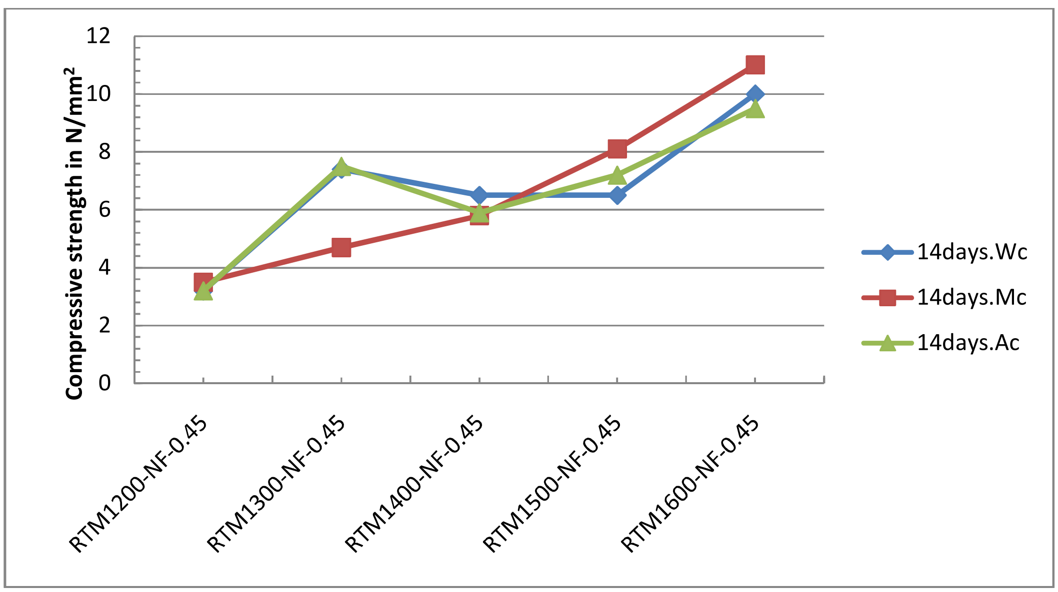

Fig. 5. Compressive strengths of the samples at different curing regime for 14 days
RTM–Research trial mix; WC–Water cured; Mc–Moisture cured; Ac–Air cured

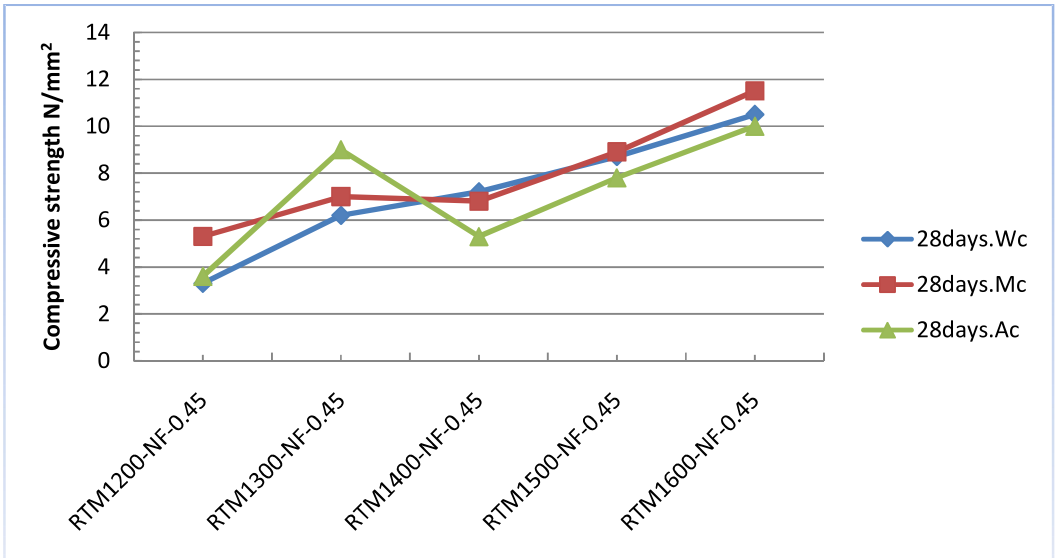

Fig. 6. Compressive strengths of the samples at different curing regime for 28days RTM–Research trial mix; WC–Water cured; Mc–Moisture cured; Ac–Air cured

4. CONCLUSION AND RECOMMENDATIONS

The paper presented the results of an experimental study of the effects of curing method on the compressive strength of foamed concrete without admixtures. The result revealed that the specimens cured under moisture achieve higher strength at 28 days than all others curing methods considered. This revealed that moisture curing has a significant effect on the compressive strength of foamed concrete at early stage better than those cured by water and air. This can be a good means of achieving higher strength at an early stage in the production of lightweight foamed concrete.

The researcher hereby recommends a further study on the effects of curing method on the lightweight foamed concrete with admixtures at an early age, so, as to determine the effect of curing regime on the foamed concrete produce with admixture and in extension the interaction between the curing methods and the admixtures relative to compressive strength.

ACKNOWLEDGEMENTS

The authors acknowledge the research funding body, Universiti Sains Malaysia through the Research University grant scheme. (RU-PRGS No-1001/PPBGN/8461

Authors have declared that no competing interests exist.

REFERENCES

1. Hossain M, Inoue S. A comparison of the mechanical properties of ferrocement elements under compression for square and chicken meshes. Journal of ferrocement. 2000;30(4):319-343.
2. Mohamad N, Samad AAA, Adnan W. Preliminary study on Structural Behaviour of Precast Lightweight Foamed Concrete Sandwich Panel. in International Building & Infrastructure Technology Conference; 2011. Penang, Malaysia.
3. Brady K, Watts G, Jones IVR. Specification for foamed concrete. Specification for foamed concrete. 2001;1(1):1-65.
4. Kearsley E. The Use of Foamcrete for Affordable Development in Third World Countries; 1996. Taylor & Francis.
5. Liang S, Chen H. Investigation on the square cell honeycomb structures under axial loading. Composite structures. 2006;72(4):446-454.
6. Chen A. Strength evaluation of honeycomb FRP sandwich panels with sinusoidal core geometry. West Virginia University; 2004.
7. Visagie M, Kearsely E. Properties of foamed concrete as influenced by air-void parameters. Concrete Beton. 2002;101:8-14.

8. Jones M, McCarthy A. Heat of hydration in foamed concrete: Effect of mix constituents and plastic density. Cement and concrete research. 2006;36(6):1032-1041.
9. Nambiar E, Ramamurthy K. Models relating mixture composition to the density and strength of foam concrete using response surface methodology. Cement and Concrete Composites. 2006;28(9):752-760.
10. Kearsley E, Wainwright P. Porosity and permeability of foamed concrete. Cement and concrete research.2001;31(5):805-812.
11. Giannakou A, Jones M. Potential of foamed concrete to enhance the thermal performance of low-rise dwellings, Innovations and developments in concrete materials and construction; 2002.
12. Davalos JF, Pizhong Q, Frank Xu X, Robinson J, Barth KE. Modeling and characterization of fiber-reinforced plastic honeycomb sandwich panels for highway bridge applications. Composite structures. 2001;52(3):441-452.
13. Jones M, McCarthy A, Dhir R. Recycled and secondary aggregates in foamed concrete. DTI/WRAP aggregates research programme STBF13/13 C; 2005.
14. Marc Böttcher, Lange J. Sandwich Panels with Openings; 2006. ASCE.
15. Serrano-Perez JC, Vaidya UK, Uddin N. Low velocity impact response of autoclaved aerated concrete/CFRP sandwich plates. Composite structures. 2007;80(4):621-630.
16. Kearsley E, Mostert H. Opportunities for expanding the use of foamed concrete in the construction industry; 2005. Thomas Telford.
17. Ramamurthy K, Kunhanandan Nambiar E, Indu G, Siva Ranjani. A classification of studies on properties of foam concrete. Cement and Concrete Composites. 2009;31(6):388-396.
18. Lok TS, Cheng QH, Elastic stiffness properties and behavior of truss-core sandwich panel. Journal of Structural Engineering. 2000;126(5):552-559.
19. Arif M, Akhtar S, Masood A, Basit F, Garg M. Flexural behavior of fly ash mortar ferrocement panels for low-cost housing. Journal of Ferrocement. 2001;31(2):125-135.
20. Noor AM, Salihuddin RS, Mahyuddin RM. Anovel approach to produce sandwich composite. Materials letters. 2007;61:4035-4038.
21. EN B. 197-1. Cement: composition, specifications and conformity criteria for low heat common cements. London (United Kingdom): British Standards Institution; 2000.
22. Othuman MA, Wang Y. An Experimental Investigation of Mechanical Properties of Lightweight Foamed Concrete Subjected to Elevated Temperatures up to 600°C. Concrete Research Letters. 2011;1(4):142-157.
23. ASTM, Standard test method for foaming agents for use in producing cellular concrete using preformed foam, in ASTM C 796-97; 1997. Philadelphia.
24. ASTM, Standard test method for compressive strength of cylindrical concrete specimens, American Standard Test Method. 2004;4:2.
25. ASTM, C78/C78M Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading. America Standard Testing Method; . 2004.,

---

© 2015 Richard and Ramli; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=758&id=31&aid=7113