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Behaviour of Concrete Incorporating yeast, a by-product of brewery factory, for production of light weight foamed concrete

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Abstract: Now a days in Ethiopia there are so many brewery factory that produced by- product of yeast that used for an air entrained in concrete. Million liters of brewery by-product yeast wastes produced every year with no commercial return on it. Thus, the aim of this research is to study the effects of by-product of brewery yeast on engineering properties of light weight foamed concrete with of its density in terms of compressive strength, splitting tensile strength, workability, Water absorption capacity, setting time and consistency. Six types of concrete were prepared, namely

i) CC (control concrete) and AAC (artificial foam) with 100 % water and 3% by weight of the cement as control mix respectively.
ii) AC-FA 25 Light weight foamed concrete with 25% brewery yeast foam as part of water
iii) AC-FA 50 Light weight foamed concrete with 50% brewery yeast foam as part of water
iv) AC-FA 75 Light weight foamed concrete with 75% brewery yeast foam as part of water
v) AC-FA 100 Light weight foamed concrete with 10% brewery yeast foam as part of water. All the specimens were water cured before being tested. The laboratory results showed that the incorporation of brewery yeast foaming agent into the concrete has decrease its compressive strength, splitting tensile strength, dry density and also increases water absorption capacity and workability. Besides, it was found that the light weight foamed concrete was lighter and has large pore size due to the presence foaming agent compared with that of the control mix which results a volume change of 24.52%, 33.82, 37.54% and 48.8% compared to the controlled concrete for the 25%, 50%, 75% an 100% water replacement by yeast respectively.

Keywords: foamed concrete **,** brewery yeast, artificial foam, foaming agent

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1. Introduction

Concrete is one of the most widely used construction materials in the world today. It is made by mixing small pieces of natural stone (called aggregate) together with a mortar of sand, water, Portland cement and possibly other cementations materials. (1)

In concrete construction, self-weight represents a very large proportion of the total load on the structure, and there are clearly considerable advantages in reducing the density of concrete. The chief of these are the use of smaller sections and the corresponding reduction in the size of foundations. Furthermore, with lighter concrete the form work need withstand a lower pressure than would be the case with ordinary concrete , and also the total weight of materials to be handled is reduced with a consequent increase in productivity. Light weight concrete also gives better thermal insulation than ordinary concrete, the practical range of densities of lightweight concrete is between 300 and 1850 kg/m3, the weight reduction of a concrete structure would require less structural steel reinforcement. (1)

There are several ways to reduce the concrete density include using lightweight aggregates, foam, high air concrete and no-fine concrete. (1)

Foamed concrete is one of the lightweight concrete and it's referred to cellular material which is consisting of Portland cement, fine aggregate, water, foaming agent and compressed air. It is a lightweight material composed of cementitious mortar surrounding disconnected bubbles in which either air is introduced into the mortar mixture or gas is formed within it. It is a versatile material consisting of either Portland cement paste or cement filler matrix (mortar) with homogeneous pore structure created by entrapped air voids roughly 0.1-1.0 mm size.(2)

Light weight foamed concrete LFC is defined as a cementitious material having a minimum of 20 percent by volume of mechanically entrained foam in the mortar slurry in which air-pores are entrapped in the matrix by means of a suitable foaming agent. (3) The prominent advantage of aerated concrete is its lightweight, which economizes the design of supporting structures including the foundation and walls of lower floors. It provides a high degree of thermal insulation and considerable savings in material due to the porous structure. (4)

Characteristics of lightweight foamed concrete depend on the mix design; there are however a number of general properties which are constant across a range of mix designs including high strength to weight ratio, low coefficient of permeability, low water absorption, good freeze/thaw resistance, high modulus of elasticity, low shrinkage, thermal insulating properties, and fire resistance. (5)

Foamed concrete is a highly workable, low density material, generally self-leveling, self-compacting and maybe pumped. Risk of plastic shrinkage or settlement cracking is significantly lower than that of normal concrete. Foamed concrete is ideal for filling voids such as disused fuel tanks, sewer systems, pipelines and culverts – particularly where access is difficult. It is a recognized medium for the reinstatement of road trenches. Its good thermal insulation properties make foamed concrete also suitable for sub-screeds and filling under floor voids. (21)

Foamed concrete has entrained air content typically of between10-50%, dependent upon production method and preformed foam or admixture dosage. It is similar to conventional concrete as it uses the same ingredients. However, foamed concrete is differing from conventional concrete in that the use of aggregates is eliminated. Dry densities are typically between 800 to 2000 kg/m^3. The material typically remains fluid for 2/3 hours after mixing with the foam (dependent upon ambient conditions). (21)

According to foaming type, lightweight foamed concrete is classified as pre-foaming type foamed concrete which is mixed by pre foamed foams in cement slurry, after-foaming type foamed concrete which is mixed with foaming agents such as aluminum powder and zinc powder, and mixed-foaming type foamed concrete which is mixed with surface active agent into cement slurry during mixing. Lightweight foamed concrete is manufactured by the pre-foaming type because of its advantages for controlling the quantity of the foam and easiness of placing during construction. (6)

The foaming agent is the most important factor for the foamed concrete and foam agents are classified as polymer foam agent, protein foam agent and surface active agent. Protein foam agent compounded of animal blood and gelatin is made of several kinds of amino acid and makes about 0.2~0.8mm size of a pore in the cream at the time of foaming. Surface active agent is made of alkyl benzene sulfonate and is hard to obtain stable foams in cement slurry at the time of foaming. In this study, locally available foaming agents are investigated in the formation of light weight foamed concrete. (6)

2. Experimental Program

Foamed concrete has been identified as a versatile construction material with excellent properties that include being light, durable, simple for use, environmentally sustainable and versatile without being restricted by factory requirements. The use of foamed concrete is recognized as suitable for lower strength applications. This chapter describes the materials used, the mixing procedures and the test methods followed in conducting various experimental investigations.

2.1 Materials and their property

As mentioned earlier, the main raw materials of foamed concrete (FC) are ordinary Portland cement, sand, water and foam; but we use a maximum aggregate size of 9.5mm to control problem of cracking and for economy i.e. to reduce the amount of cement. Combinations of the following constituent materials were used to produce foamed concrete in this research.

- ✓ Aggregate: According to ASTM C33 Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or crushed hydraulic-cement concrete.
- ✓ Coarse Aggregate: 2.88 bulk specific gravity (SSD) conforming ASTM C 127-88 standard test method for specific gravity and absorption of coarse aggregate. We use maximum aggregate size of 9.5mm.

- ✓ Portland cement: CEM I-42,5 N, 3.15 specific gravity (S.G.), conforming to ASTM C-150-00
- ✓ Fine aggregate (sand): 2.3 S.G., conforming to ASTM C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates.
- ✓ Fresh, clean and drinkable water.

2.2 Ordinary Portland cement

- ✓ The OPC used complied with Type I Portland Cement in accordance with ASTM C150 (2005). Based on BS 12:1996, ordinary Portland cement is usually used as the main binder for foamed concrete. Portland cement is a hydraulic cement that when mixed in the proper proportions with water, will harden under water (as well as in air). The basic ingredient for Portland cement consists of:
- ✓ i). Lime-rich materials, such as limestone, seashells, marl, and chalk that provided the calcareous components;
- ✓ ii). Clay, shale, fly ash, or sand to provide the silica and alumina;
- ✓ iii). Iron ore, iron containing shale, mill scale or similar material to provided the iron or ferriferous component.
- ✓ Ordinary Portland cement of ASTM type I was used. The cement had a specific surface of 350 m^2/kg and a compound composition C_3S 54.3%, C_2S 17.6%, C_3A 11.6% and C_4Af 6.4%. The sodium oxide equivalent of the cement was 0.59%, while the silica and iron modulus were 2.62% and 2.71% respectively.

2.3 Water

A brief review of this role is helpful in understanding the importance of water in foamed concrete. In the production of concrete, water is essential to precipitate chemical reaction with the cement, to wet the aggregate and to lubricate the mixture for easy workability .The chemical reaction between cement and water produces the character of the colloidal gel or cement, hence, the proportion of water to the cement is of more concern and not the proportion of water relative to the whole mixture of dry materials.

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2.4 Fine aggregates /sand

The main type of fine aggregate to be used throughout this study is coarse sand of fines modules 3.14 conforming to ASTM C 128-01. The sand was not air-dried in the laboratory to a surface dry condition but we have done moisture adjustment for the mix.

Generally, the fine aggregate consists of natural sand, manufactured sand or combination of them. The fine aggregate for concrete that subjected wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any material that deleteriously reactive in cement to cause excessive expansion of mortar concrete.

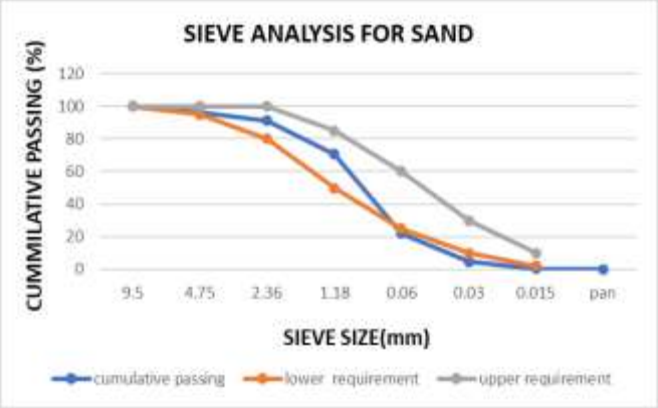


Figure 2.1 Gradation of fine aggregate

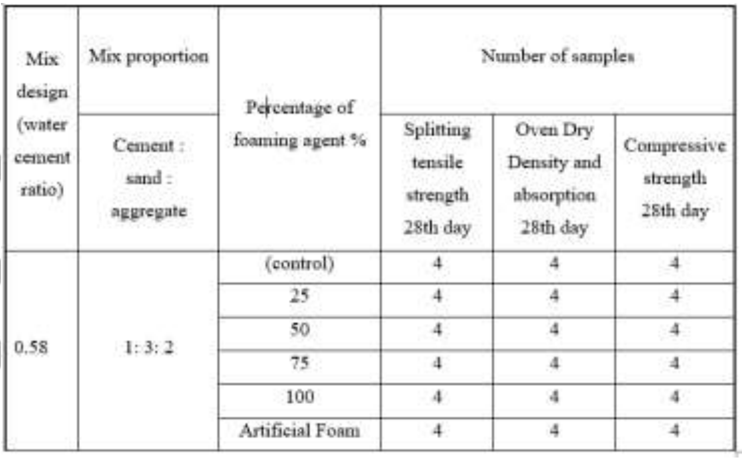
2.5 Mix proportion

The mix proportion of the lightweight foamed concrete is determined based w/c ratio. The optimum mix proportion was determined based on density and strength of lightweight foamed concrete.

In this research, mix proportioning began with the selection of suitable slump, maximum aggregate size, unit weight (wet density), the cement content and the water to cement ratio. The mix was then proportioned by the method of absolute volumes (ACI-523.3R-93, 1993).

In this study, the lightweight foamed concrete was produced to investigate the compressive strength and tensile strength using different percentage of foaming agent diluted with water. The percentage of foaming agent diluted with water by total weight of water such as 0%, 25%, 50%, 75% and 100%.foaming agent is mixed with cement, fine aggregate (sand), water and coarse aggregate of 9.5mm size. The design of density for lightweight foamed concrete obtained is 1600-2000 kg/m^3 with different foam mix proportion ratio. Otherwise, the lightweight foamed concrete without foaming agent were designed as a control mix and also artificial foamed concrete. 24 small size cylinder concrete were prepared to be tested on compressive strength, 24 large size cylinders are prepared to be tested on splitting tensile strength and 24 cubes for dry density and absorption. Minimum four samples will be prepared for each parameter and the sample must go in accordance to ASTM C 796-79 for 0%, 25%, 50%, 75%, and 100%. For cubes and cylinder we have dimension 150mm x 150 mm x 150 mm, and 150 mm x 300 mm and 100 x 200 respectively. All the specimens were tested after exposed to air, curing at 28 days.

Table 1 Numbers of Cube Specimens for compressive strength test



Mix design (water cement ratio)	Mix proportion	Percentage of foaming agent %	Number of samples		
	Cement : sand : aggregate		Splitting tensile strength 28th day	Oven Dry Density and absorption 28th day	Compressive strength 28th day
0.58	1: 3: 2	(control)	4	4	4
		25	4	4	4
		50	4	4	4
		75	4	4	4
		100	4	4	4
		Artificial Foam	4	4	4

2.6 Mixing, Casting and Curing

According to ASTM C-192 to prevent evaporation of water from the unhardened concrete, cover the specimens immediately after finishing, preferably with a no absorptive, nonreactive plate or a sheet of tough, durable, impervious plastic. Wet burlap may be used for covering, but care must be exercised to keep the burlap wet until the specimens are removed from the molds. Placing a sheet of plastic cover the burlap will facilitate keeping it wet. Protect the outside surfaces of cardboard molds from all contact with wet burlap or other sources of water for the first 24 h after cylinders have been molded in them. Water may cause the molds to expand and damage specimens at this early age. In our research we use submerged curing method.

Removal from Molds - Remove the specimens from the molds 24±8 h after casting. But in our case the molds containing the foaming agent are removed after one week. There is delay on setting time of the concrete. Curing was done by submerging all specimens in a water tank (Figure 2.4). Mixing and casting are also done in accordance with the ASTM C-192 Procedures.

Figure 2.2 Foamed concrete freshly poured into cylinder and cube

Figure 2.3 Samples after the molds are removed

Figure 2.4 cubes soaked in water

2.7 Testing

According to ASTM C 495:

- ✓ Size and Shape - Use cylindrical test specimens 3±1/16 in.(75±1.6 mm) in diameter and 6±1/8 in. (150±300 mm) in length, with the base of each specimen perpendicular to the longitudinal axis within the limits prescribed in 6.8.
- ✓ Number - Obtain at least four test specimens for compressive strength tests from each sample of lightweight insulating concrete.

As soon as possible after casting, strike off the top surface of each specimen and cover the specimen with a plastic bag to prevent evaporation, without marring the surface.

- ✓ Removal from Molds and Curing - Follow the applicable requirements of the Test Specimen section of Test Method ASTM C 495. Do not oven dry specimens that are to be load-tested.

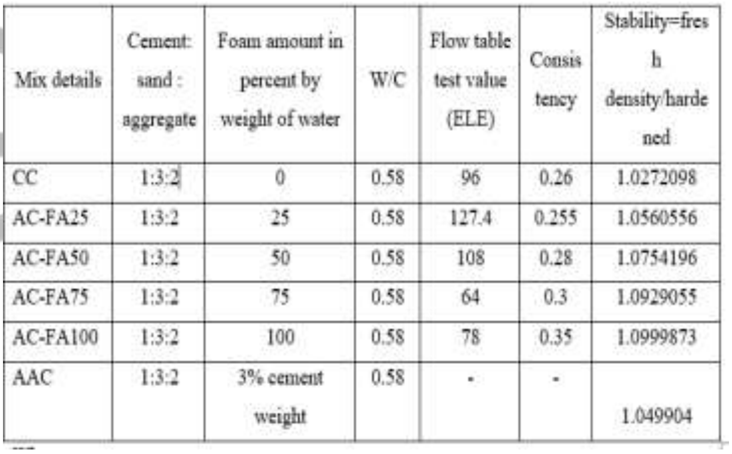
- Compressive Strength - Test four 3 by 6-in. (76 by 152-mm) cylinders for compressive strength in accordance with Test Method ASTM C 495, C 39.
- Tensile Splitting Strength - Test four 6 by 12-in. (152 by 305-mm) cylinders for tensile splitting strength at age 28 days in accordance with Test Method ASTM C 496, for lightweight concrete.
- Oven-Dry Weight - Determine the oven-dry density in accordance with the section on Oven-Dry Weight of Test Method ASTM C 495. Use three 6 by 12-in. (152 by 305-mm) cylinders from 7.9 at age 28 days.
- Water Absorption - Take three 6 by 12-in. (152 by 305-mm) specimens from 8.9 at age 28 days. Take the dimensions with calipers as described in the Test Specimen Section of Test Method C 495. Submerge the specimens in water for 24 h. Remove from water, allow excess water to run off (30 s) and weigh. This is the wet weight of the specimen.
- Workability and consistency - The test is carried out by ASTM standard C- 143

3.0 Results and Discussion

This chapter discusses about the results of tests carried out on concrete incorporated with brewery by-product yeast namely compression, splitting tensile, water absorption, dry density, Workability and consistency. Specimens were water cured for 28 days before undergoing test sessions. The effects of incorporating brewery by-product yeast foaming agent into concrete on its engineering properties in terms of the above mentioned test results is discussed at the later part of the chapter.

The mix proportion used in this study is shown in the following table;

Table 3.1: Mix proportion, W/C, consistency and stability



Mix details	Cement: sand : aggregate	Foam amount in percent by weight of water	W/C	Flow table test value (ELE)	Consistency	Stability=fresh density/hardened
CC	1:3:2	0	0.58	96	0.26	1.0272098
AC-FA25	1:3:2	25	0.58	127.4	0.255	1.0560556
AC-FA50	1:3:2	50	0.58	108	0.28	1.0754196
AC-FA75	1:3:2	75	0.58	64	0.3	1.0929055
AC-FA100	1:3:2	100	0.58	78	0.35	1.0999873
AAC	1:3:2	3% cement weight	0.58	-	-	1.049904

Where;
CC = control concrete
AC-FA 25 =aerated concrete with 25% brewery yeast foaming agent
AC-FA 50 =aerated concrete with 50% brewery yeast foaming agent
AC-FA 75 =aerated concrete with 75% brewery yeast foaming agent
AC-FA 100 =aerated concrete with 100% brewery yeast foaming agent
AAC= Artificial aerated concrete with 3 % by weight of cement

3.1 Effects of brewery yeast on the concrete

3.1.1 Volume Change

This study has shown that the brewery yeast has the ability to create pore space within the concrete. This results a change in volume of the concrete. Figures - shows the volume change obtained by adding the yeast on the concrete compared to the control.

Figure 3.1: control concrete volume remained after casting

Figure 3.2: AC-FA 25 volume remained after casting

Figure 3.3: AC-FA 50 volume remained after casting

Figure 3.4 : AC-FA 75 volume remained after casting

Figure 3.5: AC-FA 100 volume remained after casting

Figure 3.6 : AAC volume remained after casting

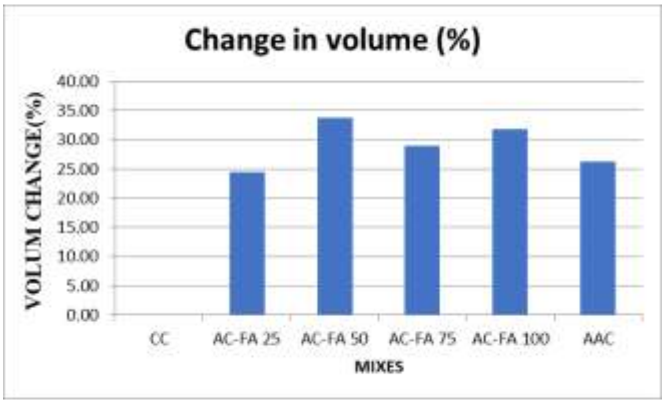


Figure 3.7 : Volume change graph

3.1.2 Retarding effect

The yeast has shown a retarding effect on the concrete. It retards the initial and final setting time of the concrete. This is clearly shown on the setting time test of the cement. In addition to this while performing compressive strength test on oven dry concretes it is noticed a decrease in the binding effect of the cement which is clearly observed on the crashed concretes. The binding effect decreases as the dosage of the foaming agent increases.

3.2 Physical properties

3.2.1 Water absorption capacity

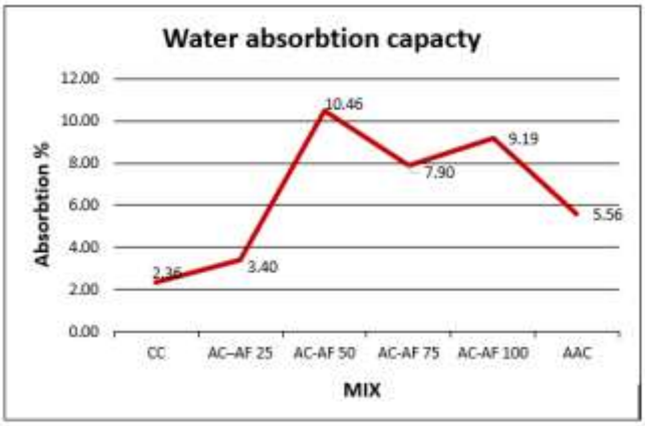


Figure 3.8: Water absorption graph (28 days of age)

Figure 3.8 shows water absorption capacity of different mixes is increasing with increase in the percentage of brewery yeast. However, the maximum water absorption capacity is recorded at 50% yeast incorporation. This water absorption capacity of the yeast aerated concrete is also greater than the artificial aerated concrete except the 25% yeast incorporated concrete that shows relatively small water absorption capacity.

3.2.2 Dry density

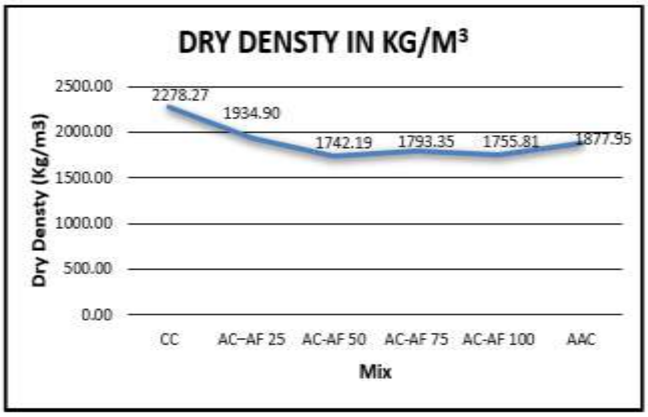


Figure 3.9: Dry density (28 days of age)

As shown on figure 3.9, the dry density of the brewery yeast incorporated concrete decreases as the percentage of the yeast increases but it is up to the 50% yeast replacement. Further increase of the water replacement by the yeast increases dry density up to 75 % replacement and decreases up to 100% replacement.

3.2.3 As cast density

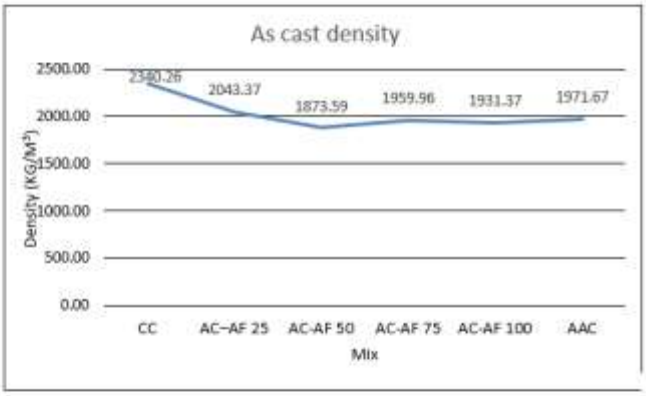


Figure 3.10: As cast density

3.2.4 Water absorption capacity vs. dry density

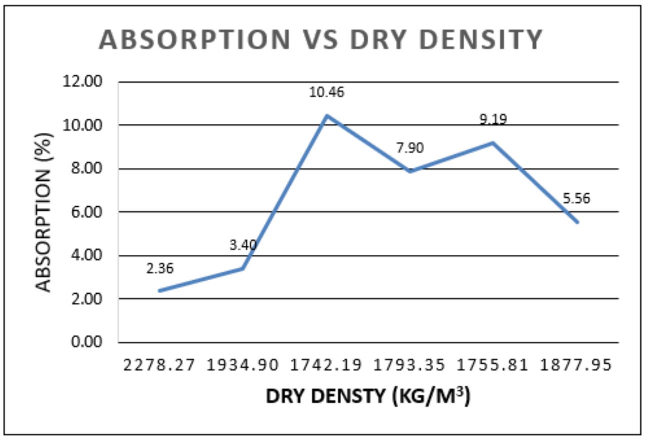


Figure 3.11: Water absorption vs. Dry density (28 days of Age)

Figure 3.11 shows the relationship of the absorption capacity of different mixes and their dry density. This illustrates that as the percentage of the brewery yeast increases their absorption capacity increases with decreasing of the dry density up to 50% yeast added. Generally as the dry density increases the water absorption capacity of the concrete decreases.

3.2.5 Workability, Consistency and setting time

3.2.5.1 Workability

According to ASTM standards, a mortar is said to be workable if the sum of the four diameters obtained from flow table test is between 95 and 100 (ELE measurement) or 15.2-16 inches.

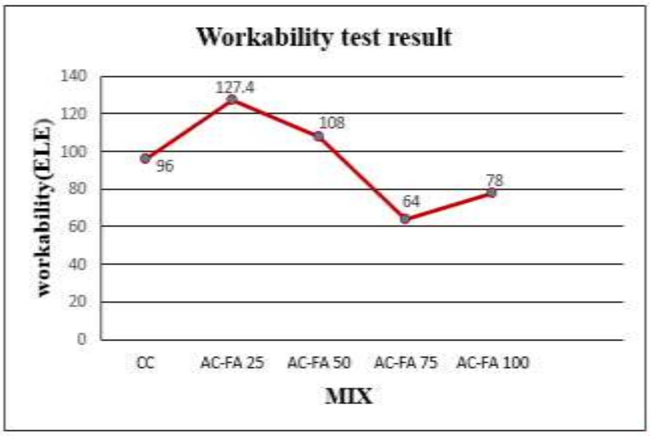


Figure 3.12: workability test result graph

a) Mortar test for CC

(b) Mortar test for AC-FA 25

(c) Mortar test for AC-FA 50

(d) Mortar test for AC-FA 50

(e) Mortar test for AC-FA 100

(f) method of measurement

Figure 3.13 Mortar test

On the literature review it is mentioned that foamed concrete is highly workable compared to conventional concrete, however as shown in figure 26 (a – e) it is shown that only the 25% and 50 % brewery yeast incorporated concrete have higher workability than the conventional concrete.

3.2.5.2 Consistency

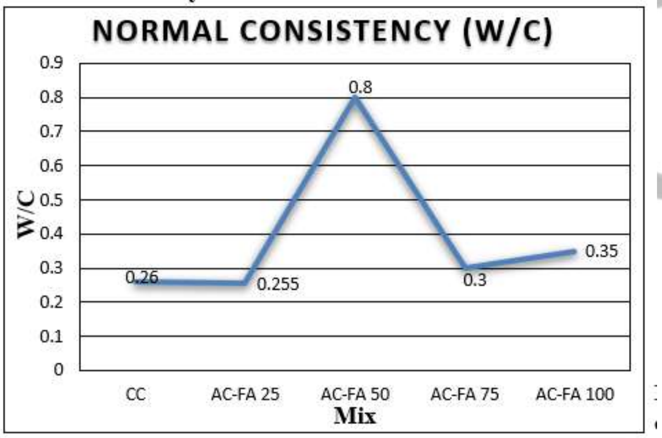


Figure 3.14 Normal consistence graph

The usual range of water – cement ratio for normal consistency is between 26% (0.26) and 33% (0.33). The results shown in figure 27 demonstrate that concrete incorporated with 25 % and 100 % yeast has consistency result which is out of the recommended range.

3.2.5.3 Setting Time

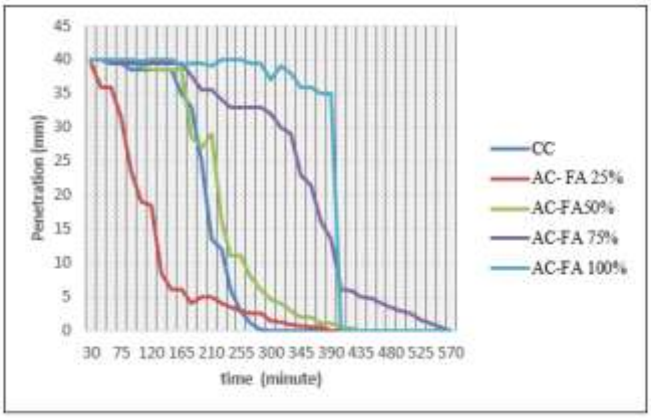


Figure 3.15 : Setting time graph

From graph shown in figure 3.15, setting time of cement increases with increasing the percentage of brewery byproduct yeast. However the initial setting time of AC-FA 25 has smaller setting time than CC. This is a good demonstration to show the retarding effect of the yeast.

3.3 Mechanical properties

3.3.1 Compressive strength

The compressive strengths for CC, AC–AF 25 and AAC are illustrated in Figure 28 (**N.B:** since AC-AF 50, AC-AF 75, AC-AF 100 concretes did not get ready to be tested for compressive test, their result is taken as zero for document completion purpose)

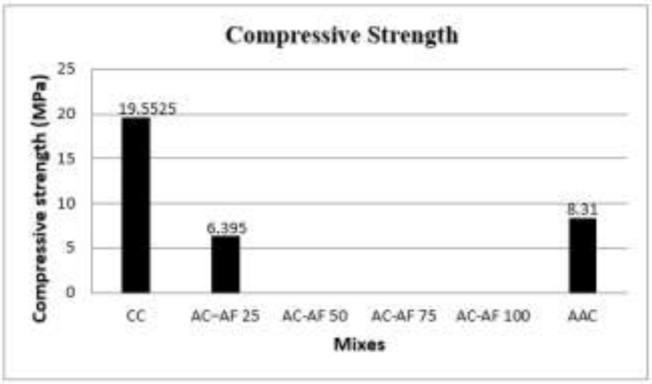


Figure 3.16 Compressive strength of different mixes at 28 days of age

Figure 3.17 shows the compressive strength of the concrete with artificial foaming agent is smaller than the normal concrete but larger than the compressive strength of the concrete with 25% brewery yeast.

Incorporation of brewery yeast foaming agent into lightweight foamed concrete has decreased the compressive strength of lightweight foamed concrete. This is mainly due to the formation of large pore spaces within the concrete. The brewery yeast also decreases the binding strengths of the cement in the foamed concrete.

Figure 3.18 compressive strength test machine

3.3.2 Splitting tensile strength

The splitting tensile strengths for CC and AAC are illustrated in Figure 30 (**N.B:** since AC–AF 25, AC-AF 50, AC-AF 75, AC-AF 100 concretes did not get ready to be tested for splitting tensile strengths test, their result is taken as zero for document completion purpose)

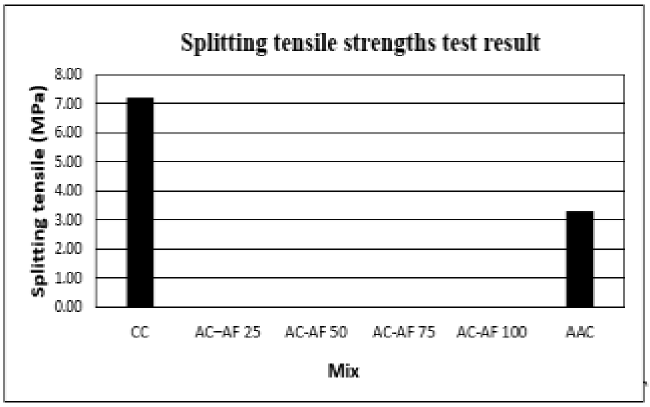


Figure 3.19: Splitting tensile strength of different mixes at 28 days of age

Figure 3.19 shows the splitting tensile strength of the concrete made of the artificial concrete is much smaller than conventional concrete. AAC achieved splitting tensile strength of 3.27 MPa at 28-day curing age. Generally, the splitting tensile strength development shared the same trend with compressive strength development. Theoretically, splitting tensile strength is related to compressive strength, although this relationship depends on multiple factors namely aggregate type, particle size distribution, age of concrete, curing process and air content.(19) Based on splitting tensile strength-compressive strength relationship illustrated in Figure 29 and 30, the splitting tensile strength is directly proportional to compressive strength. Referring to Table 30, the splitting tensile strength of AAC at 28 days of age was 45.5 % lower than that of CC. Normally splitting tensile strength is much lower than compressive strength. This is because in this test, the cylinder specimen is placed with its axis horizontal between the plates of a testing machine.

Figure 3.20: splitting tensile test

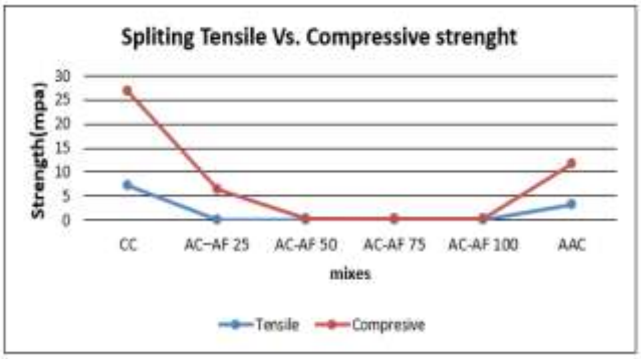


Figure 3.21: Relationship of Splitting Tensile Strength-Compressive Strength (28 days of Age)

3.3.3 Compressive strength vs. dry density

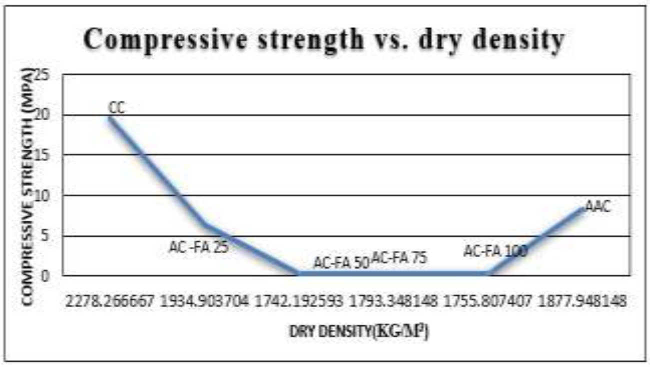


Figure 3.22: Compressive strength vs. Dry density graph (28 days of Age)

As shown in figure 3.22, compressive strength decreases with decreasing of the dry density. As mentioned in chapter two light weight foamed concrete is 87 %- 23% lighter than conventional concrete with dry density ranging from 300kg/m^3 to 1840 kg/m^3. This range is achieved by AC-FA 50 but it has small compressive strength. As a result, the 50% yeast incorporation is not the optimum amount of foaming agent. AC-FA 25 has higher compressive strength than the other foamed concrete and also has higher dry density. Therefore this amount of yeast is not recommended to produce light weight foamed concrete. So that the optimum dosage of brewery yeast that can achieve the light weight concrete criteria is between 25% -50% by weight of water.

4. Conclusion

Based on the laboratory test results, the following conclusions can be drawn corresponding to the respective objective of this study.

The main objective is to investigate the potential of the yeast, a by-product of brewery factory, to be used as a foaming agent for the production of light weight concrete. However, since the compressive strength and splitting tensile strength test were not conducted, it cannot be concluded whether this study has achieved its objective or not.

The other objective is to produce lightweight foamed concrete incorporated with brewery yeast foaming agent . This was achieved by AC-AF 50 bearing in mind that the strength tests are not conducted.

Generally, the dry density decreases and Water absorption capacity increases as the amount of the yeast increases, but workability and consistency shows varying result on different amount of foaming agent. In addition, mechanical properties of lightweight foamed concrete in terms of compressive strength and splitting tensile strength are not investigated since the samples were not dry until this research paper is written.

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References

[1] Gelim & Khalid.ali.m., Mechanical and physical properties of fly ash foamed concrete, 2011

[2] Hilal & Ameer A., Properties and Microstructure of pre-formed foamed concretes, February 2015

[3] Md Azree Othuman Mydin & Y. C Wang, An Experimental Investigation of Mechanical properties of light weight foamed concrete to elevated temprature of 600oc, December 2010.

[4] N. Narayanan & K. Ramamurthy, Structure and properties of aerated concrete, 2000

[5] Hui & Khaw yong, performance of lightweight foamed concrete using laterite as sand replacement, 2010

[6] Byun, H.-W. Song and S. Park., development of structural light weight foamed concrete using polymer foaming agent, 1998

[7] Wainright & Kearsley, Porosity and permeability of foamed concrete, 2001

[8] Aldridge, Use of Foamed Concrete in Construction, 2005

[9] Guan & Lee Kun, Performance Of Foamed Concrete Using Laterite As Sand Replacement , November 2010

[10] Rudnai, Lightweight concretes, 1963

[11] Dangni Gao, analysis on domestic and oversea concrete foaming agent and foaming technology, 1997

[12] John Newman & B.S Choo, Advanced Concrete Technology, 2003

[13] Steven H. Kosmatka, Beatrix Kerkhoff & William C. Panarese, Design and Control of Concrete Mixtures, 2002

[14] Wainright & Kearsley, The effect of porosity on the strength of foamed concrete, 2002

[15] Ramamurthy, K. Kunhanandan Nambiar, E.K. & Indu Siva Ranjani, classification of studies on properties of foam concrete, Cement & Concrete Composites, 2009

[16] Bai, Yun, properties of lightweight concrete manufactured with fly ash, February 2003

[17] Mohammad Maziah, Development of foamed concrete enabling and supporting design, December 2011

[18] Noordin, Md Azree Othuman Mydin & Norizal Md, Mechanical, Thermal and Functional Properties of Green Lightweight , 2012

[19] Lim Ooi Yuan, Engineering Properties of Lightweight Foamed Concrete Incorporated With Palm Oil Fuel Ash (POFA), July 2012

[20] Mr.S.Yuvaraj, Experimental research on foam concrete with partial replacement of sand by m-sand, August 2015

[21] www.cemex.co.uk

[22] Jones and McCarthy, Behavior and assessment of foamed concrete for fill and highway application, 2005

[23] Dransfield,The potential of laterite as fine aggregate in foamed concrete, 2000

[24] Ruiwen, Indian concrete Journal, 1989; ACI, 1993; Valore, 1954, 2004

[25] ACI Commitee 318, Building Code Requirements for Structural Concrete (ACI 318-14) AND Commentary on Building Code Requirements for Structural Concrete (ACI 318R-14), 2014

[26] ACI Committee 445, Recent Approaches to Shear Design of Structural Concrete, 1998

[27] Aruna M., Shear Behavior of Concrete Beams Reinforced with High Performance Steel Shear Reinforcement, 2008

[28] Bentz, C. E., Vecchio, F. J., Collins M. P., Simplified Modified Compression Field Theory for Calculating Shear Strength of Reinforced Concrete Elements, 2006

[29] Collins, M. P., Bentz, E. C., Sherwood, E. G., Xie L., An adequate theory for the shear strength of reinforced concrete structures, 2007

[30] Frank & J. Vecchio, Analysis of shear-critical reinforced concrete beams, 2000

[31] Ghoneim, M., EL-Mihilmy, Design of Reinforced Concrete Structures, 2008

[32] Nilson, A. H., Darwin, D. & Dolan W. C, Design of Concrete Structures, 2010

[33] Peter M., Truss Models in Detailing, 1985

[34] Transportation Reasearch Board Executive Commitee, Simplified Shear Design of Structural Concrete Members, 2005

[35] Weight, K. J. & Macgregor, J. G., Reinforced Concrete Mechanics & Design, 2012

[36] Zakaria, M., Ueda, T., Wu, Z. & Meng,, Experimental Investigation on Shear Cracking Behavior in Reinforced Concrete Beams with Shear Reinforcement, 2009

[37] BS 12:1996, EN 1008, 8110, 1997

[38] Highways Agency and TRL (2001)

[39] ASTM standard C-39, 128-01, C 143, C 192, C 495, C 496 , 796-97, C150, 128-01,C-192

[40] Eurocode 2: Design of Concrete Structures, 1992

Abebe Dinku, Construction Materials Laboratory Manual, June 2002