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The Effects of Different Additives of the Compressive and Flexural Strengths of Light Foamed Concrete (LFC)

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Abstract: Foamed concrete was established for void filling and insulation purposes, but the interest is progressively changing towards structural characteristics in today's society. This paper describes the results of experimental study that have been performed to investigate the effects of different densities and additives on the on the mechanical properties foamed concrete. Additionally, control foamed concrete samples with different densities(600kg/m3,1000kg/m3 and 1400kg/m3) and different additives were prepared independently to study the impacts of specimens were prepared with locally available materials which are fuel ash, polypropylene fiber, silica fume and jute fiber. This study has revealed that the compressive strength of foamed concrete was affected by its density due to the percentage of porosity. On the other hand, it was found that foamed concrete sample with coconut fiber yield better enhancement of the mechanical properties. Coconut fiber as reinforcement in foamed concrete is adequate and has high failure strain which can be able to provide a better compatibility between fibers and matrix. Output from this research would give better understanding of the potential utilization of waste by-products and natural fibers in foamed concrete. Foamed concrete can be used as a new energy-conservation and environmental-protection building material, particularly suitable for the construction of monolithic building envelope in Malaysia.
Key words : : Lightweight Foamed Concrete, Supplementary Cementing Materials, Natural Fibre, Strength, Jute Fiber.

Introduction

Need and use of foamed concrete as building material become privileged in construction industry due to its promising properties such as lighter in weight, superior thermal insulation and durable performance. Foamed concrete is lighter than normal weight concrete due to artificial air bubbles trapped in its cement mortar by means of suitable foaming agent (Jalal et al., 2019). No utilization of coarse aggregate in fabrication of foamedconcreteandfineaggregate(sand)canbepartiallyoffullyreplacedbyrenewable materialssuchaspulverizedfuelashandjutefibers.Moreover,foamedconcretehasstrong potential to be used as structural material. Generally, the strength value for foamed concrete of ranging densities between $600/m^3$to $1400kg/m^3$is from $1N/mm^2$to $9N/mm^2$respectively.

It should be pointed out that the density and porosity play significant role in controlling the strength of foamed concrete (Elrahman et al., 2019). Since early civilization, pozzolan materials has been practice replacing cement or sand in concrete either naturally or artificially. Besides economic and environmental concerns, it has been proven to give enhancements to the strength of foamed concrete as its natural strength is low.Mechanicalpropertieshavebeenoneofthefundamentaltopicstobeinvestigatedbut there is lack of knowledge in the effects of various types of additives on mechanical properties of foamed concrete.

Eventhoughlightweightfoamedconcretehasbeenexpansivelystudied,somelimitations such as low flexural strength still restrict its wider applications (Ramli et al., 2013). The strength of foamed concrete is determined by different cementitious materials, cement dosage,mixproportion,water-cementratio,foamvolume,foamingagent,curingmethod, additive and addition of waste by-product. To a certain extent, the density controls the strength of foamed concrete. Thus, it is always to seek a balance between strength and density, for thepurpose to maximizestrength while reducing density as much aspossible (Munir et al., 2015). Sometimes, this can be achieved through

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optimizing cementitious materials and selecting high-quality foaming agents and ultralight aggregates. The filler typesandinclusionofoilpalmbiomasswillinfluenceth ewater-solidratioswhenconcrete

density is constant, and the reduction of sand particle size will help to improve strength (Memon et al., 2018).

The pozzolanic effect of fiber biomass waste is to react with the secondary product, Ca(OH)2 (calcium hydroxide, also known as portlandite), of cement hydration to form additional C-S-H gel (secondary C-S-H). During the pozzolanic reaction, the longer silicate chains are formed as the Ca:Si molar ratio of C-S-H drops (Mydin et al., 2018). This secondary C-S-H reduces the porosity in bulk cement paste and improves the interfacialbondbetweenaggregateparticlesandfiber,t husincreasesthestrength,density, and ion diffusion resistance of LFC (Fu et al., 2020). Lately, LFC has gained major attention among the industrial players and building material manufacturers owing its excellent thermal and mechanical properties such as high flowability, low self-weight, good thermal performance, and sound insulation properties (Jhatial et al., 2017).

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2. Methodology

1.1 *Typicalpropertiesoffoamedconcrete*

Inthispaper,thepropertiesoffoamedconcreteareclassi fiedintofresh,mechanical,physical, durability, and functional properties. Each property has its own specific characteristics influenced by the manufacturing process and performance quality. The fresh state of the foamedconcreteincludesthemixtureconsistency,rheo logyandstability.Inthehardenedstate, the authors focus on physical, functional and mechanical properties as described in the following paragraphs.

1.1.1 Freshproperties

In the fresh state, the foam concrete mix has a flowing and self-compacting rheology. Hence, differentparameterssuchasconsistencyandrheology, stability,workabilityandcompatibility should be taken into account. These parameters are mostly influenced by the proportion of itherwatertocement(w/c),supplementarymaterials,fi ne/courseaggregate,plasticizers,and the volume and type of foam agents added.

1.1.2 Consistencyandrheology

The consistency and rheology arefirst assessments of fresh foamed concrete; they are usually measured by aflow cone and theflow marsh testto investigate the mixture performance. The performance of consistency and rheology of foamed concrete is acceptable when the spreadabilityoffreshconcretemixesislimitedbetween 40%and60%oftheflowingtime.The flowing time should be within 20 s for a sufficient mix to be placed into molds and get self- compacted without any external aids. Reportedly, different factors influence the consistency and rheology of the mix; which are basically related to the mix design constituents. One importantfactorthataffectsrheologyandconsistencyofthefreshfoamedconcreteisthewater content in the mix design. It was recommended that the water to cement ratio should be minimized because the excessive volume of water causes segregation of foamed concrete during casting which affects the workability performance. For that, the mixture components should be calculated accurately in order to enhance the consistency and rheology of foamed concrete,to achieve the selfcompacting characteristics, to improve the cohesion and adhesion between foam agent and the binder. The other important factor is the density of coarse aggregate in the mix. For example, the addition of lightweight coarse aggregate adversely affectstheconsistencyofthemix.Tosettlethisproblem, itwassuggestedtoaddflyashtothe

mix, albeit, the content of the course aggregate with the maximum size of 4 mm should be limitedto25%ofthetotalvolumeofaggregatesincetheexcessivevolumeofcoarseaggregates would drop the foam air-voids (bubbles). Also, an increase in w/c ratio and reduction of the foam content proportionally increase the plastic density and reduces the consistency and rheology of foamed concrete. It was reported that the consistency of foamed concrete wasreducedwhenthefoamcontentwasaddedduetoahighervolume ofaircontentwhileaddition of superplasticizers increased the flow rate.

1.1.3 Stability

The state of stability is an adhesive behavior of foamed concrete mix design constituents, and their consistency and cohesiveness as a system. Foamed concrete is classified as a homogeneous foamed concrete when mixes have a creamy, easily pourable and closely fluid consistencywhichresultsinafreshmixfreeofbleedingandsegregation.Itisreportedthatthe mixture composition is prepared with a right mix design method and a correct calculation procedure when the difference between the achieved plastic density and the desirable plastic densitydoesnotexceed2–7%.Also,aspreadflowof45%wasreportedasanappropriatevalue of workability to confirm a good stability of any produced foamed concrete mix. So far, different tests have been proposed by researchers to measure the stability of the mix. For instance, Kunhanandan Nambiar et al. Assessed the stability of the foamed concrete by measuring the density of fresh foamed concrete filled in standard containers and compared it with the ratio of the target density. The other method to investigate the stability of foamed concrete mix is to check the difference between an actual and a calculated w/c ratio which shouldbecloseto2%.Differentfactorsmayinfluencethestabilityofthemixsuchasinclusion of mineral admixtures. For example, the use of ground granulated blast furnace slag (GGBS) in the mixreduceditsstabilityandcausedsegregationandbleedingofthemixbecauseGGBFs paste had lower packing density compared to cement paste under the same pressure. Also, it was reported that superplasticizers allow the reduction of w/c ratio to less than 0.3 and enhancedthestabilityby43%.Itwasalsoshownthatthe stabilityreducedwhenan excessive amount of foam agent was added. Furthermore, it was reported that mixes formed from protein based surfactants were prone to segregation, probably due to incompatibility of the additive of surfactant type with the superplasticizer. In brief, the water to cement ratio and plasticizers are also recommended to be proficiently added to avoid segregation or bleeding.

1.1.4 Compatibility

Thecompatibilityoffoamedconcreteisknownasasituationofstronginteractionbetweenthe mix design and its constituents specifically between chemical admixtures and foam agent. Therefore, where there was no collaboration between the mixture constituents, the compatibility of foam mortar would be reduced. Therewith, due to incompatibility of design admixtures, the segregation problem usually occurs when there is no interaction between the surfactant and plasticizers. The compatibility between foam agents and the chemical admixtures is strongly recommended conforming to BS EN 934-2. In general, the dosage of plasticizersisrecommendedtobeinavolumenotexceeding0.2%byweightofcement.Itwas also reported that foamed concrete mixes made from protein-based surfactants tended to segregates due to incompatibility of the surfactant with the superplasticizer. The incompatibility of foamed concrete has become a common issue reported by site workers in Dundee University. They suggested that this issue might occur due to a lack of knowledge about the plasticizers added to the foamed concrete mixes. The degree of compatibility of concrete could be measured by dividing the full height of a proposed cube before compacting overfull height recorded minus the reduction in height due to retraction after compacting (for example at 3 days of curing age).

1.1.5 Workability

Workability of foamed concrete shows an excellent performance through the presence of air- voids in the fresh mix due to the addition of stable foam agent. Workability test, commonly conducted by a slump test for the normal concrete is not applicable for low density fresh concretespecifiedbyBS EN12350: Part2,part6.Foamedconcreteworkabilityperformance is visually evaluated, which aims to achieve an appropriate viscosity of the mix. Besides, Brewer measured the workability of foamed concrete using a method called spread ability. Brewerrecommendedthistestonafreshmixofflow-strengthmaterials(e.g.foamedconcrete) bymeasuringthespreadintwodirectionsofasampleplacedina75mmdiameterand150mm long open-ended cylinder, after the cylinder was raised vertically. The average of the two measureddiameterswascalculatedandreportedtothenearest5mm.Dhiretal.recommended thatforan acceptableworkability offoamedconcretethespreadabilityofthebasemixshould bebetween85and125mmforacement/sandmixandbetween115and140mmwhenflyash was also included. To date, few research works have been undertaken to determine the minimumworkabilityrequiredforthedesirablemix.Forexample,highworkabilityoffoamed

concrete was reported in mixes with GGBS, albeit, segregation was also observed. It was reported that the plasticizers should not be commonly used in foamed concrete unless the amount is limited to less than 0.2% by weight of cement; to improve the workability for the case of low w/c ratio.

1.2 *Physicalproperties*

Some physicalproperties of foamed concrete includedensity, drying shrinkage,porosity, and sorptivity (capillarity).

1.2.1 Density

The density of mix can be measured in two phases; fresh and dry densities. The difference betweenvaluesoffreshanddrydensityisrecommended tobelimitedto100–120kg/m3.The actual fresh mix density is usually measured by filling and weighing a pre-weighted standard container of known volume with the produced foamed concrete. Then, the variation between the design and achieved densities should be assessed. The most acceptable tolerance for dry densityislimitedtobe±50kg/m3whichmightreachthe differenceupto±100kg/m3forhigh densityfoamedconcretemixes(i.e.1600kg/m3).Themethodisdescribedin BSEN12350: Part 6: 2000 . The purpose to determine the fresh density is to prepare the actual volume for thedesignmixandthecastingcontrolwhilethedrydensityrigorouslycontrolsthemechanical, physical and durability properties of hardened foamed concrete. So far, the effect of mix constituents such as foam agent volume and supplementary cementitious materials on the densityhasbeenreportedintheliterature.Forexample,itisreportedthatthefoamedconcrete fresh density commonly decreases with an increase in the foam volume content. On the other hand, the addition of fly ash reportedly increased the dry density of the foamed concrete at a given foam agent volume (10%), nonetheless, the changes in the density as a result of ash inclusion could be controlled with foam agent volume. In general, the lightweight foam concreteobtainsupto50MPaofstrengthwhenthefresh densityvolumeisonlyupto65%of normal concrete (the surfactant solutions are foam agent having a density between 20 and 90 kg/m3) .

1.2.2 Drying shrinkage

Drying shrinkage is considered as one of drawbacks of foamed concrete that usually occurs duringthefirst20daysofcastingtime.Thetypicalrange ofdryingshrinkageoffoamed

concreteisbetween0.1%and0.35%ofthetotalvolume ofthehardenedconcretematrix.Also, dryingshrinkageoffoamedconcreteisdeemedas4–

10timeshigherthannormalconcretedue to aggregate type in the mix design, higher cement and water contents and mineral admixture in foamed concrete. Actually, there is a lack of knowledge about the effect of cement content onthedryingshrinkageoffoamedconcrete,butsomeresearchersreportedthatcementcontent had negative influences on the performance of foamed concrete in terms of drying shrinkage which can be overcome by partial substitutions of Portland cement with other supplementary materials such as fly ash, silica fume, and lime due to a lower heat of hydration. It is also reported that the drying shrinkage is decreased due to the restraining effect of increased aggregate and moisture contents. In the range of higher moisture content, loss of moisture would be from relatively larger pores which do not cause significant shrinkage. Jones et al. reportedthatthehighershrinkagerestrainingcapacityoffoamedconcretewithsandwhenthey compared the drying shrinkage of foamed concrete with sand and fly ash as filler, in which foamedconcretewithflyashparticlesrevealedhigherdryingshrinkage.Also,theinclusionof lightweightaggregatesofflyashhasbeensuggestedasanefficientwaytodecreasethedrying shrinkage.Besides it is reportedthatthe increase in the foamvolume decreased the shrinkage duetogrowin theporesize.Adecreaseofupto36%in dryingshrinkage wasobservedwhen the foam volume increased to 50% of the total volume.

1.2.3 Porosity

Porosity of foamed concrete is an important characteristic to be taken into account because it influencestheotherconsiderablepropertiessuchascompressiveandflexuralstrengthsaswell asdurability.Arelationshipbetweenwatervaporpermeabilityandporosityinfoamedconcrete andcementpasteswasstudiedbyKearsleyandWainwright.However,studiesshowedthatthe permeability and the degree of fluid flow through concrete matrix were more a function of larger capillary pores rather than the total porosity. Reportedly, the water movement into concrete is not a simple function of porosity but depends on the pore diameter, distribution, continuity and tortuosity. Porosity of foamed concrete is measured by apparent, total vacuum saturation and mercury intrusion porosimetry (MIP) methods. However, the most significant method to measure the porosity of foamed concrete is the total vacuum saturation method as theaccuracyofresultsisreportedly66%and13%higher thanapparentandMIP,respectively. Theporosityoffoamedconcreteeasesthetransportofaggressivefluidsinsidehardenedmatrix offoamedconcrete.Theporositydependsondegreeofinfusioncharacteristicssuchaswaterabsorption, sorption, and permeability. Many factors can affect the porosity of hardened concrete such as the mix design compositions, foam agents and the curing type. It is reported that high w/c ratio significantly affects the foamed concrete and caused porosity. Previous works indicated that the permeability and pore size distribution of Portland cement pastes increased when w/c ratio was incremented from 0.3 to 0.9 at which considerable volumes of larger pores with larger diameters were observed.

1.2.4 Sorptivity

The sorptivity is defined as a measure of the capability of the medium to absorb a liquid by capillarity action. Sorptivity affects the durability of foamed concrete, and it mainly depends onfoamagent,typeofmineraladmixtures,density aswellaspermeabilitycharacteristicsand curing conditions. The abovementioned parameters influence the tendency of water transmissions intermsofsizeofbubbles(pores),tortuosity,andtheuniformityofdistribution and continuity characteristic. The sorptivity can be determined based on the theory of unsaturated flow and the measurement of the capillary rise absorption rate in reasonably homogeneous concrete such asfoamedconcrete. Tableshows formulas used to determine the sorptivity. The reasonable range of sorptivity of foamed concrete is controlled by air content ranging from 4 to 8% as stipulated by ACI 213R for lightweight material.

1.3 OBJECTIVE:

In this investigationto decreasetheselfweightby usingfoamand fiberintheconcrete.Study the compressive and flexural behavior of concrete contains foam in concrete.

Figure1CompressiontestofLFC

1.4 *Experimentalprograms*

(i) Compressivestrength

Cubeswereusedforcompressivestrengthwit hsizeof150x150x150mm.Eachcube will be wrapped with polythene sheets for curing purposed. Each cube will be tested on 7, 28, 60 and 180 days. The cubes were kept in oven for ±24 hours to achieve a drier density. The sample then was left to cool to achieve normal temperature after oven drying is completed. The weight of each cube was recorded for detailed data analysis. The compressive test is based on BS EN 12390-3:2009.

(ii) *Flexuralstrength*

Two type of sample were used to determined the flexural strength. Prism with size of100x100x500mmwereusedforthefour-pointflexuraltest.Ascomparison,three–point flexural test also wasconducted with 100 x 25 x350 mm ofspecimen. Each sample also will bewrappedwithpolythenesheetsandplacedinto oventoachievedrydensity.Thesamplewill also be left to cool to normal temperature. The flexural tests are based on BS 12390-5:2009.

LITERATUREREVIEW

SinceLFCis notamainstreamconstructionmaterial,abriefintroductiontoLFC will firstbe provided. LFC is defined as a cementitious material having a minimum of 20 per cent by volume of mechanically entrained foam in the mortar slurry (Van Deijk, 1992) in which airpores are entrapped in the matrix by means of a suitable foaming agent. The air-pores are initiatedbyagitatingairwithafoamingagentdilutedwithwater;thefoamthencarefullymixes together with the cement slurry to form LFC. Integrating the air-pores into the base matrix gives a low self-weight, high workability, excellent insulating values, but lower strength in contrast to normal weight concrete. LFC canbe fabricatedanywhere in any shape or building unit size.

LFC is not a new material in the construction industry. It was first patented in 1923 (Valore, 1954)andalimitedscaleofproductionwasinstigatedin1923.TheuseofLFCwasverylimited untilthelate1970s,whenitwasstartedtobeconsumedin Netherlandsforgroundengineering applicationsandvoidsfillingworks.In1987afullscaleassessmentontheapplicationofLFC as a trench reinstatement was carried out in the United Kingdom and the achievement of this trial led to the extensive application of LFC for trench reinstatement and other applications followed (Brady et al., 2001). Since then, LFC as a building material has become more widespread with expanding production and range of applications.

Over the past 20 years, LFC has primarily been used around the world for bulk filling,trench reinstatements,backfill toretainingwalls andbridgeabutments, insulationtofoundationsand roof tiles, sound insulation, stabilising soils (especially in the construction of embankment slopes),groutingfortunnelworks,sandwichfillforprecastunitsandpipelineinfill.However, in the last few years, there is developing interest in using LFC as a lightweight nonstructural andsemi-structuralmaterialinbuildingstotakeadvantageitslightweightandgoodinsulation properties.LFCcanhaveawiderangeofdensitiesandeachdensityisproducedforaparticular type of application.

2.1 T. Divya Bhavana and Ropula Kishore Kumar, S. Nikhil, P. Sairamchander had workedonthestudyoflightweightconcreteinwhichtheyconcludedthecompressivestrength of light weight concrete is lower than the ordinary conventional concrete and from this compressivestrengthresult,itisobservedthatasthepercentageofECAisincreasingthecompressive and flexure strength is decreasing since, the density of concrete is reduced by additionofECA.Alsotheworkabilityoflightweightconcreteisgoodwhenitiscomparedto theordinaryconventionalconcreteandthislightweight concretehaslowthermalconductivity and has an ability to absorb sound.

2.2 Miss Akshata A Mulgund and Dr. Dilip K Kulkarni had worked on the light weight concretein whichtheyshownthecomparisonofboththedensitieso fnormalconcreteaswell as light weight concrete. As per the density of light weight concrete is much more lesser than normal concrete, so the lesser density of light weight concrete is helps to reduce dead load of structure, increases the progress of building and it maintain the economy of structure.

2.3 Yasar et.al. have performed a study on the design of structural lightweight concrete(SLWC) made with basaltic pumice (scoria) as aggregate and fly ash as mineral admixtures that will provide an advantage of reduction in dead weight of a structure. The compressiveandflexuraltensilestrengthsofhard enedconcrete,thepropertiesoffreshconcrete including 0.45ofcement:sand:waterwasusedinthisstudy. Thewaterratiousedforthemixinfluenced the cement paste. The experiment shows that each additives react as early in mixing process. The mixture of all materials needs to be blended well as it will affect the mix target design. The best mixing time to get good mix is between 15-20 minutes depending on the weather, densityofLFC,typeofsandandmixerused.Type ofadditivesalsowill influencethemixing timeasthereactionofeachmaterialaredifferent. AstudydonebyJustandMiddendorfstates that approximately 20 to 40 minutes is the period for mixing to get the reaction to complete, depending on temperature.

Fig4.Fineaggregate

Figure1,ParticlesizedistributionofSand

(i) *StableFoam*

Theproteinfoamingagentknownas"NORAITE PA-1,"whichwasmanufacturedinMalaysia was used. The foaming agent was diluted in water with a ratio of 1:33 by water volume. The foamdensityneedstobebetween75to80g/L beforebeingmixedwithothermaterials. Flow ability times are also calculated as the time will be used as a reference to add the required amountoffoamintothemix.Theflowability,kno wnasflowrate,usuallyvaluedbetween2.3 to 2.7 litres per second to achieve 75 to 80 g/L density of the foam depended on the foam machine used, was monitored. The density of LFC was determined by the volume of foam addedforcertainmixes.Thestabilityofthefoamis importantinproducingLFC.Afoaming

generatorwillactasamediumtotransferthechemicalint ostablefoam.TM1thatwassupplied by DRN resources was used as a foaming generator in this study. This type of foaming generator has a mixing capacity of up to 7m3 of lightweight foamed concrete per day.

Fig.5–Foamingagent

The hydrolyzed proteins or the synthetic surfactants are the most common forms based on which foams are made. The synthetic based foam agents are easier to handle and are cheap. They can be stored for a longerperiod. Lesser energy is required to produce thesefoams. The proteinbasedfoamarecostlybuthavehighstrengthand performance.Thefoamcanbeoftwo types: wet foam and dry foam. Wet foams with densities lesser than 100 kg/m3 are not recommended for the manufacture of foam concrete. They have a very loosely place large bubble structure. To a fine mesh, the agent and the water are being sprayed. This process producesfoamthathasbubbleswithsizerangingfrom2t o5mm.Dryfoamishighlystablein nature. A solution of water and the foaming agent is forced by restrictions into a mixing chamberbycompressorair.Theproducedfoamhavebu bblesizewhichissmallerthanthewet foam.Thatislessthan1mm.Thesegiveastructureofbub bles,whichareevenlyarranged.BS 8443:2005 covers the foaming admixtures.

(ii) *Additives*

Each type of additives has it own properties that cause different result and reaction. Different percentage of additives was used in this study. Fly ash and Jute fibre were used in this study. Class F fly ash according to ASTM C618 was used and characterized as pozzolanic material. Fly ash as cement replacement reacts as filler that contributes to strengthen LFC. Lime that alsoreactsasfillerwillbeuseasaggregatereplacement.J utefibreusedinthisstudywasMega Mesh polypropylene fibre. This type of fibre is specifically engineered and manufactured in accordance to ISO9001 certified facility. Properties of each additive were shown in Table.

FlyAsh

Fly Ash particles are mostly spherical tiny glass beads. Ground materials such as Portland cementaresolidangularparticles.FlyAshparticlespro videagreaterworkabilityofthepowder portion of the concrete mixture which results in greater workability of the concrete and a lowering of water requirement for the same concrete consistency.

Fig6. Fly Ash

The physical ropertiesoffly ash.

- Type-ClassFFly ash
- Densityoffly ash- 1400kg/m3
- Colour-white
- Specificsurfacearea-4000cm2/g
- Codal provision-IS.3812.1.2003
- Chemicalcomposition of fly ash

Table1. Physicalproperties ofjutefiber

Property	Jute fibre
Ultimatecell length, L(mm)	0.8-12
Ultimatecell breadth, B (mm)	10-25pm
Length/breadth(LB) ratio	110
Fineness(denier)	15-35
Specificheat(cal/g/g)	0.324
Specificgravity (gm/cc)	2.26
Coefficientofstaticfriction	0.45-0.54
Refractiveindex	1.577
Density(gm/cc)	1.46
Tenacity(gm/denier)	3-5

4.1 RESULTSANDDISCUSSIONS:

This section will give comprehensive justifications on the studies of foamed concrete withdifferentdensitiesandadditives.Table2dem onstratesclearlythatdensityinfluencesthe mechanical properties due to pores production in foamed concrete. The strength of foamed concrete specimens is parallel with the ages.

Low density consumed high dosage of foam; henceitsdensityandvalueofstrengthweredropped.Highamountofporesinducedwillcreate weak cell structure between pores and matrix as there was insufficient surface area that connects pores and matrix. At low density, the pores will fuse close together and some of the bubbles merge with another and creates larger pores, thus cracks easily formedwhen external forceswereappliedontheconcrete. Itshould bepointedoutthatthecompressiveandflexural strength have similar strength development trend with the splittingtensile strength.

Compressive strength

ProcedureforCompressivestrength of concrete orCubetest:

1. Placethe prepared concretemix in thesteelcubemouldfor casting.

2. Onceitsets, After 24 hoursremove the concretecubefrom the mould.

3. Keepthetest specimenssubmergedunderwaterfor stipulated time.

4. Asmentionedthespecimenmustbekeptinwaterfor7or14or28daysandforevery 7 days the water is changed.

6. Ensurethatconcretespecimen mustbewell driedbeforeplacing it on theUTM.

7. Weightofsamplesisnotedinordertoproceedwithtestinganditmustnotbelessthan 8.1Kg.

8. Testingspecimensare placedin thespacebetweenbearing surfaces.

9. Care must be taken to prevent the existence of any loose material or grit on the metal plates of machine or specimen block.

10. Theconcrete cubesareplacedon bearingplateandalignedproperly withthecentreof thrust in the testing machine plates.

11. The loading must be applied axially on specimen without any shock and increasedat the rate of 140kg/sq cm/min. till the specimen collapse.

12. Due to the constant application of load, the specimen starts cracking at a point & final breakdown of the specimen must be noted.

Fig18. Compressivestrength test

$$\text{Compressive Strength of Concrete} = \frac{\text{Max Load Carried by Specimen}}{\text{Top Surface Area of Specimen}}$$

COMPRESSIVESTRENGTHOFCONCRETEFORMULA:

The Compressive strength of specimen can be calculated by dividing maximum load carried by the specimen by cross-sectional area of the specimen cubes.

Thesurfacearea ofspecimen: = 150 x 150 =22500mm² =225cm²

Important Note:As per IS: 516-1959Minimum three specimens should be tested at each selected age (that means three specimens at 7 days, threespecimens @ 14 days & 28 days) If strengthofanyspecimenvariesbymorethan15%ofaveragestrength,suchspecimenshould be rejected.

Sample	Flexuralstrength(N/mm^2)		
	7days	14 days	28days
NF	1.56	1.59	1.61
FA(15%)	1.45	1.50	1.67
FA(30%)	1.49	1.52	1.88
JF (0.1%)	1.66	1.75	1.90
JF (0.2%)	1.58	1.63	1.78

JF (0.3%)	1.45	1.50	1.55
JF (0.4%)	1.40	1.62	1.70

Table 5 shows compressive strength result of LFC with different density and additives. The results are recordedup to 180 days as some additives give slow reaction in hydration process. ItcanbeseenclearlythatthedensityofLFCinfluencesthecompressivestrength.Lowdensity LFCresultsinpoorcompressivestrengthduetolargeamountandsizeofpores.Basedonthe result, fly ash as cement replacement contributes to strength with all densities. Due to pozzolanic reaction, longer period of curing is needed to achieve the ultimate.

Table5, Compressive strength oflightweight foamed concrete withadditives

Sample	Compressivestrength(N/mm^2)		
	7days	14 days	28days
NF	6.9	8	8.1
FA(15%)	7.6	9.8	11.4
FA(30%)	4.03	9.2	11.8
JF (0.1%)	7.22	8.6	9.5
JF (0.2%)	6.13	9.4	10.3
JF (0.3%)	4.55	7.9	8.3
JF (0.4%)	2.7	7.6	8.3

Flexuralstrength

Theflexuralstrengthdevelopmentgivessametrendwiththecompressivestrength.Bothtwo set up of tests indicate the same trend of result. Table 4 shows that fly ash as cement replacement aid in performing better flexural strength with longer curing period. Lime as aggregatereplacementgivesgoodresult linearly developmentofstrength. Themicrostructure formationduetohydrationprocessgivesclearreasononhowthemechanicalpropertiesofLFC wereaffected.TheresultsfromthisstudyalsosupportthestatementbyIzaguirreetal,2010[10] that the mechanical properties for both compressive and flexural strength showed similar behaviour. As mentioned before, addition of polypropylene fibre results in poor strength for LFC.Forflexuralstrength,slightincreasewasobservedasfibreincreasedthetensilestrength ofLFC.Comparedwithotheradditives,thetypeof failurewasdifferentasadditionoffibredid not cause the sample to break apart. The fibre reacts as a mechanism to create bond between each particle in LFC and crack was observed as failure.

CONCLUSIONS

Theexperimentalinvestigationshowsthattherea reseveralfactorsthatneedtobeinvestigated as they will influence the mechanical properties of LFC. Fly ash and lime that react as filler will cause chemical reaction due to hydration process. Jute fibre has less influence on the compressive strength but increases the tensile strength of LFC. The followings are important findings observed from the investigation:

- Different density of LFC affects LFC strength, as low density of LFC required large amount offoamcomparedwithhighdensity.ThemicrostructureformationoflowdensityLFCcauses connection between pore, voids and matrix to become weak. The large size and number of pores cause weak bond thus affect the strength of LFC.

- Fly ash as cement replacement gives most contribution in this study. Fly ash required longer curingperiodtoachievetheultimatestrengthas pozzolanicreactionhappened.Somecomplex particleis producedin hydrationprocesswhich affectsthemechanicalpropertiesofLFC.This complex particle will evolve with different shape and size until more rigid and consolidated structurewasformed.Duetopozzolanicreaction,sizeandnumberofporesreduceandprovide uniform distribution of pores. Fly ash as cement replacement controlsthe heat in hydration process thus aids in performing better drying shrinkage.

- Limecausesgoodearlydevelopmentofstrengthduetoaccelerationofpozzolanicreaction.

The reactions of hydration process produce more porosity thus affects the microstructure formation of LFC. The prismatic form of needle produced in hydration process causes less interlockingbetweeneachmicrostructureelements.Thisaffectsthemechanicalproperties of LFC.

- Jutefibrecausesmoreporesandvoidsproduceduetohydrophobiccharacterization.Thiswill affect the compressive strength as more pore and voids areproduced. Jute fibre contributes to compressivestrengthinrelationtodensity.Usage ofjutefibreforlowdensityLFCgivesslight increase for compressive strength. The production of pore and voids did not affect the compressivestrengthduetocompactcompositionofexistingmicrostructureformationforlow densityLFC.Polypropylenefibreresultsinanincreaseinthetensilestrengthof LFC.Fibreas anti micro- crack agent will prevent cracks form widening.

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