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A Review Article On Light Weight Foam Concrete: State-of-the-Art

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***Abstract*—Foam concrete also known as lightweight cellular concrete, low density cellular concrete & other term is defined as a cement based slurry with a minimum of 20% (per volume) foam entrained into the plastic mortar. As mostly no coarse aggregate is used for production of foam concrete usually varies from 400kg/m^3 to 1600kg/m^3. The density is normally controlled by substituting full or part of fine aggregate with foam.**

Light weight foam concrete enables to reduce the dead weight of the aggregate structure. The compressive strength of the light foam concrete varies from 6mpa to 14mpa. The property of foam concrete is to develop air bubbles with greater strength, through mixing of the material during weathering conditions at the time of placing and drying of foam concrete.

Foam con concrete has the potential to be a substitute for ordinary concrete as it reduces dead load on the structure and foundation contributes to energy conservation & reduces the cost of production & labor costs during construction & transportation. The paper reports a state-of-the-art review of foam concrete in terms of its components, preparation & material properties such as drying shrinkage, compressive strength & durability. This study may help ease consumer concerns & encourage further wide spread application of foam concrete in civil engineering.

Keywords—foam concrete, foaming agent, drying shrinkage, compressive strength.

I. INTRODUCTION

The foam concrete has magnificent properties of heat insulation, sound insulation, light weight, & fire- proofing. In incorporation, the fresh foam concrete paste can not recognize the situ casting, which is generally used on the structural material of building compound but also used in the field. Foam concrete is made up of cementitious material with fly ash, GGBS, gypsum, lime powder. Many researchers has done research on the properties of foam concrete. Researchers has amended the mechanical properties & thermal conductivity of foamed concrete by adding fibers & expanded perlites. In foam concrete compaction need not to be necessary because foam concrete is a highly watery fluid. The unit weight of foam concrete is determined by its major factor components. It has both property fire and resistant. A proposed study on the different cement content weighed using expanded clay mix incorporation of fly ash in various percentages and to obtain high strength light weight concrete.

Experimental work done on recycling concrete mixer and rice husk results seen are improved performance in physical and mechanical properties as compared to conventional concrete. A light weight concrete is proposed using locally available light weight materials and evaluated in fresh and hardened nature. Experimented with partial replacement of coarse aggregate with pumice stone and adding different cement ingredients mix to achieve light weight aggregate concrete and identified a strength increase with weight reduction in various tests. Conducted an experimental investigation on foamed polythene waste as a suitable use in light weight concrete construction to inhibit the coefficient of thermal expansion in concrete.

However, it has many drawbacks including low strength, large shrinkage, large water absorption and easy cracking. Its tensile strength is low. If the shrinkage of foamed concrete is restricted then it breaks very easily which has negative effects on its intended use. It can reduce the intensity of manual labor by using this type of concrete and by reducing the weight of blocks it improves construction efficiency.

A. Material Components of Foam Concrete

The primary elements of foam concrete consists (1) water, (2) binder, (3) foaming agent, (4) filler, (5) additive, (6) fiber. These elements are described as follows.

(1) Water

Water requirement for constituent material depends on stability consistency and composition of the mortar. Leads to less water content a hard mixture resulting in the formation of bubbles easily burst. High water content causes mixing to thin to assist the bubble which causes bubbles separating from the mixture.

(2) Binder

Although cement is a major binder in foam concrete, supplementary cementitious material are commonly applied for the refinement of mix design stability, pores and void structures as well as foam bubble stability.

(3) Foaming Agent

Light weight foamed concrete normally prepared by initiate foaming agent such as hydrogen peroxide and plant surfactants into the cement paste to create high amount of pores and voids in the matrix.

Fig:1 Foaming agent in foam concrete

(4) Fillers

Many fillers such as silica fume, fly ash, limestone powder, granulated blast furnace slag and fly ash ceramic have been broadly acquire for purpose enriching foam concrete mechanical performances. Adding these fillers helps to improve mix ratio design, long term strength and reduce cost. Furthermore, some fine sets such as aggregate, recycled glass powder and surface modified chips are commonly used for production of high density of foam concrete.

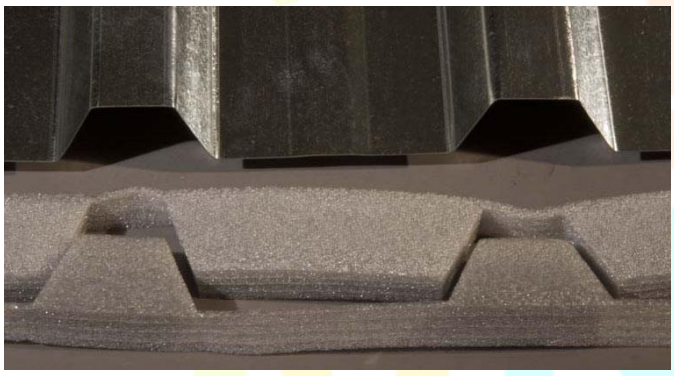


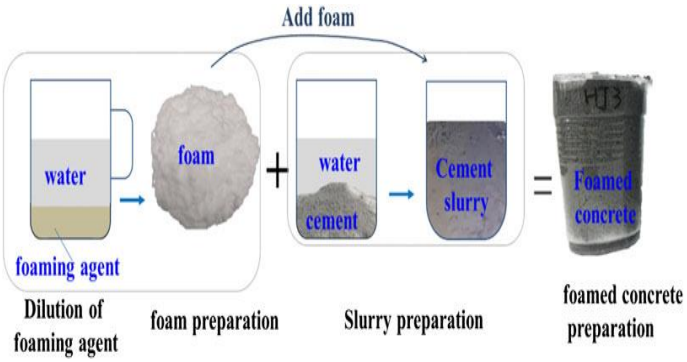
Fig: 2 Fillers in foam concrete

(5) Additive

Commonly used additive includes the water reducer, water proofing additive, retarder, coagulation additive etc. Thus, the introduction of peat additives into the foam concrete mix increases the strength of foam concrete by 44%-57% increases porosity by 27% and reduces thermal conductivity by 14%.

(6) Fiber

Polypropylene fiber are added to the foam concrete mix to increase the compressive strength, flexural strength and split strength of the foam concrete. Hazlin proved that with the addition of 0.05% polypropylene fibers to foam concrete the tensile strength increased by 35.06% and 40.3%.



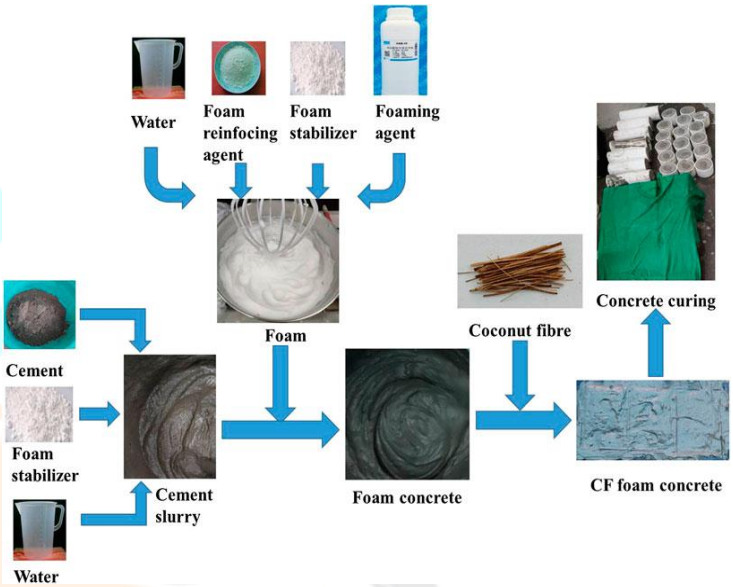


Fig: 3 Preparation of foam concrete

II. APPLICATIONS OF FOAM CONCRETE IN CONSTRUCTION WORK

The demand for foam concrete in its vast application is based on its following properties:

- Good void filling ability.
- Provides a rigid structure.
- No deflection at low load condition.
- Low density structure.
- Enhanced thermal and fire resistance.

Some of the widespread applications of foam concrete are mentioned below:

A. ***Foam concrete for void filling***

The application of void filling has become more prominent due to its associated range of advantages such as thermal insulation, its rigidity, and controlled water absorption properties.

The problem of ground instability is mostly encountered in old mines and tunnels. They have now used foamed concrete to fill voids as a solution to achieve stability in sewers, service trenches and many highway structures such as subways and culverts.

B. ***Foam concrete to increase bearing capacity***

In weak soils, foam concrete poured in situ pile is installed to serve the purpose of skin friction pile. The foam concrete used for the purpose has a density of 1200kg/m^3.

C. *Replacement of existing soil by using foamed concrete*

The theory of balanced foundation can be employed with the help of foam concrete. In areas where the soil is weak, the total weight that is the weight of foam concrete and the weight of the structure to be constructed is designed in such a way that it is equal to the excavation. It will not allow stress to build up in the soil below and thus the chances of settlement will be reduced. The density of foam concrete used for this purpose varies from 300-600kg/m^3.

D. *Applications of foam concrete in roof slope*

According to the study by L Cox and S Van, 2003, the addition of sand to the mix will provide sufficient strength and tolerance to maintain the slope in rood construction.

For the construction of the roof, foam concrete of low density can be used. But it is more commonly used to design positive slope gutters in the construction of flat concrete roofs.

E. *Applications of foam concrete for rafter foundation construction*

The application is widespread in housing construction. For thermal properties as well as behaving as a light weight raft foundation, foam concrete is the best option. This built- up layer is secured by means of concrete layer also behaves as a mode for load propagation.

A foam concrete with a density of 400 to 600kg/m^3 is used built into the raft foundation.

F. *Applications of Foam Concrete for Trench Reinstatement*

The excavation by utility companies is a major cause of deterioration of road pavements. When settlement of backfill occurs, damage to the pavement surface occurs with age. To overcome this problem, patching should be done continuously.

Foamed concrete is a good solution, as it behaves as a superior backfilling technology. It gets the following properties:

- Foamed concrete does not set once placed.
- It doesn't need any compaction.
- No transmission of axle load to services in trench.
- Final resuscitation can be done the next day.
- Material readily available.
- Allows easy excavation.
- No need for skilled labor or complicated equipment.

G. *Soil Stabilization by Foam Concrete*

Part of the soil used in the backfill of embankments can be replaced with foam concrete to ensure slope stability. Weight reduction is the advantage of going through this type of method, as high level of weight is the root cause of backfill collapse. Foamed concrete of density ranging from 400 - 600 kg/m3 is used for this purpose.

H. *Application of Foam Concrete in Filling the Pipes*

Foam concrete with a density of 600 to 1100 kg/m3 can be used to fill underground pipes, sewers or fuel tanks that are no longer in use.

Their negligence can lead to a fire hazard or any kind of collapse. Once these are filled with foam concrete, they are supported and blocked

III. PREPARATION TECHNIQUES OF FOAMED CONCRETE

Foam concrete can be prepared by two techniques, which are called pre-foaming method and mix foaming method. Both methods control the mixing process and quality of foam concrete.

The pre-foaming method includes generating base mix and stabilizing performed aqueous foam freely. Then the foam gets completely mixed into the base mix. Pre-foamed foam can be produced either dry or wet method. Foam pushes dry foam agent solution as high density barriers and by sequences concurrently pushing compressed air inside a mixing chamber. Dry is quite stable and produces bubbles with small size less than 1mm. Small sized bubbles facilitate a stable and uniformly mixing the foam with the parent material to produce pumpable foam concrete.

Wet foam is produced by spraying foam agent solution through a fine mesh. The size of the wet foam bubble is generally between 2mm to 5mm and the foam is produced by any means less stable than dry foam.

In mixed foaming method foaming agent are mixed with base mixture together (specially cement paste). The foam produces cellular structures in foam concrete.

Although in these two methods the mixing process and the quality of foam concrete can be controlled, but the performance method is considered better than the mixing method because of the following:

- Lower needs for foaming agent.
- The foaming agent material is closely related to air ingredients in the mixture.

IV. TYPICAL PROPERTIES OF FOAMED CONCRETE

At present weakness and poor durability still exists on foam concrete. Discussion on the content properties in this section are mainly based on practical applications where potential problems like insufficient structure strength, stabilization issue, corrosion, underground water, structure failure. The properties of materials such as drying shrinkage, compressive strength and durability are discussed below.

A. *Drying Shrinkage*

In absence of coarse aggregate the relative impact of factors affecting the shrinkage of foam concrete are likely to be different from that of normal concrete. The shrinkage of the foam concrete is less than that of the corresponding base mix. For foam concrete with 50% foam material, the shrinkage was notice to be approximate 36% less than that of the base mix. The shrinkage of foam concrete is a function of the amount of foam and is thus indirectly related to amount and properties of the shrinkable paste. Shrinkage increases greatly in range of low moisture content. Although removal of water from approximately large artificial air pores will not put up to shrinkage, artificial air voids may have to some range, indirectly influence volume stability by allowing some shrinkage. The effect was greater at higher amount of foam.

Table-1 The drying shrinkage values observed in typical cement-based materials

Material	*Drying shrinkage (%)*
Cement paste	0.15-0.3
Cement mortar	0.08-0.2
Cement concrete	0.06-0.09
Foam concrete	0.15-0.35

B. Compressive Strength

Although foam concrete has been deeply studied, some flaws such as low strength still restrict its wider applications. The strength of foam concrete is preventive mining by different cement material, mixing ratio, water-cement ratio, cement dosage, foam volume, foaming agent, curing method, additive, etc.

To a certain extent, density controls the strength. Therefore, one must always seek a balance between the strength and density with the aim of maximizing strength while minimizing density as possible. Sometimes thus can be achieved through the optimization and selection of cement materials high quality foaming agent and ultralight aggregates.

The investigation indicated that the strength of foam concrete decreases with increment in vacancies. The aspects of foam agent on the strength is mostly exhibit in aspects of bubble size foam stability, foam ability, and distribution uniformity of bubbles. Ideally the foaming agent have strong foaming ability should be characterized by poor per unit water carrying capacity and little adverse effects on foam concrete. Experiment and investigate can be consider with concern to the section of high performance foaming agent to produce a fine and uniform formulation bubbles. The experimental results showed that water cement ratio and air ash ratio have a significant effect of foam concrete strength. It also pointed out that apart from fiber is helpful to increase strength. Some researchers prediction model was also investigated on compressive strength. These findings are mostly based on the extreme learning machine, artificial neutral work and regression analysis based empirical models.

C. Durability

The durability property of foam concrete is defined as the ability to resist any external interference effect or cause deterioration and reduce the serviceability of concrete life. In this study, the permeability inspect are discussed below:

Permeability

The ability of any material such as rocks to pass fluids or gases through its pores. The porosity and the shapes of the pores define the permeability of the medium. The higher the permeability, the more rapidly the fluids will flow through the pores.

The water absorption of the foamed concrete is approximate twice that of normal concrete on water similar to the binder ratio, but individualistic air volume, ash type and content.

To now, the researchers have studied the aggregate effect and mineral admixture on the permeability of foam concrete.

Nyame found that the permeability of concrete mortar decreased because the porosity was reduced by the inclusion of aggregates. He also pointed out that the increase in the total amount of the mix resulted in an increase in permeability. Beyond that air entraining the cement paste produces discrete nearly circular bubbles are approximately 50 micrometers in diameter for water to flow and very small increment in the permeability.

CONCLUSION

On the basis of the review carried out, it was found that most studies on foam concrete have been conducted to evaluate on foam features rather than its properties.

The compressive strength is considered as primary work of the desirable density design as a main consideration for light weight concrete which can ultimately can be used to manufacture structural, non or semi-structural components. Simultaneously, the durability is another property of foamed concrete that should be on a level which can allow it to effectively resist aggressive environment. This can be achieved by selecting the most appropriate type foam agent added. Foam agent produce a uniformed distribution of pores where they reduce the segregation problem.

The purpose of the above review is primary to evaluate the present physical property of foam concrete and then expanded to improve the foam concrete design ratio and using supplements such as selecting ingredients as partial replacement for Portland cement is used mine dust in the form of partial/complete foamy solid aggregate and enriching the workability of foamed concrete in the fresh state with an appropriate amount of plasticizers.

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REFERENCES

[1] R.C. Valore Jr., Cellular concretes Part 2 physical properties, ACI J. Proc. 50 (6) (1954).

[2] K. Ramamurthy, E.K. Nambiar, G.I.S. Ranjani, A classification of studies on properties of foam concrete, Cem. Concr. Compos. 31 (6) (2009) 388–396.

[3] M.R. Jones, A. McCarthy, Preliminary views on the potential of foamed concrete as a structural material, Mag. Concr. Res. 57 (1) (2005) 21–31.

[4] T.G. Richard, J. Dobogai, T.D. Gerhardt, W.C. Young, Cellular concrete – a potential load-bearing insulation for cryogenic applications?, IEEE Trans Magn. 11 (2) (1975) 500–503.

[5] N. Uddin, F. Fouad, U.K. Vaidya, A. Khotpal, J.C. Serrano-Perez, Structural characterization of hybrid fiber reinforced polymer (FRP)-autoclave aerated concrete (AAC) panels, J. Reinf. Plast. Compos. 25 (9) (2006) 981–999.

[6] A.S. Tarasov, E.P. Kearsley, A.S. Kolomatskiy, H.F. Mostert, Heat evolution due to cement hydration in foamed concrete, Mag. Concr. Res. 62 (12) (2010) 895– 906.

[7] P.J. Tikalsky, J. Pospisil, W. MacDonald, A method for assessment of the freeze–thaw resistance of preformed foam cellular concrete, Cement and Concrete Research 34 (5) (2004) 889–893.

[8] H. Weigler, S. Karl, Structural lightweight aggregate concrete with reduced density-lightweight aggregate foamed concrete, Int. J. Cem. Compos. Lightweight Concr. 2 (2) (1980) 101–104.

[9] M.A.O. Mydin, Y.C. Wang, Structural performance of lightweight steel-foamed concrete–steel composite walling system under compression, Thin-walled Struct.

[10] K.J. Byun, H.W. Song, S.S. Park, Development of structural lightweight foamed concrete using polymer foam agent, Congr. Polym. Concr. 19 (1998).

[11] BS EN12350-6, Testing Fresh Concrete: Density, British Standards Institution, London, UK, 2009.

[12] N. Narayanan, K. Ramamurthy, Structure and properties of aerated concrete: a review, Cem. Concr. Compos. 22 (5) (2000) 321–329.

[13] A.M. Neville, Properties of Concrete, 4th ed., Longman Group Limited, Essex England, UK, 1995. ISBN: 0-582-23070-5.

[14] F. Zulkarnain, M. Ramli, Durability of performance foamed concrete mix design with silica fume for housing development, Journal of Materials Science and Engineering 5 (5) (2011) 518–527.

[15] D. Aldridge, T. Ansell, Foamed concrete: production and equipment design, properties, applications and potential, in: Proceedings of One Day Seminar on Foamed Concrete: Properties, Applications and Latest Technological Developments, Loughborough University, 2001, pp. 1–7.

[16] R.J. Pugh, Foaming, foam films, antifoaming and defoaming, Adv. Colloid Interface Sci. 64 (1996) 67–142.

[17] I.T. Koudriashoff, Manufacture of reinforced foam concrete roof slabs, ACI J. Proc. 46 (9) (1949).

[18] R.C. Valore Jr., Insulating concretes, ACI J. Proc. 53 (11) (1956).

[19] M.R. Jones, M.J. McCarthy, A. McCarthy, Moving fly ash utilization in concrete forward: a UK perspective, in: Proceedings of the 2003 International Ash Utilisation Symposium, Centre for Applied Energy Research, University of Kentucky, 2003, pp. 20–22.

[20] P. Mellin, Development of structural grade foamed concrete (Ph.D. diss., M.Sc. dissertation), University of Dundee, 1999.

[21] N. Narayanan, Influence of composition on the structure and properties of aerated concrete (M.S. thesis), IIT Madras, 1999.

[22] Anon, UK's largest foamed concrete pour for railway embankment, Qual. Concr. 2 (2) (1996) 53.

[23] C.D. Lawrence, Laboratory studies of concrete expansion arising from delayed ettringite formation, British Cement Association, Report no. BCA-Pub-C-16, 1993.

[24] A.F. Roslan, H. Awang, M. Mydin, Effects of various additives on drying shrinkage, compressive and flexural strength of lightweight foamed concrete (LFC), Adv. Mater. Res. 626 (2013) 594–604.

[25] E.P. Kearsley, P.J. Wainwright, Porosity and permeability of foamed concrete, Cem. Concr. Res. 31 (5) (2001) 805–812.

[26] M.R. Jones, Foamed concrete for structural use, One-day Awareness Seminar on ''Foamed Concrete: Properties, Applications and Potential", vol. 1(1) University of Dundee, 2000, pp. 54–79.

[27] M. Röbler, I. Odler, Investigations on the relationship between porosity, structure and strength of hydrated Portland cement pastes I. Effect of porosity, Cem. Concr. Res. 15 (2) (1985) 320–330.

[28] ASTM, Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM C496-96, ASTM International, West Conshohocken, PA, 1996.

[29] A.M. Neville, C.W. Glover, Properties of Concrete. Magazine of Concrete Research, vol. 16(48), Pitman, 1964.

[30] L.W.G. Zhenhai, Experimental investigation of strength and deformation of concrete at elevated temperature, J. Build. Struct. 1 (1993) 1.

[31] Y. Anderberg, S. Thelandersson, Stress and deformation characteristics of concrete at high temperatures. 2. Experimental investigation and material behaviour model, Bulletin 54 (1976).

[32] F. Oluokun, Prediction of concrete tensile strength from its compressive strength: an evaluation of existing relations for normal weight concrete, ACI Mater. J. 88 (3) (1991).

[33] C.E.B.F.I.P. MC90, Design of Concrete Structures. CEB-FIP Model Code 1990, Thomas Telford, London, 1993.

[34] C.F.M. Code, Model code for concrete structures, Bulletin D'Information (1990) 117-E.

[35] M.R. Jones, A. McCarthy, Utilising unprocessed low-lime coal fly ash in foamed concrete, Fuel 84 (11) (2005) 1398–1409.

[36] A. Saint-Jalmes, M.L. Peugeot, H. Ferraz, D. Langevin, Differences between protein and surfactant foams: microscopic properties, stability and coarsening, Colloids Surf., A 263 (1) (2005) 219–225.

[37] M.E. Kamara, L.C. Novak, B.G. Rabbat (Eds.), Notes on ACI 318-08, Building Code Requirements for Structural Concrete: with Design Applications, Portland Cement Assn, 2008.

[38] E. K. K. Nambiar and K. Ramamurthy, "Influence of filler type on the properties of foam concrete," Cement and Concrete Composites, vol. 28, no. 5, pp. 475–480, 2006.

[39] Y. Wang, S. H. Zhang, D. T. Niu, L. Su, and D. M. Luo, "Strength and chloride ion distribution brought by aggregate of basalt fiber reinforced coral aggregate concrete," Construction and Building Materials, vol. 234, Article ID 117390, 2020.

[40] J. Narayanan and K. Ramamurthy, "Identification of set□accelerator for enhancing the productivity of foamed con crete block manufacture," Construction and Building Ma terials, vol. 37, pp. 144–152, 2012.

[41] M. R. Jones, K. Ozlutas, and L. Zheng, "High-volume, ultra low-density fly ash foamed concrete," Magazine of Concrete Research, vol. 69, no. 22, pp. 1146–1156, 2017.

[42] S¸. Kilincarslan, M. Davraz, and M. Akça, ",e effect of pumice as aggregate on the mechanical and thermal prop erties of foam concrete," Arabian Journal of Geosciences, vol. 11, no. 11, Article ID 289, 2018.

[43] D. T. Niu, L. Zhang, F. Qiang, B. Wen, and D. M. Luo, "Critical conditions and life prediction of reinforcement corrosion in coral aggregate concrete," Construction and Building Materials, vol. 238, Article ID 117685, 2020.

[44] D. Falliano, D. D. Domenico, G. Ricciardi, and E. Gugliandolo, "Experimental investigation on the compressive strength of foamed concrete: effect of curing conditions, cement type, foaming agent and dry density," Construction and Building Materials, vol. 165, pp. 735–749, 2018.

[45] X. J. Tan, W. Z. Chen, J. H. Wang et al., "Influence of high temperature on the residual physical and mechanical properties of foamed concrete," Construction and Building Materials, vol. 135, pp. 203–211, 2017.

[46] T. Liu, Y. J. Zhong, Z. L. Han, and W. Xu, "Deformation characteristics and countermeasures for a tunnel in difficult geological environment in NW China," Advances in Civil Engineering, vol. 2020, Article ID 1694821, 16 pages, 2020. Advances in Materials Science and Engineering 17

[47] Y. Wei, W. Guo, and Q. Zhang, "A model for predicting evaporation from fresh concrete surface during the plastic stage," Drying Technology, vol. 37, no. 11, pp. 12–23, 2019.

[48] M. A. Othuman and Y. C. Wang, "Elevated-temperature thermal properties of lightweight foamed concrete," Con□struction and Building Materials, vol. 25, pp. 705–716, 2011.

[49] A. A. Sayadi, J. V. Tapia, T. R. Neitzert, and G. C. Clifton, "Effects of expanded polystyrene (EPS) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete," Construction and Building Materials, vol. 11, pp. 716–724, 2016.

[50] S. Tada, "Material design of aerated concrete–an optimum performance design," Materials and Structures, vol. 19, no. 1, pp. 21–26, 1986.

[51] H. K. Kim, J. H. Jeon, and H. K. Lee, "Workability, and mechanical, acoustic and thermal properties of lightweight aggregate concrete with a high volume of entrained air," Construction and Building Materials, vol. 29, pp. 193–200, 2012.

[52] R. C. Valore, "Cellular concrete part 2 physical properties," ACI Journal Proceedings, vol. 50, no. 6, pp. 817–836, 1954.

[53] Z. M. Huang, T. S. Zhang, and Z. Y. Wen, "Proportioning and characterization of Portland cement-based ultra-light weight foam concretes," Construction and Building Mate rials, vol. 79, pp. 390–396, 2015.

[54] M. Deck´y, M. Drusa, K. Zg´utov´a, M. Blaˇsko, M. H´ajek, and W. Scherfel, "Foam concrete as new material in road con□structions," Procedia Engineering, vol. 161, pp. 428–433, 2016.

[55] M. Kadela and M. Kozłowski, "Foamed concrete layer as sub□structure of industrial concrete floor," Procedia Engineering, vol. 161, pp. 468–476, 2016.

[56] Z. H. Zhang, J. L. Provis, A. Reid, and H. Wang, "Mechanical, thermal insulation, thermal resistance and acoustic ab sorption properties of geopolymer foam concrete," Cement and Concrete Composites, vol. 62, pp. 97–105, 2015.

[57] A. S. Tarasov, E. P. Kearsley, A. S. Kolomatskiy, and H. F. Mostert, "Heat evolution due to cement hydration in foamed concrete," Magazine of Concrete Research, vol. 62, no. 12, pp. 895–906, 2010.

[58] ASTM, Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes, ASTM C1585, Philadelphia, PA, 2004.

[59] B.K. Nyame, Permeability of normal and lightweight mortars, Mag. Concr. Res. 37 (130) (1985) 44–48.

[60] R.L. Day, B.K. Marsh, Measurement of porosity in blended cement pastes, Cem. Concr. Res. 18 (1) (1988) 63–73.

[61] L. Cox, S. van Dijk, Foam concrete: a different kind of mix, Concrete 36 (2) (2002) 54–55.

[62] E.P. Kearsley, H.F. Mostert, The Use of Foamed Concrete in Refractories. Use of Foamed Concrete in Construction, Thomas Telford, London, 2005. pp. 89–96.

[63] A. Just, B. Middendorf, Microstructure of high-strength foam concrete, Mater. Charact. 60 (7) (2009) 741–748.

[64] P. Prim, F.H. Wittmann, Structure and water absorption of aerated concrete, in: Autoclaved Aerated Concrete, Moisture and Properties, Elsevier, Amsterdam, 1983, pp. 43–53.

[65] M.K. Hubbert, Darcy's law and the field equations of the flow of underground fluids, Hydrol. Sci. J. 2 (1) (1957) 23–59.

[66] H.T. Cao, L. Bucea, A. Ray, S. Yozghatlian, The effect of cement composition and pH of environment on sulfate resistance of Portland cements and blended cements, Cem. Concr. Compos. 19 (2) (1997) 161–171.

[67] J. Prasad, D.K. Jain, A.K. Ahuja, Factors influencing the sulphate resistance of cement concrete and mortar, Asian, J. Civ. Eng. 7 (8) (2006).

[68] P. Brown, R.D. Hooton, B. Clark, Microstructural changes in concretes with sulfate exposure, Cem. Concr. Compos. 26 (8) (2004) 993–999.

[69] M. Sahmaran, O. Kasap, K. Duru, I.O. Yaman, Effects of mix composition and water–cement ratio on the sulfate resistance of blended cements, Cem. Concr. Compos. 29 (3) (2007) 159–167.

[70] R. Dhir, M. Jones, L. Nicol, Development of Structural Grade Foamed Concrete, vol. 39(3), Final Report, DETR Research Contract, 1999, p. 385.

[71] G.I.S. Ranjani, K. Ramamurthy, Behaviour of foam concrete under sulphate environments, Cem. Concr. Compos. 34 (7) (2012) 825–834.

[72] J. Newman, B.S. Choo (Eds.), Advanced Concrete Technology 3: Processes, 075065105-9, ISBN no: Butterworth-Heinemann, 2003. 1004 Y.H.M. Amran et al. / Construction and Building Materials 101 (2015) 990–1005

[73] E.P. Kearsley, P. Booysens, Reinforced foamed concrete-can it be durable?, Concrete Beton (91) (1998)