Study on Mechanical Properties of Foam Concrete Incorporating GGBFS and Filler Materials- A review

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Abstract - *This paper summarizes about foam concrete and its properties. Density value of foam concrete varies from of 400- 1600 kg/m^3, and therefore it can be economically used as structural members, partitions, embankment fills etc. It also provides good thermal insulation and material savings because of its porous structure. This paper also discusses about the partial substitution of cement with ground granulated blast furnace slag (GGBFS). Experimental studies proved that the partial substitution of cement with GGBFS did not affect the workability of the mix. Disposal of waste materials like plastic, rubber tires and quarry dust poses a serious threat to environment. Taking this into account this paper also studies the usage of these waste materials in foam concrete.*

Key Words: **Foam concrete, Ground Granulated Blast Furnace Slag (GGBFS), Quarry dust, Crump rubber, Plastic granules, Compressive strength, Density**

1. INTRODUCTION

Many endeavors have been made to reduce the dead weight of the structures without compromising the strength. Light weight concrete is an effective solution for resolving this problem. Light weight concrete can be compared to timber as it can be easily sawed, screwed and nailed. However these concretes are of non combustible nature [1]. Light weight concrete can be manufactured by using light weight aggregates or by incorporating air bubbles which is known as aerated concrete or by eliminating the fine aggregate fraction , which is called the no fines concrete or employing certain foaming agents to produce the foam concrete. The common methods of aeration are by using stabilized foam or introducing air with the help of air entraining agents [1]. Some of the advantages of using light weight concrete are the reduction in dead load, improved thermal insulation, improved fire resistance, savings in the cost of transportation, reduction in formwork requirement etc. Pervious concrete reduces the runoff water and improves the pavement skid resistance during storms. These qualities make pervious concrete an environment friendly choice for pavement applications.

Foam concrete is a kind of pervious concrete in which air bubbles are incorporated using suitable foaming agents. Foamed concrete possess good flowability properties [2]. Due to the omission of coarse aggregates, foam concrete is having a relatively homogeneous mix. Since the density value of foam concrete varies between 400- 1600 kg/m^3, it can be economically used as structural members, partitions, embankment fills etc. It also provides better manipulation, better possibility of treatment and repairing, good thermal insulation and material savings because of its porous structure. Age, porosity, dry density water/ cement ratios, type of foaming agent used, curing, filler type, air void shape are some of the factors that greatly influence the compressive strength of foam concrete [2].

2. FOAM CONCRETE

Foam concrete is cement based slurry which contains at least 20% by volume of foam. It is also called foamcrete or reduced density concrete. Coarse aggregate is not involved in the manufacture of foam concrete. Hence it is also known as foamed cement or foam cement [3]. The main constituent materials for foam concrete are the binder, fine aggregate (sand), water and a foaming agent. The commonly used binder is the ordinary Portland cement. Partial replacement of cement with supplementary cementitious materials (SCMs) can be utilized to turn down costs, increase long term strength and improves mix design consistency. A foaming agent is a material which helps in the formation of foam. Because of the inclusion of foaming agents enclosed air voids called foam bubbles are formed. The foam can be manufactured using two processes: the pre foaming process and the mixed foaming process. Foaming agents can be protein-based, detergents, synthetic, resin soaps etc. As in case of conventional concrete the increase in water cement ratio increases the consistancy, but it will cause segregation in concrete. In order to prevent the cement from absorbing water from the foam, a minimum water cement ratio of 0.35 is to be adopted. Foam concrete shows good workability because of the presence of air bubbles. As there are no chemical reactions involved, the foaming method is more economical and controllable pore forming process compared to air entraining process. The foaming agent reduces the surface tension, which ensures the initial stability of liquid foam. The addition of superplasticizers can ensure the stability and workability of foam concrete and also improves the void structure of foam concrete. Segregation and bleeding can be avoided by using appropriate amount of plasticizer and correct water cement ratio [4].

The strength of foam concrete is greatly influenced by the air void distribution. Higher strength is exhibited by the foam concrete having narrower air void size distribution. The pore structure and micro structure of foam concrete has got a great influence on its properties. Gel pores, capillary pores and air voids are the common classification of pore structure. Creep and shrinkage is related to gel pores. However it does not affect the concrete strength [5].

G. Indu Siva Ranjani and K. Ramamurthy examined the effect of sulphate environment on foam concrete properties. Specimens prepared were exposed to both sodium sulphate and magnesium sulphate environments. Compared to base mix (without foam) the expansion values were 8% and 30% lower for sodium sulphate and magnesium sulphate exposure conditions respectively. Under very severe exposure to sulphate environment, specimens showed about 3.75 to 4.5 times higher expansion than severe exposure condition. More expansion was observed in specimens exposed to sodium sulphate than magnesium sulphates. This is chiefly due to the greater amount of ettringite formation in sodium sulphate environment [6].

Frost resistance of foam concrete can be increased considerably by incorporating pozzolanic powder. Using pozzolanic powder like silica fume and slag powder reduced the porosity and a more uniform pore size distribution was obtained [7].

Compared to aerated autoclaved concrete foam concrete suffer from decreased strength, shrinkage and durability issues in wet and cold climates. A better water resistant and durable foam concrete can be manufactured by using pozzolanic admixtures and turbulence mixing technology. The foam concrete produced in this way has got a frost resistance which is comparable to the frost resistance of normal concrete [7].

2.1 Properties of foam concrete

Compressive strength of foam concrete is dependent on many factors like water cement ratio, cement sand ratio, density, curing period, rate of foaming agent etc. A 28 day compressive strengths of 43MPa and 0.6MPa were obtained for a density of 1800kg/m^3 and 180 kg/m^3 respectively. Using a water cement ratio of 0.17 and 0.19 gives high strength foam concrete. Foam concrete is cured in a moist room at 100% relative humidity [8].

Tensile strength for foam concrete is less than that of normal concrete. Tensile strength of foamed concrete is not as much as that of conventional concrete. Ratio of tensile strength to compressive strength of foamed concrete is between 0.2 and 0.4. The flexural and tensile strengths were between 15% and 35% of compressive strength [8].

The modulus of elasticity value of foam concrete is less as against normal concrete. Modulus of elasticity value of foam concrete is around 1 KN/m^2 and 12 KN/m^2 for densities 500 kg/m^3 and 1600 kg/m^3 respectively. Elastic modulus also depends on aggregate type and content [8].

The size and volume of pores determines the severity of aggressive environment on foam concrete. Foam concrete shows good resistance to sulphate attack and carbonation. Evaluation of foam concrete concretes with density range between 1000 kg/m3 and 1500 kg/m3 for 1 year using 0.5% and 5% of sodium sulphate and 0.424% and 4.24% by mass of magnesium sulphates solutions showed that there was a 28% higher expansion for foam concrete in sodium sulphate solution than in magnesium sulphate solution. Lower the porosity of concrete greater will be its carbonation. Corrosion resistance also showed considerable improvement on using low density concrete [8].

3. EFFECT OF FOAMING AGENT

Air voids is limited to 10% - 70% for cellular concrete. These air voids which are created by entrapping air can be made by using protein based or synthetic based foaming agents [9]. Different methods can be used to produce these air voids. A volume fraction of preformed foam can be introduced into cement paste, which is known as the physical foaming method. Air entraining agents such as H_2O_2, fine aluminium and zinc powder can be used for entrapping air in cement paste by chemical reaction. This method is known as the chemical air entraining technology [10]. Both these materials have different air entraining mechanism. Protein based foaming agent create air bubbles by protein degradation. Due to the creation of hydrogen bonds among molecular groups, they produce stable air bubbles [11]. Synthetic forming agents get easily dissolved in water because of its hydrophilic nature and thereby produce air bubbles. Drainage, coalescence and disproportionation may damage the stability of foam. Therefore different foaming agents produce foam concrete of varying performance [11, 12]. The kind of foaming agent used significantly influences the fluidity of the fresh foamed concrete, compressive strength, water absorption, drying shrinkage and frost resistance [12]. It also affects the thermal resistance and sorptivity coefficient of foam concrete.

X. Wang et al. scrutinized the effect of silica fume on foam stability. The performance and cellular structure of foam can be improved using particle stabilized foam. Silica fumes were added at various stages and its effect on foam concrete was checked. On adding silica fume particles to hardened foam, it attains higher compressive strength, density and higher strength/density ratio. The reason for this can be ascribed to the pozzolanic action of silica fume. Hydrated calcium silicate is formed by the accelerated hydration of the matrix [13].

4. EFFECT OF SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCMS) ON FOAM CONCRETE

From sustainability point of view, we need to minimize the usage of cement and conventional aggregates. An effective solution for this is by utilizing SCMs as partial replacement for cement and using recycled aggregates rather than natural aggregates [14].

SCMs are the by-products of industrial production processes which can be used to improve the strength and durability of foam concrete due to its pozzolanic action [15]. Silica fume, metakaolin, fly ash, ground granulated blast furnace slag are some of the important SCMs. These SCMs can be used wither individually or as a partial replacement for cement. Even though they do not contribute much to the early strength development, considerable increase in later strength is obtained [16]. Calcium hydroxide, which is formed during hydration process react with the silica present in these mineral admixtures to form CSH gel. This calcium silicate hydrate gel has good cementitious capacity and imparts strength to the concrete [17]. Compared to other SCMs, silica fume gives a greater compressive strength. However its workability is less compared to specimens containing GGBFS [18]. The pore structure of foam concrete affects its frost resistance and is greatly influenced by the water cement ratio. The pore structure can be improved by employing industrial by products such as slag powder, silica fume etc. The pore structure interior becomes more compact by the addition of pozzolanic material. The amount pores in 100-300 μm range increased and the pores of size above 900μm decreased due to partial replacement of cement with pozzolanic materials.

Nambiar et al. considered the effect of filler type (fly ash) on foam concrete. A locally available foaming agent, 53 grade portland cement, coarse river sand and class F fly ash were used for the experiment. Mixes which were prepared with fly ash as filler showed a better consistency value, increased strength due to increase in fineness, higher flow characteristics and an improved strength to density ratio. However with rise in density, water absorption decreased [19].

K.H. Yang et al. tried to establish the sustainable applications of alkali activated GGBFS foamed concrete. They carried out experiments of 15 concrete mixes. Concrete mixes having dry densities between 300 and 500kg/m^3 were only taken. Mainly three alkali activators were used: 10% $Ca(OH)_2$ and 4% $Mg(NO_3)_2$, 5% $Ca(OH)_2$ and 6.5% Na_2SiO_3, and 2.5% $Ca(OH)_2$ and 6.5% Na_2SiO_3. Pre foamed foaming procedure was adopted to produce foam concrete. Most of the mixes showed good workability and the quick setting of concrete were also prevented. This indicated that the activators used were efficient enough. The type of activator did not very much affect the compressive strength. The main influencing factor for compressive strength was the dry density. From the sustainability point of view, these concrete mixes proved to be good. Comparing to OPC, the CO_2 emission was considerably lower (by 85-93%). However the cost of production is a little higher compared with OPC [20].

Very few studies have been made by incorporating GGBFS in foam concrete. The ground granulated blast furnace slag (GGBFS) is a by-product of iron manufacturing which when added to concrete enhances its properties like workability, strength and durability [21]. It can be used as a partial replacement for cement because of its inherent binding properties. For achieving a better cementitious property, slag is ground finer than the cement. Usage of GGBFS gives an improved workability compared with normal concrete and therefore the water cement ratio can be reduced to some extend without compromising on the compressive strength of concrete. If more than 40% replacement of cement with GGBFS is done, it has got a retarding effect on the setting time [21]. Temperature is among the major issues that affect the early age compressive strength of concrete. When concrete containing GGBFS is exposed to a temperature up to 100°C, it did not show much drop in the mechanical properties. The strength drop was lower than 40% for compressive and tensile strengths. At room temperature (27°C), 28-day compressive strength of concrete with 20%, 40% and 60% GGBFS was respectively 16.8%, 23.9% and 28.5% less than the control blend (34.8 MPa). The splitting tensile strength of concrete with 20%, 40% and 60% GGBFS was respectively 17.4%, 8.2%, and 15.6% less than the control (3.2 MPa) at room temperature. The modulus of elasticity of concrete with 20%, 40% and 60% GGBFS was respectively 22.5%, 39.98% and 41.7% less than the control (15.98 GPa) at room temperature [22]. Concrete shows slightly higher modulus of elasticity value when about 60% GGBFS is used as substitute for cement. Some of the many advantages of using GGBFS in concrete are it improves the abrasion resistance, reduces water, chloride and gas permeability, increases flexural strength, and also helps to reduce environmental pollution. In addition to this, GGBFS also helped to resist corrosion of steel reinforcement. Corrosion rates were considerably decreased on 60% replacement with GGBFS. Also the chloride ion permeability decreased and concrete resistivity increased due to addition of GGBFS [23].

Experimental studies proved that the partial substitution of cement with GGBFS did not affect the workability of the mix. Due to the exclusion of coarse aggregates, foam concrete showed greater drying shrinkage. Addition of fibers helps to boost the compressive strength. When foam concrete is subjected to a high temperature, between 90°C and 170°C, the free water and chemically bound water is released which will decrease the compressive strength. The density of foamed concrete may vary greatly for the same water cement ratio because of the variation in the amount of foam. It results in varying porosity, which will result in the decrease of mechanical properties of the foamed concrete [24].

Patra et al. investigated about the feasibility of partial replacement of fine aggregates with GGBFS in concrete. Experiments were done for 20%, 40% and 60% replacement levels. Due to high absorbing nature of GGBFS, the slump value decreased after 40% replacement level, which recommended the use of superplasticizers. The pozzolanic nature of GGBFS contributes to an increased compressive strength, and 60% replacement was found to be the optimum percentage. For the same reason, the flexural strength as well as tensile strength improved with an optimum value at 60% replacement level. Non destructive tests were also performed at various locations and an increase in rebound number was obtained, which is indicative of the reduced voids in the concrete specimen [25].

Yuksel et al. investigated about how durability of concrete was affected by using a combination of bottom ash and GGBFS as a replacement for fine aggregates. Various replacement percentages of 10%, 20%, 30%, 40% and 50% were studied. The amount of surface cracks formed was lower at high temperatures when these SCMs were used. So this can be a feasible solution for concreting at high temperatures. At lower replacement levels (10-30%), freeze thaw resistance was more. At higher replacement levels, strength loss is more. 20% replacement shows the best performance. The problem of using these SCMs is that, it will considerably increase the porosity of concrete. This is one of the main issue which influence the durability [26].

O.H. Oren et al. reported that sand can be completely replaced with GGBFS in foam concrete and it showed superior properties compared to the control mix. They performed tests in foam concrete by using fly ash as binder and GGBFS as replacement to fine aggregates. A reduction in bulk density, thermal conductivity and ultrasound velocity was observed for foam concrete with 100% GGBFS and a w/b ratio of 0.68 and 0.91. At a w/b ratio of 0.68 the specimen showed a comparatively higher compressive strength. But with increasing w/b ratio porosity also increases, which will decrease the compressive strength [27].

5. EFFECT OF WASTE MATERIALS ON LIGHT WEIGHT CONCRETE

Reduction in non recyclable waste materials and production of energy efficient concrete can be achieved by using industrial wastes such as quarry dust, crump rubber and plastic wastes in the preparation of concrete. They are capable of improving the hardened concrete properties [28]. Induction furnace slag is also another potential waste material which can partially substitute fine aggregates [29].

5.1 Plastic waste

The excessive dredging of sand from rivers is causing severe environmental impact which has resulted in certain restrictions on river sand dredging across India. This has a direct economic impact on the construction industry. Recycling of plastic waste is rarely taking place in India. Building up of these plastic wastes is also causing a severe impact on our environment. Plastics contain non degradable polymers. One of the promising properties of plastics which make it suitable for the usage in concretes is that it does not get easily degraded even after a long period of exposure. Both these issues can be solved by partially replacing sand with plastic waste in concrete. Plastic aggregates are prepared by grinding plastic bottles and then sieving it to get the required size aggregates. There are three different ways of incorporating plastic into concrete and mortars. It can be included as a resin or as a binder (after being melted with sand and clay) or as fibres or pellets as a partial replacement for aggregates [30]. Commonly used type of recycled plastic aggregate is the Polyethylene terephthalate (PET). In the works conducted by Hameed et al. when the percentage of PET added to concrete was increased, it resulted in a decrease in the densities of the concrete mix . This shows that incorporating plastic wastes can help us to produce light weight concrete. Compared to the reference batch, concrete with 1% PET showed a 58% hike in the compressive strength. Using PET at 1% and 3% exhibited an increase in flexural strength values of 23.11%, 25.59% respectively when compared with the reference batch [31]. Most of the studies conducted for concrete with plastic aggregates, showed a lower slump value. Angular particle size and sharp edges of plastic aggregates are the reasons why the concrete mix shows lower slump value. However some studies by Saikia et al. showed a higher slump value because of the presence of additional free water in the mix. Due to low binding strength between plastic and cement, regardless of the kind of plastic and amount of replacement, the plastic aggregate lowers the various strength properties [32].

PVC is yet another frequently used thermoplastic polymer which comes second to polyethyelene plastics in terms of usage. Experiments were carried out by incorporating PVC aggregates in concrete specimens and evaluating its performance. A slump value of 160- 180mm is required to produce a workable light weight concrete. Using PVC aggregate can reduce the workability. The slump loss PVC aggregate concrete is because of the larger size and angular shape of the aggregates. So in order to increase the workability sufficient dosage of superplasticizers are to be added. By adding 10%, 20%, 30%, 40% and 50% PVC aggregates, the slump value decreased from 10cm to 7.5, 6.8, 5.5, and 5.2 cm respectively. With partial replacement by PVC granules, density showed a decreasing trend. The compressive strength is not much affected by the curing regime. However it has a significant on initial and final absorption. Greater the PVC content, greater the reduction in initial and final absorption values. Compressive strength and tensile strength showed a steady drop in its values with increasing percentage of replacement with PVC granules. When these PVC granules are used in aerated concrete with flyash as partial replacement for cement, at the minimum density, a compressive strength of 5MPa was obtained [33].

Thorneycroft et al. conducted experiments on partial replacement of sand with five different types of plastics. Only variable used was plastic and 10% by volume was taken as a constant replacement level. Plastic granules which are sufficiently small irregularly shaped, rough surfaced and which are graded similar to sand act as the most competent plastic aggregate. The decrease in strength levels with plastic replacement can be minimized to an acceptable range with proper mix design [34].

5.2 Crump Rubber

Waste tyre rubbers are non recyclable in nature is another major environmental pollutant. These tyres are made of materials which do not easily decompose [35]. Burning of tyres is the easiest way to get rid of these wastes. But it would release a huge amount of CO_2 into the atmosphere. An innovative solution for this problem is to incorporate waste tire rubbers into conventional concrete [36]. In addition to the overall improvement in concrete properties like ductility, energy absorption, resistance to freezing and thawing and penetration of chemicals, it results in economical save and cleaner environment. Although incorporating rubber crump into concrete decreased the strength parameters, the material toughness has found to be improved [37]. For pervious concrete consisting of waste tire rubbers the range of water content preferred is 0.25 to 0.35 (mostly 0.27). Experimental investigation done by Gesoglu et al. established that the porosity, compressive strength and permeability values shown by these concrete are 15-25%, 3-30 MPa and 0.025-0.61 cm/s respectively. Fine crump rubber can act as fine aggregates and they filled the space between concrete particles which increased the density by around 2-5%. Therefore smaller rubber particles had a greater negative effect on permeability of pervious concrete. The compressive strength value showed a decrease in contrast to normal concrete. The size of rubber particles also had an influence on the strength. Smaller size particles do not greatly affect the strength parameters. But with increase in the amount of rubber content, the rate of compressive strength showed a decrease in strength between 16% -68% depending on the type and amount of materials used. Due to this decreased compressive strength values, it limits the use of pervious concrete to pavement constructions. Since the compressive strengths showed a decrease on using crump rubber, the modulus of elasticity values also decreased. Usage of different sized particles did not show much difference in the elastic static modulii. In case of light weight aggregate concrete, as the amount of rubber crump increases it showed a decrease in the static mechanical properties. While flexural toughness showed an increase with the replacement values of 80% and 100%, showing negligible change at 80% [37].

L. He et al. conducted studies on the surface modification of crump rubber and its effect on mechanical properties of concrete. Figure 1 shows the flowchart for rubber modification process.

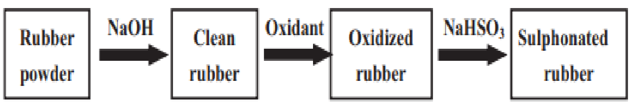

Fig -1: Flowchart for rubber modification process

Amid rubber and cement matrix a huge amount of ionic and hydrogen bonds were formed on the rubber surface due to oxidation and sulphonation of added polar carbonyl, hydroxyl and sulfonate groups. This improved the mechanical properties of concrete. Compressive strength reduction of rubber incorporated concrete is because of the elastomeric nature of rubber. For the modified rubber concrete the declination in strength was found to be slower in contrast to normal rubberized concrete. It also imparted greater toughness and smaller cracks to concrete [38].

Crump rubber can also be utilized as replacement for fine aggregates in masonry blocks. However the compressive strength of these blocks is less compared to conventional blocks owing to the low binding property of crump rubber. The compressive strength of these crump rubber incorporated blocks can be improved by the addition of SCMs like silica fume [39].

5.3 Quarry Dust

Due to the many environmental and socio economic problems caused by the extraction of sand from river beds, coastal areas and due to the depleting sand reserves, quarry dust (by product of stone grinding, crushing and cutting) can be employed as a feasible solution for the replacement of sand as fine aggregates [40,41]. In addition to the environmental problems, being in the form of fine dust it causes several health problems also. Quarry dust cannot completely replace sand as its load bearing capacity is very less. The physical properties of quarry dust were found to be comparable with that of sand except the granular shape possessed by river sand [41]. When used as fine aggregate, quarry dust showed improved strength, mechanical properties and durability properties. The flexural strength of normal concrete is about 10-15% of its compressive strength. On replacing quarry dust as fine aggregate, this thumb rule was satisfied. Meisuh et al. reported that with 100% replacement of sand by quarry dust, concrete showed a 5.4% increase in flexural strength. Studies also show that at around 50% replacement of fine aggregate with quarry dust, it shows the maximum compressive strength [42].

From the findings of Lim et al. it was concluded that the fluidity of light weight foamed concrete decreased with the presence of refined quarry dust at a given water cement ratio. Due to refinement of pore formation and dense microstructure, thermal conductivity of foam concrete was slightly increased. Self compacting concrete, high strength concrete and brick production were some of the areas where replacement of river sand with quarry dust found application. Also using quarry dust to produce light weight foamed concrete showed a greater environmental sustainability than those which were made out of natural materials alone.

G.K. Febin et al. analyzed the feasibility of using quarry dust as partial replacement for sand for preparing concrete building blocks. An increased compressive strength and modulus of elasticity value was obtained at 30% replacement level and it was obtained as the optimum value. At higher replacement levels concrete showed decrease in strength and it was attributed to low compaction and workability because of high amounts of quarry dust. It showed a considerable hike in thermal conductivity which makes it unsuitable for thermally insulating materials [43]. Studies on foam concrete masonry blocks with flyash as partial substitution for cement and quarry dust as partial substitution for fine aggregate gave 30% as optimum replacement percentage for both [44].

6. CONCLUSIONS

Density value of foam concrete varies from 400- 1600 kg/m^3. It can be economically used as structural members, partitions, embankment fills etc. It also provides good thermal insulation and material savings because of its porous structure. Due to the addition of foaming agents enclosed air voids called foam bubbles are formed. 28-day compressive strength of concrete with 20%, 40% and 60% GGBFS was respectively 16.8%, 23.9% and 28.5% less than the control blend (34.8 MPa). The splitting tensile strength of concrete with 20%, 40% and 60% GGBFS was respectively 17.4%, 8.2%, and 15.6% less than the control (3.2 MPa) at room temperature. The modulus of elasticity of concrete containing 20%, 40% and 60% GGBFS was respectively 22.5%, 39.98% and 41.7% lower than the control (15.98 GPa) at room temperature. Experimental studies proved that the partial substitution of cement with GGBFS did not affect the workability of the mix. Compared to the reference batch, concrete with 1% PET showed a 58% hike in the compressive strength. Using PET at 1% and 3% showed an increase in flexural strength values of 23.11%, 25.59% respectively when compared with the reference batch. When quarry dust substituted fine aggregate, concrete showed improved strength, mechanical properties and durability properties.

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