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Effect of Incorporating Foamed Glass on the Flexural Behaviour of Reinforced Concrete Beams

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Abstract: The flexural behaviour of concrete containing Foamed glass as partial replacement of coarse aggregate is investigated. The coarse aggregate was replaced with 0%, 25%, 50%, 75% and 100% Foamed glass. All other constituents were maintained the same. Reinforced concrete beams were cast using 2 bars of 8mm in diameter in the tensile zone. The density and compressive strength of concrete decreased as the percentage of Foamed glass in the concrete increased. The maximum flexural load and the load at which the first crack appears increased the presence of Foamed glass. However, there seems to be an improvement in the ductitily of the reinforced concrete beams for the majority of beams containing Foamed glass, in that the deflection at failure is noticeably higher than that of the control.

Key words: Foamed glass · Coarse aggregate · Reinforced concrete beams · Flexural behaviour

INTRODUCTION

While traditional and heavy-weight concrete provide high strength, it can pose risk and cause damage during earthquake [1-3]. The use of light-weight concrete can provide cost savings and enhanced engineering performance due to the reduction in self-weight [4].

Glass is amongst the oldest man-made materials and as such has been used for many years in various applications. Therefore, there is an ongoing generation of waste glass.

Foamed glass is produced by generating a gas in glass at a temperature between 700 and 900°C, Foaming agents are also added such as calcium sulphate ($CaSO_4$) or calcium carbonate ($CaCO_3$). The gas expands and produces a structure of cells that form a porous end product with highly consistent characteristics [5]. This product is referred to as foamed glass.

Authors [6] stated thatFoamed glasshas been used in construction applications as lightweight non- and semi-structural material.The use Foamed Glass aggregates in concrete production as partial replacement to natural aggregates has caused a decrease in compressive strength compared to control mix [7].

Due to the numerous advantages in conjunction to sustainability as one of the key requirements for construction industry to lower environmental impacts and rapid depletion of natural resources, there has been an increasing interest in production and also investigation of properties of lightweight aggregates. With this background, the main focus of this study was to investigate the flexural behaviour of lightweight Foamed glass aggregates as partial or full replacement in concrete.

There is little work on the structural behaviour of reinforced concrete elements containing foamed glass. This study reports the results of an experimental investigation on the flexural behaviour of reinforced concrete beams containing varying amounts of foamed glass.

MATERIALS AND METHODS

Mix Proportions: The materials used in the concrete mixes were cement, fine aggregates, coarse aggregates, foamed glass and water. The cement used was ordinary Portland cement. The fine aggregates used were river sand with particles ranging from 63ìm to 4mm in size. The coarse aggregates were natural gravel and stones with particles

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Table 1: Details of mixes (* all content in kg/m^3)

Mix	Mix code	FG%	Cement*	Water*	Sand*	CA*	FG*	Slump (mm)	Density kg/m^3
C1	FG 00	00	329	164.5	657.96	1315	0	35	2328
C2	FG 25	25	329	164.5	657.96	986.25	46.7	35	2135
C3	FG 50	50	329	164.5	657.96	657.96	93.5	35	1958
C4	FG 75	75	329	164.5	657.96	328.75	140.2	25	1624
C5	FG 100	100	329	164.5	657.96	0	186.9	20	1401

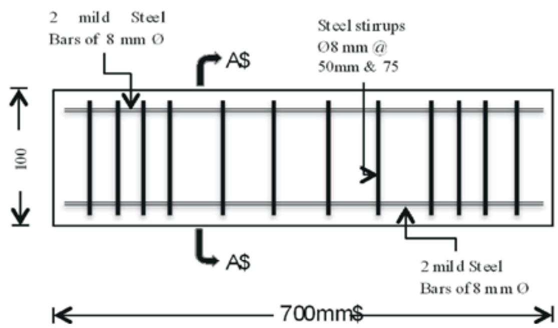

Fig. 1: Reinforcement Details and layout for Beams

ranging from 4mm to 20mm in size. The Foamed glass coarse particles used as partial replacement of natural coarse aggregates were also similar in size ranging from 4mm to 20mm. The control mix C1 consisted of mixtures had proportions of 1 (cement): 2 (sand): 4 (coarse aggregate). In mixes C2-C5, the coarse aggregate was replaced with 25%, 50%, 75% and 100% foamed glass. For all concrete mixes, the cement content and the free W/C ratio were kept constant at 329 kg/m^3 and 0.5 respectively. Table 1 presents the details of the various mixes Mild steel bars were used to reinforce the beams.

Preparation, Casting and Curing: Reinforced concrete beams of dimensions 700mmx150mmx100mmand cubesof 100mm in size were prepared from each mix. Before casting began, the slump test was conducted. Plywood mould was used for the beams whereas steel moulds conforming to BS EN 12390-2 was used for the cubes. After casting, beams and cubes were covered and left for approximately 24 hours at room temperature (~20°C) until de-moulding. After de-moulding the beams and cubes were placed for curing at room temperature for 41 days (i.e. a total curing period of 42 days since casting).

The number of compression and tension bars was two for all beams. The compression reinforcement at the top was primarily for holding purposes and ease of holding stirrups. The shear links were 8mm diameters and placed at 50mm centres to the sides and 75mm centres towards flexural zone. The dimensions and the reinforcement arrangement of the beams are shown in Figure 1.

Testing: The workability and the consistency of concrete were determined by undertaking the slump test conforming to BS EN 12350-2:2009 [8]. The compressive strength testing was according to BS EN 2390-2:2009 [9].

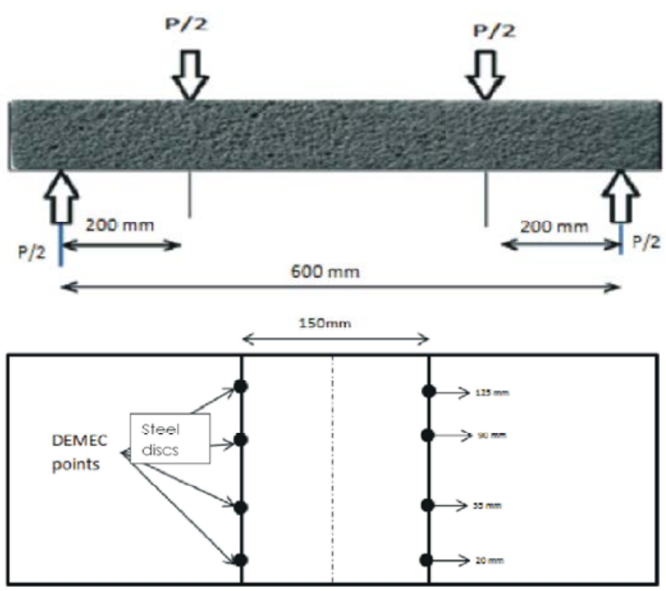

Fig. 2: Loading pattern and locations of steel discs on the surface of the beam

The beams were simply supported and tested in flexureless than four points loading(i.e. two supports and two point loads). Steel discs were attached to the beams surface in a pair using a suitable adhesive. From mid-span, the points were attached at 75mm on both sides at various depths; two points were placed in the compression zone of the beam while the other two were placed below the centreline of the beam towards the bottom flexural zone. The steel discs were used to determine the strain distribution along the depth of the beam. Figure 2 illustrates the loading pattern andthe locations of steel discs on the surface of the beam. Further details about testing are given elsewhere [10].

The beams were loaded in 2 KN increments until failure to compare flexural performance of concrete with and without foamed glass. The central deflection and the strain readings were noted at each load increment. Also the load at which first crack appears was determined.

RESULTS AND DISCUSSION

Table 1 presents the slump and density values for the various concrete mixes. All slump values are 30±10mm indicating that the slump is similar for mixes with and without foamed glass. The density value drops rom 2328 kg/m^3 for the control mix to 1401 kg/m^3 for the concrete with 100% foamed glass. The percentage drop in density for all mixes is shown in Figure 3. As the content of foamed glass increases the percentage drop in density increases and this increase is systematic and appears to be linear. At 100% foamed glass the percentage reduction in density is around 40%.

Figure 4 shows the compressive strength of concrete with different percentages of Foamed glass as coarse aggregate replacement. There is a systematic decrease in compressive strength with the increase in foamed glass compared to the control mix. Replacing coarse aggregate with 75% or 100% of foamed glass resulted in a

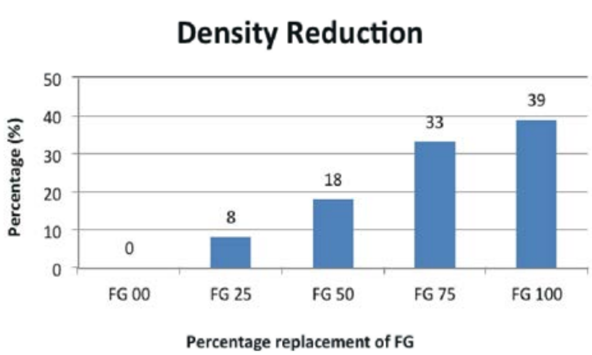

Fig. 3: Reduction of density for all concretes

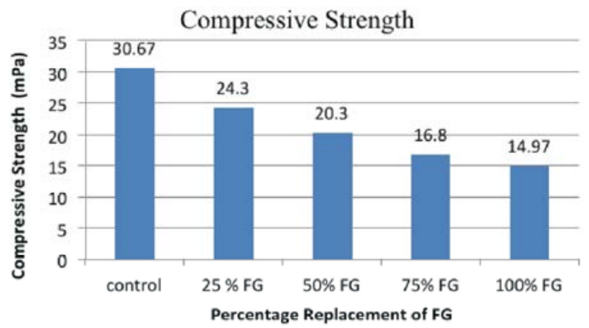

Fig. 4: Effect of foamed glass (FG) on the compressive strength of concrete

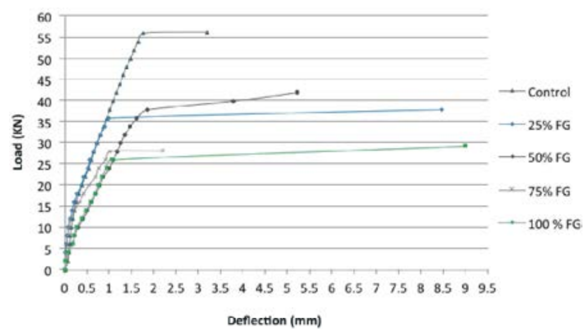

Fig. 5: Load-Deflection curves for beams containing various percentages of foamed glass

considerable drop in the compressive strength of concrete which does not meet the minimum requirements of 28-day design strength of 17 Mpa for lightweight aggregates. This finding is consistent to the work of Limbachiya [7] who also reported that 100% replacement of foamed glassas coarse aggregates did not meet the minimum required strength for use as lightweight concrete in structural applications.

It was observed that the density has a direct correlation with concrete compressive strength. A reduction is density is associated with a drop in compressive strength. High content of foamed glass results in a lower density and a lower compressive strength.

Figure 5 shows the load-deflection curves for reinforced concrete beams containing 0%, 25%, 50%, 75% and 100% coarse Foamed glass particles. Generally, in all the beams, the initial slope of the load-deflection curve is steep and fairly linear during the elastic stage up to the first crack where the deflection is also minute. After the first crack, there is a decrease in the slope of the load deflection curve that remained fairly linear until yielding of the steel. With further load increase beyond the yielding of the reinforcement, there were large deflections under smaller loads. Incorporation foamed glass had a

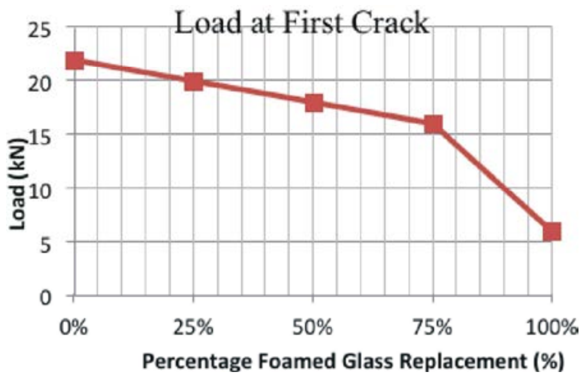

Fig. 6: Load at first crack for the various beams

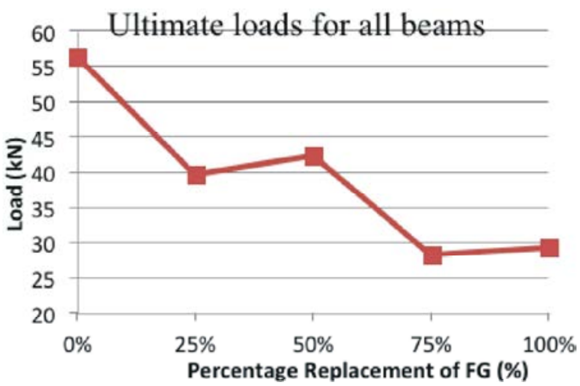

Fig. 7: Failure load for the various beams

noticeable effect on the load deflection behaviour. As the percentage replacement of Foamed glass increased the deflection also increased. This is in agreement with results reported elsewhere [11, 12].

The load at which the first crack appears for the various beams is plotted in Figure 6. As the percentage replacement of foamed glass increases the load at which the first crack appears decreases. The reason for this could be due to reduction in the modulus of elasticity of foamed glass concrete as Limbachya [7] reported a decrease in the modulus of elasticity with increasingamounts of foamed glass.

As the percentage replacement of foamed glass increases the failure load decreases. This is shown in Figure 7 where the failure load is plotted against foamed glass content. For 100% foamed glass replacement there is a reduction of almost 50% in the load carrying capacity in comparison withthe control beam (i.e. 0% foamed glass). It seems that the compressive strength of foamed glass holds key significance in this reduction as the percentage reduction in concrete compressive strength correlates to the percentage of reduction in the load carrying capacity. For example, the compressive strength of control mix was 30.67 Mpa and the load capacity of the beam from that mix was 56.29kN whereas for 100% replacement the compressive strength and failure load for the beam was 14.97 Mpa and 29.9 kN respectively, a reduction of almost 50% in strength and load carrying capacity.

CONCLUSION

The addition of increasing percentages of Foamed glass particles as coarse aggregate replacement showed a decrease in the compressive strength ranging from 20 to 50%. Increasing the percentage of foamed glass particles showed decrease in the density of concrete. Ductility is influenced by the addition of foamed glass content. As the content of foamed glass increases the beams behave in a more ductile manner providing ample amount of warning. Increase in percentage replacement of foamed glass slightly decreased the load at which the first cracks appears but drastically reduced the load carrying capacity.

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