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Fly Ash as Fine Aggregate in Polyester Based Polymer Concrete

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Abstract

Polymer concrete mixes based on polyester resin as an organic binder, fly ash and river sand as fine aggregates and granite as a coarse aggregate have been prepared. Fly ash has been used as a replacement for river sand, which is usually employed in the construction of ordinary cement concrete systems. Properties such as cure time flexural strength and resistance to water absorption have been studied by varying the level of fly ash. It has been noted that fly ash can be used as a fine aggregate material for partially or fully replacing ordinary river sand in polymer concrete systems. Fine aggregates in combination with fly ash and river sand show synergism in strength behaviour and resistance to water absorption up to the level of 75% by weight of fly ash. At the higher level of fly ash, properties decline as the mix becomes unworkable. Cure time, strength and resistance to water absorption of fly ash filled polymer concrete, using unsaturated polyester as the resin binder, can further be improved by increasing the amount of resin in the mix. Copyright © 1996 Published by Elsevier Science Ltd.

INTRODUCTION

Polymer concrete serves as a unique concrete composite in the construction industry because of its quick setting characteristics, high mechanical strength, chemical resistance and wear resistance. Similar to ordinary cement concrete, polymer concrete consists of fine and coarse aggregates which are mixed together with a thermosetting resin and curing agents till a homogeneous slurry like mix is obtained with which the moulds are filled by tamping or vibrating. The amount of the resin binder volume does not exceed that of the cement paste in ordinary cement concrete.

The final strength property and the curing behaviour of polymer concrete depend on the selection and the content of the resin, curing agents, temperature and aggregates used. Mix proportioning by varying the levels of styrene monomer, initiator and accelerator with polyester systems were studied by earlier workers.[1,2] Studies based on epoxy mortar systems point out that its strength property is a parameter dependent on testing conditions.[3] In some other studies, it has been reported that the use of reclaimed polymethyl methacrylate or recycled polyethylene terephthalate is promising from the view points of cost reduction and property improvement for polymer mortar and concrete.[4,5]

Fly ash obtained as the inorganic waste material of pulverised coal in thermal power stations poses problems of its disposal and effective utilisation. Presently the most important uses of fly ash are based on its pozzolanic characteristics such as (i) corrective raw material in portland cement industry[6] and (ii) in the design of concrete mixes.[7,8] However, only very little of the fly ash produced could be consumed in this fashion. More ways of utilisation have to be explored to consume the enormous quantities of fly ash produced.

Recent studies on fly ash as a filler in epoxy mortar suggest that it can replace quartz filler with improved mechanical properties.[9] While unsaturated polyester is used as the most important binder in polymer concrete systems, the effect of fly ash, as fine aggregates, on their strength property and cure behaviour are not studied in detail.

The present paper deals with the use of fly ash as a filler in polyester based polymer concrete as replacement for the commonly used river sand. Effects of the amount of fly ash for two different mixes on flexural strength, water absorption, and cure time are studied.

EXPERIMENTAL

Materials

The materials used were (i) isophthalic unsaturated polyester resin, containing 36% styrene of Reichold Chemicals India Limited; (ii) initiator: methyl ethyl ketone peroxide (50% in dimethyl phthalate); (iii) accelerator: cobalt octoate (2% in 50:50) mixture of turpentine/o-xylene); (iv) fine aggregates (ASTM Mesh No.: 50-325) of fly ash and locally available river sand and (v) coarse aggregate: locally available gravel (ASTM Mesh No. 5-50). The composition of fly ash used is given in Table 1.

METHODS

The formulations of mixes are given in Table 2. The proportions of resin: fine aggregate: coarse aggregate are 1:2:4 and 1:3:6 and they are hereafter designated as 1 2 4 and 1 3 6 mixes, respectively. The amount of initiator and accelerator were fixed at 2 and 1 parts, respectively with respect to the weight of the resin binder.

The samples were cast into moulds of size $4 \times 4 \times 16$ cm and cured at 50 °C. The cure time measured was the period of time enough to obtain a stable and measurable hardness value on a shore D scale and was in the range of 50–55. The samples were then post-cured for another 1 h at the same temperature to get a steady hardness which was in the range of 85–90. Attainment of final steady hardness is an indication of equilibrium curing. Flexural testing was carried out in a Shimadzu dynamic testing machine at a speed rate of 0·5mm/s. Water absorption of all samples were noted after immersing them for 24 h.

Table 1. Chemical composition of fly ash (%)

Silica	63·14
Alumina	23·83
Ferric Oxide	3·90
Calcium Oxide	2·15
Titanium Dioxide	2·15
Magnesium Oxide	1·65
Alkali Oxide	2·11
Manganese Dioxide	0·91
Phosphorous Pentoxide	0·06

RESULTS AND DISCUSSION

Fly ash characteristics and composition vary from source to source as they are not only the function of quality of coal used for burning in thermal power plants but they also depend on coal grinding, boiler operation, etc. Fly ash consists of silica as the major ingredient, which is also the major constituent of any sand aggregate used in concrete mixes. Fly ash and river sand contents have been varied at the entire composition range for two different mixes.

Effects of mix proportioning on cure time, flexural strength and water absorption with fly ash are shown in Figs 1, 2 and 3, respectively. In this study, there are two different mixes, wherein the amount of polyester resin is not the same. Hence, it is also possible to obtain an understanding on the effect of resin binder on properties. The quantity of polyester resin in 1 2 4 and 1 3 6 mixes are 14·3 and 10% by weight, respectively. Cure time of both mixes varied from 25 to 41 min and it gradually decreased with the amount of fly ash. Polymerisation of styrene monomer and crosslinking between

Table 2. Formulation of polymer concrete mixes

Mix designation	*Fine aggregate*	*Coarse aggregate*	*Resin:Fine aggregates: coarse aggregate*
1 2 4	River Sand (0–100%) Fly ash (0–100%)	Granite	1:2:4
1 3 6	As above		1:3:6

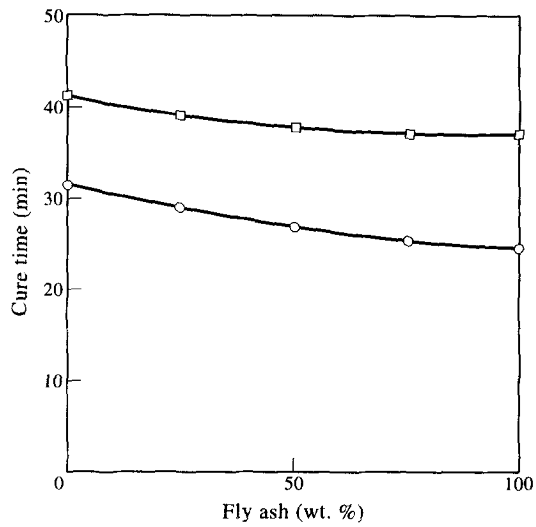

Fig. 1. Effect of fly ash on cure time of 1 2 4 (o) and 1 3 6 (□) polymer concrete mixes.

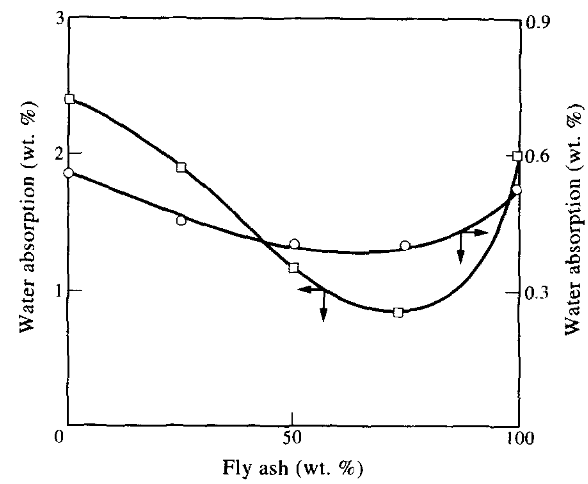

Fig. 3. Effect of fly ash on water absorption of 1 2 4 (o) and 1 3 6 (□) polymer concrete mixes.

polyester chains in polymer concrete are activated by the presence of fly ash which is a complex mixture of inorganic substances. Hence, it can be seen that fly ash aggregates can activate the setting of polymer concrete.

Resin binder in polymer concrete is the constituent which performs the setting process in the presence of initiator and accelerator. The fact that the cure time of 1 2 4 mix is lower than that of the 1 3 6 mix proves that an increase in the amount of the resin binder decreases the cure time of polymer concrete mixes.

In Fig. 2, the dashed line represents theoretical flexural strength of composites for any given composition of fly ash and river sand calculated from the pure flexural strength values with only river sand and only fly ash. The equation fitting this line can be written as

$$\phi = \phi_1 w_1 + \phi_2 w_2$$

where ϕ is the theoretical flexural strength of composites for any given composition; ϕ_1 and ϕ_2 are the experimental flexural strength values with only river sand and only fly ash, respectively as fine aggregates; and w_1 and w_2 are weight fractions of river sand and fly ash, respectively for any given composition. Synergism or antagonism in any property of composites, when considered at the entire composition range, is determined from the data points lying above or below the theoretical values. In the present case, it is seen that the experimental values of flexural strength fall above the dashed line indicating significant synergistic effect in this property due to the fly ash–river sand combination.

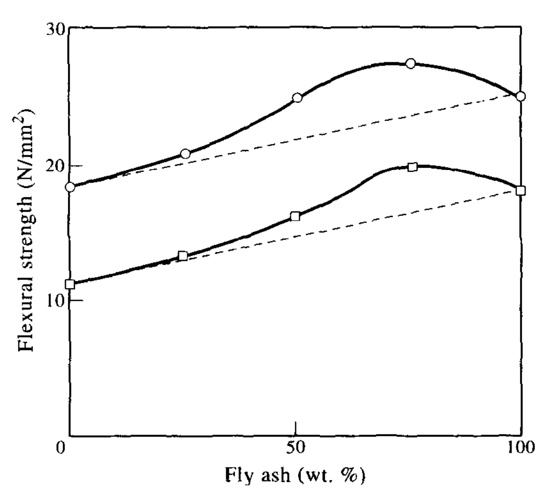

Fig. 2. Effect of fly ash on flexural strength of 1 2 4 (o) and 1 3 6 (□) polymer concrete mixes.

Pure fly ash, due to its large surface area, does not mix with resin binder very effectively and as the fly ash content gradually increases the mix becomes unworkable. Weak bonding between fly ash particles and resin binder is developed in composites with a higher loading level of fly ash. Hence, the reinforcement in flexural strength can be seen to reach maximum at 75% fly ash content and beyond that this property declines. Nevertheless, flexural strength of composites based on pure fly ash is higher than that of pure river sand. In epoxy mortar systems also fly ash has been reported to have exhibited higher strength than the system containing quartz filler.[9] The effect of the amount of resin binder on flexural strength of polymer concrete mix, as evident from Fig. 2 is that the higher its amount the greater its strength property.

Water absorption levels of 1 2 4 and 1 3 6 mixes based on pure river sand are 0·55 and 2·40%, respectively. Replacement of river sand with fly ash further reduces the water absorption till the level of 75% of fly ash in composites. Resistance to water absorption due to fly ash has also been noted in systems of clay stabilised with cement and lime.[10] Higher loading of fly ash tends to weaken the particle–resin bonding. Hence, the resistance to water absorption decreases when the fly ash is used as fine aggregate beyond the level of 75%. It is also evident that, as the amount of the polyester resin increases, the mix exhibits low water absorption. This is explained by the fact that such mixes have lesser voids due to strong matrix–aggregate bonding to prevent the penetration of water.

CONCLUSIONS

Fly ash can be used as a fine aggregate material either partially or fully replacing ordinary river sand in polymer concrete systems. Fine aggregates in combination with fly ash and river sand show synergism in strength behaviour and resistance to water absorption up to the level of 75% by weight of fly ash. At the higher level of fly ash, properties decline as the mix becomes unworkable. Cure time, strength and resistance to water absorption of fly ash filled polymer concrete, using unsaturated polyester as the resin binder, can further be improved by increasing the amount of resin in the mix.

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