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# Experimental Investigation of Waste Glass Powder and Fly Ash as Partial Replacement for Cement in Concrete

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*Abstract* - **Concrete is one of the most widely used construction material in the World and it comprises of cement, fine aggregate, coarse aggregate and water. Cement manufacturing industry is one of the carbon dioxide emitting sources and the global cement industry contributes 7% of greenhouse gas emission to the earth's atmosphere. In the construction industry, environmental issues are a major concern for a sustainable development by the usage of cement and concrete. Hence there is a need to look out for an alternative material to partially replacement for cement by some pozzolonic material to reduce the cement usage. As a result many researches were carried out to use waste materials like waste glass, fly ash, blast furnace slag, etc., Glass is used in many forms in our everyday life. After using it once, the glass is either stocked up or used as a land fill. Glass is an inert material that can be recycled many times without changing any of its chemical property. As glass is non-biodegradable using it as a landfill is not an environment friendly solution to the construction industry whereas if it is used as a partial replacement for cement, fine aggregate and coarse aggregate to some extent it can be less hazardous to the environment.**

**Glass when used in powder form shows pozzolonic properties that when partially replaced with cement can achieve the required compressive strength. In India, the annual fly ash generation is about 110 million tonne but the utilization is less than 20% of its generation. The engineers have to create an awareness to utilize waste fly ash into a resourceful material in the construction industry. Fly ash of type F is available from the nearby paper industry. It has got most of the cementitious properties but it is left unused that are hazardous to the environment. It is either dumped along the roadside or as a landfill. By partially adding fly ash along with glass powder in the concrete mix increases the workability and durability of the cement concrete. Also, with the addition of fly ash along with the glass powder, the Alkali Silica Reaction can be prevented. The objective of our study is to partially replace glass powder of size 80 μm and fly ash of type F in various percentages for cement and the strength characteristics of this new type of concrete is compared with that of the conventional concrete. The test results show that the partial replacement of the glass powder and fly ash combination can be a good substitute for cement. Apart from the strength, the new type of concrete helps to recycle the waste glass powder and fly ash thereby protecting the environment and reduce the construction cost.**
*Keywords:* **waste glass powder and fly ash, concrete, strength, replacement**

## I. INTRODUCTION

Cement manufacturing industry is one of the carbon dioxide emitting sources besides deforestation and burning of fossil fuels. The global warming is caused by the emission of greenhouse gases, such as $co_2$, to the atmosphere. Among the green house gases, $co_2$ contributes about 65% of global warming. The global cement industry contributes about 7% of green house gas emission to the earth's atmosphere.

In order to address the environmental effects associated with cement manufacturing there is a need to develop alternative binders to prepare concrete. Consequently extensive researches are going on to replace cement by using many waste materials and industrial by products. Today many researches are conducted to replace Portland cement by, using a variety of waste materials and industrial by products, for example, pulverized fly ash (PFA), ground granulated blast furnace slag (GGBS) etc. Like PFA and GGBS, a glass powder (GLP) is also used as a binder with partial replacement of cement which takes part in reaction at the time of hydration; Also it act as a filler material. The susceptibility of glass to alkali implies that coarse glass or fine glass could undergo Alkali – Silicate Reaction (ASR) in concrete that can damage the stability of the concrete. However, ASR can be prevented or reduced by adding mineral admixtures in the concrete mixture. Some of the common admixtures used to minimize ASR are pulverized fuel ash (PFA) silica fume (SF) and Meta kaolin (MK). Whereas fine ground glass powder exhibit pozzolonic properties and does not undergo ASR. Efforts have been made in the concrete industry to use waste glass and fly ash as a partial replacement for cement in concrete.

## II. MATERIALS

The ingredients of concrete consist of Cement, fine aggregate and coarse aggregates, water. When the reaction of water with cement takes place hydration process is done and a hard material is formed. In this research we used waste glass powder as a partial replacement and filler material. The ingredients are used in proper proportion. Also the cement is replaced at 10%, 20%, and 30% by glass powder. They are described in details with their properties are as follows

*A. Cement*

Cement is as important ingredient in the manufacturing of concrete and acts as a binding material i.e. having adhesive and cohesive properties. Cement is obtained by pulversing clinker formed by calcining raw materials primarily comprising of lime (CaO), Silica ($SiO_2$), Alumina ($Al_2O_3$), and Ferric Oxide ($Fe_2O_3$) along with some minor oxides.

*B. Fine aggregates and course aggregates*

Fine and coarse aggregate make up the bulk of concrete mixture. Sand, natural gravel and crushed stone are mainly used for this purpose. For fine aggregates natural sand is provided with maximum size of 4.75 mm. Coarse aggregates are used with size between 20mm-4.75mm.

*C. Waste Glass Powder*

Glass is a transparent material produced by melting a mixture of materials such as silica, soda ash, and $CaCO_3$ at high temperature followed by cooling during which solidification occurs without crystallization. Glass is widely used in our lives through manufactured products such as sheet glass, bottles, glassware, and vacuum tubing. The amount of waste glass is gradually increased over the recent years due to an ever-growing use of glass products. Most waste glasses have been dumped into landfill sites. The Land filling of waste glasses is undesirable because they are not biodegradable, which makes them environmentally less friendly. So we use the waste glass in concrete to become the construction economical as well as eco-friendly. Composition of cement and Glass Powder is as shown in Table I.

TABLE I CHEMICAL COMPOSITION OF CEMENTING MATERIAL

| S. No | Properties % | Waste Glass Powder (GLP) % | Cement % | Fly Ash % |
|---|---|---|---|---|
| 1 | $SiO_2$ | 72 | 20.2 | 59.40 |
| 2 | CaO | 10 | 61.9 | 27.68 |
| 3 | MgO | 2.5 | 2.6 | 8.79 |
| 4 | $Al_2O_3$ | 0.5 | 4.7 | 33.99 |
| 5 | $Fe_2O_3$ | 3.5 | 3.0 | 29.63 |
| 6 | $SO_3$ | - | 3.9 | 4.71 |
| 7 | Cr2O3 | 1.00 | - | - |
| 8 | $Na_2O$ | 10.2 | 0.19 | 6.90 |
| 9 | $K_2O$ | - | 0.82 | 6.68 |
| 10 | Specific gravity | 2.6 | 3.13 | 2.23 |

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The accumulation of waste glass is gradually increased over the recent years due to an ever-growing use of glass products. Most waste glasses have been dumped into landfill sites. The Land filling of waste glasses is undesirable because they are not biodegradable, which makes them environmentally less friendly. So we use the waste glass in concrete to as a construction material and make the construction economical and eco friendly.

Fig. 1 Waste glass powder

*D. Fly Ash*

Fly ash is one of the residues generated in combustion,and c omprises of fineparticles that rise withthe flue gases. Ash whi ch does not rise is termedas bottom ash.Inan industrial contex t, fly ash usually refers toash produced during combustion of coal. The utilization of fly-ash in concrete as partial replacement of cement is gaining immense importance today, mainly on account of the improvement in the long term durability of concrete combined with ecological benefits. Technological improvements in thermal power plant operations and fly-ash collection systems have resulted in improving the consistency of fly-ash.

Fig. 2 Class C fly ash

Fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime

(CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulphate (SO4) contents are generally higher in Class C fly ashes

TABLE II MIX PROPORTONS

| Mix Base | Water (ℓ) | Cement (Kg /m$^3$) | Fine Aggregate (Kg / m$^3$) | Coarse Aggregate (Kg / m$^3$) |
|---|---|---|---|---|
| Weight | 191.58 | 384 | 559.91 | 1219.3 |
| Ratio | W/C=**0.5** | Ratio = **1 : 1.45: 3.30** | | |

## III. MECHANISM OF PORTLAND CEMENT AND GLASS POWDER

Glass wastes as a cullet are used in the production of building materials mainly as an inert aggregate. However, finely grained glass powder with its well developed surface cannot be regarded as passive toward cement solutions which has actually been proven in practice. Literary sources provide no information about chemical influence of finely grained glass on the process of hardening, especially in its early pre-induction hydration period – the period which considerably conditions the cement stone structure formation and its properties. It is well-known that glass is a material with an amorphous structure, characterized by a large supply of free energy. The glass that has been used in our investigations– contains approximately 14% of $Na_2O$ and $K_2O$.

In the glass structure the ions of these metals have considerably less binding energy as compared to covalent bond of Si-O in the structural fragment of Si-O-+Na or Si-O-+K. In water solution Na+ and K+ ions are easily diffused from glass to the solution and form sodium and potassium hydroxides in the solution, correspondingly. They are displaced by H+ ions from water and thus hydrate the surfaces of glass grains. This is a so called ion-exchange mechanism of interaction between glass and water. Since the area of glass grain surface is very large, comparable to the area of cement grain surface, ionic exchange is very active. Titration analyses show that alkalinity of cement solution without glass additives is near 6 ml of 0.1N HCl. Separate glass powder in water under normal conditions has alkalinity in the range from0.15 (colourless glass) to 0.55 ml of 0.1N HCl (green glass). Thus, the total alkalinity has to increase, however alkalinity of cement mixture with glass additives is 35-40 % less. In our opinion, it is connected with high content of $SiO_2$ in the glass (near 70 %), which results in the formation of calcium hydro silicate (CSH), as shown in chemical reaction:

$2(3CaO.SiO_2)+6H_2O=3\ CaO.2SiO_2.3H_2O+3Ca\ (OH)_2$
(Tricalcium Silicate) (Calcium Silicate Hydrate) (Calcium Hydroxide….(1) $3Ca(OH)_2 + SiO_2 + (n-1)\ H_2O = aO.SiO_2.nH_2O$ (Calcium hydroxide) (Glass) (Calcium Silicate Hydrate) ((2)

As a result of reaction (1) the amount of calcium hydroxide in the cement solution decreases. Consequently, the alkalinity of solution with glass powder additives decreases as well and additional amount of CSH crystal phase in a cement stone is formed. It has been established that addition of finely grained glass to Portland cement or to Portland cement based concrete accelerates the binding process during preinduction period of hydration (2–4 min.) but retards it during after-induction period. However, this does not affect the mechanical strength of the concrete samples after the first day of hardening. The strength of samples with glass is higher as compared to the control samples, because, as has been stated above, glass additives modify cement stone structure.

## IV. EXPERIMENTAL WORK

For this study we were used M20 grade of concrete. Mix design carried out for M20 grade of concrete by IS 10262:2009, yielded a mix proportion as shown in Table II.

Specimens were prepared according to the mix proportion and by replacing cement with glass powder in different proportion. To find out the Compressive strength, specimens of dimensions 150X150X150mm were cast and tested using a compressive testing machine (CTM) for 7 days characteristic compressive strength, 14 days characteristic compressive strength and 28 days characteristic compressive strength.

## V. RESULTS AND DISCUSSION

### *A. Compressive Strength*

Table III, IV, V shows the 7, 14 and 28 days compressive strength. For this three samples cube were taken and the average compressive strength is founded.

TABLE III TEST RESULT FOR CONVENTIONAL CONCRETE

| Specimen | Cube Size (mm) | 7 days compressive strength (N/mm$^2$) | 14 days compressive strength (N/mm$^2$) | 28 days compressive strength (N/mm$^2$) |
|---|---|---|---|---|
| C1 | 150 | 14.82 | 20.49 | 22.24 |

TABLE IV TEST RESULT FOR GLASS POWDER CONCRETE

| Specimen | Cube Size (mm) | 7 days compressive strength (N/mm$^2$) | 14 days compressive strength (N/mm$^2$) | 28 days compressive strength (N/mm$^2$) |
|---|---|---|---|---|
| C2 | 150 | 13.52 | 17.8 | 18.88 |
| C4 | 150 | 17.05 | 20.93 | 23.12 |
| C6 | 150 | 18.31 | 20.10 | 23.54 |

*Legend
C2 = 15 % of Glass powder concrete
C4 = 20 % of Glass powder concrete
C6 = 25 % of Glass powder concrete

TABLE V TEST RESULT FOR GLASS POWDER + FLY ASH CONCRETE

| Specimen | Cube Size (mm) | 7 days compressive strength (N/mm | 14 days compressive strength (N/mm | 28 days compressive strength (N/mm |
|---|---|---|---|---|
| C3 | 150 | 14.82 | 19.62 | 21.36 |
| C5 | 150 | 19.62 | 21.36 | 24.85 |
| C7 | 150 | 18.31 | 20.10 | 23.12 |

*Legend
C3 = 7.5 % of Glass powder + 7.5% of Fly ash concrete
C5 = 10 % of Glass powder + 10 % of Fly ash concrete
C7 = 12.5 % of Glass powder + 12.5 % of Fly ash concrete

TABLE VI COMPARISON OF ALL THREE TESTS

| Specimens | 7 days ($N/mm^2$) | 14 days ($N/mm^2$) | 28 days ($N/mm^2$) |
|---|---|---|---|
| Conventional Concrete | 14.82 | 20.49 | 22.24 |
| Glass powder Concrete | 18.31 | 20.10 | 23.54 |
| GLP + Fly ash Concrete | 19.62 | 21.36 | 24.85 |

The concrete prepared with the combination of glass powder and fly ash has a good compressive strength when compared with the conventional concrete. The increase in strength is for all ages of the concrete.

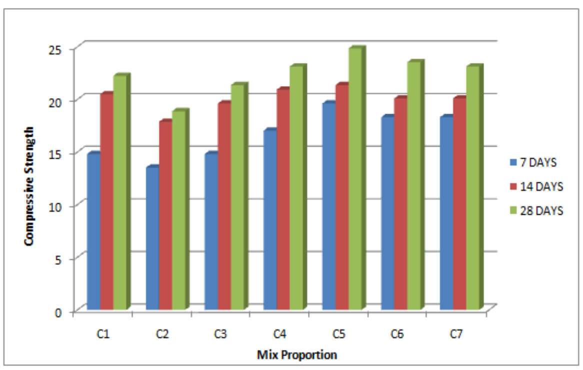


Fig. 3 Optimum level of replacement of GLP and Fly ash

### *A. Flexural Strength of Concrete*

Table VI, VII, VIII shows the 14 and 28 days compressive strength. For this three samples cube were taken and the average Flexural strength is founded.

Prism size is 500mm x 100mm x 100mm

TABLE VII TEST RESULT FOR CONVENTIONAL CONCRETE

| Specimen | 14 days Flexural strength ($N/mm^2$) | 28 days Flexural strength ($N/mm^2$) |
|---|---|---|
| C1 | 6.64 | 7.03 |

TABLE VIII TEST RESULT FOR GLASS POWDER CONCRETE

| Specimen | 14 days Flexural strength ($N/mm^2$) | 28 days Flexural strength ($N/mm^2$) |
|---|---|---|
| C2 | 6.78 | 7.18 |
| C4 | 6.68 | 6.88 |
| C6 | 7.1 | 7.4 |

*Legend
C2 = 15 % of Glass powder concrete
C4 = 20 % of Glass powder concrete
C6 = 25 % of Glass powder concrete

TABLE IX TEST RESULT FOR GLASS POWDER + FLY ASH CONCRETE

| Specimen | 14 days Flexural strength ($N/mm^2$) | 28 days Flexural strength ($N/mm^2$) |
|---|---|---|
| C3 | 6.68 | 7.03 |
| C5 | 6.88 | 7.03 |
| C7 | 6.88 | 7.18 |

*Legend
C3 = 7.5 % of Glass powder + 7.5% of Fly ash concrete
C5 = 10 % of Glass powder + 10 % of Fly ash concrete
C7 = 12.5 % of Glass powder + 12.5 % of Fly ash concrete

TABLE X COMPARISON OF ALL THREE TESTS

| Specimens | 14 days ($N/mm^2$) | 28 days ($N/mm^2$) |
|---|---|---|
| Conventional Concrete | 6.64 | 7.03 |
| Glass powder Concrete | 7.10 | 7.40 |
| GLP + Fly ash Concrete | 6.88 | 7.18 |

The flexural strength of concrete with the mixing of glass powder alone shows good strength when compared with the conventional concrete and the cement concrete with the mix of glass powder and fly ash shows small improvement in the flexural strength.

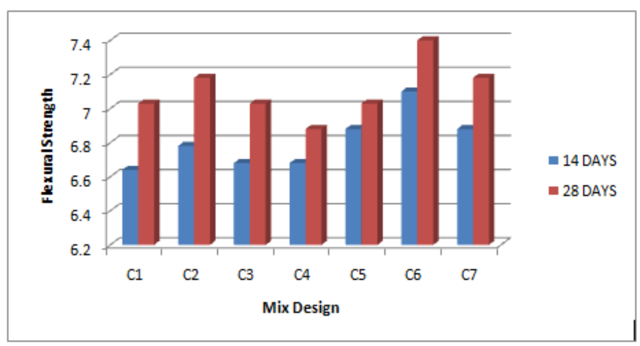


Fig. 4 Optimum level of replacement of GLP and Fly ash

### *B. Split Tensile Test*

TABLE XI TEST RESULT FOR CONVENTIONAL CONCRETE

| Specimen | Cylinder Size (mm) | 14 days Split tensile strength ($N/mm^2$) | 28 days Split tensile strength ($N/mm^2$) |
|---|---|---|---|
| C1 | 300 x 150 | 3.052 | 3.27 |

TABLE XII TEST RESULT FOR GLASS POWDER CONCRETE

| Specimen | Cylinder Size (mm) | 14 days Split tensile Strength (N/mm$^2$) |
|---|---|---|
| C2 | 300 x 150 | 2.62 |
| C4 | 300 x 150 | 2.83 |
| C6 | 300 x 150 | 2.62 |

*Legend
C2 = 15 % of Glass powder concrete
C4 = 20 % of Glass powder concrete
C6 = 25 % of Glass powder concrete

TABLE XIII TEST RESULT FOR GLASS POWDER + FLY ASH CONCRETE

| Specimen | Cylinder Size (mm) | 14 days Split tensile strength (N/mm$^2$) | 28 days Split tensile strength (N/mm$^2$) |
|---|---|---|---|
| C3 | 300 x 150 | 2.40 | 2.62 |
| C5 | 300 x 150 | 3.052 | 3.49 |
| C7 | 300 x 150 | 2.83 | 3.052 |

*Legend
C3 = 7.5 % of Glass powder + 7.5% of Fly ash concrete
C5 = 10 % of Glass powder + 10 % of Fly ash concrete
C7 = 12.5 % of Glass powder + 12.5 % of Fly ash concrete

TABLE XIV COMPARISON OF ALL THREE TESTS

| Specimens | 14 days (N/mm$^2$) | 28 days (N/mm$^2$) |
|---|---|---|
| Conventional Concrete | 3.052 | 3.27 |
| Glass powder Concrete | 2.83 | 3.052 |
| GLP + Fly ash Concrete | 3.052 | 3.49 |

With the addition of glass powder and glass powder fly ash combination, there is not much difference in the split tensile strength. However, the partial replacement of GLP and Fly ash mixed concrete gains strength as the age of concrete increases.

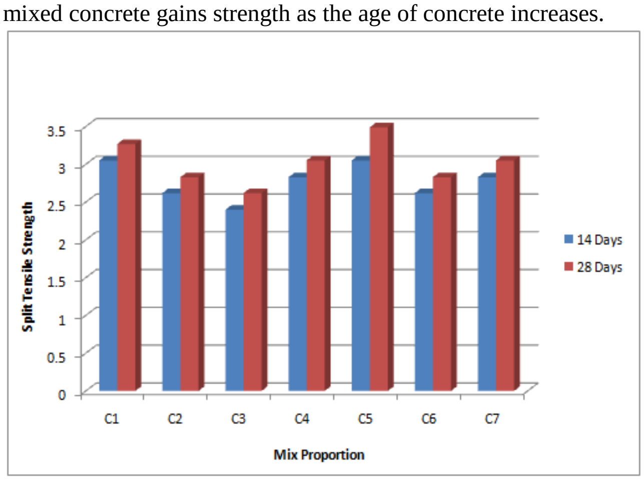


Fig. 5 Optimum level of replacement of GLP and Fly ash

## VI. CONCLUSION

Based on the experimental study and the analysis of the test result the following points are summarized

1. With the presence of silica in the waste glass the concrete gets a very good compressive strength at an early stage of 28 days. It also helps to enhance the durability and toughness of the concrete. It is highly resistant to chemical attack
2. With the partial addition of class F type fly ash, the compressive strength increases day by day. It also increases workability thereby reducing the water requirement. It also help to reduce the heat generated during hydration. The fly ash prevents (ASR) in the concrete
3. The partial replacement of glass powder and fly ash can reduce the construction cost considerably
4. The compressive strength of the concrete with partially replaced glass powder with that of the conventional concrete there is not much difference in strength
5. Whereas the compressive strength of the concrete mix with the partial replacement of 10% glass powder and 10% of fly ash for cement was found to be 24.85 N/mm$^2$ more.
6. The waste materials like fly ash and glass powder can be effectively used so as to decrease the use of cement thereby reducing the $Co_2$ emission level and recycle glass in an environment friendly way.
7. The cost when compared with the conventional concrete would certainly be less when both fly ash and glass powder been partially replaced at 20% for cement.

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