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EXPERIMENTAL INVESTIGATION OF WASTE GLASS POWDER AS PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

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Abstract— Concrete is a construction material composed of cement, aggregates (fine and coarse aggregates) water and admixtures. Today many researches are ongoing into the use of Portland cement replacements, using many waste materials like pulverized fly ash (PFA) and ground granulated blast furnace slag (GGBS). Like PFA and GGBS a waste glass powder (GLP) is also used as a binder with partial replacement of cement which take some part of reaction at the time of hydration, also it is act as a filler material. In this study, waste glass powders have been used as replacements to the concrete ingredient i.e. cement and the mechanical properties like compressive strength are measured. Also we were studied the size effect of glass powder on strength of concrete. For checking strength effect of replacement of cement by glass powder, the cement is replaced at 10%, 20% and 30%. For study of size effect of glass powder the powder is divided in to two grades one is glass powder having size less than 90 micron and another is glass powder having particle size ranges from 90 micron to 150 micron. It is found from study, Initial strength gain is very less due to addition of GLP on 7th day but it increases on the 28th day. It is found that 20% addition of GLP gives higher strength. And also GLP size less than 90 micron is very effective in enhancement of strength.

Keywords- *waste glass powder; concrete; strength; replacement*

I. INTRODUCTION

Today many researches are ongoing into the use of Portland cement replacements, using many waste materials and industrial by products, for example, pulverized fly ash (PFA) and ground granulated blast furnace slag (GGBS). Like PFA and GGBS, a glass powder (GLP) is also used as a binder with partial replacement of cement which takes some part of reaction at the time of hydration; also it is act as a filler material [1] [5]. The term glass comprises several chemical varieties including binary alkali-silicate glass, boro-silicate glass, and ternary soda-lime silicate glass. Partial replacement of cement with milled waste glass benefits the microstructure and stability of cementitious materials [4]. A denser (less porous) and more homogeneous structure is produced when milled waste glass is used as partial replacement for cement, which benefits the resistance to moisture sorption and thus the long-term durability of cementitious materials. Partial replacement of cement with milled waste glass also benefits the stability of cementitious materials when potentially deleterious reactions between cement hydrates and the reactive aggregates is a concern. Mixed-color waste glass, when milled to about the particle size of cement and used in concrete as replacement for about 20% of cement, improves the moisture barrier qualities, durability, and mechanical performance of concrete [2]. These improvements result from the beneficial chemical reactions of milled waste glass with cement hydrates, which yield chemically stable products capable of refining the pore system in concrete. Major environmental, energy, and cost savings can be realized by partial replacement of cement with milled mixed-color waste glass. Extensive studies were undertaken to solve the alkali-silica reaction (ASR) problems. Replacing cement by pozzolanic material like waste glass powder in concrete, not only increases the strength and introduces economy but also enhances the durability [3] [6].

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

Portland cement grade 43 is the most common type of cement in general usage. It is the basic ingredient of concrete, mortar and plaster.

B. Fine aggreagates and course aggreagates

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.

(a) **(b)**

Figure 1. Aggregates : (a) Fine Aggregates (b) Fine Aggregates

(a) **(b)**

Figure 2. Glass powder : (a) GLP size less than 90 microns (b) GLP size between 90 micron to 150 micron

C. Waste Glaas 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. TABLE TYPE STYLES

Sr.No.	Properties	Waste Glass Powder (GLP)	Cement
1	SiO_2 (%)	70.22	23.71
2	CaO (%)	11.13	57.27
3	MgO (%)	-	3.85
4	Al_2O_3 (%)	1.64	4.51
5	Fe_2O_3 (%)	0.52	4.83
6	SO_3 (%)	-	2.73
7	Na_2O (%)	15.29	-
8	K_2O (%)	-	0.37
9	Cl (%)	-	0.0068
10	Loss on ignition (%)	0.80	7.24

The glass powder is (GLP) divided in two categories wise:

- Glass powder (GLP) particle size less than 90 microns (fig. 2 a)
- Glass powder (GLP) particle size from 90 micron to 150 micron (fig. 2 b)

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 [7].

IV. EXPERIMENTAL WORK

In this study, total of four groups of concrete mixes were prepared in laboratory. First group was cement replacement by fine glass powder (GLP) particle size less than 90 microns with replacement from 10% to 30%. Second group was cement replacement by fine glass powder (GLP) particle size from 90 micron to 150 micron with replacement from 10% to 30%. Third and fourth were normal concrete with cement and normal concrete with cement used only 90% to 70% that of design. For this study we were used M30 grade of concrete. Mix design carried out for M30 grade of concrete by IS 10262:2009, yielded a mix proportion as shown in Table II [8][9].

TABLE II. MIX PROPORTION

Water	Cement	F.A.	C.A.
193.92	416.52	582.84	1155.76
0.46	1	1.39	2.78
23 lit / bag	50 kg (bag)	69.95 kg /bag	138.75 Kg/ bag
193.92	416.52	582.84	1155.76

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 and 28 days characteristic compressive strength.

V. RESULT AND DISCUSSION

Compressive strength on 7^{th} days

MIX-N represents normal concrete of M30 grade. Table III shows the 7 days compressive strength. For this three samples cube were taken and the average compressive strength is found to be 21.98 N/mm^2. Fig. 3 shows the graphical representation of compressive strength.

TABLE III. COMPRESSIVE STRENGTH OF M30 NORMAL CONCRETE ON 7^{TH} DAY

Sr. No.	Mixtures	Compressive Strength (N/mm^2)			Average Compressive Strength (N/mm^2)
		Sample 1	*Sample 2*	*Sample 3*	
1	MIX- N	21.62	22.34	21.98	21.98

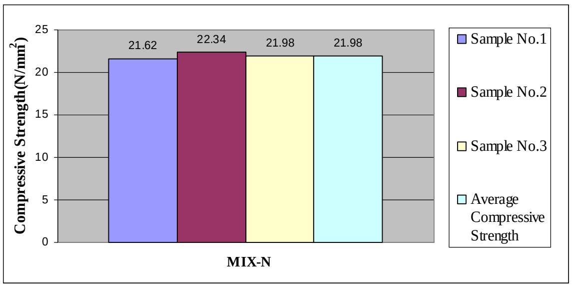

Figure 3. Compressive strength of M30 Normal Concrete on 7^{th} Day

MIX 1-10, MIX 1-20, MIX 1-30 represent concrete containing glass powder less than 90 micron with replacement of cement 10%, 20%, 30% respectively. Total 9 cubes were casted 3 cubes for each mixture. Table IV and fig. 4 shows the compressive strength of sample on the 7^{th} day.

TABLE IV. STRENGTH OF CONCRETE REPLACED BY BELOW 90 MICRON SIZE GLP ON 7^{TH} DAY

Sr. No.	Mixtures	Compressive Strength (N/mm^2)			Average Compressive Strength (N/mm^2)
		Sample 1	*Sample 2*	*Sample 3*	
1	MIX 1-10	17.42	18.32	18.08	17.94
2	MIX 1-20	19.50	19.88	18.48	19.28
3	MIX 1-30	16.24	16.48	17.19	16.64

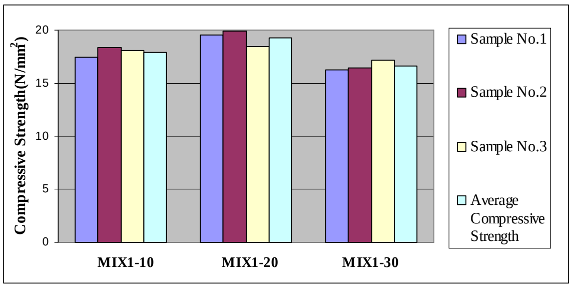

Figure 4. Strength of Concrete Replaced By Below 90 Micron Size GLP on 7^{th} Day

It is found from above result that addition of GLP in reduces the 7^{th} day strength of all samples. it is seen from above result that GLP is not taking part in earl strength gain in concrete. Also it is observed that mixture containing cement replaced by 20% GLP get higher strength to that of 10% & 30% replacement.

MIX 2-10, MIX 2-20, MIX 2-30 represent concrete containing glass powder size ranges from 90 micron to 150 micron with replacement of cement at 10%, 20%, 30% respectively. Total 9 cubes were casted 3 cubes for each mixture. Table V and fig.5

shows the compressive strength of samples on the 7th day.

TABLE V. STRENGTH OF CONCRETE REPLACED BY 90 TO 150 MICRON SIZE GLP ON 7TH DAY

Sr. No.	Mixtures	Compressive Strength (N/mm^2)			Average Compressive Strength (N/mm^2)
		Sample 1	*Sample 2*	*Sample 3*	
1	MIX 2-10	16.86	16.98	17.02	16.95
2	MIX 2-20	18.55	19.02	17.92	18.49
3	MIX 2-30	15.49	14.79	15.74	15.34

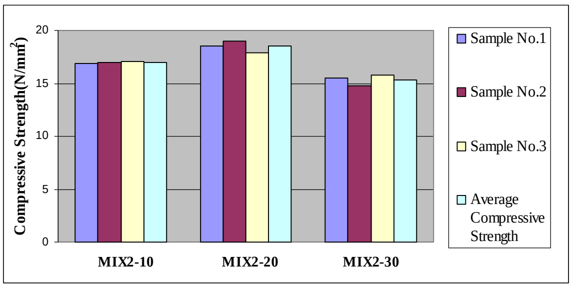

Figure 5. Strength of Concrete Replaced By 90 to 150 Micron Size GLP on 7th Day

The same nature was found in GLP size between 90 to150 micron as seen in GLP size less than 90 micron. Result shows mixture containing cement replaced by 20% GLP get higher strength to that of 10% & 30% replacement.

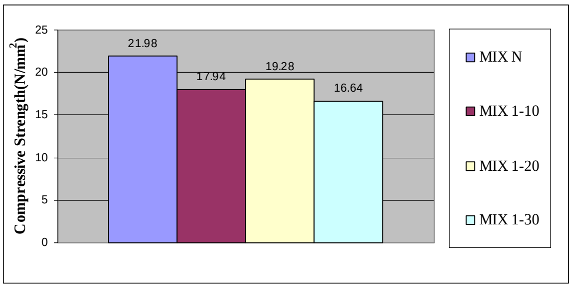

Figure 6. Strength of Normal Concrete And Concrete having GLP of size Below 90 Micron on 7th Day

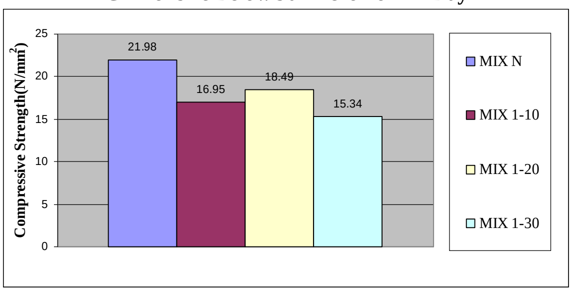

Figure 7. Strength of Normal Concrete And Concrete having GLP of size 90 to 150 Micron on 7th Day

Both the above fig.6 & fig.7 shows that the concrete containing glass powder give less strength as compare to that of normal concrete because the complete hydration process not completed at 7 days. After completion of complete hydration process the silica from glass powder reacts with cement hydrates and it gives strength.

Compressive strength on 28th days

MIX-N represents normal concrete of M30 grade. Table VI and fig 8 shows the strength on 28thday. The average compressive strength is found to be 32.74 N/mm^2.

TABLE VI. COMPRESSIVE STRENGTH OF M30 NORMAL CONCRETE

Sr. No.	Mixtures	Compressive Strength (N/mm^2)			Average Compressive Strength (N/mm^2)
		Sample 1	*Sample 2*	*Sample 3*	
1	MIX- N	33.48	32.55	32.21	32.74

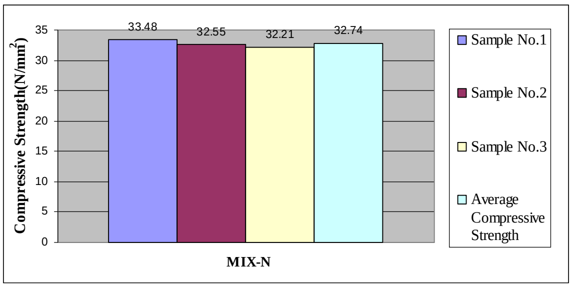

Figure 8. Compressive strength of M30 Normal Concrete

MIX 1-10, MIX 1-20, MIX 1-30 represent concrete containing glass powder less than 90 micron with replacement of cement at 10%, 20%, 30% respectively. Table VII and fig.9 shows the compressive strength of samples on 28th day.

TABLE VII. STRENGTH OF CONCRETE REPLACED BY BELOW 90 MICRON SIZE GLP ON 7TH DAY

Sr. No.	Mixtures	Compressive (N/mm^2)			Average Compressive Strength (N/mm^2)
		Sample 1	*Sample 2*	*Sample 3*	
1	MIX 2-10	32.53	32.81	31.95	32.43
2	MIX 2-20	34.60	33.42	34.97	34.33
3	MIX 2-30	30.88	31.75	31.95	31.52

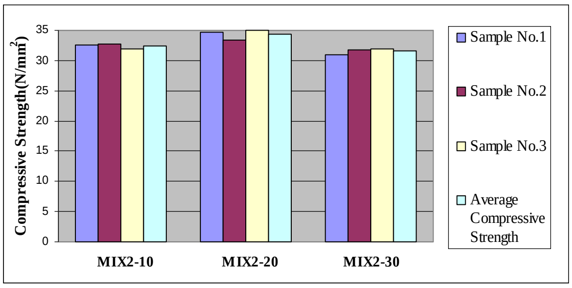

Figure 9. Strength of Concrete Replaced By Below 90 Micron Size GLP

Enhancement of strength on addition of GLP is observed in all samples. It shows mixture containing cement replaced by 20% GLP have higher strength to that of 10% & 30% replacement.

MIX 2-10, MIX 2-20, MIX 2-30 represent concrete containing glass powder size ranges from 90 micron to 150 micron with replacement of cement at 10%, 20%, 30% respectively. Table VIII and fig 10 shows the compressive strength of samples on 28th day.

TABLE VIII. STRENGTH OF CONCRETE REPLACED BY 90 TO 150 MICRON SIZE GLP

Sr. No.	Mixtures	Compressive Strength (N/mm^2)			Average Compressive Strength (N/mm^2)
		Sample 1	*Sample 2*	*Sample 3*	
1	MIX 2-10	31.31	31.04	30.32	30.89
2	MIX 2-20	33.54	32.08	32.70	32.77
3	MIX 2-30	30.08	31.09	30.84	30.67

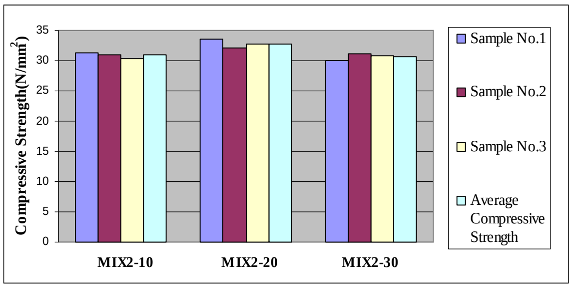

Figure 10. Strength of Concrete Replaced By 90 to 150 Micron Size GLP

It shows mixture containing cement replaced by 20% GLP get higher strength to that of 10% & 30% replacement. GLP size less than 90 micron shows higher strength than GLP size between 90 to 150 micron. Finer particle present in the GLP size less than 90 micron react with cement compound to add strength and formation of stoney compound. As stated in mechanism, reaction with GLP enhances strength of concrete.

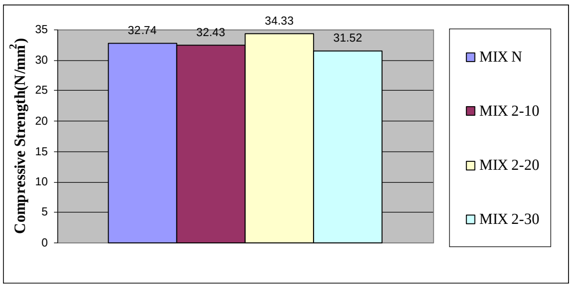

Figure 11. Strength of Normal Concrete and Concrete having GLP of size Below 90 Micron

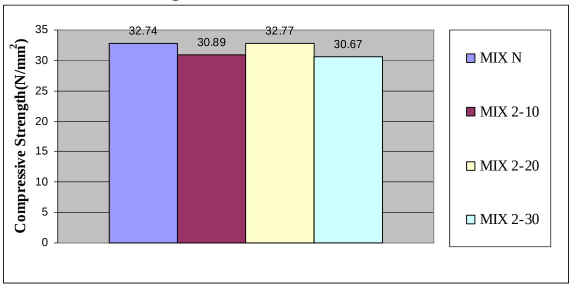

Figure 12. Strength of Normal Concrete and Concrete having GLP of size 90 to 150 Micron

The above fig.11 and fig.12 shows that concrete containing cement replaced by 20% of glass powder gives higher strength than that of normal concrete, 10% & 30% replaced GLP concrete. Because some strength in MIX 1-20 and MIX 2-20 gain by reaction with cement hydrates and some strength is gain by filling the voids in cement

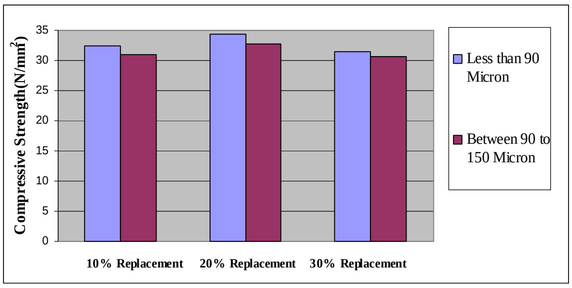

Figure 13. Strength of Concrete(GLP<90Micron) and Concrete (GLP 90 to 150 Micron)

The strength is gain by reaction with fine glass powder with cement hydrates and some amount of strength is gain due to filling the voids between cement particles. The fig.13 shows that the strength gain by concrete containing glass powder less than 90 micron is higher than that of concrete containing glass powder size from 90 micron to 150 micron. Because as the particle size is greater in concrete containing 90 to 150 micron, the glass powder cannot react with cement hydrates.

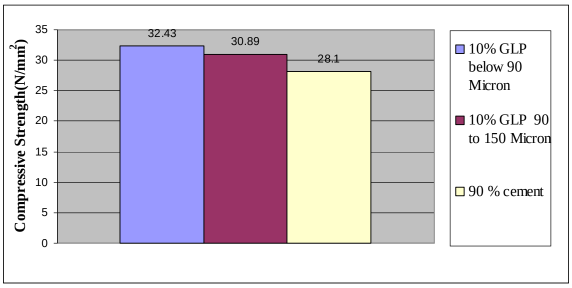

Figure 14. Strength of Concrete (GLP) and Concrete (90% cement)

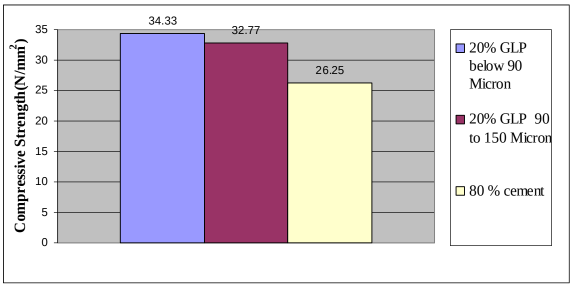

Figure 15. Strength of Concrete (GLP) and Concrete (80% cement)

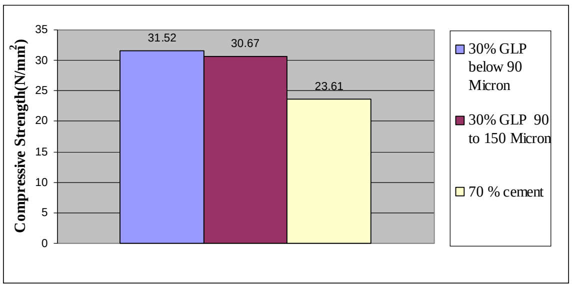

Figure 16. Strength of Concrete (GLP) and Concrete (70% cement)

From above fig.14, fig.15 and fig.16 shows that the strength gain by GLP below 90 micron have higher strength as compare to that of GLP Between 90 to

150 micron. Also the some strength is gain by glass powder is seen from the strength of concrete containing less cement as compare to that of design mixture.

For to compare actual enhancement in strength due addition of GLP we prepared sample as MIX 3-90, MIX 3-80, MIX 3-70 represents concrete containing 10%, 20%, 30% less cement that of design respectively. These proportions are used for comparing strength gain on addition of GLP. Table IX and fig 17 shows the compressive strength of samples 28th day.

TABLE IX. STRENGTH OF CONCRETE CONTAINING CEMENT 90%, 80%,70% OF DESIGN

Sr. No.	**Mixtures**	**Compressive Strength (N/mm^2)**			**Average Compressive Strength (N/mm^2)**
		Sample 1	***Sample 2***	***Sample 3***	
1	MIX 3-90	27.00	27.43	26.88	27.10
2	MIX 3-80	25.32	25.33	24.10	24.93
3	MIX 3-70	22.70	22.90	23.24	22.95

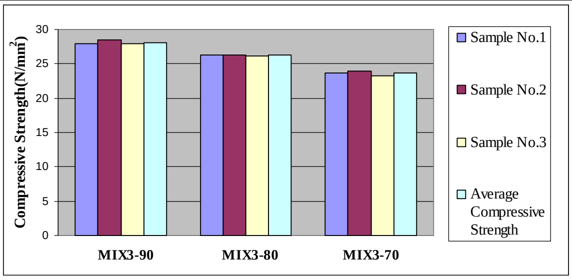

Figure 17. Strength of Concrete Containing Cement 90%, 80%, 70%

It is seen that as the percentage of cement decreases, the strength of concrete is also decreases**.**

VI. COCLUSIONS

- On addition of GLP initial the rate of gain of strength is low but at 28th day it meets required design strength.
- Addition of GLP increases the strength of concrete.
- At the level of 20% replacement of cement by glass powder meets maximum strength as compare to that of normal concrete and other percentage of replacement of cement.
- As the size of GLP particle decreases in concrete the strength of concrete increases. From results it is conclude that particle size less than 90 micron get higher strength than that of particle size ranges from 90 to 150 micron.

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