Properties of Concrete with Waste Glass Powder (Gp) as Fine Aggregate Replacement

J.Premalatha, R.Srinivasan

Abstract In the present research, the feasibility of using waste glass as replacement for natural river sand was investigated. Glass wastes dumped in landfill pose environmental pollution and research on its reuse in construction industries need to be carried out . An experimental work was performed to study the slump , unit weight, compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, ultrasonic pulse velocity, dry density and chloride ion penetration test at different curing ages at 7, 14 and 28 days of concrete. Investigation on concrete properties with various % of glass powder (0%, 5%, 10%, 15% and 20%) were done on fresh and hardened concrete. The complete stress-strain behaviour, mechanical strength and durability properties of concrete with partial replacement of natural river sand by glass powder were investigated through standard tests.The optimum glass powder content is found out by testing the specimens prepared using different grades of concrete (M20, M30, M40,M50 and M60). All the fresh concrete mixes were tested also for the workability properties by conducting slump cone tests. According to the test results, it is observed that the slump value of fresh concrete increase gradually with % of glass powder upto 40% replacements. The gradual increase in compressive strength, flexural strength and split tensile strength with the addition of waste glass powder upto 30% was observed. The addition of 40% and 50% replacements, the strength values of concrete are comparable with that of the control mix. The density and modulus of elasticity of concrete also gradually increases from 0% to 50% addition of glass powder in the concrete.

The Rapid Chloride Penetration Test (RCPT) test results show that the chloride penetration rate is considerably reduced with addition of glass powder and permeability properties of concrete is enhanced upto 50% replacement levels. In order to prepare the concrete with compressive strengthThe optimum glass powder content is found to be 50% can be used as the replacement material for fine aggregates without much compromise on the strength and durability properties and to achieve economic and environmental benefits.

I. INTRODUCTION

Solid waste management is a very crucial issue for the society worldwide. Glass wastes form a major component of solid waste and being an inert and nonorganic material, it is non-biodegradable and its disposal into landfills create serious environmental problems. Using waste glass in concrete as fine aggregate provide better solution for its disposal problem and also prevent depletion of natural resources like river sand.

Since a very large space and lands are used to stockpile waste glass, it is very essential to find ways to reuse it or recycle it. The advantage of almost 100% recyclability of waste glass makes it as one of the material considered for the concept of waste to wealth, world wide.A variety of new products can be produced using waste glass.There are two main ways of use waste glass in concrete. Glass wool is one of the important form of glass which is used as an heat insulating material on roofs, walls and floors of buildings.Glass wool insulation is recyclable and reusable, so that it can be recycled for another applicationsafter its original use. Based on the citations, it is found that waste glass can be used in concrete in two ways, one is as fine aggregate as a replacement for natural sand and another one is as aSupplementary Cementing Material in concrete.Many research works have been done on concrete with glass waste as partial replacement for fine aggregate and coarse aggregates.

Waste management has become a critical challenge in developing countries like India. Unprecedented levels of waste material are produced due to rise in population and the management of solid wastes have arised as an alarming threat for healthy environment world wide.Since glass wastes are non-biodegradable material. Innovative methodologies of recycling need to be conventional to avoid their disposal in land fills.

Objectives :

The research objectives of the current work are :

- To design the mix proportions for five various grades (M20, M30, M40,M50 and M60) of concrete with different glass powder replacements (0%, 10%, 20%, 30% 40% and 50%) for natural sand in concrete.
- To investigate the workability properties of fresh concrete, mechanical properties of hardened concrete and their durability properties by testing the specimens prepared as per standard specifications.
- To investigate the detailed stress strain behaviour of concrete with different % of waste glass powder additions.

II. MATERIALS AND METHODS

Materials

Cement

Locally available ACC cement53 grade (Ordinary Portland cement) confirming to (IS12269-1989), was used for the present research. The Standard consistency of cements was determined in accordance with (IS 4031 (Part 4)-1995). Pastes having standard consistency were used to determine the initial setting time and final setting time in accordance with IS 4031 (Part 5)-1995. The Physical and

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chemical properties of cement are given in Table1 and Table 2.

Table 1 Physical properties of OPC53 grade cement

Property	Value	Requirement(IS12269-1989)
Initial setting time	70 minutes	Minimum 30 minutes
Final setting time	360 minutes	Maximum 600 minutes
Specific gravity	3. 15	ISH99-1959
Normal consistency	30.5%	--
Fineness modulus	1.66%	<10%

Table2 Chemical composition of cement

Chemical composition	% content
Silica(SiO_2)	21.00
Alumina(Al_2O_3)	5.20
Iron Oxide (Fe_2O_3)	2.20
Calcium Oxide (CaO)	67. 39
Magnesium Oxide(MgO)	1.81
Sodium oxide (Na_2O)	2. 10
Potassium oxide(K_2 O)	0.20
Loss on ignition	0. 10

Sand

Locally available natural river sand with maximum size of 4.75 mm and confirming to zone II as per IS 383-1987 was used as fine aggregates. The specific gravity of sand is 2.66,its water absorption is 3.0% and unit weight 1690kg/m3. A sieve analysis was carried out for the sand and presented in Table 3.3. and the grading curve for sand is given in Figure 1.

Table 3 Physical properties of sand

Sieve size mm	Weight retained in gm	% retained	Cumulative % by weight retained	Cumulative % by weight passing	% passing limit for grading zone-II
10	0	0	0	100	-
4.75	90	9	9	91	90-100
2.36	120	12	21	79	75-100
1.18	170	17	38	62	55-90
0.6	250	25	63	37	35-59
0.3	220	22	85	15	8-30
0.15	150	15	100	0	0-10
		Total =	316		
		Fineness modulus =	3.16		3.37-2.1
		Specific gravity =	2.66		

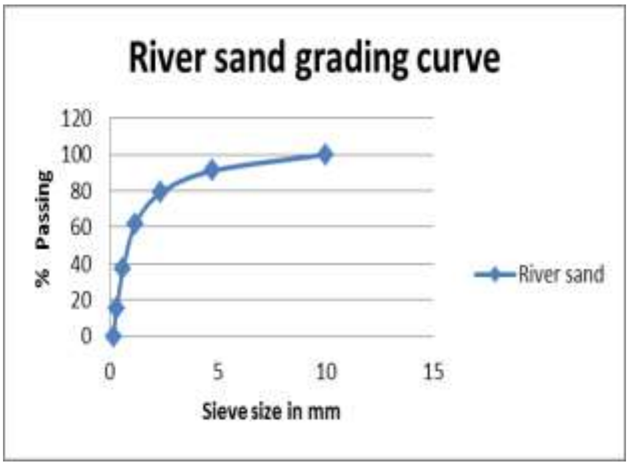

Figure 1 Grading curve of Natural sand

Coarse Aggregate :

Graded crushed granite coarse aggregates with maximum nominal size of 20 mm and down was confirming to IS:383(1987)was used as coarse aggregate in the concrete mixes.The specific gravity of coarse aggregate is 2.7 ,its fineness modulus is 6.7, bulk density is 1800 kg/m3 and its water absorption is 0.3%. According to IS 383-1987, a sieve analysis was carried out coarse aggregates and presented in Table 4. and its gradation curve is given in Figure 2.

Table 4 Physical properties of Coarse Aggregates

Sieve size mm	% retained	% passing
20	5	95.00
12.5	15	85.00
10	35	65.00
4.75	86	14.00
2.36	97	3.00

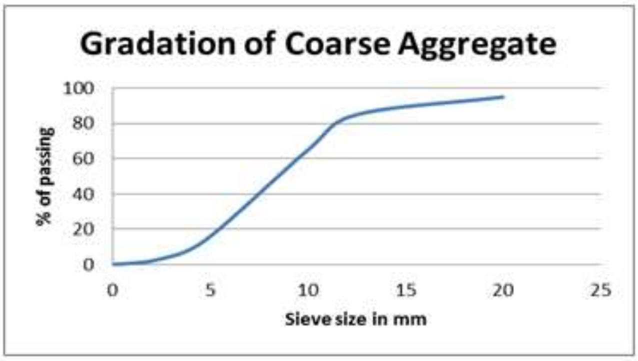

Figure 2 Gradation of Coarse Aggregates

Water:Ordinary Potable water is used for mixing and curing of test specimens.

Super plasticizer :

CONPLAST 430 received from Elkem India Pvt Ltd, Mumbai was used as the super-plasticizer in concrete mixes.

Waste Glass Powder:

Waste glass for this experiment was sourced from a glass recycling industry in the Coimbatore. This glass powder used in this research was prepared by crushing and milling process.The chemical composition and microstructure analysis of the glass powder was done using XRD analysis and SEM analysis and presented in Figure 2.3 and Figure 4. The typical chemical composition of the glass aggregate is given in Table 5 whilst particle size distribution is given in Table 6. The gradation curve for the glass powder used is given in Figure 2.5 and its sieving process is given in Figure 6.

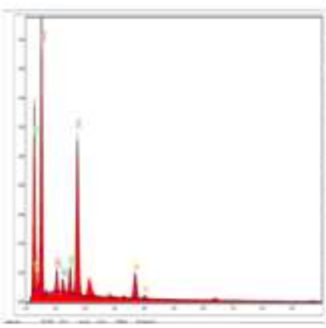

Figure 3 Chemical composition of glass powder Figure 4 Microstructure of Glass Powder by XRD Analysisby SEM Analysis

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Table 5 Chemical composition of Glass powder (% by mass)

Composition	Glass powder %	River sand %
Silica(SiO_2)	71.30	88.50
Alumina(Al_2O_3)	1.50	3.20
Iron Oxide (Fe_2O_3)	0.80	0.8
Calcium Oxide (CaO)	9.20	7.10
Magnesium Oxide(MgO)	2.50	0. 18
Sodium oxide (Na_2O)	14.05	--
Potassium oxide(K_2 O)	0. 15	0.22
Loss on ignition	0.50	-

Table6 Physical properties of Glass powder

Sieve size mm	Wt retained in gm	% retained	Cumulative % by weight retained	Cumulative % by weight passing	% passing limit for grading zone-II
10	0	0	0	100	
4.75	0	0	0	100	
2.36	0	0	0	100	
1.18	50	5	5	95	90-100
0.6	350	35	40	60	80-100
0.3	300	30	70	30	15-50
0.15	180	18	88	12	0-15
0	120	12	100	0	
		Fineness modulus =	3.16		3.37-2.1
		Specific gravity	2.49		

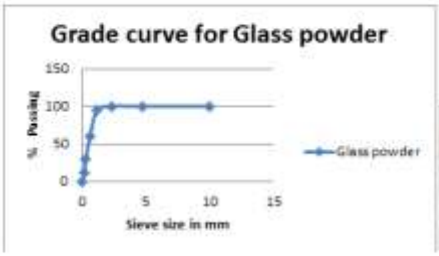

Figure 5 Gradation curve for Glass powderFigure 6 Glass powder sample

III. METHODS

Tests were conducted to find the workability properties, mechanical strength and the stress–strain behaviour of concrete with different glass powder replacement percentages of 0%,0%,20%,30%,40% and 50% are carried out. The concrete mix design for five different grades of concrete (M20, M30, M40, M50 and M60) were done in accordance with (IS: 10262 1982). The concrete mix proportions used for the test specimens are given in Table7.

Table 7 Mix proportions for concrete

Grade	w/c	Cement kg/m^3	Sand kg/m^3	Coarse aggregate kg/m^3	Water content $litres/m^3$	Super plasticizer kg/m^3
M20	0.50	360	750.12	1142.10	180	0
M30	0.45	400	734.16	1117.8	180	0
M40	0.40	420	696.17	1256.2	140	4.2
M50	0.35	480	678.00	1223.4	140	4.2
M60	0.30	500	745.8	1135.6	140	8.4

IV. MEASUREMENTS & RESULTS

Workability of fresh concrete

Slump cone Test

According to (IS: 1199 – 1959) workability test by slump cone on fresh concrete weretested and the results are plotted in Figure 2.7 The slump was in the range of 60-80 mm for M20 and M30 and its value increases to 80 -100mm for higher grades of concrete with super-plasticizer. The slump value of all the mixes increases with the addition of glass powder upto 30% and afterwards for 40% and 50% additions, the slump value got reduced. For concretes incorporating glass powder, no bleedingor segregation was detected.

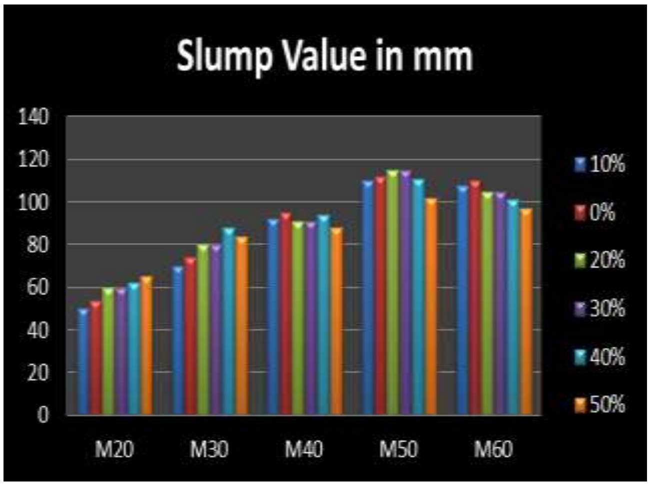

Figure 2.7 Compressive strength of M20 Concrete

Bulk Density of concrete

Very small variations in concrete density was observed with the addition of glass powder for all grades of concrete and shown in Figure 2.8 . This may be due to very small difference between the specific gravity of glass powder and the natural sand.

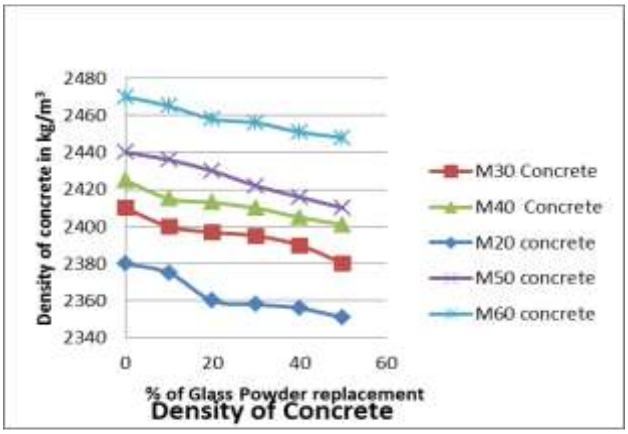

Figure 8 Bulk Density of M20 Concrete

Mechanical strength:

The compressive strength of concrete specimens of all the mixes designed was measured by compression test as per(IS: 516- 1959), the concrete cubes of size 150 mm × 150mm× 150 mm were casted and tested after 28 days strength after conventional method of curing. Cylinder specimens of size 150mm diameter and 300mm height were used for cylinder compressive strength tests. For split tensile strength tests, cylinders of 150mm diameter and 300mm height specimens were casted and tested. Flexural strength test is conducted on concrete prisms of size 100mm x 100mm x 500mm size. The mean value of the strength of three specimens are reported for all the mechanical strength values of concrete.

Tests for Stress strain behaviour of M20 concrete mix with various % of glass powder additions are done using cylinder specimens of 150mm diameter and 300mm height and compressometer was used for strain measurements during uni-axial compression test.

Test Results

Concrete mixes of 20 MPa, 30 MPa 40MPa, 50 MPa and 60MPa with glass powder partially substituting the natural river sand at 0%,10%,20%,30%, 40% and 50% were produced and numerous tests were performed to study the workability properties and mechanical strength to obtain optimum % of glass powder which gives better or comparable concrete to normal concrete. The recorded slump increased with the increase of glass powder content. The density of hardened concrete incorporated with glass powder decreases with the higher % of glass powder contents. The Test results of all the mechanical strengths are given in Table 2.8 through Table 2.22. and plotted in graphs Figure 7 to Figure 19.

Table 8 Cube Compressive strength in MPa of M20 Concrete

Glass Powder replacement	0%	10%	20%	30%	40%	50%
7 days	19.2	19.5	19.9	20. 1	18.8	18.2
28 days	26	27. 1	27.5	28.8	24.5	23.2
56 days	28	30.2	20.9	30.5	31.5	31.2

Table 9 Split tensile strength in MPa- M20 concrete

Glass Powder replacement	0%	10%	20%	30%	40%	50%
7 days	2.4	2.7	2.8	2.85	2.80	2.6
28days	2.8	2.87	2.9	2.98	2.91	2.7
56 days	2.90	2.92	2.94	3. 1	2.96	2.85

Table 10 Cube Compressive strength in MPa of M30 Concrete

Glass Powder replacement	0%	10%	20%	30%	40%	50%
7 days	27.50	27.90	28.20	28.30	27.30	26.20
28 days	38.20	39. 10	39.32	39.60	37.80	36.70
56 days	40.10	41.50	42. 10	42.90	43.0	42.80

Table 11 Split tensile strength test in MPa - M30 concrete

Glass Powder replacement	0%	10%	20%	30%	40%	50%
7 days	3.2	3.4	3.71	3.82	3.66	3.22
28days	3.92	3.96	3.98	4.03	3.80	3.65
56 days	4.1	4.15	4.22	4.26	4.02	3.82

Table 12 Cube Compressive strength in MPaof M40 Concrete

Glass Powder replacement	0%	10%	20%	30%	40%	50%
7 days	37.5	37.9	38.1	38.3	37. 1	36.20
28 days	52.30	52.90	53.50	53.8	52. 1	51.20
56 days	54.20	55. 10	55.20	56.10	56.80	57.20

Table 13 Split tensile strengthin MPa- M40 concrete

Glass Powder replacement	0%	10%	20%	30%	40%	50%
7 days	3.9	4.1	4.2	4.3	4.28	4.03
28days	4.3	4.35	4.42	4.6	4.55	4.28
56 days	4.5	4.6	4.71	4.82	4.76	4.34

Table 14 Cube Compressive strength in MPa of M50 Concrete

Glass Powder replacement	0%	10%	20%	30%	40%	50%
7 days	42.1	42.8	43.2	44.5	41.9	40.2
28 days	58.2	58.5	58.9	59.8	57.3	56.4
56 days	60.1	61.2	61.90	63.7	64.0	64.8

Table 15 Split tensile strength in MPa - M50 concrete

Glass Powder replacement	0%	10%	20%	30%	40%	50%
7 days (MPa)	4.50	4.58	4.63	4.70	4.44	4.1
28days (MPa)	4.82	4.85	4.90	5. 10	4.80	4.6
56 days (MPa)	4.94	4.98	5.20	5.60	4.89	4.75

Table 16 Cube Compressive strength in MPa of M60 Concrete

Glass Powder replacement	0%	10%	20%	30%	40%	50%
7 days	50.5	51.8	52.3	53.8	50. 10	47.4
28 days	69.8	70.30	71.2	72.3	71. 10	69. 10
56 days	73.5	73.9	74.2	75.2	76.4	77.20

Table 17 Split tensile strength in MPa- M60 concrete

Glass Powder replacement	0%	10%	20%	30%	40%	50%
7 days	4.2	4.40	4.70	5.10	4.10	3.90
28days	5. 1	5.26	5.35	5.32	5.02	4.93
56 days	5.8	6.10	6.30	6.42	5.45	5.12

Table 18 Cylinder compressive strength in MPa for various Mixes

Glass Powder replacement %	M20	M30	M40	M50	M60
0	21.2	30.65	41.9	47.20	56.1
10	22.1	31.52	42.5	47.80	56.5
20	22.7	32.10	43.2	48.1	57.3
30	23.9	32.70	43.8	49.20	58.2
40	20.2	31.54	41.9	47.2	57.1
50	19.86	30.11	41.2	46.3	55.9

Table 19 Cube Compressive strength in MPa for various concrete mixes (28 days)

% replacement of glass powder	0 %	10 %	20 %	30%	40%	50%
M20	26	27.1	27.5	28.8	24.5	23.2
M30	38.20	39. 10	39.32	39.60	37.80	36.70
M40	52.30	52.90	53.50	53.8	52. 1	51.20
M50	58.2	58.5	58.9	59.8	57.3	56.4
M60	69.8	70.30	71.2	72.3	71. 10	69. 10

Table 20 Modulus of elasticityin MPa for various % of Glass Powder

Glass Powder %	M20	M30	M40	M50	M60
0	24985	30910	33200	36200	38020
10	25500	30920	33220	36300	38120
20	25650	30930	33400	36400	38290
30	26300	30970	33450	36450	38320
40	26500	31300	34020	36600	38500
50	27200	31400	34040	36700	38620

Table 21 Cube compressive strength in MPa (28 days)

Glass Powder %	M20	M30	M40	M50	M60
0	26.0	38.20	52.30	58.20	69.8
10	27.1	39.10	52.90	58.50	70.3
20	27.5	39.32	53.50	58.90	71.2
30	28.8	39.60	53.80	59.80	72.3
40	24.5	37.80	52.10	57.30	71. 10
50	23.2	36.70	51.20	56.4	69. 10

Table 22 Cylinder compressive strength (in MPa) for various concrete mixes

% of Glass powder	M20	M30	M40	M50	M60
0	21.2	30.65	41.9	47.20	56.1
10	22.1	31.52	42.5	47.80	56.5
20	22.7	32.10	43.2	48.1	57.3
30	23.9	32.70	43.8	49.20	58.2
40	20.2	31.54	41.9	47.2	57.1
50	19.86	30.11	41.2	46.3	55.9

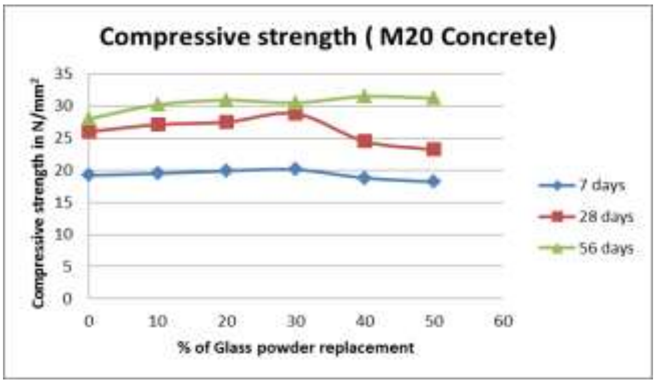

Figure 7 Compressive strength M20 concrete for various % of glass powder

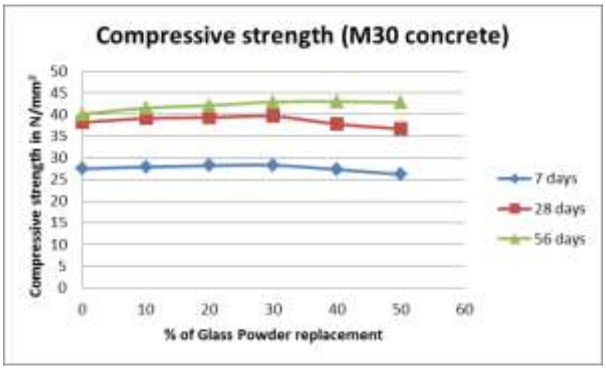

Figure 8 Compressive strength M30 concrete for various % of glass powder

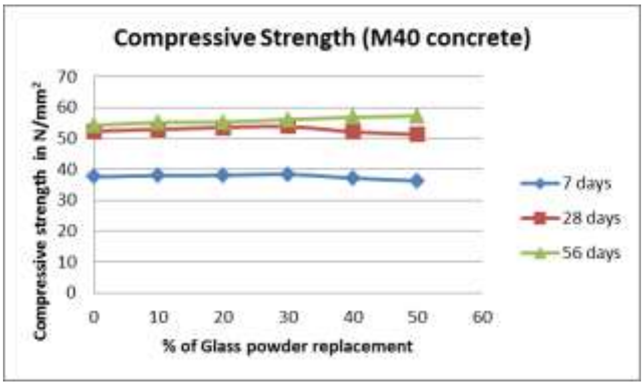

Figure 9 Compressive strength M40 concrete for various % of glass powder

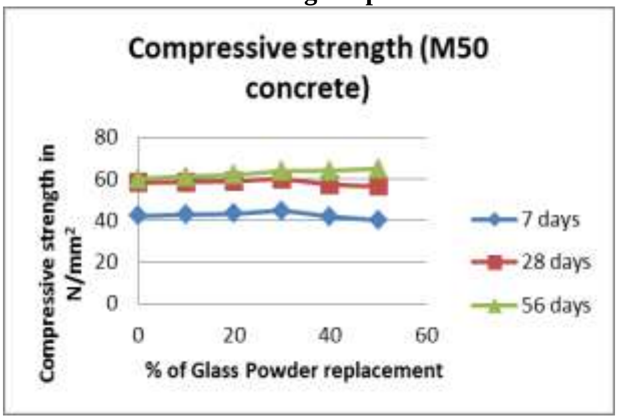

Figure 10 Compressive strength M50 concrete for various % of glass powder

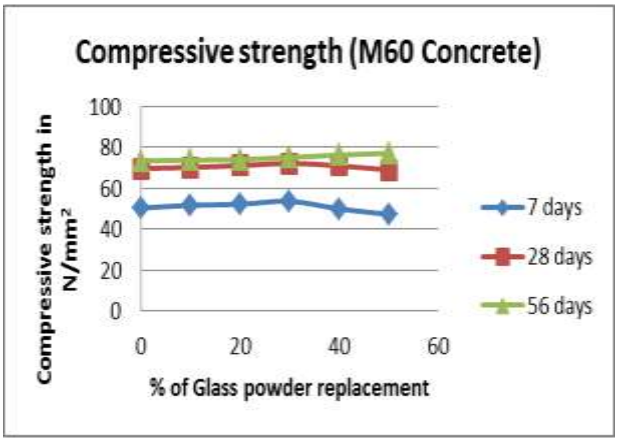

Figure 11 Compressive strength M60 concrete for various % of glass powder

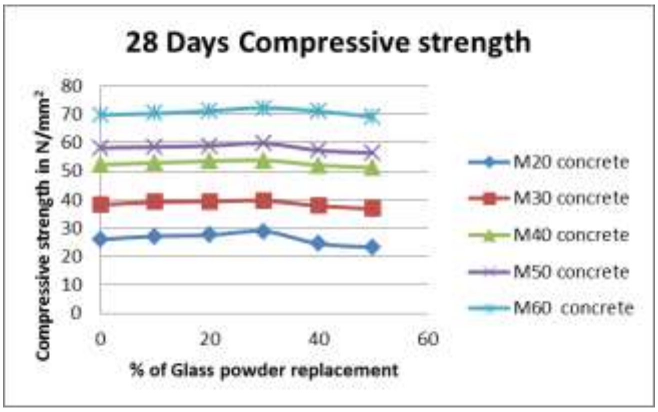

Figure 12 Compressive strength at 28 days for various grade of concrete

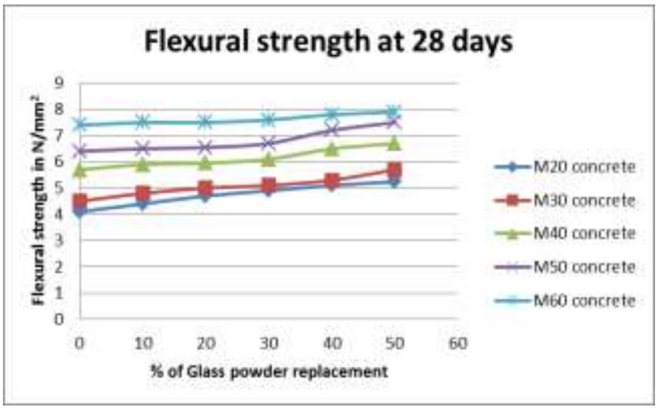

Figure 13 Flexural strength at 28 days for various grade of concrete

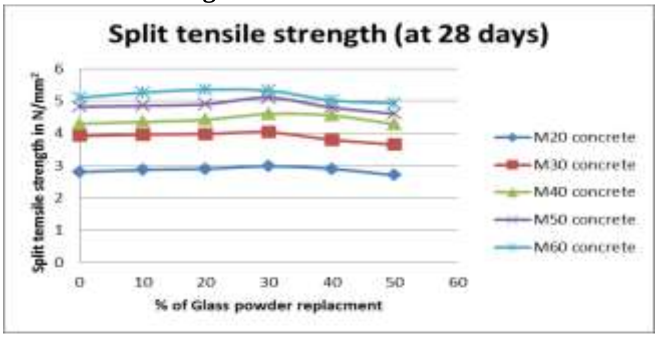

Figure 14Split tensile strength at 28 days for various grade of concrete

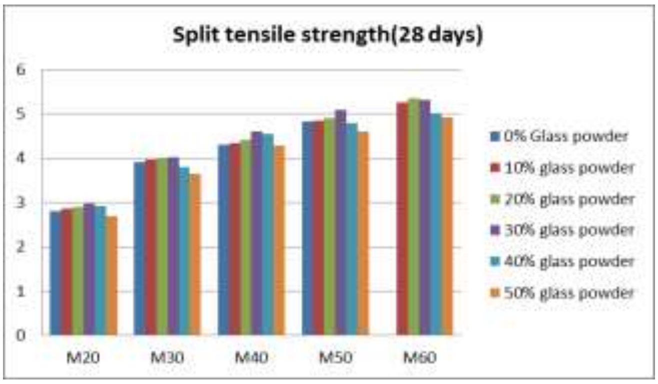

Figure 15Split tensile strength at 28 days for various % of glass powder and different concrete grades

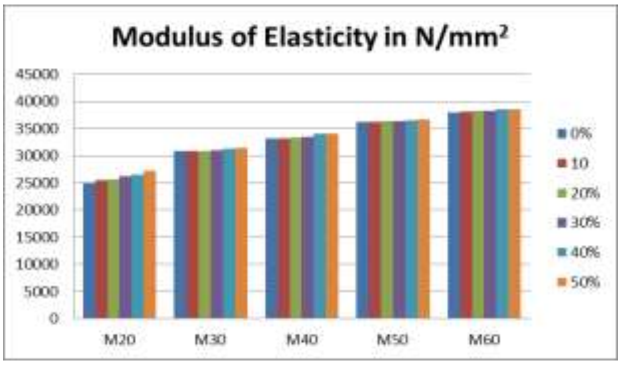

Figure 16 Modulus of elasticity of concrete with various % of glass powder

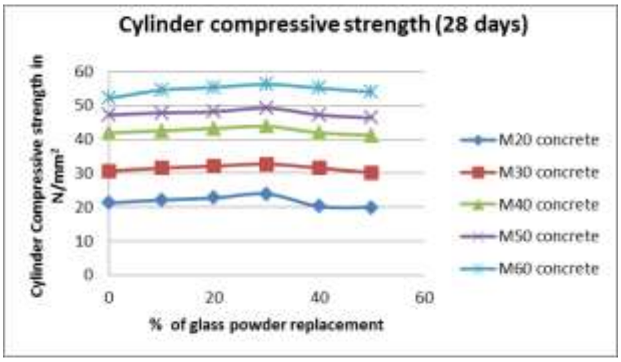

Figure 17 Cylinder compressive strength of concrete with various % of glass powder

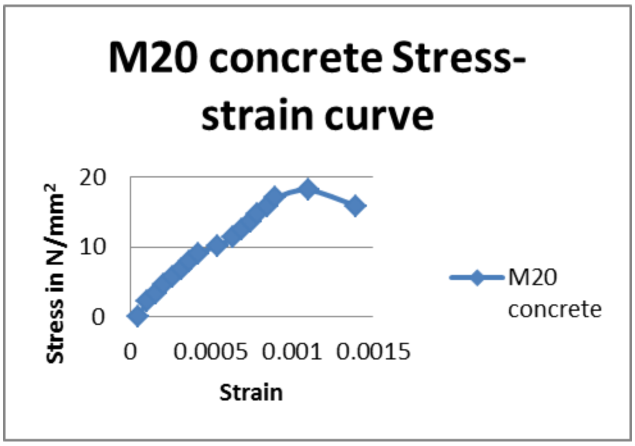

Figure 18 Stress Strain curve for M20 concrete with 30% glass powder replacement

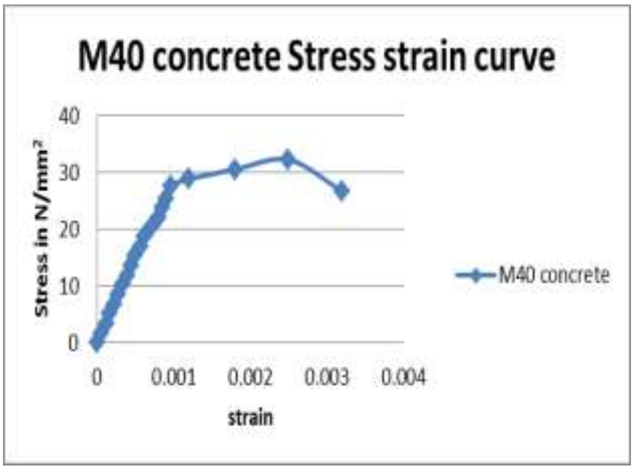

Figure 19 Stress Strain curve for M40 concrete with 30% glass powder replacement

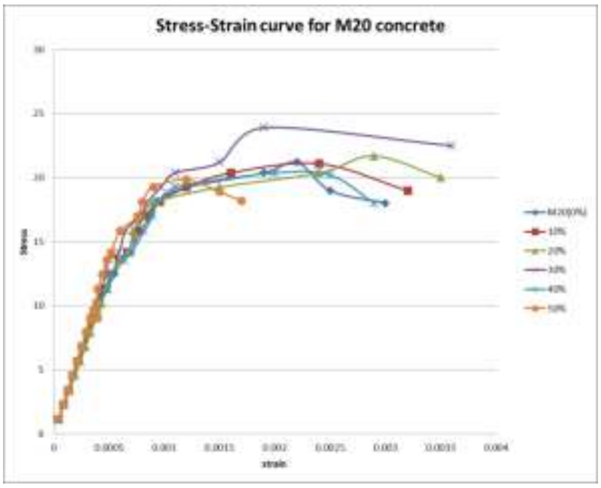

Figure 20 Stress Strain curve for M20 concrete with various % glass powder replacement

Rapid Chloride Permeability Test (RCPT) Test

The RCPT tests were doneas per ASTM C1202 for the specimens of all the mixes M20,M30,M40,M50 and M60 with various percentage of glass powder 0%,10%,20%,30%,40% and 50% after 28 days curing. The cylindrical test specimens are of size 100 mm in diameter and 50 mm in thickness which had been conditioned according to the standard were placed in the cells and subjected to a 60-V potential for 6-h. One of the cells was filled with 0.3N NaOH solution while the other filled with 3% NaCl solution. The amount of electrical current passed through the specimen is measured and the total charge passed (in coulombs) is used as an indicator of the resistance of the concrete to chloride ion penetration. The RCPT test set up is shown in Figure 3.25. The total charge passed through the concrete specimens was calculated using the following formula in Eq. (1)

$$Q = 900(I_o + 2I_{30} + 2I_{60} + ...I_{360}) \quad ...(1)$$

Where, Q = charge passed (coulombs),

Io = current (amperes) immediately after voltage is applied and

It = current (amperes) at t min after voltage is applied.

Rapid Chloride Permeability Test was conducted for the standard concrete specimens at 28 days to find the chloride permeability properties. The Chloride ion penetration properties of various mixes are indicated by the total amount of charge passing through the sample specimens (Table25,). It is observed that with increase in % of Glass powder replacement, the chloride ion permeability of concrete mixes are reduced for all the grades of concrete mixes. With the addition of glass powder the chloride ion penetration of the concrete is found to be at the moderate level. With the addition of glass powder, the chloride permeability is reduced to maximum extent by 50%, 45%,44%, 32%, 32% of normal concrete for M20, M30, M40, M50 , M60 concrete with 50% glass powder replacements respectively. Therefore, concrete with glass powder replacements for sand exhibit low chloride permeability compared to the control concrete.

Table 23RCPT Test Results (at 28 days)

	Total charge passed in Coulombs					Limits
Glass powder %	M20	M30	M40	M50	M60	> 4000 High 2000-4000 Moderate 1000-2000 Low 0-1000 . Very low
0	3600	3100	2900	2800	2500	
10	3000	2800	2700	2500	2000	
20	2500	2400	2200	2000	1800	
30	2400	2200	1800	1400	1600	
40	2000	1800	1500	1300	1200	
50	1800	1400	1300	900	800	

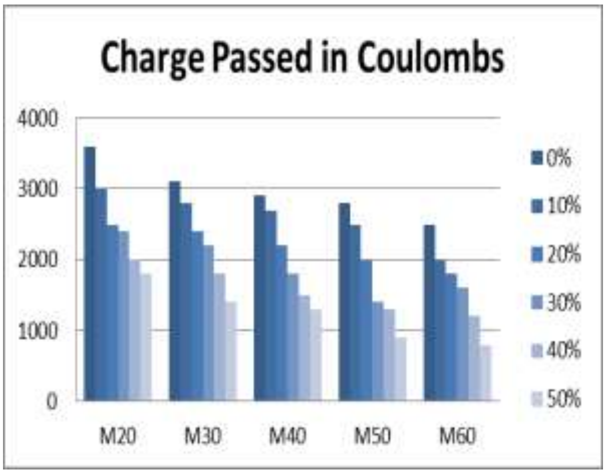

Figure 23Chloride Permeability Test Results

V. CONCLUSIONS

- The mix design for concrete with five various grades (M20, M30, M40, M50, M60) was done. Extensive experimental study on strength and durability properties of these five grades of concrete with different % of (0%, 10%, 20%, 30%, 40% and 50%) waste glass powder for fine aggregate replacement was carried out.
- The stress strain behaviour of all the above concrete mixes was investigated and reported in this section.
- According to the test results, it is observed that the slump value of fresh concrete increase gradually with % of glass powder upto 40% replacements.
- The compressive strength, flexural strength and split tensile strength gradually increase upto 30% addition of waste glass powder and for 40% and 50% replacements the strength values are comparable with that of the control specimens.
- The RCPT test results show that the chloride penetration rate is highly reduced with addition of glass powder and permeability properties of concrete is enhanced upto 50% replacement levels. Therefore 50% of glass powder can be used as the replacement material for fine aggregates without affecting the strength properties of the concrete.

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