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PARTIAL REPLACEMENT OF FINE AGGREGATES WITH RECYCLED GLASS IN PORTLAND POZZOLANA CEMENT

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Abstract

Environmental and economic concerns are big challenges in concrete industries. Glass has been fundamental to human life because of its properties, including flexibility to take any shape effortlessly, glowing surface, and protection from scraped spot, well being and toughness. At present, utilization of waste glass has gained popularity as a resource-efficient, serviceable, cost effective and sustainable material. The objective of this paper is to deal with impacts of using reused glass waste as incomplete substitution of fine aggregate in concrete of M-25 assessment by using Portland Pozzolana concrete (PPC). Fine aggregate are dislodged by waste glass powder as 10%, 20%, 30%, 40% and half by weight for blend. Fifteen solid examples are conveyed for testing compressive strength, droop test, sturdiness (water retention), splitting tensile strength and flexural strength at 7 and 28 days. Results showed the expansion in reused glass total increments compressive strength up somewhat when contrasted with typical cement. Thus substitution of reused glass total can be worth to create PPC concrete and in this way substitution of reused glass total can be worth to deliver PPC concrete and partial substitution of fine total up to 30% by weight.

Key words: Recycled glass aggregates, compressive strength and flexural strength.

Introduction

Sustainable construction practices stand for responsible management in creating a healthy built environment by considering efficient resources and ecology (Islam *et al.*, 2016). But, at present, two significant issues are of major concern: one is reduction of carbon dioxide emission and the second is recycling of waste materials. It was computed that, as results of urbanization and manufacturing industries in the country, 0.7 percent of total municipality waste generated was comprised of glass in the form of waste container, window glass, blubs, electronic equipment, medicinal bottles, liquor bottle fiber optic cable, solar panel, etc., (Malik *et al.*, 2013).

Hence, the disposition of waste glass (WG) has become a main natural concern due to the growing requirement for land-fill spaces. Natural resource creates a great impact on lessening the carbon footprint in construction industries (Mohajerani *et al.*, 2017). Huge cost has been expended on color sorting and cleaning, only a little fraction is recycled by special market, e.g. container manufacturers (Tamanna *et al.*, 2013). According to various studies in many countries, recycling of WG is particularly recycling rate is very low when contrasted with other solid wastes. In U.S. in year 2010, 11,530 Kilotons of WG mainly from container packaging were generated, out of which only 27% were recycled (Tamanna *et al.*, 2013). Glass is a material with 100 percent recyclable properties and with various aesthetic properties (Hong *et al.*, 2007). WG can be used as a raw material in the form of crushed glass in the construction industry for manufacturing of scraped material, pozzolanic addible in concrete or as an aggregate substitutes (Emam and Al-Tersawy,2012).

Yearly utilization of cement is in billion cubic meters and its interest is expanding step by step. Endeavors are made to discover substitute materials to lessen the utilization of virgin materials. Stream sand, utilized as fine total, prompts abuse of characteristic assets, decline in water table and disintegration of waterway bed (Mohajerani *et al.*, 2017). Other concern is the release of CO_2. Considering 1 ton production of Portland cement on average, the equivalent quantity of carbon dioxide (CO_2) is discharged into the atmosphere, which is the main cause of global warming and depletion of ozone layer (Tamanna *et al.*, 2013). The use of WG in specific percentage and particular size range, instead of fine aggregates, leads to decreasing fine aggregate content and minimizing ill effect on river surface. Thus, it will attain sustainable concrete industry (Malik *et al.*, 2013).

There is immense potential for utilizing WG in solid development. When WG are reused in delivering solid matter, the expense of solid will go down. This will help to create eco-friendly environment and to save relatively costlier natural

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resources. These replacements include detailed studies considering their effects on concrete properties. Various researches have been performed and according to their performances i.e. compression, tensile strength and flexure strength of concrete consisting WG as fine aggregate content reduced with an increase in mix ratio of WG (Tamanna *et al.*, 2013).

In this research, 10-50% of WG is partly used by weight of fine aggregate. Laboratory tests, including compression test, slump test, splitting tensile strength, durability (water absorption) and flexural strength, are conducted for 7-28 days. The outcome obtained from OPC with grade of M-25 are compared to normal M25 concrete mix and the outcome show that an increase in WG by fine aggregate will increment the compressive strength up to certain level when contrasted with normal cement. Thus, the supplanting of fine total with WG is frequently valuable to create PPC concrete and incomplete substitution of fine total up to 30% by weight won't have any long haul hurtful impacts.

Materials and Methods

Materials Mixes

Cement and Aggregate: Portland Pozzolana cement with specific gravity of 3.15 is utilized throughout the experiment. Crushed stone aggregates are gathered from a local quarry. In this experiment, coarse aggregate is used were 20mm and descending size aggregate.

Waste glass (WG): WG used in this research work is taken in the form of post-consumed glass bottles of aerated drinks, which are further broken into sizes of 10 & 20 mm, comparable to coarse aggregate size. Waste glass collected from Oachghat, Solan, Himachal Pradesh, India.

Water Mix: For mixing and curing of specimens, drinkable fresh water is used, which is easily accessible from local sources.

Concrete mixes Features: Atotal of fifteen numbers of concrete mixtures are produced. The mix ratio of cement, fine and coarse aggregate in the experimental work is 1:1.41:2.66 by weight and water to cement ratio is 0.45. Replacement of sand with stone-dust and coarse-aggregate (CA) with WG are at 10%, 20%, 30% 40% and 50%. For every replacement level, five samples are made for compressive strength test and cured for 7 days and 28 days. Table 1 shows concrete mix design summary for the compression test.

Results and Discussion

Concrete Mix Design

The parameters taken for Concrete Mix Design are given as follows-

1) Water quantity = 198 liter /cubic meter
2) Cement = 350kg/cubic meter
3) Water to cement ratio is 0.45
4) Aggregates quantity for:-
   a. Coarse aggregate proportion is 0.65 m^3
   b. Fine aggregate is 1- 0.65 = 0.35 m^3

Mix of M25 grade concrete is prepared as per IS 10262:2009 code.

Design Mix computation

a) Concrete Volume is 1 m^3

b) Cement Volume = (350/3.15) × (1/1000) = 0.112 m^3

c) Water Volume = (198/1) x (1/1000) = 0.198 m3

d) Aggregates Volume = 1-[0.112+0.198] = 0.69m^3

e) Coarse aggregate = Vol. of aggregates × fractions of CA × Specific gravity (G) of CA × 1000 = 0.69 x 0.65 × 2.71 x 1000 = 1215 kg/m^3

f) Fine aggregate = Vol. of aggregates × fraction of fine aggregate x Specific gravity (G) of fine aggregate × 1000 = 0.69 x 0.35 × 2.65 × 1000 = 640kg/m

Concrete Mix Design

Data Required for Concrete Mix Design

Concrete mix design of M-25 as per IS 10262:2009.

Table 2 depicts the compressive strength test for mix design for concrete.

1. Water = 198 liter /cubic meter
2. Cement quantity = 400kg/cubic meter
3. Water :cement = 0.45
4. Aggregate quantity for:
   a. Coarse aggregate is 0.65 m^3
   b. Fine aggregate is 1- 0.65=0.35 m^3

Design Mix Calculation

a) Concrete Vol. is 1m^3

b) Cement Vol. = (400/3.15) × (1/1000) = 0.126 cubic meter

c) Water Vol. = (198/1) × (1/1000) = 0.198 cubic meter

d) Vol. of aggregates = 1-[0.126+0.198] = 0.67 cubic meter

e) Coarse aggregate = Vol. of aggregates × fraction of CA × Specific gravity (G) of CA × 1000 = 0.67 × 0.65 × 2.71 × 1000 = 1180 kg/m3

f) Fine aggregate = Vol. of aggregates × fraction of fine aggregate × Specific gravity (G) of fine aggregate × 1000 = 0.67 × 0.35 × 2.65 × 1000 = 621kg/meter

The proportion of the fine aggregate and coarse aggregate taken is 1.41 and 2.66 respectively. Concrete Mix ratio is 1: 1.41: 2.66, in which Cement is 1 part, fine aggregate is 1.41 parts and coarse aggregate is 2.66 parts respectively.

The fineness of cement plays an important role in the rate of hydration and therefore on the rate of gaining the strength. The value of fineness of cement found from the experiment is 8.40% which is almost near to 10% as required by the code. Hence this value fits the codal requirements. The normal consistency of a cement paste is described as that consistency (% of water) which will allow the Vicat plunger to penetrate to a factor 10 mm from the pinnacle of the Vicat mould. The normal range of values should be between 22 to 30 percentage through weight of dry cement. The value of Normal consistency percentage found from the test is 32. The Initial setting time should be greater than or equal to 30 minutes and final setting time should be not more than 600 minutes as per IS 1489 (part-1)-1991 code. So here the codal requirements are fulfilled because we got the values from the experiment as 45 minutes and 330 minutes for Initial and final setting time respectively. The expansion of the cement is detected by Soundness test using Le Chatelier apparatus. The value should not be more than 10 mm as per code and experimental value found for mix is 3 mm. Table 3 indicates the cement properties as per experiment and codal requirement.

The Fineness modulus of Fine aggregates is found 2.52. If the size of the aggregate increases the value of the Fineness modulus also increases, so we got Fineness modulus for Coarse aggregates of size 10 mm and Coarse aggregates having size 20 mm like 6.69 and 7.44 respectively. From the experiment we also got that the Fineness modulus of stone dust is 2.31. Flakiness index and Elongation index are found 6.25% and 21.2% respectively. Table 4 shows the experimental values of fine and coarse aggregate.

Glass is a brittle material and fractures from the tensile stress so we use it here for compressive stresses. Glass also has heat retention properties because glass has low thermal conductivity. Therefore when it is mixed with the concrete mix it helps to decrease the depth of frost penetration. Waste Glass consisits of Silicon Oxide (SiO_2), Magnesium Oxide (MgO), Sodium Oxide (Na2O), Aluminium Oxide (Al2O3), Potasium Oxide (K2O), Ferric-Oxide (Fe2O3), Calcium-Oxide (CaO), Boric Oxide (B2O3), Zinc Oxide (ZnO) and Lead Oxide (PbO). The percentage of these constituents is 50.65, 3.13, 10.35, 9.15, 10.88, 0.07, 5.78, 8.23, 1.29 and 20.87 respectively. Table 5 shows the Typical Chemical composition of Waste Glass. The standard values of the constituents are also given in the table 5.

Individual Five concrete-mix samples are designed, where the selected mix design ratio is 1:1.41:2.66 and the W/C ratio 0.45 is used. In Portland Pozzolana cement the fine aggregate quantity is 0.5 mm less and stone dust is used. Fixed proportions of two types of WG (20 mm glass and 5 to 10 mm glass pieces) as coarse aggregate are used for five different mixtures. The crushed waste glass is passed through the IS sieves of size 20mm, 16mm, 12.5mm, 10mm, 4.75mm and Pan. The weight of aggregate retained on 20mm, 16mm, 12.5mm, 10mm, 4.75mm IS sieves and Pan is 649gm, 808gm, 843gm, 600gm, 891gm and 201gm respectively. Cumulative Retained Weight IS sieves of size 20mm, 16mm, 12.5mm, 10mm, 4.75mm and Pan is 649gm, 1457gm, 2300gm, 2900gm, 3791gm and 3992gm respectively. Also the Cumulative Weight Retained as percentage of Total aggregate and Cumulative percentage passing as percentage of Total aggregate is given in the table 6.

Coarse aggregate mix ratio

Coarse aggregates are replaced by glass of two different classes of glass size. The first class is 5-10mm and another class is 20mm glass size. The percentage of the glasses and coarse aggregates are shown in the table 7.

Fine aggregate mix ratio

The size of the Fine aggregates is 0.5mm.

Sample Mix-1 consist of 90% Fine aggregates and 10% Stone Dust.

Sample Mix-2 consist of 80% Fine aggregates and 20% Stone Dust.

Sample Mix-3 consist of 70% Fine aggregates and 30% Stone Dust.

Sample Mix-4 consist of 60% Fine aggregates and 40% Stone Dust.

Sample Mix-5 consist of 50% Fine aggregates and 50% Stone Dust.

The compression strength of glass and stone dust has been computed for 7 days and for 28 days shows in table 8. The maximum compressive strength at 7 days is 17.60 MPa and at 28 days is 24.45 MPa.

In PPC the Silicon-Oxide (SiO2) is 29.1%, Magnesium-Oxide (MgO) is 1.5%, Aluminum-Oxide (Al2O3) is 7.2%, Calcium-Oxide (CaO) is 42%, Loss on Ignition (LOI) is 3%, Ferric-Oxide (Fe2O3) is 5.2% and Sulphur-Trioxide (SO3) is 2.6%. As we have prepared two different concrete mixtures, one is concrete mixture consisting cement as 350 kg/cubic meter and another concrete mixture consisting cement as 400 kg/cubic meter. Water cement ration taken is 0.45.

Group 1: Concrete Mix constituents for 350 kg/cubic meter cement

$M_{1\text{-}350\text{-}10\%}$ represents concrete Sample Mix-1 for cement quantity of 350 kg/cubic meter with 10% combined replacement of fine and coarse aggregates.

$M_{2\text{-}350\text{-}20\%}$ represents concrete Sample Mix-2 for cement quantity of 350 kg/cubic meter with 20% combined replacement of fine and coarse aggregates.

$M_{3\text{-}350\text{-}30\%}$ represents concrete Sample Mix-3 for cement quantity of 350 kg/cubic meter with 30% combined replacement of fine and coarse aggregates.

$M_{4\text{-}350\text{-}40\%}$ represents concrete Sample Mix-4 for cement quantity of 350 kg/cubic meter with 40% combined replacement of fine and coarse aggregates.

$M_{5\text{-}350\text{-}50\%}$ represents concrete Sample Mix-5 for cement quantity of 350 kg/cubic meter with 50% combined replacement of fine and coarse aggregates.

Group 2: Concrete Mix constituents for 400 kg/cubic meter cement

$M_{1\text{-}400\text{-}10\%}$ represents concrete Sample Mix-1 for cement quantity of 400 kg/cubic meter with 10% combined replacement of fine and coarse aggregates.

$M_{2\text{-}400\text{-}20\%}$ represents concrete Sample Mix-2 for cement quantity of 400 kg/cubic meter with 20% combined replacement of fine and coarse aggregates.

$M_{3\text{-}400\text{-}30\%}$ represents concrete Sample Mix-3 for cement quantity of 400 kg/cubic meter with 30% combined replacement of fine and coarse aggregates.

$M_{4\text{-}400\text{-}40\%}$ represents concrete Sample Mix-4 for cement quantity of 400 kg/cubic meter with 40% combined replacement of fine and coarse aggregates.

$M_{5\text{-}400\text{-}50\%}$ represents concrete Sample Mix-5 for cement quantity of 400 kg/cubic meter with 50% combined replacement of fine and coarse aggregates.

Workability

Slump test is carried out at the time of casting of cubes with respective replacement level, in accordance with IS: 1199-1959 code.Workability increase with increasing glass content (Table 9 & 10).

Compression strength test

Compression test is constructed in accordance with IS 516:1959. For all replacement level, 5 cubes are constructed and after 7 days and 28 days curing and crushing is completed. Compression strength results for different design mixes are shown in table 11 and 12.

Group 1

The maximum Compressive strength (N/mm^2) is for $M_{1\text{-}350\text{-}0\%}$ grade concrete and minimum Compressive strength (N/mm^2) is for $M_{5\text{-}350\text{-}50\%}$grade concrete in 28 days.

Group 2

The maximum Compressive strength (N/mm^2) is for $M_{2\text{-}400\text{-}0\%}$ grade concrete and minimum Compressive strength (N/mm^2) is for $M_{5\text{-}400\text{-}50\%}$grade concrete in 28 days.

Figure 1, 2, 3 and 4 shows the relationship of percentage of recycled glass with compressive strength test, split tensile strength test and flexural strength experiment. The compression experiment, splitting tensile and for flexural strength of reused glass Portland Pozzolana concrete (PPC) reduces with increment in reused glass content. The slump will increase by raising the quantity of waste glass content. WG particle absorbs low water as of sand and consequently improves the workability of concrete mixes. WG has the potential to replace Fine aggregate equal to 30 percent by weight. Indicating 9.7 percent increment in compression evaluated at 28^{th} day. The utilization of WG in cement-concrete eliminates the dumping problems and has proved environment friendly and much responsive toward environmental concern. Thus it is a better way for green concrete or sustainable construction.

Conclusion

The consumption of WG in mixes of concrete will conserve natural fossil fuels, specifically waterway sand. Therefore it renders the sustainable concrete manufacturing industries. The composition of WG in concrete has proved very cost-effective and efficient as it is non-useful waste and free of charge.

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Table 1: Mix -Proportion for volume of items per m^3

Water	Cement	Fine aggregates	Coarse aggregates
198 litre	350 kg/m^3	640 kg/m^3	1215 kg/m^3

Table 2: Mix Proportions per m^3 volume of concrete

Water	Cement	Fine aggregates	Coarse aggregates
198liter/cubic meter	400kg/cubic meter	621 kg/ cubic meter	1180 kg/ cubic meter

Table 3 : Cement Properties

S. No.	Properties	Experimental Values (in percent)	Code requirement IS 1489 (part-1)-1991
1	Fineness of cement (percent retained on 90 micron IS sieve)	8.40	10%
2	Normal consistency percentage	32	-
3	Initial and final setting time	45 min and 330min	Not less than 30min/ Not more than 600 min
4	Soundness of cement (Le Chatelier expansion)	3 mm	Not more than 10 mm

Table 4 : Fine and coarse aggregates

S. No.	Properties	Experimental Value
1	Fine aggregates (Fineness modulus)	2.52
2	Coarse aggregates (Fineness modulus-10 mm size)	6.69
3	Coarse aggregates (Fineness modulus- 20 mm size)	7.44
4	Stone dust (Fineness modulus)	2.31
5	Flakiness index	6.25%
6	Elongation index	21.2%

Table 5 : Typical Chemical composition of Waste Glass (WG)

S. No.	Waste glass component	Percentage	Standard Value
1	Silicon Oxide (SiO_2)	50.65	45-90
2	Magnesium Oxide (MgO)	3.13	2.5-7.50
3	Sodium Oxide (Na_2O)	10.35	14.20 max
4	Aluminium Oxide (Al_2O_3)	9.15	0.50-16.0
5	Potasium Oxide (K_2O)	10.88	12.0 max
6	Ferric-Oxide (Fe_2O_3)	0.07	0.10
7	Calcium-Oxide (CaO)	5.78	10.0 max
8	Boric Oxide (B_2O_3)	8.23	4.0-12.0
9	Zinc Oxide (ZnO)	1.29	1.50 max
10	Lead Oxide (PbO)	20.87	25.0 max

Table 6 : Result of sieve analysis for waste glass (WG)

S. No.	IS Sieve	Weight of aggregate Retained (gm)	Retained Cumulative Weight (gm)	Cumulative Weight Retained a s % of Total aggregate	Cumulative % Passing as % of Total aggregate
1	20mm	649	649	16.25	83.75
2	16mm	808	1457	36.45	63.55
3	12.5mm	843	2300	57.5	42.5
4	10mm	600	2900	72.5	27.5
5	4.75mm	891	3791	94.71	5.28
6	Pan	201	3992	99.8	0.2

Table 7: Coarse aggregate mix ratio

Mix Designation	Coarse aggregates (10-20mm)	Glass (20mm)	Glass (5-10mm)
Sample Mix-1	90%	0%	10%
Sample Mix-2	80%	10%	10%
Sample Mix-3	70%	20%	10%
Sample Mix-4	60%	30%	10%
Sample Mix-5	50%	40%	10%

Table 8: Compressive Strengths of Glass & Stone Dust Based Concrete for 7 days and 28 Days

S. No.	Average compressive strength in 7 days (MPa)	Average compressive strength in 28 days (MPa)
1	10.88	19.11
2	13.33	22.22
3	17.60	24.45
4	15.90	24.22
5	15.67	23.12

Table 9: Slump Value of fresh concrete for Group 1

Designation	Slump Flow (mm)
$M_{1-350-10\%}$	675
$M_{2-350-20\%}$	715
$M_{3-350-30\%}$	735
$M_{4-350-40\%}$	860
$M_{5-350-50\%}$	885

Table 10 : Slump Value of fresh concrete for Group 2

Designation	Slump Flow (mm)
$M_{1-400-10\%}$	675
$M_{2-400-20\%}$	695
$M_{3-400-30\%}$	715
M_{4}-$_{400-40\%}$	735
M_{5}-$_{400-50\%}$	745

Table 11: Compression test, Tensile and Flexural strength results

Designation	Compressive strength (N/mm^2)		Splitting Strength (N/mm^2)		Flexural Strength (N/mm^2)	
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
$M_{1-350-0\%}$	35.1	45.2	4.6	10	5.6	14.7
$M_{1-350-10\%}$	33.2	43.7	4.4	9.9	5.4	14.4
$M_{2-350-20\%}$	31.7	41.7	4.4	9.6	4.9	14.6
$M_{3-350-30\%}$	30.8	40.6	4.3	9.2	4.7	13.8
$M_{4-350-40\%}$	29.3	38.4	3.9	8.9	4.9	13.5
$M_{5-350-50\%}$	26.6	35.8	3.3	8.6	4.3	13.3

Table 12 : Compression, Split Tensile test and Flexural strength results

Designation	Compressive Strength (N/mm^2)		Split Tensile Strength (N/mm^2)		Flexural Strength results (N/mm^2)	
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
$M_{2-400-0\%}$	47.5	61.8	6.5	11.8	7.7	17.6
$M_{1-400-10\%}$	46.2	59.5	6.3	11.3	7.3	17.3
$M_{2-400-20\%}$	42.4	53.3	5.9	10.9	6.7	16.7
$M_{3-400-30\%}$	39.3	51.7	5.8	10.8	6.6	15.7
$M_{4-400-40\%}$	36.8	48.5	5.3	10.3	5.8	14.8
$M_{5-400-50\%}$	36.2	47.6	4.8	9.8	5.7	14.7

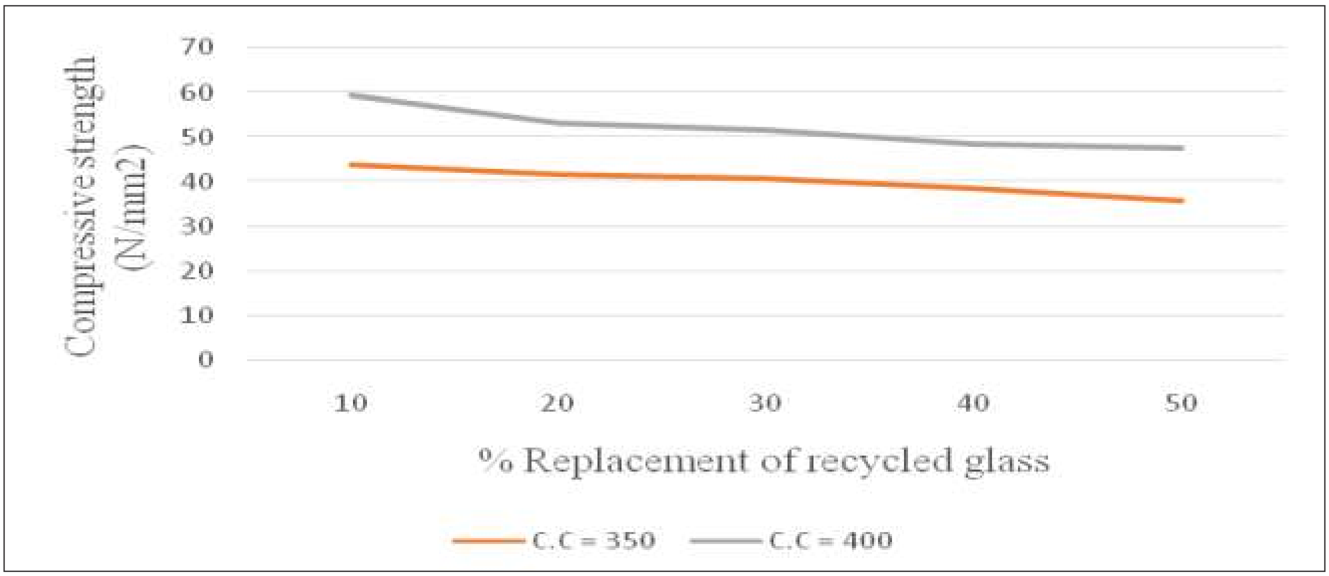

Figure 1: Correlation of compressive strength and percentage of recycled glass after 7 days

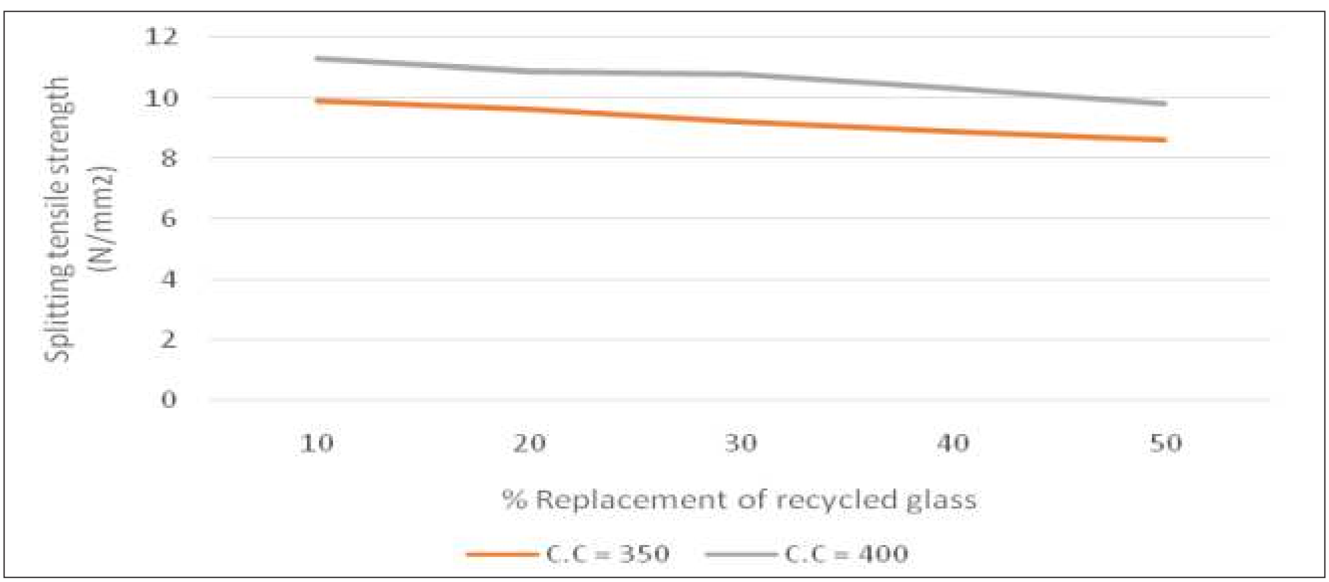

Figure 2: Correlation of compressive strength and percentage of recycled glass after 28 days

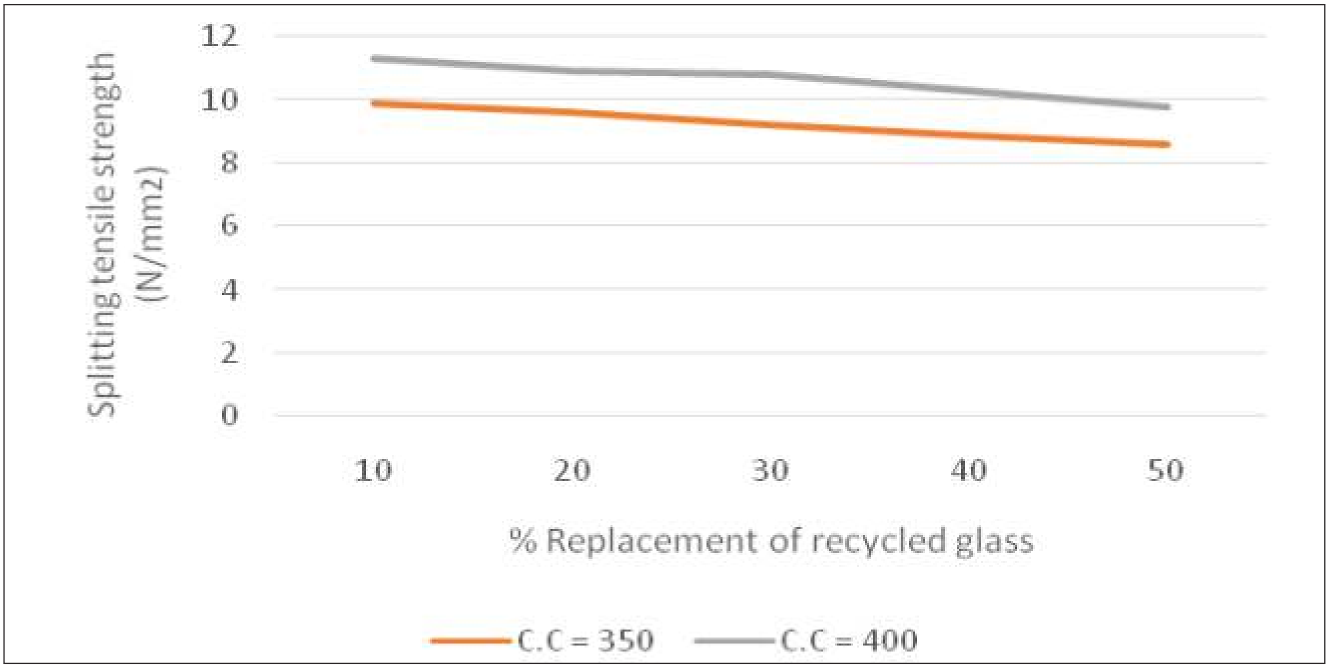

Figure 3: Relation between split-tensile strength and percentage of recycled glass after 7 days

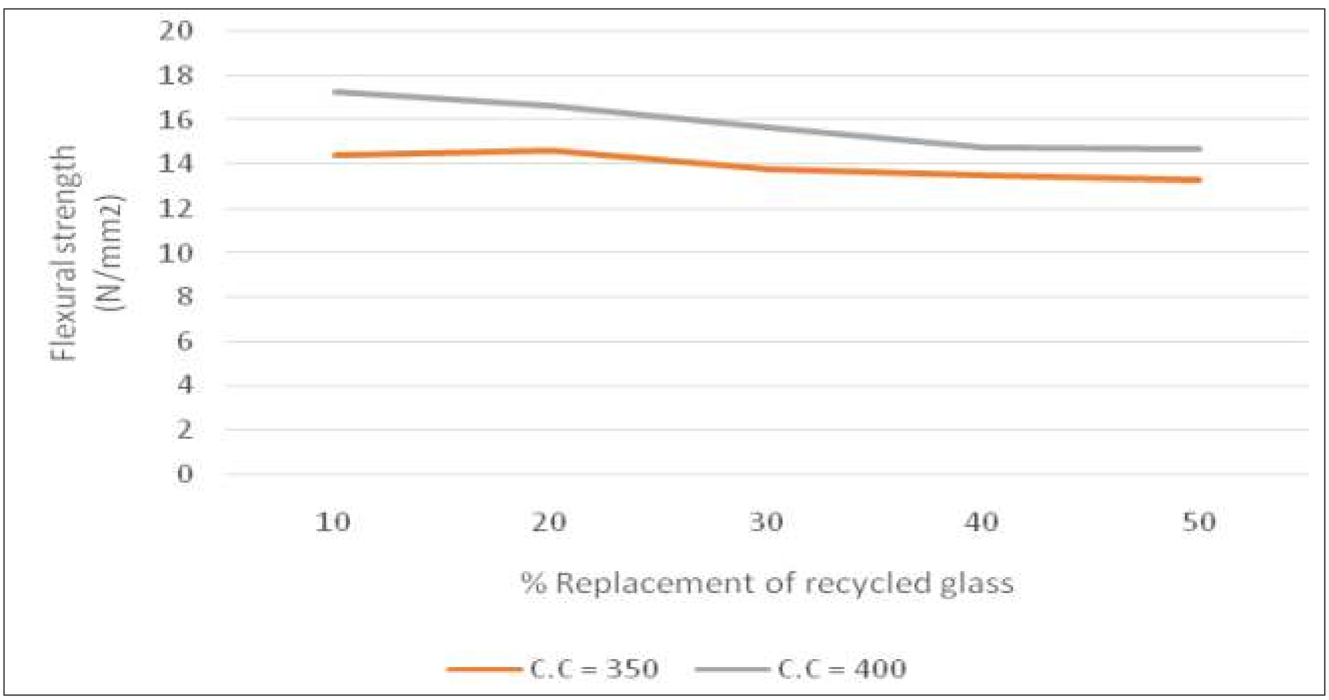

Figure 4: Relation between flexural strength and percentage of recycled glass after 28 days