INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
Vol. 13 No. 2 (2022) 135-146

IJSCET

http://penerbit.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Prediction of Compressive Strength of Normal Concrete with Partial Replacement of Sand by Waste Glass Using Fuzzy Model

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DOI: https://doi.org/10.30880/ijscet.2022.13.03.013
Received 19 April 2021; Accepted 20 August 2022; Available online 10 December 2022

Abstract: The objective of the study is a partial replacement of natural fine aggregate with crushed waste glass for M 30 concrete production. To determine the compressive strength of such concrete for using 10% 15%, 20%, and 25% of partial replacement including control samples using 0.45, 0.47, and 0.50 water-cement ratios. Quality tests, slump, compressive strength, density, permeability, and Ultrasonic pulse velocity test are performed; the cube of concrete mix design test follows the American Concrete Institution (ACI) guideline. And to develop a predictive model for the 7days and 28days compressive strength using a fuzzy model. The result has shown that the physical properties, of course, fine aggregate and crushed waste glass satisfy the standard specification, when the replacement percent increases, the compressive strength and ultrasonic pulse velocity of concrete are increased up to 15% of replacement level Due to the angular nature of waste glass particles contributes more effective cement past. Thus reduction of microscopic voids in concrete. The study also found the depth of penetration for concrete indicates the increased replacement percent increase in the depth of penetration increase due to increase microscopic void space. It was concluded that the natural sand is effectively partially replaced by crushed waste glass, maximum compressive strength was achieved at 15% of replacement level. The result showed that quite satisfactory in predicting the Compressive strength for 7 and 28 days strength of the M-30 concrete mix using the fuzzy logic technique with a coefficient of correlation, R^2 of 0.87 and 0.85 respectively for training and validation set. The significance of the study is that the compressive strength of concrete made with partial replacement of natural fine aggregate by the crushed waste glass can be predicted by using the predictive model developed.

Keywords: Crushed waste glass, water cement ratio, concrete, compressive strength, mix design

1. Introduction

Concrete is one of the most important building materials. In the construction sector, concrete is the oldest material (K. Alilou & Teshnehlab, 2010). The concrete industry is one of the largest consumers of natural resources due to which the sustainability of the concrete industry is under threat. Waste glass is a big environmental problem, because of the

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inconsistency of waste glass streams. with increasing environmental stress to reduce waste glass and reuse. The process of converting waste glass into usable items is known as glass recycling. Glass waste should be sorted by chemical composition, and then divided into distinct hues depending on the end-use and local processing capabilities (Rajeshwari & Mandal, 2019). In fast-track projects when 28-day test results are not expected, a solid and trustworthy fuzzy model capable of forecasting the compressive strength of a concrete sample at any age is crucial. Due to the quick construction, this can reduce the time waiting for test results, which can be turned into advantageous monetary values. Nowadays, the utilization of waste glass as a high-value market and high-quality resource is currently attracting a lot of attention. Due to changes in environmental legislation, waste glass has become a major concern for districts all over the world, therefore it may be a big motivator to use waste glass in various construction applications (Reddy et al., (2015).

Different scholars investigated the partial replacement of waste glass for concrete production. According to O et al., (2019), this investigation found in concrete mixtures, glass (Aluminium window)was utilized to replace up to 35% of coarse particles. The study concluded successfully used as a partial substitute for coarse aggregates, with the optimum strength of the concrete being observed at 25% waste glass against 75% granite for coarse aggregate, with the compressive strength of the concrete cube at 28 days of curing being 15.78N/mm2. Kittur et al., (2019) investigated in the M-20 mix, that waste glass powder was used to substitute fine aggregates at 0%, 5%, 10%, 15%, 20%, and 25% by weight. The study concluded that waste glass powder may be used as a partial substitute for fine aggregates up to 15%. Gupta et al., (2018) investigated concrete produced by replacing discarded glass in different amounts, including 2, 5, 7, and 10%. The study concluded that when 10% waste glass material was substituted for fine aggregate in M30 grade concrete, the compressive strength was higher than the desired mean compressive strength of regular M30 grade concrete Malik et al., (2013) investigated the use of discarded glass in concrete as a partial substitute for fine aggregates in proportions of 10%, 20%, 30%, and 40% by weight M-25 mix. The study concluded that waste glass powder may be used as a partial substitute for fine aggregates up to 30% by weight for particle sizes ranging from 0 to 1.18mm. The objective of this study is to investigate the effect of waste glass on the compressive strength properties of M-30 concrete also to predict the compressive strength of concrete using the fuzzy model.

2. Materials and Methods

2.1 Materials

The coarse and natural fine, aggregate used in this study from a local market at Nefas Silk Lafto sub-city, Addis Abeba Ethiopia, and ordinary Portland cement (Dangote Grade 42.5) made by Dangote Cement Company in Ethiopia were used. The Waste glass (Cullet) was collected from the locally available waste in shops and disposals at the location of Nefas Silk Lafto Sub-city, condominium building around Jemo one, and from Bazeto Industry and Trading P.L.C Addis Ababa Bottle and Glass Share Company in Ethiopia. Also, potable tap water was used for the study for concrete mixing and curing.

2.1.1 Waste Glass (Cullet)

The waste glass used for the study was collected from the waste dumping area around Jemmo 1. In this research, flint-type waste glass is used and crushed by the Addis Ababa Bottle and Glass Share Company crusher, and the first step is to make sure the glass is well crushed; on the other hand, all the crushed waste glass in this test was washed before testing starts. The grain size of Crushed waste glass between 4.75mm to 0.075mm is employed as a partial replacement of natural fine aggregate(natural sand) within particle size diameter.

2.2 Methods

This study investigated the effect of partial replacement of river sand by the crushed waste glass in 0.45, 0.47, 0.50 water-cement ratios, with percentage replacement of 10%, 15%, 20%, and 25% including the control sample. The physical property of material for fresh concrete to cheek the workability by using slump test method and for mechanical property compressive strength, ultrasonic pulse velocity and also durability of concrete were investigated. The concrete mix design test is performed using the concrete grade M 30 and the ACI method used for prediction of compressive strength of concrete will be used fuzzy logic approaches and the experimental result used in the modeling procedure.

2.3 Batching and Mixing Proportion

The proportion of partial replacement of river sand by the crushed waste glass can be determined for each sieve size in 10%, 15%, 20%, and 25% with 0.45, 0.47, and 0.50 water-cement ratios based on the control mix of 0%. Detailed proportions of River sand and Crushed Waste glass (Cullet) for the trial mix are presented in table 1.

Table 1 - Replacement matrix and mix proportion

W/C	% of Crushed waste glass	Cement (Kg)	Coarse aggregate (Kg)	River sand aggregate (Kg)	Crushed waste glass (Kg)	Water (Lit)
0.45	Control Mix	10.70	29.40	18.43	0.00	4.90
	10%	10.70	29.40	16.59	1.84	4.90
	15%	10.70	29.40	15.67	2.76	4.90
	20%	10.70	29.40	14.74	3.69	4.90
	25%	10.70	29.40	13.82	4.61	4.90
0.47	Control Mix	10.30	29.40	18.90	0.00	4.90
	10%	10.30	29.40	17.01	1.89	4.90
	15%	10.30	29.40	16.06	2.84	4.90
	20%	10.30	29.40	15.12	3.78	4.90
	25%	10.30	29.40	14.18	4.72	4.90
0.50	Control Mix	9.70	29.40	19.52	0.00	4.90
	10%	9.70	29.40	17.57	1.95	4.90
	15%	9.70	29.40	16.59	2.93	4.90
	20%	9.70	29.40	15.62	3.90	4.90
	25%	9.70	29.40	14.64	4.88	4.90

The M-30 concrete grade mix-design proportion of partial replacement of river sand by the crushed waste glass can be determined for each sieve size in 10%, 15%, 20%, and 25% with 0.45, 0.47, and 0.50 water-cement ratios based on the control mix 0%.

The mixing was conducted by using a rotary type mixer for all mixes. The river sand and crushed glass were used in dry conditions. The dry elements of each mixture were initially mixed for 2 to 3 minutes until a uniform mix was obtained. The required w/c ratio according to the mix's workability then added all ingredients and mixed for additional 3-6 minutes.

A sampling of Concrete is taken for this experimental work based on ASTM for compressive strength of concrete taking 90 cubes for 7 and 28 days and 27 cubes for ultrasonic pulse velocity and concrete permeability for 28 days. In this study, I would produce total a sample of 117 cubes for different percentages proportions of fresh concrete, representative samples.

3. Results and Discussions

3.1 Engineering Properties of Materials

The engineering properties of river sand, coarse aggregates, and crushed waste glass are found and the results are given. Sieve analysis, fineness modulus, Silt content (material finer than 75 micro sieves), Organic impurities, Specific gravity, Water absorption, Unit weight, were conducted. The physical properties of river sand, coarse aggregates, and crushed waste glass were determined and shown in table 2.

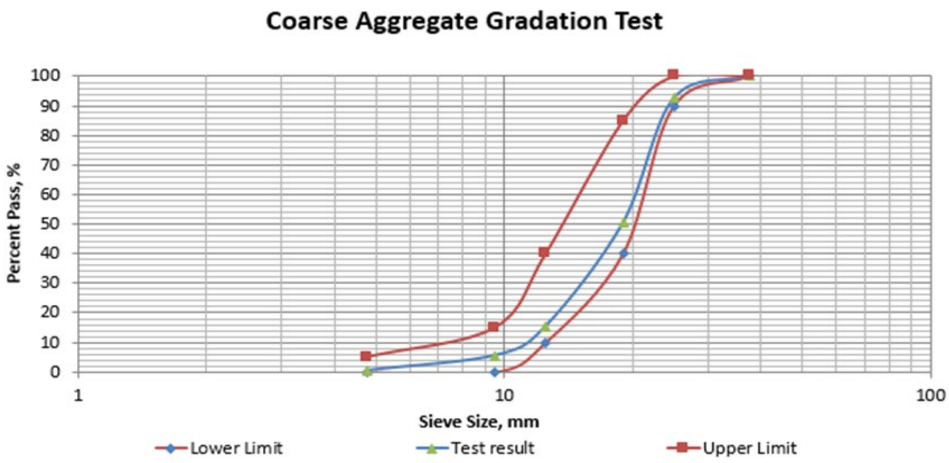


Fig. 1 - Particle size distribution of coarse aggregate

The sieve analysis test result of coarse aggregate is within the Standard limit ASTM C 33. The sieve analysis test result shows that the cumulative percent passing is within the standard limit.

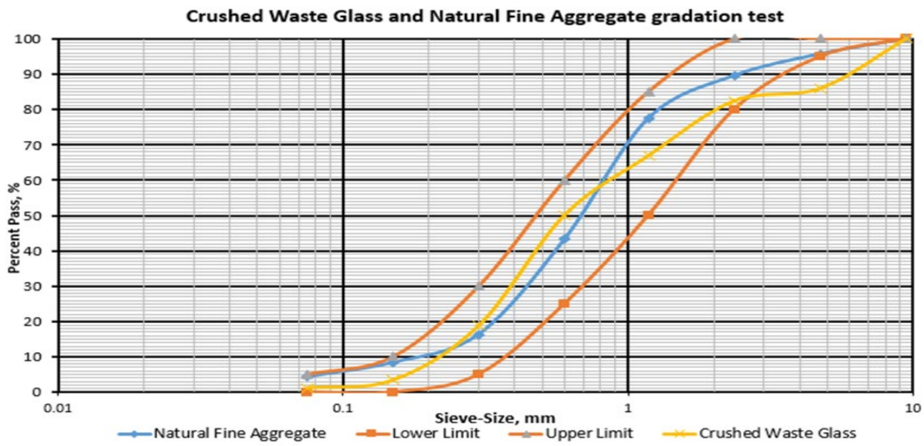


Fig. 2 - Particle size distribution curve for comparison of waste glass with river sand

The test result of each sieve number complies with the standard; hence the river sand and crushed waste glass fulfills the requirements as per ASTM C 33-03 standard except for crushed glass sieve size 4.75mm.

Fig. 3 - Different particle size for crushed waste glass

Table 2 - Engineering properties of materials

Test description	Crushed waste glass	Natural fine aggregate	Course aggregate
Maximum size(Mm)	4.75mm	4.75mm	25mm
Material finer than no 200	1.18	4.30	-
Fineness modulus	2.93	2.69	-
Organic impurity plate no	No 1	No 1	-
Bulk specific gravity	2.49	2.64	2.83
Bulk specific gravity(ssd)	2.50	2.68	2.86
Apparent specific gravity	2.51	2.75	2.86
Water absorption (%)	0.26	1.46	1.15
Unit weight (Kg/M$^{3)}$			
Loss	1466	1600	1527
Compacted	1608	1715	1662

3.2 Properties of Fresh Concrete

3.2.1 Effect of Partial Replacement of Sand by Crushed Waste Glass on Workability (Slump)

The target slumps values were 25mm-75mm, based on ACI Table A1.5.3.4.(a) The slump values were conducted in each partial replacement river sand by the crushed waste glass in 0%, 10%, 15%, 20%, and 25% percentages.

Table 3 - Slump test result for different % crushed waste glass at different W/C

Water-cement ratio	Percent of crushed waste glass	Average slump value, mm	Type of slump failure (ACI)
0.45	0%	30	True slump
	10%	40	
	15%	45	
	20%	45	
	25%	60	
0.47	0%	35	True slump
	10%	45	
	15%	55	
	20%	60	
	25%	65	
0.50	0%	45	True slump
	10%	55	
	15%	65	
	20%	65	
	25%	70	

The incorporation of crushed waste glass in the concrete mix is the replacement percent increase the workability of fresh concrete is increased also the water-cement ratio increase the workability of fresh concrete is increased this is due to the capacity of water absorption crushed waste glass is less due to this the water is released so the fresh concrete is more workable.

A small percentage of crushed waste glass mixes are less workable compared with larger waste glass mixes. All mixes are true failure which ranges between 25mm and 70mm depending on the ACI mix design method standard.

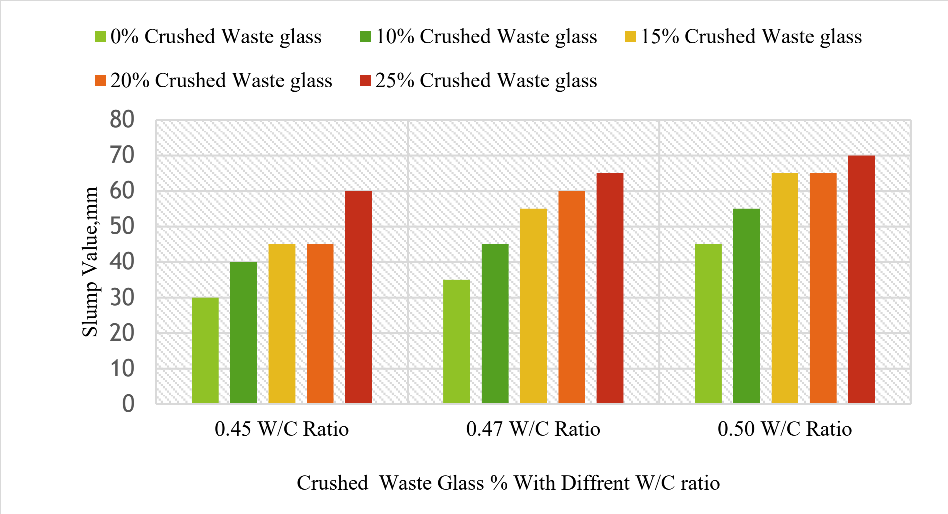


Fig. 4 - Variation of slump with change W/c ratio (mm)

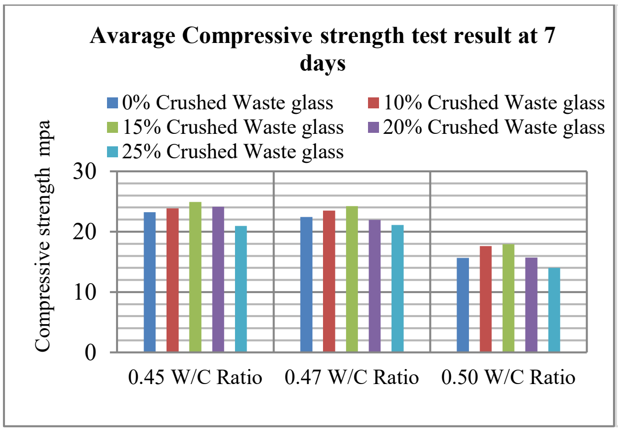
3.3 Properties of Hardened Concrete

3.3.1 Effect of Partial Replacement of Sand by Crushed Waste Glass Compressive Strength Test

The effect of partial replacement of river sand by the crushed waste glass in 0%, 10%, 15%, 20%, and 25% with the water-cement ration 0.45, 0.47, and 0.50 on compressive strength results for 7 and 28 days is shown in Table 4.

Table 4 - Average compressive strength test result (mpa)

Water-cement ratio	Percent of crushed waste glass	Average compressive strength at 7 days (N/mm2)	Average compressive strength at 28 days (N/mm2)
0.45	0%	23.25	41.90
	10%	23.84	42.27
	15%	24.94	43.16
	20%	24.14	41.20
	25%	20.94	37.51
0.47	0%	22.44	37.45
	10%	23.51	38.24
	15%	24.22	40.25
	20%	21.96	35.96
	25%	21.10	34.97
0.5	0%	15.67	26.94
	10%	17.62	27.83
	15%	17.91	28.63
	20%	15.73	25.65
	25%	14.02	23.63



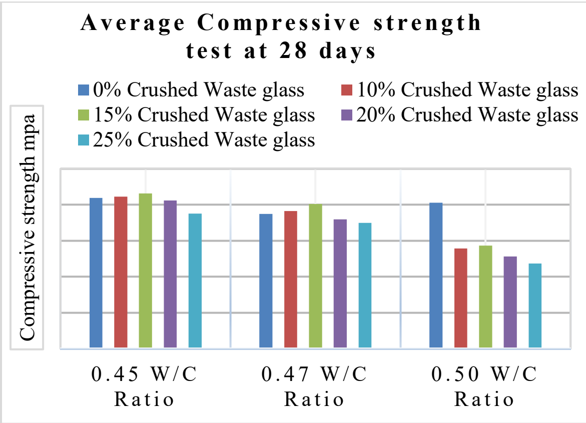


Fig. 5 - Compressive strength results from different % of waste glass with different W/C ratios at 7 and 28 days

The results showed the partial replacement of river sand by the crushed waste glass at 15% is the maximum compressive strength 43.16Mpa, 40.25Mpa, 28.63Mpa at 28 days for 0.45, 0.47, 0.50 water/cement ratio. But at 0.45and 0.47 water-cement ratio is satisfied the target min strength for concrete grade M 30, while at 0.50 water-cement ratio is not satisfy the required target mine strength. Because the angular nature of waste glass particles contributes more to making effective cement. This has resulted in the reduction of microscopic voids in concrete, increasing concrete compressive strength.

3.3.2 Effect of Partial Replacement of Sand by Crushed Waste Glass Ultrasonic Pulse Velocity Test

The Ultrasonic Pulse Velocity test results indicate all percent of partial replacement of sand by the crushed waste glass is good. But the concrete quality of a larger percent of crushed waste glass is at 0.50 water-cement ratio is medium. This is due to the amount of waste glass being increased the void space of concrete is high because the waste glass interlocking effect is poor.

Table 5 - Average ultrasonic pulse velocity at 28 days (km/sec)

Water-cement ratio	Percent of crushed waste glass	Average ultrasonic pulse velocity at 28 days (km/sec)	Concrete quality
0.45	0%	4.20	Good
	15%	4.22	Good
	25%	4.07	Good
0.47	0%	4.18	Good
	15%	4.18	Good
	20%	4.00	Good
0.5	0%	3.70	Good
	15%	3.75	Good
	25%	3.47	Medium

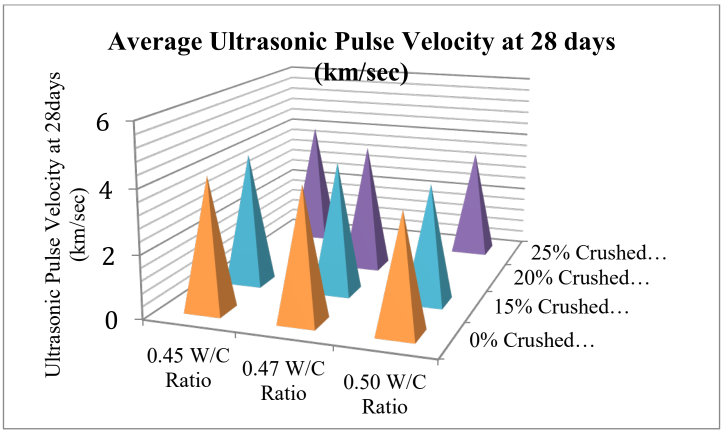


Fig. 6 - Ultrasonic pulse velocity results from different % of waste glass with different W/C ratios @28 days

3.3.2 Effect of Partial Replacement of Sand by Crushed Waste Glass Permeability of the Concrete Obtained by the Depth Penetration Method Test

The depth of penetration and porosity vary directly. As a result percent of replacing crushed waste glass increases the depth of penetration increase due to an increased microscopic void within the concrete as the percentage increase due to insufficient cement paste. The maximum depth of penetration for concrete is 27.2 mm, which is less than 50mm, thus the concrete's durability is unaffected.

Table 6 - Average depth of penetration for concrete test result (mm)

Water-cement ratio	Percent of crushed waste glass	The average depth of penetration for concrete at 28 days (mm)
0.45	0%	10.8
	15%	9.2
	25%	16.5
0.47	0%	11.4
	15%	12.4
	20%	19.2
0.50	0%	12.6
	15%	22.0
	25%	27.2

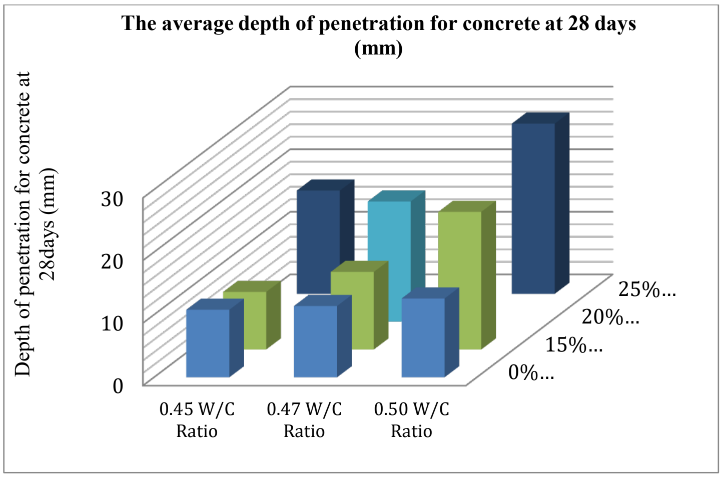


Fig. 7 - Concrete permeability test results from different % of waste glass with different W/C ratios @28 days

Fig. 8 - Cube specimens testing for concrete permeability test

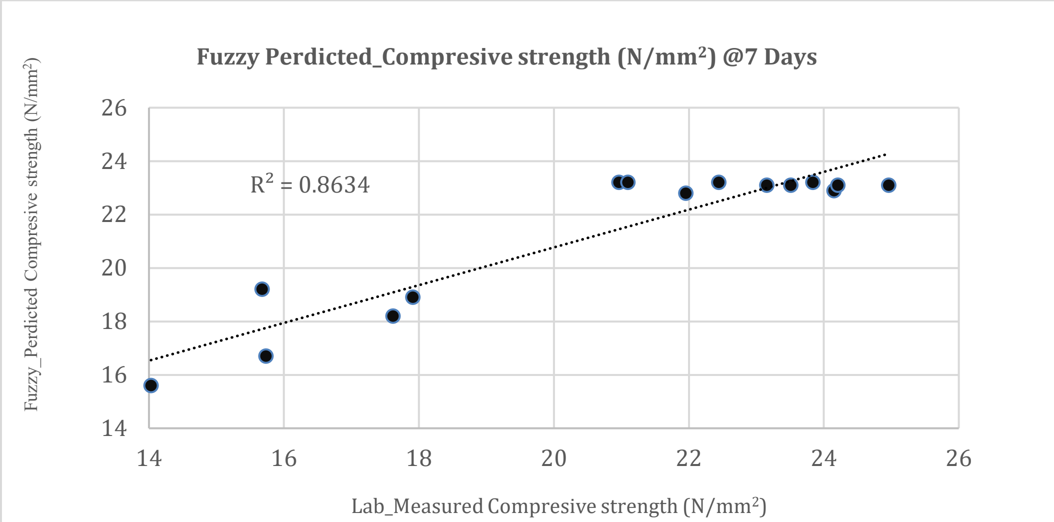
3.4 Fuzzy Model to Predict Concrete Compressive Strength

The assessment of the relationship between compressive strength of partial replacement of sand by crushed waste glass 10%, 15%, 20%, and 25% including a control sample(0%) with varying water-cement ratio was investigated in this research, four input parameters cement, fine aggregates, crushed waste glass, w/c ratio and one output target parameter compressive strength for 7 and 28 days was considered using the concept of fuzzy model.

The fuzzy model was developed bas ed on the Mamdani inference system and the model developed is completely based on experimental data of laboratory test results. The triangular membership function method was used. Also, random select samples are used for a total of 15 mixed design samples, ten samples for the training set and five samples for the validation set, and the fuzzy models were examined using the correlation coefficient (R2), Mean Squared Errors (MSE) and Root Mean Squared Errors (RMSE). The table below showed the predicted output from defuzzification results for 7 and 28days compressive strength for all the15 experimental data.

Table 7 - Prediction output from difuzzification results for 7 and 28 days compressive strength

Mix code	W/C	Cement (kg)	% of WG	Sand (kg)	WG (kg)	Measured compressive strength (N/mm2) @7 Days	Fuzzy predicted compressive strength (N/mm2) @7 Days	Measured compressive strength (N/mm^2) @28 Days	Fuzzy predicted compressive strength (N/mm^2) @28 Days
A1	0.45	10.70	0%	19.67	0.00	23.16	23.10	41.90	39.68
A2	0.45	10.70	10%	17.70	1.97	23.84	23.20	42.28	39.90
A3	0.45	10.70	15%	16.80	2.96	24.96	23.10	43.17	39.90
A4	0.45	10.70	20%	15.80	3.94	24.15	22.90	41.21	39.50
A5	0.45	10.70	25%	14.80	4.93	20.96	23.20	37.51	40.10
B1	0.47	10.30	0%	20.22	0.00	22.44	23.20	37.45	40.00
B2	0.47	10.30	10%	18.20	2.02	23.51	23.10	38.24	39.80
B3	0.47	10.30	15%	17.10	3.03	24.21	23.10	40.25	39.90
B4	0.47	10.30	20%	16.10	4.00	21.96	22.80	35.96	39.40
B5	0.47	10.30	25%	15.10	5.00	21.10	23.20	34.97	40.00
C1	0.5	9.70	0%	20.78	0.00	15.67	19.20	26.94	32.90
C2	0.5	9.70	10%	18.70	2.08	17.61	18.20	27.83	31.10
C3	0.5	0.46	15%	17.70	3.12	17.91	18.90	28.63	32.40
C4	0.5	9.70	20%	16.60	4.20	15.73	16.70	25.65	28.30
C5	0.5	9.70	25%	15.60	5.20	14.03	15.60	23.63	26.50



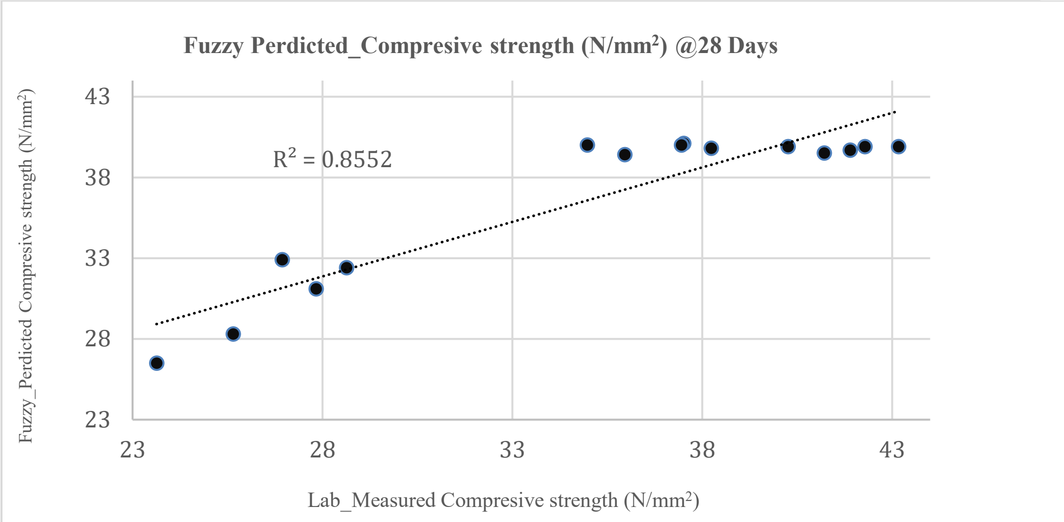


Fig. 9 - Correlation of predicted data with experimental measured data

The predicted versus measured strengths for 7days ad 28 days were very close to the experimental results, which indicate that Fuzzy Logic provide successful predictions as shown table.

Table 8 - Statistic indicator of models prediction performance results for 7 & 28 days

Data sets	7-day compressive strength			28-day compressive strength		
	R^2	MSE	RMSE	R^2	MSE	RMSE
Training set (10 Data set)	0.86	2.8	1.67	0.87	9.76	3.12
Validation set (5 Data set)	0.92	1.34	1.16	0.85	11.03	3.32

4. Conclusion

1. The physical property of course aggregate, fine aggregate, and crushed waste glass satisfies standard specifications.
2. The maximum replacement of fine aggregate with crushed waste glass occurred at a 15% replacement level to achieve the maximum strength and durability in M 30 concrete grade production when compared with the control mix.
3. The partial replacement of sand with crushed waste glass affects the workability of fresh concrete. The crushed waste glass increase the workability of concrete is decreased because the water absorption capacity of crushed

waste glass is less due to this the water is realized and the fresh concrete is more workable.

4. The maximum compressive strength of 28 days was achieved at a 15% replacement level. The partial replacement of sand by crushed waste glass values of 43.16Mpa, 40.25Mpa, 28.63Mpa with w/c ratios of 0.45, 0.47, and 0.5 respectively. However, the target means strength for concrete grade M-30 is satisfied at 0.45 and 0.47 W/C ratios, but the target mean strength is not satisfied at 0.50 w/c ratios. The angular nature of waste glass particles contributes to a more effective cement past. So the reduction of microscopic voids in concrete increases concrete compressive strength by up to 15%. After 15% of replacement, it no contributes to strength resulting in the formation of microscopic voids which reduce concrete compressive strength.
5. The ultrasonic pulse velocity test result of concrete at 28 days all percent of partial replacement of sand by the crushed waste glass is a good quality of concrete. But the concrete quality of a large percentage of crushed waste glass is medium. Due to the amount of waste glass being increased the void space of concrete is high because of the waste glass interlocking effect.
6. The concrete permeability test result of at 28 days the crushed waste glass replacement level increased the penetration depth increased. Due to increase microscopic void space. The minimum penetration depth values at 0.45 water-cement ratio in 15% of crushed waste glass replacement level.
7. The use of waste glass in concrete will preserve natural resources, particularly river sand and thus making the concrete construction industry sustainable.
8. The use of waste glass in concrete will eliminate the disposal problem of waste glass and prove to be environmentally friendly for concrete production. And economical as it is non-useful waste and free of cost.
9. The training and testing results obtained from FL model are very close to the experimental results. It was demonstrated that the developed FL model was successfully trained and tested. The statistical parameter values of R2, MSE, and RMSE have shown clearly this condition. As a result, the fuzzy logic model was able to predict the compressive strength values of normal concrete containing waste glass as a partial replacement of river sand.
10. The study of fuzzy logic in this research work showed an alternative approach that can provide an efficient and rapid means of obtaining optimal solutions to normal concrete containing waste glass as a partial replacement for river sand.

5. Recommendation

Depending on the above study and other similar studies that were particularly conducted in this area, the following recommendation is forwarded:-

For government body

1. Concerned government body shall focus or device directives on the means of collecting waste glass and utilizing it for making material for concrete purposes.
2. Provide continuous awareness to society for disposal system and wise utilization of waste glass from other waste the study of recyclable wastes.

For academic community

1. Academic universities should do more extensive research into the long-term properties and consequences of concrete made from recycled crushed glass.
2. The long-term effects of concrete made with recycled crushed glass in place of fine aggregate require more research and investigation, not well covered needs further study
3. Since the influence of the alkali-silica reaction was not studied in this review, further research is required.
4. The impact of larger-sized recycled crushed glass (greater than 9.5mm BS sieve) on the properties of fresh and hardened concrete shall be investigated.

For different stakeholders

1. Glass is a popular waste product in both residential and industrial settings, but it can be turned into a valuable resource by mixing it into concrete as a partial substitute for concrete-making materials. In both structural concrete, waste glass can be used in place of fine aggregate.
2. Based on current combustion equipment and technology it is difficult to produce a high quantity of coffee husk ash at a time. Thus, the respected stakeholders' have to enrich the technology.

Acknowledgment

The authors would like to thank the Ambo University for giving me the opportunity to conduct this research.

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