

Effect of Recycled Coarse Aggregates (RCA) on Geo-Polymer-Based Concrete

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Received November 07, 2022; Revised April 02, 2023; Accepted July 10, 2023

Abstract

The construction industries are looking towards the production of environmentally friendly concrete, with the use of fewer natural resources, less energy, and minimum carbon dioxide emissions. For this reason, the geo-polymer concrete is one of the best options. The concrete produced with a polymerization process; a reaction between alkaline compounds containing alumina and silica; is called geo-polymer-based concrete. This study is focused on investigating the density and strength properties of geo-polymer concrete with Recycled Coarse Aggregates (RCA). Three mixes were designed with 0%, 50%, and 100% RCA with a fixed water-binder ratio equal to 0.4. The results revealed that the compressive, tensile, and flexural strength of geo-polymer-based concrete with RCA reduced and depended on the percentage of RCA used. The flexural performance of the concrete was observed better compared to compressive and tensile strength. However, the density of concrete is decreased by approximately 14% with the addition of RCA resulting in lighter concrete than the control mix.

Index Terms: Compressive Strength, Conventional and Recycled Coarse Aggregates, Flexural Strength, Geo-Polymer Concrete, Tensile Strength.

I. INTRODUCTION

Due to the rapid growth of the population in the world, to be in line with the pace of development, and the need for a high standard of life, which is increasing day by day, every person tries to live in a well-constructed and architected house [1]. Hence, according to the need of people and the increasing demand of different heavy industrial and residential buildings, large quantity of construction materials like cement is utilized to get the targeted requirement, but it still is difficult to achieve [2]. According to the most recent survey, approximately 2.6 million tons of cement is required each year. Within the next ten years, this amount will be increased by 25%. Due to the fact that limestone is the main source material for ordinary Portland cement, there is a possibility that there will be a critical shortage of limestone within the next 25 to 50 years. In addition, the manufacturing of one ton of cement results in the emission of nearly one ton of carbon dioxide into the atmosphere, which poses a significant threat to the environment. Also, the production of cement requires a significant amount of energy. Consequently, finding an alternative binder is of the utmost importance [3]. Geo-polymer concrete is an option worth considering if you want to produce environmentally friendly concrete that uses fewer natural resources, less energy, and produces the fewest possible emissions of carbon dioxide. Joseph Davidovits, a French materials scientist known for the invention of geo-polymer chemistry, first introduced the concept of the polymerization process of binder in 1978. A reaction between alkaline compounds containing

alumina and silica produces geo-polymers. In contrast to Portland cement, geo-polymers do not rely on calcium-silicate-hydrates for matrix formation and strength; rather, the silica and alumina reaction of an alkaline solution forms an aluminum silicate gel that holds aggregates and provides concrete strength [4]. Davidovits predicted that an alkaline liquid could be used to create a binder by reacting with aluminosilicate in a geological resource material or a by-product material such as fly ash [5]. Waste products such as fly ash and silica fumes, as well as Grounds Granulated Blast Furnace Slag (GGBS), are used to create geo-polymer cement concrete [6]. Materials for the production of geo-polymers can be chosen based on their cost and availability, which is determined by user demand [7]. The chemical and physical properties of fly ash geo-polymer concrete are excellent, making it suitable for structural construction [8-9]. In general, fly ash of Class-F can be utilized in the production of geo-polymers with high strength [10]. To produce geo-polymer, reactive aluminosilicate material is mixed with strong alkaline solutions that include Potassium Hydroxide (KOH), Sodium Hydroxide (NaOH), potassium silicate, or sodium silicate [11]. To create the geo-polymer precursors and final alumino-silicate material, the alkaline activation solution must dissolve Silica (Si) and Alumina (Al) atoms [12-16]. The type of alkaline liquid used is crucial in the polymerization method [17]. Both potassium hydroxide and sodium hydroxide are strong bases with nearly identical solubility in water at room temperature [18]. The setting time of geo-polymer concrete decreases as alkaline concentration increases [19]. It demonstrates that the



higher the alkaline, the faster the polymerization and the shorter the initial time. As the alkaline concentration rises, geo-polymer concrete's compressive strengths will rise [20]. Additionally, different sodium silicate and sodium hydroxide mix ratios and curing techniques affect compressive strengths [19]. Geo-polymer concrete can be baked or left to cure at room temperature [21]. When curing in the oven, compressive strength will set more quickly [22-23].

It is evident that a good quantum of work has been produced by the research community on the topic, yet various aspects are inconclusive due to scatter in results. Also, very limited work has been undertaken on this topic regarding the use of recycled coarse aggregates in the production of geo-polymer concrete in Pakistan. Therefore, this research study aims to investigate the effect of recycled aggregates from demolished waste on geo-polymer-based concrete by conducting laboratory investigations of the density, compressive, tensile, and flexural strength of the proposed concrete.

II. MATERIALS AND METHODOLOGY

A. Materials

a) Micro Fly Ash:

Micro fly ash of Class-F conforming ASTM C 618 is used [24]. The material was obtained from the power sector of the Thar Desert of the Sindh Province. Figure I shows the pictorial view of the material.



Figure I: Pictorial View of Micro Fly Ash

b) Silica Fume:

Silica fume conforming ASTM C1240-20, [25] and obtained from BASF Chemicals Karachi was used throughout the study. The pictorial view of the material is shown in figure II.



Figure II: Pictorial View of Silica Fume

c) Sodium Hydroxide (NaOH):

Sodium Hydroxide (NaOH) is a byproduct of the chlorine alkali process. It is also called Caustic soda. It is a white and crystal-like substance locally available in the vicinity of Nawabshah. The same was used in the present study.

d) Sodium Silicate Na_2SiO_3 :

Sodium Silicate (Na_2SiO_3) is a substance locally named 'Glass-Water' that is thick and heavy. It was used as additional material for the formation of geo-polymers.

e) Alkaline Liquid Solution:

In this study, a working mixture of sodium hydroxide and sodium silicate solutions with a molarity equal to 13 was selected [9]. The solution of sodium silicate and potable water was used to form sodium hydroxide solution.

f) Fine Aggregate:

Sand from a nearby river that has a specific gravity of 2.81 and a fine modulus equal to 2.75 was used.

g) Coarse Aggregate:

In this study both the crushed and recycled coarse aggregates having specific gravities equal to 2.73 and 2.51 respectively were used. The particle size of the aggregates was 20-15mm.

h) Water:

Potable water used for drinking purposes was used throughout the study. The pH value of the water was recorded as equal to 6.9.

B. Methodology

a) Preparation of Alkaline Activator Solution:

A solution of sodium hydroxide and sodium silicate serves as an alkaline activator for polymerization. In order to make 1 liter of NaOH solution with a molarity of 13 M, 520g of sodium hydroxide (13 molarity x 40 molecular weight) flakes were dissolved in potable water. The mass of NaOH solid in a solution varies with solution concentration expressed in molarity. The presence of 350g/kg of solid NaOH yielded a NaOH solution with 13 Molarity. This demonstrates that the main component of the sodium hydroxide solution is water. After mixing, the solution is left to sit for 24 hours. Figure III shows the pictorial view of NaOH, Na_2SiO_3 , and alkaline solution.

b) Preparation of Geo-Polymer Concrete:

The alkaline solution was made one day before to activate the solution. A 1:1:2 ratio of concrete was adopted. Three different batches were produced by using Recycled Coarse Aggregates (RCA) in the dosage of 0%, 50%, and 100% and named as CM, B1, and B2 respectively. In all the mixes 70% fly ash and 30% silica fume were used as binder content. The water binder ratio was kept constant at 0.4 throughout the study. The dry mix was combined with the wet alkaline solution, and the mixer was run for four minutes. The required workability of concrete was maintained by using a 2% superplasticizer (optimum dosage).



Figure III: Pictorial View of NaOH, Na₂SiO₃, and Alkaline Solution

c) Casting of Specimens:

In each batch of geo-polymer concrete six cube specimens (4"x4"x4"), six cylinders (4"/8"), and six prisms (4"x4"x20") were cast. Weight batching was done during the casting of the specimen. The casting of the specimens was done in steel molds. Before pouring the concrete, the molds were oiled to make it easier to remove the concrete from the mold. The casting was completed in accordance with ASTM C470's standard operating procedure [26]. Molds were removed and kept for curing after 4 days.

d) Curing of Geo-Polymer Concrete Specimens:

After 4 days of being in molds, the hardness of specimens was ensured by scratching with nails, then de-molded. For curing, the specimens were kept in plastic foil for 28 days (Ambient curing) at room temperature.

e) Instrumentation and Testing:

The weight of the cube specimens was determined in turn to compute the density of the concrete. Obtained results are given in table I. Following density determination compressive strength of the specimens was determined in accordance with ASTM C39 [27] using UTM with 1800kN loading capacity. Each specimen's weight was observed before exposure to the test, and its density was determined. The specimens on the machine were arranged so that the load was distributed evenly across their top and bottom. The test configuration is depicted in figure IV. The load was gradually increased at a rate of 100 N/mm²/min without applying any shock. The peak load was recorded and converted into compressive strength using the standard formula of stress. The obtained results for all six specimens are listed in table I.

Following the compressive strength determination split tensile strength of cylinder specimens was determined as instructed by ASTM C496 [28] using the same machine and configuration explained earlier. The selected specimen

during testing is shown in figure V. The failure load was recorded and converted into split tensile strength using a standard formula for split tensile strength of cylinder specimens. Obtained results are listed in table II.

The prism specimens were then used to determine the flexural strength in accordance with ASTM C293 [29]. Again, UTM was used for the purpose. The specimens were loaded using a central point load (figure VI). The load was gradually increased till failure. Failure load was then used to evaluate the flexural strength. The obtained results are shown in table II.

Table I: Density and Compressive Strength

S. No.	Density (kg/m ³)			Compressive Strength (MPa)		
	CM	B1	B2	CM	B1	B2
1.	2299	2096	1989	15.36	12.55	9.13
2.	2281	2128	2015	14.80	10.68	9.57
3.	2325	2149	1993	13.25	11.59	8.98
4.	2335	2171	2054	14.83	12.49	10.12
5.	2314	2182	2008	14.45	10.89	9.69
6.	2389	2134	2034	13.47	11.23	9.39

Table II: Tensile and Flexural Strength

S. No.	Tensile Strength (MPa)			Flexural Strength (MPa)		
	CM	B1	B2	CM	B1	B2
1.	20.28	16.66	12.32	2.30	1.95	1.71
2.	18.94	15.41	13.83	2.16	1.96	1.77
3.	18.68	15.51	12.25	1.88	1.85	1.67
4.	17.65	15.85	13.91	2.40	1.81	1.62
5.	19.79	14.45	12.65	2.49	1.83	1.68
6.	16.97	14.54	12.57	2.05	1.88	1.72



Figure IV: Test for Compressive Strength



Figure V: Test for Tensile Strength



Figure VI: Test for Flexural Strength

III. RESULTS AND DISCUSSIONS

A. Density (Unit-Weight)

The average density of the individual samples was evaluated and is shown in figure VII for dosages of RCA used in this work.

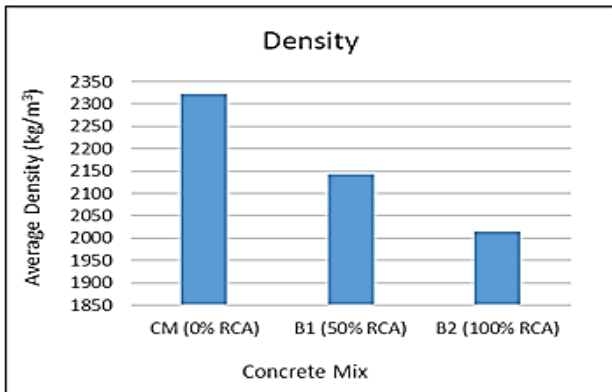


Figure VII: Average Density of Geo-Polymer-Based Concrete

It can be observed that the density of geo-polymer-based concrete with conventional coarse aggregates is higher. The maximum density value of 2323 kg/m³ is recorded. It reduced with an increase in the replacement of conventional coarse aggregates with RCA. The geo-polymer concrete prepared with 50% RCA and 50% conventional aggregates is approximately 8% less than the geo-polymer concrete with all conventional coarse aggregates. This implies that the geo-polymer concrete with RCA is lighter than the conventional geo-polymer concrete. The geo-polymer concrete mix with 100% RCA was found 13% lighter than conventional geo-polymer concrete. It is indeed due to the attached mortar with RCA and the porous nature of the same which results in reduced weight of the specimen. However, it is not the only property to conclude the dosage. Strength properties should also be considered before making the final decision on the dosage of RCA.

B. Compressive Strength of Geo-Polymer-Based Concrete

The compressive strength computed for individual specimens was averaged within batches. The obtained results are illustrated in figure VIII. The comparison of the

parameter for geo-polymer concrete with and without recycled aggregates shows that the compressive strength of geo-polymer-based concrete is decreased with the addition of RCA. The mix with 100% conventional coarse aggregates exhibits 14.36 MPa compressive strength at the age of 28 days. By replacing the conventional coarse aggregates with RCA at 50% and 100% the compressive strength is decreased by 20% and 34% respectively. From figure VIII, it may be concluded that geo-polymer concrete manufactured with coarse aggregates from demolished concrete possesses lesser compressive strength than concrete with fresh coarse aggregates. It is mainly due to the age and exposure of the concrete used to produce the recycled aggregates. Both of the factors result in lesser strength of aggregates also the old mortar adhered with the aggregates increases the water demand of the concrete matrix, thus the final strength of the product is affected.

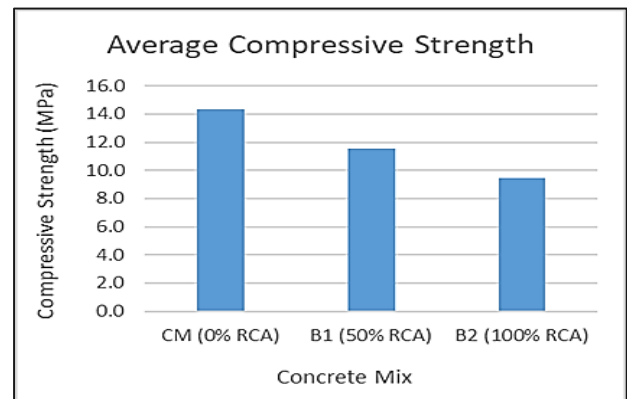


Figure VIII: Average Compressive Strength of Geo-Polymer-Based Concrete

C. Tensile Strength of Geo-Polymer-Based Concrete

The tensile strength of individual specimens in each batch of concrete was averaged and is illustrated in figure IX. Again, like compressive strength the decline in the parameter value may be observed with an increase in dosage of RCA. Concrete batch B1 with 50% RCA observed about 18% whereas the mix B2 with 100% RCA observed about 31% decline in the parameter value in comparison to the geo-polymer concrete with all conventional aggregates. Although slight betterment in the average tensile strength than compressive strength is observed, yet the weakness is evident due to the same reasons as mentioned earlier.

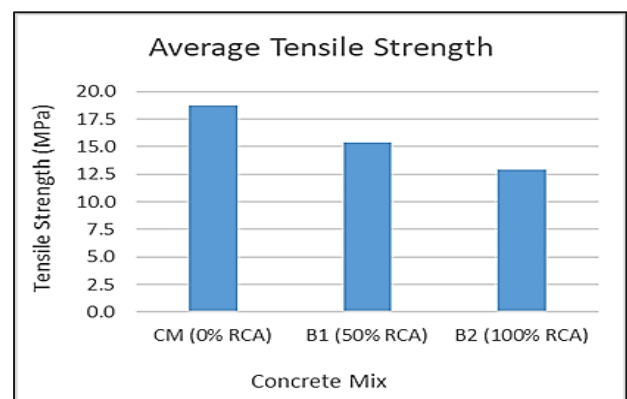


Figure IX: Average Tensile Strength of Geo-Polymer-Based Concrete

D. Flexural Strength of Geo-Polymer-Based Concrete

The flexural strength of individual samples presented earlier was averaged and for all three mixes is illustrated in figure X. Analogous to compressive and tensile strengths, the flexural strength of geo-polymer concrete with RCA also observed declined trend with an increase in dosage of RCA. The percent deviation of the parameter for mix B1 was recorded as equal to -15%. The same for mix B2 was equal to -24%. The values show that the performance of geo-polymer concrete with RCA in flexure is better compared to the compressive and tensile strength. However, the weakness of concrete in comparison to its counterpart without RCA is evident. It may further be noted that the percentage difference in flexural strength of B1 and B2 is less compared to the same for compressive and tensile strength. It shows that a change in dosage of RCA from 50% to 100% has less impact on the flexural strength.

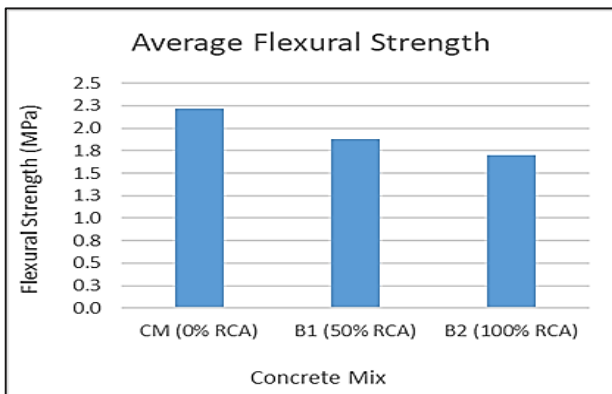


Figure X: Average Flexural Strength of Geo-Polymer-Based Concrete

For better visualization and checking the percent loss of the properties considered in this work is plotted in figure XI.

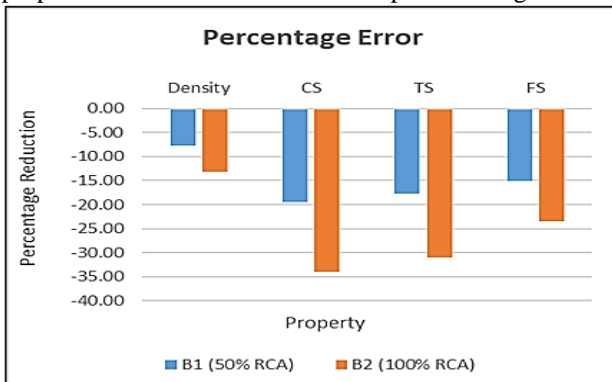


Figure XI: Percentage Reduction in Density and Strength Properties

Although the bonding force of geo-polymer material is reasonably good, but it is not in line with conventional cement, with which the hydration process yields better bonding than geo-polymer. However, further fine-tuning of the materials including the dosage of RCA used in this research study is required to check their impact on the hardened properties of the concrete. It is also evident that the use of 100% recycled aggregates in geo-polymer-based concrete is not feasible as the residual strength of the concrete is less, hence is not suitable for structural elements. However, the geo-polymer-based concrete with 50% RCA may be recommended for the non-structural element or low load-carrying element.

IV. CONCLUSION

From the outcome of laboratory investigations presented in this research work, it may be concluded that both the density and strength properties of geo-polymer-based concrete depend on the proportion of RCA used to replace the traditional aggregates based on the results of laboratory investigations presented in this research work. With the addition of RCA in geo-polymer concrete, it was observed that the density, compressive strength, tensile strength, and flexural strength of the concrete all decreased. The maximum decrease in unit weight was observed at 13% for the mix with 100% RCA.

The residual compressive strength of mix B1 and B2 was 81% and 66%, the residual tensile strength was 82% and 69% and the residual flexural strength was 85% and 77% respectively. It shows a decreasing trend of the hardened properties of the concrete. The flexural performance of the concrete is better compared to the compressive and tensile strength of the concrete. However, it is evident that higher dosages of RCA may be avoided as the residual strength properties are less compared to the lower dosages of RCA.

Acknowledgment

The authors would like to pay thanks to the Quaid-e-Awam University of Engineering, Science and Technology, Sindh, Pakistan for supporting this study.

Authors Contributions

The contribution of the authors was as follows: Muneeb Ayoub Memon's contribution to this study was the concept, technical implementation, and correspondence. The methodology to conduct this research work along with supervision were proposed by Bashir Ahmed Memon, Shahzeb Khan Jamali. Data collection, data compilation and validation, project administration, and paper writing were performed by Ali Arsalan Memon, and M. Umair Bhatti.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Data Availability Statement

Upon request, the corresponding author will deliver the information used to support the study's findings.

Funding

No funds, grants, or other support was received.

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