Enhancing Properties of Geopolymer Concrete with Recycled Coarse Aggregates

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Abstract:

Among the resources that people use the most worldwide is concrete. Alternatives to traditional concrete, such as geopolymer concrete, are being investigated in light of the rising focus on environmental issues worldwide, including global warming, sustainable development, and recycling. Portland cement is not present in the alternative binder used in geopolymer concrete, which takes the place of cement-based binder. A particular kind of geopolymer binder is one that has fly ash in it that has been activated by a sodium hydroxide and silicate alkaline solution. There may be financial and environmental advantages to using recycled concrete waste from building and demolition sites as a supply of aggregate rather than having it dumped in a landfill. Aggregate made from crushed building and demolition waste is referred to as recycled concrete aggregate (RCA). When combined, recycled concrete aggregate and geopolymer concrete employ waste materials and do away with the requirement for Portland cement. Recycled concrete aggregate (RCA), regular Portland cement concrete, and geopolymer concrete have all been the subject of extensive research; but, at the time of this study, there was little information available regarding the use of RCA in geopolymer. Investigating the mechanical characteristics of geopolymer concrete with recycled concrete aggregate in place of some of the natural coarse aggregate was the goal. The research findings that point to the possibility of adding RCA to geopolymer concrete mixtures are presented in this research work.

Keywords: Geopolymer Concrete, Recycled Coarse Aggregates, Compressive Strength.

1. Introduction

As the importance of climate change and global warming increases, several governments are exploring various strategies to cut greenhouse gas emissions in order to meet their obligations under the Kyoto Protocol [1]. One of the most harmful greenhouse gases is carbon dioxide, which is responsible for 65% of global warming [2]. With an estimated 1.35 billion tons of emissions from cement production each year, Portland cement is a major contributor to greenhouse gas emissions [3]. About 0.8–1 tonne of carbon dioxide are released each tonne of cement produced [4], which is equivalent to about 3% of all greenhouse emissions worldwide [1]. Using Geopolymer concrete is one way to cut down on the amount of cement used. As the world's natural resources are being depleted and the quantity of waste being dumped in landfills worldwide is rising, recycling is also receiving more attention. Reusing construction and demolition waste is therefore becoming more and more crucial as industrial development progresses, and numerous methods for the large-scale utilization of recycled concrete have been investigated. Previous studies and presentations have examined the characteristics of concrete that contains either recycled natural aggregate or recycled concrete as the coarse aggregate [5–9]. Using recycled concrete aggregate as a base and in pavement construction is an extensively investigated and implemented solution [10–14]. Davidovits [15] is credited with creating geopolymer concrete when he originally suggested in 1978 that a geopolymer matrix may take the place of cement as the binder in concrete.

According to Davidovits theory, a cement-like binder might be created by adding an alkaline solution to a source material rich in silicon and aluminum. This type of binder was dubbed a "geopolymer." In Australia, fly ash is the most often utilized raw material for geopolymer concrete due to its accessibility and ideal composition—it has a low calcium concentration and minimal ignition loss. Other materials, such as rice husk ash, blast furnace slag, metakaolin, and naturally occurring Al-Si minerals, can be utilized instead because they are high in silicon and aluminum. One by product of the coal industry is fly ash. There is ample evidence supporting its use in Portland cement concrete [16]. It is a fine particulate generated during the burning of coal that gathers in the combustion system's particle cleaning system. The production of fly ash in Australia alone reached 14 million tons in 2008 [17]. Still, despite higher use for certain applications, less than 30% is utilised advantageously [17]. A mixture of potassium hydroxide and potassium silicate or sodium hydroxide and sodium silicate is typically employed in the alkaline solution that activates the fly ash or other source material. A far faster reaction than that produced by the hydroxides is produced by the silicates [18]. As a result, a mix of the two is utilized to create a matrix that is strong, practical, and sets rather quickly. It has been demonstrated that fly ash-based geopolymer concrete has compressive and tensile strengths up to 65 MPa, which is comparable to general Portland (GP) concrete [19]. The alkaline liquidto-fly ash ratio by mass, the water-to-geopolymer solids ratio by mass, the wet-mixing time, the heat-curing temperature, and the heat-curing duration are the parameters that primarily determine the strength [20]. The fly ash utilized in this study usually contains less than 2% by mass of calcium oxide and a loss of ignition of 1.6% [21]. Rubbish from construction and demolition projects makes for up to 40% of all rubbish produced globally. Since recycled concrete aggregate (RCA) is the best substitute for natural coarse aggregate, it makes up the bulk of recycled aggregate used in Australia. RCA is created from building and demolition waste. Although less often, fine recycled aggregates are also utilized in place of natural sand [22]. For every cubic meter of concrete produced, using recycled aggregate can reduce waste by 60% and mineral depletion by 50% [23].

2. Materials and Methodology

Based on the geopolymer mix designs created at Curtin University in earlier studies, the basic mixture design for the non-RCA geopolymer combination was created [19]. From this, different percentages of the natural aggregate were substituted with the RCA to create the other combinations. To keep the combined aggregates' grading comparatively continuous, only the 20 mm natural aggregate was changed; nevertheless, the replacement % was calculated as a proportion of the coarseaggregates total mass. Since it has been discovered that greater replacements of the natural aggregate may have a negative impact on the mechanical qualities, thirty percent replacement of the natural aggregate is the typical percentage of RCA used in recycled aggregate general purpose concrete. In order to identify any trends resulting from variations in the replacement % of RCA in the mechanical properties of the geopolymer concrete, a starting point of 30 percent was selected for comparison, and batches of 20 and 40 percent were also employed. This resulted in the mixing designs that Table 1 shows. The symbol R#, where # is the batch's percentage of recycled aggregate, is used to refer to the batches. For instance, R20 designates a batch in which recycled concrete aggregate (RCA) replaces 20% of the total aggregate mass. After the aggregates were soaked, drained, and dried on trays in the laboratory, samples of the aggregates that had been brought to surface saturated dry condition (SSD) had their moisture content measured. The water content of the aggregates at the time of mixing was adjusted to SSD moisture content by adding water to the aggregates before the addition of fly ash or chemicals, after the SSD moisture content for each kind of aggregate was established (0.8% for coarse aggregate and 2.5% for fine aggregates). In addition to the water mentioned in Table 1's mixture details, this additional water is added to the aggregates to achieve SSD. About one-third of the nominal 20 mm aggregate in the RCA contained steel fibers and included crushed concrete, granite, and quartz. There were trace amounts of pollutants from masonry and plaster. With only

25% of the aggregate remaining on the 20 mm sieve, the aggregate did not meet the AS 2758.1 limitations for a 20 mm aggregate (AS 2758.1 limit 85-100%). All of the mixtures' graded aggregates had a fineness modulus of roughly 5.0, which was previously determined to be appropriate for geopolymer blends. An alkaline solution consisting of 8 M sodium hydroxide and sodium silicate was utilized. In terms of cost, accessibility, and ease of use, a sodium-based solution with a hydroxide to silicate ratio of 2.5 was chosen over a potassium-based solution. [19].

Table 1: Mixing Details

Constituent	Mixture constituents (kg/m^3)			
	R0	R20	R30	R40
20 mm	450	302	23	54
10 mm	214	217	220	225
7 mm	455	457	458	460
RCA	0	235	367	489
Sand	545	545	545	545
Flyash	395	395	395	395
Sodium Silicate (55.9% solids)	110	110	110	110
Sodium Hydroxide 8M	46	46	46	46
Water	25	25	25	25
Total Mass	2215	2307	2164	2654
Slump (mm)	220	210	200	200

The casting and mixing procedures were followed as closely as feasible to the GP cement concrete process. This will facilitate the industry's commercial adoption of geopolymer concrete and enhance quality control due to the methodology's familiarity. As such, casting was done using the procedure outlined in AS1012.8.1[25]. The geopolymer cylinders were cured for eighteen hours at sixty degrees Celsius in a steam curing facility. This curing regime was found to be successful in earlier Curtin University study. Temperature data logging in the steam room chamber using K type thermocouple wires revealed that the temperature fluctuated between 50 and 65 degrees Celsius, and that the temperature inside the geopolymer specimens was 40 to 50 degrees Celsius in a matter of hours. These findings are in line with other curing regimens at Curtin University [26].

3. Results and Discussion

3.1 Compressive Strength

In compliance with AS1012.9 [27], three compression cylinders were tested one day, seven days, twenty-eight days, and ninety-one days following casting. To increase the testing surface, sulfur caps were placed on all of the compression cylinders before testing. The compressive strengths obtained from the compressive cylinder tests are depicted in Figure 1, whereby the compressive strength was seen to be between 25 to 33 MP after 28 days, and the mean compressive strength ratio from day 1 to day 28 was approximately 70%. These values correlate to a typical strength of about 30 MPa (25 MPa for the R40 combination) and are appropriate for a wide range of applications. Despite the RCA's compositional variability, the addition of the RCA to the geopolymer concrete did not cause the standard deviation of the compressive strengths to increase, indicating that the batches' consistency was satisfactory when compared to the non-RCA batch. All of the batches containing RCA had 28-day mean compressive strengths that were lower than the R0 batch. The strength decrease of the R20 and R30 batches, however, was not statistically significant.

The average ratio of the relative compressive strengths in Table 2 represents the strength decline. This ratio is computed by comparing the compressive strengths for each age group with the corresponding R0 compressive strengths. For example, for R20, the ratio was 29/33 = 0.88 on day 28. Strength reduction (less than 10%) for R20 and R30 mixtures reported in OPC mixtures with equal concentrations of RCA is within the range of strength reduction observed with GP concrete including RCA. But compared to other studies on GP cement concrete with RCA, the R40 mixture exhibits a more severe loss (of the order of 20% for the mean compressive strengths) [28]. This implies that, in light of strength considerations, the percentage of RCA should be restricted to 30%.

3.2 Tensile Strength

The Brazilian indirect tensile method was used to test the tensile cylinders. In compliance with AS1012.10 [20], tensile tests were performed on two cylinders at one day, twenty-eight days, and ninety-one days. The tensile strengths shown in Table 2 were obtained from the tensile cylinder testing. Because of the percentage substitution of aggregate with RCA, the tensile strengths of the various batches don't seem to be trending, and the scant data makes analysis difficult. For all blends, the indirect tensile strength was found to be roughly 2.5 MPa. Overall, it was found that the tensile strength exceeded the expected value by about 15% using A.S. 3600-2009, where fct = 0.9 fct.sp, or 0.36-fcm in the absence of such data.

Table 2: Compressive Strength Properties

Property	Mixture Designation			
	R0	R20	R30	R40
Day 1 Compressive Strength fcm1 (MPa)	21±2	19±2	18±2	16±2
Day 7 Compressive Strength fcm7 (MPa)	23±1	23±1	21±2	19±2
Day 28 Compressive Strength fcm28 (MPa)	30±2	27±2	27±1	23±2
Day 91 Compressive Strength fcm91 (MPa)	32±3	31±2	31±2	29±2
Relative (to R0) compressive strength (average for all days 1, 7, 28 and 91)	1	0.93	0.91	0.80
Day 1 Indirect Tensile Strength fct.sp1 (MPa)	2.3±0.1	2.2±0.4	2.2±0.2	1.4±0.1
Day 28 Indirect tensile Strength fct.sp28 (MPa)	2.4±0.1	2.3±0.3	2.2±0.5	2.2±0.3
Day 91 Indirect Tensile Strength fct.sp91 (MPa)	2.6±0.2	2.5±0.5	3.4±0.2	3.0±0.2

4. Conclusions

Fly ash and alkaline solutions can be used to create geopolymer concrete using standard casting and mixing techniques. When compared to GP concrete with the same compressive strength, geopolymer concrete with steam curing for 16 hours at a temperature of 60 degrees Celsius results in mid-range compressive strengths of about 32 MPa, as well as much less shrinkage and more tensile strength.

However, the shrinkage findings of the geopolymer mixtures with RCA were much lower than the results predicted by AS3600, as has been shown in prior research on geopolymer concrete. The shrinkage rose as the proportion of recycled concrete aggregate (RCA) increased. These advantages could be used in structural applications, and studies on the endurance and design of goods made with geopolymer concrete are still ongoing. Given that less cement is used and industrial byproducts—which are usually destined for landfills—are reused in geopolymer concrete with RCA, a partial substitution of coarse aggregate with recycled concrete aggregate may have a positive ecological impact.

Comparable GP cement-based concrete with RCA has a similar loss in compressive strength as geopolymer concrete mixtures where natural coarse aggregate is partially substituted with RCA. This indicates that geopolymer concrete containing up to 30 percent RCA can be used to develop strengths for nominal grade 32 MPa concrete without affecting the mix design. It may also be possible to produce higher strengths with minor mix design adjustments, similar to modifying the water to cement ratio byadusting the water to Geopolymer solids ratio. Low standard deviations were seen in the compressive strength results of the RCA geopolymer batches, suggesting that the RCA may not have an impact on the mix's consistency and quality in terms of compressive strength. Curtin is currently conducting additional research to determine the impact of the RCA in both Geopolymer and GP cement base cocretes.

5. References

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