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Use of Pulverized Recycled Glass in Concrete

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The potential to use recycled products in building methods and materials is important to consider. A problem exists in the recycling process where many city municipalities have removed glass recycling from their recycled waste stream forcing consumers to waste glass into a common waste stream for all waste. At Central Washington University (CWU), use of pulverized glass in concrete was analyzed to determine the difference in strength of the concrete when reducing the amount of virgin concrete sand in concrete as a material. With an applied research methodology, the researcher studied the effects of reducing virgin sand and replacing it with locally sourced pulverized glass. A control was used for a typical 3,000 psi concrete mix commonly found in structural concrete applications on roads, bridges, buildings, and foundations. Reductions in virgin sand were made at 25% and 50% and replaced with pulverized glass at the same percentage within the concrete mixture. Concrete compression tests were performed on three concrete 6-inch by 12-inch cylinder samples at the specified virgin sand and sand reduction levels using the American Society of Testing Materials (ASTM) standards. Results showed an eleven percent (11%) and twelve percent (12%) reduction in concrete strength using pulverized glass for sand.

Key Words: Pulverized Glass Sand, Virgin Sand, Recycled Glass, Concrete, Sustainability

Introduction

There are many consumer products that are recyclable. As Jacoby (2019) states, glass is a 100% recyclable material, nearly 10 million metric tons of glass is disposed of every year in the U.S., and 33% of waste glass gets recycled in the U.S. This compared to several European nations where 90% of glass gets recycled on average each year is quite low. Glass is made from readily available domestic materials such as sand, soda ash, limestone, and “cullet.” It is also known that some glass products cannot be used in the manufacturing of new glass storage containers because the glass may be contaminated, or the recycled glass particles are too small to meet manufacturing standards to be reused. Glass that cannot be recovered for the creation of new containers can then be used for non-container use or “secondary” uses include tile, water filtration, sandblasting, concrete pavements, and parking lots (www.gpi.org/glass-recycling-facts).

There are many municipalities where residents could take their used glass to be deposited to a common location to be processed and recycled. In some locations, the collection and movement of the glass to be recycled provides the consumer or individual depositing the glass to be paid a certain amount of money based on collections made in the initial purchase the glass product. About ten (10) states have laws established for consumers who get paid to recycle glass, these states include California, Connecticut, Hawaii, Iowa, Massachusetts, Maine, Michigan, New York, Oregon, and Vermont (Williams, 2019).

While some states have laws established for consumers to be paid for recycling glass and other materials, other states may have drop off locations for recyclables using a multi-stream or single stream collection point. In the state of Washington, there are some site locations consumers can drop their recyclables that will be transferred to a different location to be processed into a usable material. There are costs associated with the transfer of the recycled material to each individual processing location. In some cases, especially in rural areas, the material will be handled multiple times until it is processed, this creates an additional cost associated with the processing effort that some entity must absorb. Glass may be collected at a single transfer station but will ultimately be trucked to additional locations to be sorted and processed to become a usable material. In 2019, the City of Ellensburg, Washington eliminated the collection of glass at the local transfer facility. Within Washington state there were several other locations where collection points were eliminated to collect and process recycled glass due the cost of transportation. This forces consumers to find alternative locations or methods to either recycle glass or dump glass into the landfill.

The City of Ellensburg, Washington eliminated the recycling and transportation of glass due to the costs, market use of recycled glass, and cross contamination of glass that make it difficult to process. Other cities and states like Sarasota County, Florida, and Mecklenburg County, North Carolina were also forced to rethink their glass recycling efforts due to costs associated with the production and processing of recycled glass (Rogoff & Gardner, 2016). Once glass is recycled there are the challenges associated with the collection, transportation, and processing and recycling of glass. In other areas around the country the challenge of collecting and transporting consumer glass has been either eliminated or redirected to a different waste stream. Some recycling centers have a focused waste stream for different recycled materials to include paper, glass, cardboard, tin, steel, and various plastics. Other locations will have a multi-stream system that allows the consumer to dispose of their recycled material in one place to be either picked up curbside or dropped at a transfer center to be processed. When these materials are collected, in many cases the bulk recycled materials must be transported to a different location to be processed into a material that can be re-used as another material for different product applications. A prime example of this is the use of plastic bottles that are collected and recycled to be used in clothing applications (Bastone, 2022).

The use of recycled glass has been around for many years in the production of new products and different building applications. Glass has been found to be utilized as subgrade material for pipe installation, coarse aggregate, hot mixed asphalt, structural and architectural concrete, mortars, and precast concrete (Afshinnia, 2019; Dehghanpour & Yılmaz 2019; Meyer & Xi, 1999). These secondary uses provide an additional use for recycled glass that would normally be placed in the landfill and increase demand for the use of recycled glass.

Literature Review

The recycling effort from consumer to the processing of recycled glass to be utilized in new materials and construction means and methods has been researched. There have also been advantages and disadvantages associated with the application of recycled glass in concrete. As Afshinnia (2019) has identified the fact that most mixed glass usually cannot be recycled into some building materials due to its chemical properties that can have a reaction with other materials in the material mixing process.

To properly recycle glass, it is advisable to separate the different colors of glass due to the chemical composition of the colored glass which consist of sand, soda ash, limestone, and cullet. This is especially true when using concrete for household counter tops. When converting used glass to a building material there are challenges associated with recycled glass to be considered so the material can be used with other material applications. A challenge when recycling glass into concrete is a chemical reaction that is created known as an alkali-silica reaction (ASR). In concrete applications, this must be neutralized in the mixture to assist with the quality of the final product (Afshinnia, 2019 & https://www.concrete.org/).

An ASR reaction creates a siliceous gel in the cement paste and swells at different times either during the mix of fresh concrete or during the curing process. The ultimate physical reaction comes in the form of cracking in the final concrete product (Klemenc, 2011). As Afshinnia (2019) has identified, the way to treat ASR is to neutralize the reaction using low alkali Portland cement, supplementary cementitious materials (SCMs) to include silica flume, fly ash, slag, and metakaolin, and pozzolans. Afshinnia (2019) also cites the fact that using recycled glass show a reduction in the strength of the concrete can be 10% to 20% less than when using virgin aggregate materials. This effect has been mapped to show the variability of cracking that can occur through ASR with the different colors of glass. It was also found through this research that green glass exhibits less distress due to the presence of chromium used to produce the glass.

Using pozzolans helps reduce the reactivity of ASR in concrete. The American Concrete Institute (ACI) specifically defines the use of pozzolans to “combine with calcium hydroxide in the concrete to calcium silicate hydrate where the use of pozzolan may increase or decrease water demand depending on the particle shape, surface texture, and fineness.” Product manufacturers also cite the use of pozzolans reduce the concrete permeability, decreases efflorescence & controls ASR, improves mix rheology, color, and appearance, reduces drying shrinkage, increases the density and tightness of concrete, and improves surface characteristics of the concrete (concretecountertopsupply.com). ACI also states that this will reduce bleeding due to the fineness of the pozzolan material and reduce the maximum rise in temperature when used in large amounts by slowing the rate of the chemical reactions (https://www.concrete.org/).

Other studies have been conducted on replacing virgin sand with recycled waste glass. Nafisa, Rabin, & Nagaratnam (2020) researched the utilization of waste glass as a partial replacement for sand in concrete. Their study relied on a control and three samples reducing natural river sand in concrete at 20%, 40%, and 60%. They maintained a control sample which met its design concrete strength within twenty-eight (28) days of cure. Additionally, from their control group there was a slight reduction in strength in replacement of glass for sand, yet the compressive strength still met the design strength required for the concrete mixture. Therefore, their tests showed only about a 2% reduction strength at twenty-eight (28) days when sand was replaced with up to 60% recycled waste glass sand. There was also a slight ASR reaction, but little effect on the overall concrete strength.

Methodology

The purpose of this applied exploratory research was to determine if there was an effect on concrete strength when pulverized glass is introduced in place of virgin sand aggregate. This applied exploratory research design tested three different concrete mix designs to identify the strength relationship associated with the use of virgin sand and locally sourced pulverized glass to replace a portion of virgin sand in the concrete mix. A limitation of this study included a small sample size due to limited material resources. The basic procedure to perform the tests included research into the types of materials that could properly be used to avoid the ASR and the use of standardized concrete testing procedures. A simple procedure was used and followed to create nine (9) cylinders is identified below:

1. Acquire materials
2. Weigh ingredients based on a water cement ratio of 0.50
3. Cast three (3) cylinders each representing the control of virgin sand and the reduction of sand being replaced by pulverized glass as listed:
    a. Standard mix with virgin sand
    b. -25% Reduction of sand replaced with pulverized glass
    c. -50% Reduction of sand replaced with pulverized glass
4. Let cylinders cure for 24hrs
5. Release cylinders and place in PH temperature-controlled water bath at 73°F
6. Let cylinders cure for 28 days per American Society for Testing Materials (ASTM) standards
7. Cap cylinder
8. Perform compression test

Concrete Standards

To perform the test, the procedures used to make the concrete followed the ASTM standards for concrete aggregate and sand moisture content testing, concrete sand gradation analysis (ASTM C33) and making, curing, capping, and testing 6-inch by 12-inch concrete cylinders (ASTM C31, C192, C511, C617, C39) (Kosmata & Wilson, 2011). The standards are shown in table 1 below:

Table 1

ASTM Standards for Making, Curing, Capping, and Testing Concrete

Standard	**Title**
C31	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C33	Concrete aggregate and sand moisture content testing, concrete sand gradation analysis
C192	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
C511	Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
C617	Standard Practice for Capping Cylindrical Concrete Specimens
C39	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

Concrete Mix Designs

While all the above standards were followed, researchers used a standard mix design with a water to cement ratio (W/C) of 0.50 with no reduction in sand as the control measure to perform the study. This mixture utilized a 100% virgin sand mix with the ingredients as shown below in Table 2:

Table 2

Standard Concrete Mix Design (100% Virgin Sand)

Mix Ingredients	Standard Mix Design (Lbs)	Absorption	Moisture Content
Coarse Aggregate	22.00	1.80%	1.91%
Fine Aggregate	12.00	1.50%	5.29%
Cement	6.50		
Water	2.78		
Total Weight	43.28		

Note: W/C Ratio = 0.50

Once the standard mix design was identified, mix designs were created with the reduction of virgin sand to be replaced with locally sourced pulverized glass. The following mix design in Table 3 was created for a concrete mixture that would reduce the virgin sand by twenty-five (25%) and percent 50% and replace it with pulverized glass respectively. The mix design is shown below with all weights shown in pounds (Lbs).

Table 3

Concrete with Sand Reduction Replaced with Pulverized Glass

Mix Ingredients	-25% Sand Reduction (Lbs)	-50% Sand Reduction (Lbs)	Absorption	Moisture Content
Coarse Aggregate	22.00	22.00	1.80%	1.91%
Fine Aggregate	9.00	6.00	1.50%	5.29%
Pulverized Glass	3.00	6.00	0.00%	0.00%
Cement	5.36	5.36		
Bottle Poz	1.14	1.14		
Water	2.89	3.00		
Total Weight	43.39	43.50		

Note: W/C = 0.50. *A standard value of 17.5% of the cement weight was reduced and replaced with pozzolan to reduce the Alkali Silica Reaction in the concrete mixture.*

As identified by Afshinnia (2019) to prevent ASR, it was recommended to use a supplementary cementitious material to neutralize the reaction caused by the recycled glass. To prevent ASR researchers used a Fishstone Bottle Pozzolan in place of Portland cement. Manufacturer's recommendations identified the amount of pozzolan that could be used can range between fifteen (15%) to twenty (20%) percent. For this project, researchers used a value of 17.5% pozzolan by weight as the best amount to replace cement and reduce the potential for ASR. Figure 1 below shows the physical mixture components which include course and fine aggregate (sand), cement, pulverized glass, and the pozzolan additive.

Figure 1. Concrete mix components

Results

The researcher's goal with this project was to test the feasibility of using pulverized glass in concrete. Other researchers have performed similar research with processed recycled pulverized glass (Nafisa, Rabin, & Nagaratnam, 2020). The difference in this study was that all the pulverized glass was locally sourced, cleaned for impurities, and then placed in the concrete mixture. Ultimately, the researcher's wanted to determine if there was a strength relationship when the amount of virgin sand was reduced and replaced. Compression tests were performed on the six (6) inch by twelve (12) inch concrete cylinders. By removing virgin sand by weight at -25% and -50% then replacing sand with pulverized glass, there were a total of three concrete cylinders casted for each test variable with a total of nine (9) compression tests performed. Shown below in Table 4 are the results of the compression tests for each of the cylinders in pounds per square inch (psi) with the reductions in virgin sand content.

Table 4

Compression Test Results

Cylinder Test	**Standard 100% Virgin Sand (psi)**	**-25% Sand Reduction and Replacement (psi)**	**-50% Sand Reduction and Replacement (psi)**
1	6203	5630	5255
2	4993	5389	5333
3	7193	5340	5545
Average	6163	5452	5377

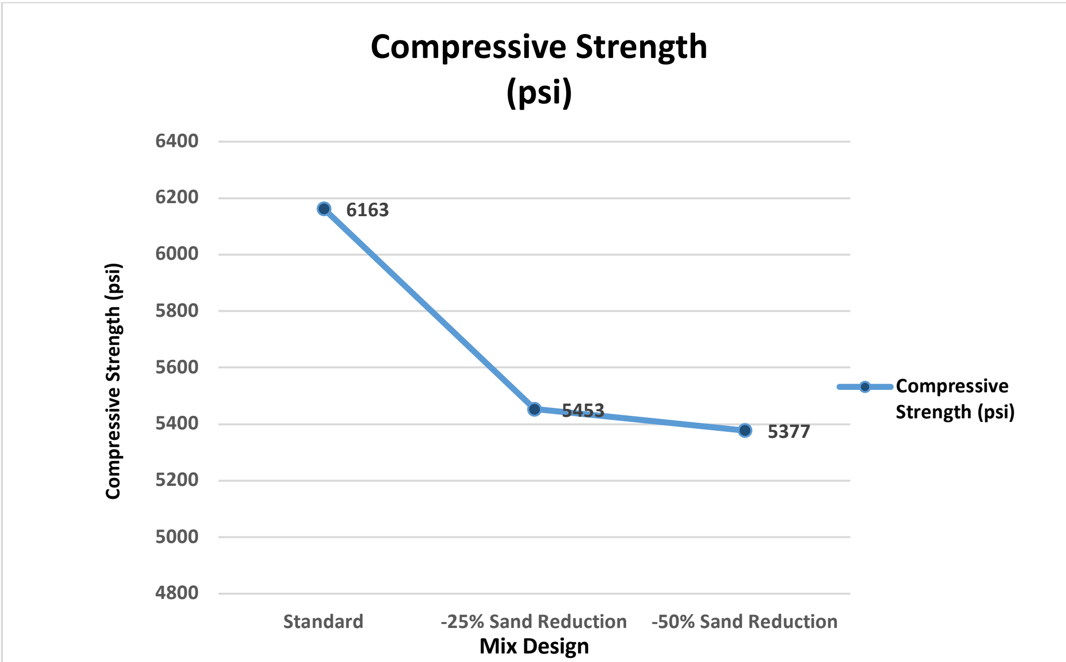

Figure 2. Compressive strength of concrete cylinders from 0% to 50% sand reduction

While a limitation to this study was a small sample size, the results suggested that there was a reduction in strength when pulverized glass is added to the concrete mixture. Similar to the findings by Nafisa, Rabin, & Nagaratnam (2020), when reducing the amount of sand from the control cylinders there was slightly over eleven percent (11.5%) loss in strength when reducing the sand and replacing with twenty-five (25%) pulverized glass. And, by reducing the sand and replacing with fifty (50%) pulverized glass there was just over twelve percent (12.8%) loss in strength. With the reduction of virgin sand from the concrete mix, the compressive strengths of the samples still met or exceeded their design strength of 3,000 psi.

What should be observed is within the mix design, for the two test samples, as the fine aggregate was reduced by their respective amounts of 25% and 50%, this changed the total amount of water to be added to the mixture. Both the cement and pozzolan admixtures remained the same, this was due to the retained water that had to be accounted for in the aggregate to maintain the water cement ratio of W/C = 0.50.

Conclusion & Discussion

What this exploratory study provides is that recycled glass can be used as a material to replace virgin sand. Comparatively, when averaging the compression strengths at the 25% and 50% sand reduction levels it the average strength for these compression strengths is at 5,415 psi. This was surprising to the researchers because most high strength concrete for structural applications is specified at compression strengths above 5,000 psi.

Replacing sand with pulverized glass in concrete has shown that it can be a viable material for concrete applications but must be treated to attain the necessary outcomes. By using pozzolans, they do help by improving the concrete mechanical and durability properties associated with the use of pulverized glass in the final product. Use of pulverized glass with the reduction of virgin sand is also an environmentally conscious application to reuse a material that is readily available in many different locations, but has proven to be a costly operation when going from a consumer glass product to a usable recycled construction material. Although there was a decrease in concrete strength, there are many architectural and structural concrete applications where pulverized glass can be used. As seen in this study, the tests proved to hold concrete compressive values close to those needed for many structural applications, but further testing would be required if this practice could be used as a standard in highway or structural applications. What this study also shows, is the ability to use pulverized glass as sand to potentially reduce concrete production's impact on the carbon footprint for construction materials.

At Central Washington University and within the Ellensburg community this project started further discussion on the use of recycled pulverized glass in many different applications. Since the completion of this study local non-profits have created a glass recycling cooperative to collect and crush glass for use. Some uses have included crushed glass in plant growing operations to conserve water, fill in piping operations, outdoor architectural features, and farming. There have been several presentations made to bring the awareness of recycling efforts locally and around the state as well.

Future research on this subject would be to further expand on the use of pulverized recycled glass in building and industrial applications. Further studies would look at the use pulverized glass in a mass concrete application such as a sidewalk or concrete wall to determine the durability of the finished product in different environmental applications over several years. Additionally, there would be a strong interest to determine the actual carbon footprint that exists with the complete operation from consumer glass acquisition to the final reuse of recycled glass in building products. As many have mentioned, the operation of recycling glass is an expensive venture for any city or municipality to undertake. Researching the costs associated with glass recycling starting with the transportation of glass along with the processing operation would prove to be beneficial when considering deploying a glass recycling operation. In construction education, it would be interesting to have students investigate the recycling efforts needed to create the pulverized glass and process it to be ready for use in concrete applications by looking at the costs and impact on the carbon footprint to produce concrete. Studies like these would help to determine how environmentally sustainable the use of recycled glass would be in concrete or other materials. Overall, this research does show there is a potential for the application of recycled glass to be used in many areas of construction means and methods.

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