The Effects of Waste Marble Powder on Sustainable Concrete

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Sustainability has been growing consistently more popular in construction, with projects introducing innovative ideas to build greener every year. One material that has not experienced many innovations since emerging in building use is concrete. The reason behind this could be the chemical process of curing concrete being unique compared to most materials. While concrete can be broken down into some of its original components, water, cement, and admixtures used are not retainable. This makes it difficult to recycle the material, and the aggregates recovered from recycling also experience a loss in strength. With admixtures being involved in most concrete mixes today, it is hypothesized that a sustainable additive could be discovered to use in concrete for strength retainage. The review of literature focuses on modern concrete mixes, recycled aggregate, concrete admixtures, and marble powder. This research analyzes waste marble powder in concrete. Waste marble powder is a byproduct of marble processing and contains properties similar to cement. Experiments involving the use of both marble powder and recycled aggregate are carried out in the form of concrete cylinder batching and breaking over seven-day periods. Findings of this process show that marble powder could be a promising component of concrete upon further research.

Key Words: Sustainability, Concrete, Compressive Strength, Recycled Aggregate, Marble Powder

Introduction

Sustainability in construction has become more popular over the past couple decades, with innovative creations being introduced every year. These sustainable projects have come in the form of energy saving window designs, smart HVAC systems, motion sensor lighting, and more. With all the innovative building strategies, concrete seems to be the least sustainable material and least addressed when concerning green building. Since concrete is a hardened mixture of other materials it stands out from other building options in that it does not break back down to what it was crafted from.

Concrete that is demolished from a project can only be recycled to recover a few of the original materials used. Once used concrete is removed from a project, it is crushed and grinded down to small fragments that are then screened and separated into coarse or fine aggregates. The water, cement, and any additives used in concrete mixes are unable to be salvaged from demolished concrete due to the binding process that occurs when a mix is placed. Because of this, recycling concrete is limited to breaking down the aggregates used.

Once screened, the aggregates recovered are generally used for street pavement, permeable pavers, base rock, and in less common instances, new concrete. The reason it is not used as often to make new concrete is because recycled aggregate does not retain the same strength that it once had. When used in concrete, recycled aggregate can only replace a portion of the total aggregate used. This is where the term “partial replacement” comes into use for sustainable mix designs. According to Cement

Concrete and Aggregates Australia (CCAA), recycled aggregate can be used to replace up to 30% of natural aggregate in sidewalks, curbs and gutters and in structural concrete with a mix adjustment (CCAA, 2008).

If concrete batched with recycled aggregate maintained the same strength as that of concrete batched with new aggregate, concrete designs would integrate recycled material more frequently. One material that has not experienced much research in the construction industry is waste marble powder (MP). What is known about the ingredient is that it acts as a bonding agent, as it is mainly used in sculpture as an applied finish to pieces of art. The goal of this research is to further expand knowledge on what marble powder is capable of contributing to concrete, specifically whether it increases compressive strength. If marble powder works as a partial replacement for cement and increases compressive strength of a mix, then designs using recycled aggregate and MP could potentially be incorporated for columns and slab-on-grade mixes.

Literature Review

Modern Concrete Mixes

Today's concrete mixes involve the following general ingredients: coarse aggregate, fine aggregate, cement, water, and admixtures. These ingredients will vary from mix to mix, by percentage of material as well as size and type of material. For instance, there are many different sizes of coarse aggregate that are used for various purposes, 1" diameter aggregate being one of the most common sizes. Larger aggregate sizes generally decrease the tensile strength of concrete mixes, making smaller aggregate sizes efficient for mixes intended for slab on grade foundations, columns, and other concrete members that face little tension. (Tsiskreli, 1970)

These basic materials have not changed significantly since they were initially used, however the admixtures of concrete are a topic of constant research and innovation. Additives such as fly ash, slag, and superplasticizer have changed the way concrete is made, increased the compressive strength, and improved the resulting workability.

Recycled Aggregate

Recycled aggregate is not a recent innovation in the concrete industry. It is something that originated during World War II and has become more popular for the sustainable aspects it offers (Buck, 1977). A large downside to recycled aggregate, however, is the lower compressive and flexural results it yields. Because of this, the use of the recycled material is fairly limited. It is integrated mainly in paving, sidewalks, driveways, and non-concrete uses such as gravel base. Any usage of concrete that places bending or lateral loads on the material is where recycled aggregate would not be a sufficient ingredient.

This however does not mean that concrete containing recycled material should be eliminated as a building option. The CCAA states that a replacement of aggregate of up to 30% recycled aggregate has very little effects on the compressional strength of the concrete (CCAA, 2008). The little effects still provide reasons not to integrate recycled aggregate into mixes such as slab on grade and column mixes, although, could be resolved by the incorporation of a strength additive. American Concrete

Institute indicated in a study that mixes containing reused concrete aggregate best result from a water/cement ratio that is roughly 15% higher than that of conventional concrete (Lamond, 2001).

Concrete Admixtures

Admixtures play an incredibly important part in concrete. Of the tens of admixtures available, their purpose can be to give mixes higher strength, accelerated cure time, and improve workability depending on what the job calls for. Some are used as fillers for other materials, such as fly ash partially replacing cement, to create a more affordable mix design. For this experiment, only one admixture will be used to ensure results are easily interpretable. This admixture will be marble powder and will be expected to increase the overall strength of the mix.

Marble Powder

Marble is currently a growing sector across the world as more buildings are making use of the material (Tunc, 2019). Marble powder is a byproduct of marble processing and is normally used to provide marble finishes to mold castings. It is able to adhere to marble surfaces due to its pozzolan qualities that react with water, creating a binding reaction that allows hardening to occur (Shah, 2015). A pozzolan is any material that reacts with calcium hydroxide and water resulting in cementitious qualities (ASTM, 2019). With these properties of marble powder, studies have been performed on the material also be used in concrete to mix in with the cement content. The benefits of this partial replacement in a concrete mix are that it provides a more sustainable product without significantly compromising compressive strength.

One study took data from a number of past experiments to show that marble powder gave an increase in compressive strength as a result (cited by Tunc, 2019). The data provided consisted of multiple mixes that used marble powder in percentages ranging from 0-10% partial replacement for cement. Compressive strength yields increased as the amount of marble powder content in the mix increased.

Research Objective

To create a more sustainable mix design of concrete that competes with today's mixes, strength and workability would need to be equivalent to existing designs. The goal of this research is to test the pozzolanic properties of marble powder in concrete and conclude whether it provides enough strength to make up for strength lost from recycled aggregate while having sufficient workability. To accomplish this, the use of marble powder will be experimented with for a new mix design involving the recycled material.

Methodology

This research uses the preparation of three concrete mixes to be tested for slumps and compressive strengths. One batch is set up as a control consisting of course aggregate, fine aggregate, cement, and water. The second batch (Mix RA3010) is set up to be the same materials as the control with the incorporation of 30% partial aggregate replacement with recycled aggregate and 10% partial cement replacement with marble powder. The final batch (RA5015) has the same qualities as the second with a change from 30% RA to 50% RA as well as increasing 10% MP to 15% MP. These three mixes are all to be mixed in one day and placed into cylinders accounting for four break tests: 7-day, 14-day, 21-day, and 28-day.

Table 1

Mix Design Components in Pounds (lb.)

Mix Design	1” Agg	Concrete Sand	Water	Cement	Coarse RA	Fine RA	Marble Powder
RA0000	90	70	18	40	0	0	0
RA3010	63	49	18	36	27	21	4
RA5015	45	35	18	34	45	35	6

Marble powder was purchased from Blick Art Materials and is crafted from pH neutral basic calcium carbonate. Unwashed recycled aggregate was received from Negranti Construction in Cayucos, California. It is expected that the partial replacement of marble powder will give the concrete an increase in compressive strength, allowing it to be a competitive mix design. While this could balance the loss of strength from recycled aggregate, it may create a concrete mix with little workability. It is also important that the concrete batches are prepared without any admixtures. This will allow inferences to be made on what admixtures would improve on the base mixture.

Analysis

As the cylinders were being prepared, it should be noted that water had not thoroughly mixed into the experimental mixes (RA3010 & RA5015). This is likely due to marble powder being less of a pozzolan compared to cement or fly ash, another filler used in concrete (Shah). A pozzolan, as stated in the literature review, is what causes concrete to bind and thus cure. Because marble powder is not as strong of a pozzolan, it could be assumed that the inconsistency of the water in the mix was caused by the marble powder not binding as sufficiently (N. Shwiyhat, March 12, 2021). This has a potential of creating honeycombing within curing cylinders and decreasing the resulting strength yields.

Another note to be made is that mixes RA3010 and RA5015 each contain both marble powder and recycled aggregate. Results would be more easily interpretable if mixes containing zero marble powder and a percentage of recycled aggregate were involved as well. Data from these mixes would allow for a more significant finding before adding in marble powder. The potential increase of compressive strength would be clearer by comparing data from a mix containing zero marble powder to mix RA3010, for example. The reason this was not accomplished is due to the time of this project being limited to eleven weeks.

Results

Results of this project are shown in slump tests and compressive tests as shown in Table 1. Mix RA0000, the control batch, showed a fairly unusual strength yield. Only gaining roughly 200 PSI between the first two break tests, it peaked in strength on the 21-day break reaching 4,195 PSI, then fell to about 3,860 PSI on the 28-day break. Mix RA3010 experienced this same drop of strength more severely between the 21-day and 28-day break test. One of the two experimental mixes was found successful in reaching a standard compressive strength of 4,000 PSI before 28 days of age. Mix RA3010 (shown below) reached a strength of 4,130 PSI at 21 days. Mix RA5015 only yielded 3,231 PSI at 28 days, likely due to the high percentage of recycled material that it contained.

Table 2

Slump and compressive strength results of mix designs

Mix Design	Slump (in.)	7-Day Strength (psi)	14-Day Strength (psi)	21-Day Strength (psi)	28-Day Strength (psi)
Mix RA0000	4.5	1,755	1,845	4,195	3,860
Mix RA3010	2.0	1,110	3,820	4,187	3,332
Mix RA5015	3.5	1,215	2,597	2,091	3,231

Slump quantities resulted in acceptable numbers with the exception of mix RA3010, measuring a low slump of 2.0 inches. This mix was much less workable than the other two, yet it is uncertain if this was caused by the marble powder content or an inconsistent water/cement ratio. Regardless, mix RA3010 displayed the highest strength of the three mixes on the 14-day break.

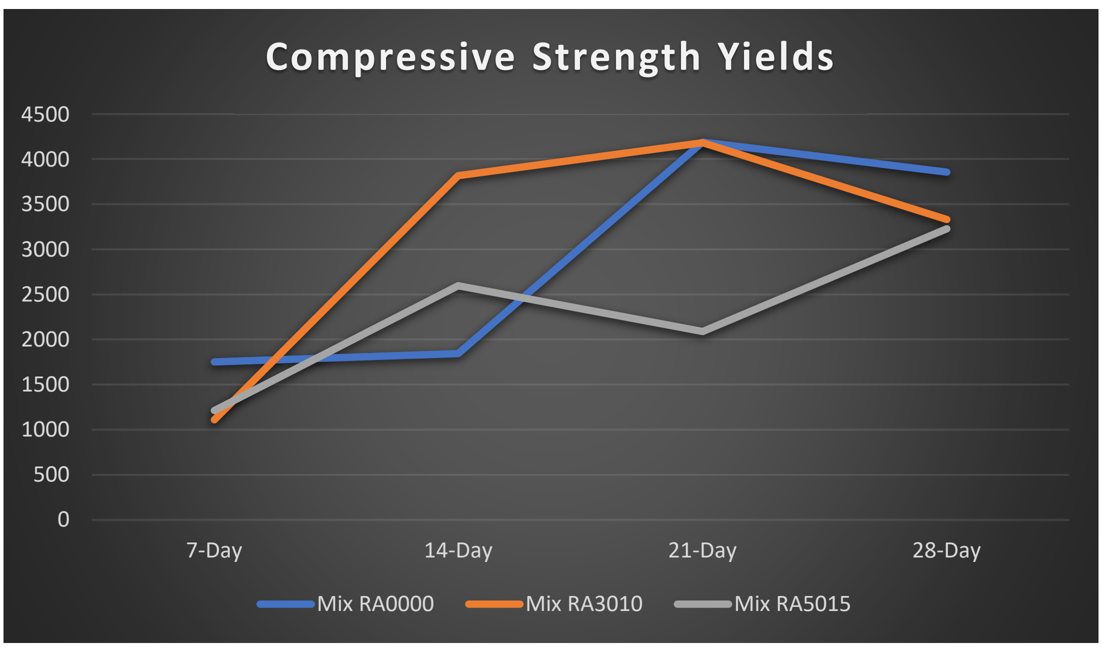

Figure 1. Compressive Strength Results per Mix

Although two concrete mixes reached 4,000 PSI at 21 days, the overall results of cylinder breaks did not meet expectations. Concrete strength never decreases over time as these results indicate, meaning there must be a human error. Considering this, an adjusted graph could be made to show what strength yields were expected to be where they did not follow a logical pattern. See figure 2 below for the adjusted graph.

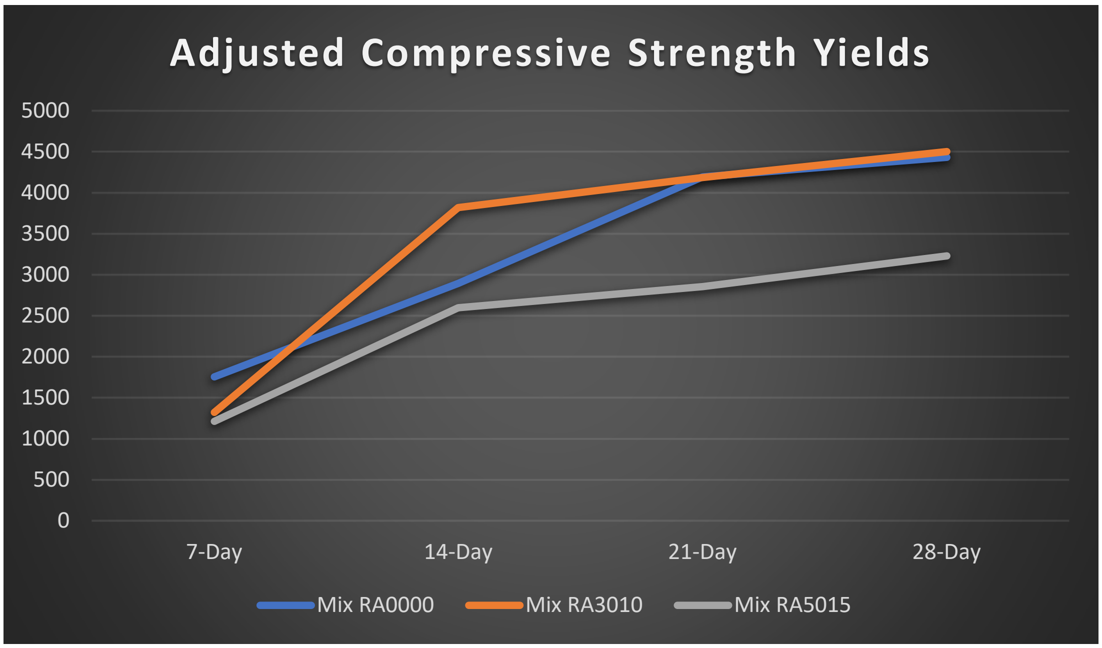

Figure 2. Compressive Strength Results Adjusted

Conclusion

With the results of this experiment, it seems that Mix RA3010 was most promising with its high compressive strength yield so early on. Unfortunately, the mixes with partial replacements of recycled aggregate and marble powder experienced poor slump measurements. This however could be resolved by incorporating admixtures to the concrete mixes such as those used in self-consolidating concrete (SCC). Admixtures used in SCC make a more fluid mix while retaining a fairly thick viscosity, much like molasses or honey (J. Arciero, June 15, 2020). This would help increase the slump and workability, potentially creating a balanced mix that could be used for concrete slabs or columns. Another thought on the workability and results of the two non-conventional mixes is that the water/cement ratios were designed to be the same as the conventional mix and may have improved from having a ratio 15% higher as stated in the review of literature.

Aside from slump results, the compressive strength data indicates that not all cylinders were either prepared or crushed properly. A reasonable assumption is that mixes were not mixed thoroughly enough, creating water separation before being placed into cylinders. This would cause low water/cement ratios for certain cylinders, resulting in a weaker product. Since marble powder acts similarly to cement, lower water content would mean less binding strength during the curing stage.

The presence of recycled aggregate in mix RA3010 did not show a weaker design than the control design. It could be concluded that MP caused an increase of compressive strength if an additional mix were batched consisted of 30% recycled aggregate and 0% marble powder. The batch results would compare the change in strength once marble powder is added.

Areas of Further Research

One aspect that was not explored in this project was the concrete mixes' reactivity and swelling potential once placed in soil. If either of the two experimental mixes were used for footings or slabs in the future, there would be a need for field experiments to confirm the mix is suitable for direct contact with soil. This could easily become another student's research project by recreating the experimental mixes used and placing them as mockup footings to test reactivity.

Many elements in the experiment could be perfected in a revised experiment and result in newfound qualities of marble powder. Since this experiment did not have successful results, it could be assumed that there was human error, and a new set of batches could be prepared. A new set of batches would include designs that can compare the absence of marble powder to mixes that incorporate a percentage of it.

Since marble powder used in this experiment was received from an art supply, it is unknown at what cost waste marble could be obtained. Another opportunity for further research would be to conduct interviews with waste management facilities or art supply businesses to discover how mass amounts of marble powder could be managed and at what price.

References

ASTM Standard C618-19. (2019). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, ASTM International, West Conshohocken, PA. doi:10.1520/C0618-19

Buck, A. D. (1977). Recycled concrete as a source of aggregate. *ACI Journal Proceedings, 74*(5), 212-219. doi:10.14359/11004

CCAA. (2008, May). *Use of Recycled Aggregates in Construction* (Rep.). Retrieved January 26, 2021, from Cement Concrete & Aggregates Australia website: https://www.ccaa.com.au/imis_prod/documents/Library%20Documents/CCAA%20Reports/RecycledAggregates.pdf

De Brito, J., & Agrela, F. (Eds.). (2019). Influence of recycled aggregates on the mechanical performance of concrete. *New Trends in Eco-efficient and Recycled Concrete, 1*, 49-54. doi:10.1016/c2017-0-01898-0

Garcia-Lodeiro, I., Palomo, A., & Fernandez-Jimenez, A. (2015). An overview of the chemistry of alkali-activated cement-based binders. *Handbook of Alkali-Activated Cements, Mortars and Concretes,* 19-47. doi:10.1533/9781782422884.1

Lamond, J.F., Chairman., Campbell, R.L., Giraldi, A., Jenkins, N.J., Campbell, T.R., Halczak, W., Miller, R., & Cazares, J.A. (2001). Removal and Reuse of Hardened Concrete ACI 555 R-01 Reported by ACI Committee 555.

Provis, J.L. (2014). Geopolymers and other alkali activated materials: Why, How, and What? Materials and Structures 47, 11–25. doi:10.1617/s11527-013-0211-5

Shah, N. (2015). Suitability of Porcelain and Marble Industrial Waste Powder to Produce High Performance Concrete. *American Journal of Civil Engineering and Architecture, 3*(3), 59-63. doi:10.12691/ajcea-3-3-1

Southararajan, V.M., Sivakumar, A. (2013). Effect of the lime content in marble powder for producing high strength concrete. *ARPN J. Eng. Appl. Sci. 8*(4), 260–264. ISSN:1819-6608.

Tsiskreli, G. D., & Dzhavakhidze, A. N. (1970). The effect of aggregate size on strength and deformation of concrete. Hydrotechnical Construction, *4*(5), 448-453. doi:10.1007/bf02376145

Tunc, E. (2019). Recycling of marble waste: A review based on strength of concrete containing marble waste. *Journal of Environmental Management, 231*, 86-97. doi:10.1016/j.jenvman.2018.10.034.

Valentini, L., Mascarin, L., Dalconi, M. C., Garbin, E., Ferrari, G., & Artioli, G. (2020). Performance and properties of alkali-activated blend of calcined laterite and waste marble powder. *RILEM Bookseries,* 375-380. doi:10.1007/978-981-15-2806-4_44

Walker, S., & Bloem, D. L. (1960). Effects of aggregate size on properties of concrete. *ACI Journal Proceedings, 57*(9), 283-298. doi:10.14359/8021