

Using Countertop and Construction Waste for Green Concrete

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This experimental research analyzes the feasibility of using countertop and finishes waste from construction as a replacement for virgin coarse aggregate and cement. Marble, terrazzo and granite countertop scraps were collected from countertop suppliers and construction sites in the San Francisco Bay Area. Twelve mixtures were prepared to analyze the impact of up to 15% of marble dust and up to 30% recycled aggregate on the workability and compressive strength of the concrete. The experimental results show that the analyzed by-products can be effectively used as a replacement for up to 30% aggregate in concrete without negatively affecting the slump, the 7-day compressive strength or 28-day compressive strength. The crushed marble acted as an effective recycled aggregate. However, its use as a pulverized marble dust to replace cement significantly reduced the 7-day compressive strength (19%) and reduced the slump by 1 inch. The environmental significance of this replacement of aggregate and cement by marble is twofold. First is the reduction of construction waste deposited in landfills. Secondly, it reduces the use of natural resources to produce virgin aggregate and cement.

Key Words: Recycled concrete aggregate, marble dust, recycled crushed aggregate, marble, terrazzo, granite, sustainability.

Introduction

In recent years, the search to develop construction materials which are environmentally friendly and reduce the carbon footprint has been growing. The application of sustainable practices has also become increasingly important. Construction projects are one of the biggest generators of waste in the USA, constituting 29% of the total solid waste and 35% of landfill space (Kofoworola, O. F., and Gheewala, S. H.., 2009). In order to minimize such impacts and fulfill state and local regulations, the implementation of sustainable practices has become an important part of the development of a construction project.

As natural resources are becoming exhausted, it is urgent to further develop technologies that are capable of incorporating "recycled materials, byproducts or waste" in the production of construction materials. The University of Tennessee Center for Clean Products (2009) conducted a survey to evaluate the amount of quarried marble that is wasted. It concluded that only 70 tons of marble are used per 1,000 tons that are extracted from the quarry. Significant marble waste is generated from fracturing, sawing, polishing and rejection of broken or damaged blocks and slabs. One approach to minimize the negative effects of waste marble, is to use it as recycled aggregate or cementitious material that can replace cement (Aruntas, *et al.*, 2010), as a cement additive (Topçu et al, 2008; Aruntas *et al.*, 2010; Alyamaç and Ince, 2009), or also as a replacement for fine (Omar *et al.*, 2012; Corinaldesi *et al.*, 2010; Valeria and Moriconi., 2009; Demirel, 2010) and coarse aggregates (Hebhoub *et al.*, 2011; Binici *et al.*, 2008; Gencela. 2012; Nepomuceno, *et al.*, 2012).

While researchers have analyzed the effect of replacing cement, sand, and coarse aggregate with marble by-product in Turkey, Italy, Egypt, and Portugal, there is a lack of research analyzing the use of marble waste in the United States. This is especially true for postindustrial byproducts such as countertop installation waste, or postconsumer products after a building deconstruction. The use of such recycled materials in concrete is attractive because of potential cost, regulatory, and green certification benefits. For instance, the cost of delivering waste materials to landfills and the landfills' fees are especially high in localities that have stringent environmental regulations such as the San Francisco Bay Area. Also, the use of recycled materials could contribute to the awarding of points in the

Materials and Resources and Innovation categories of the Leadership in Energy and Environmental Design (LEED) certification process.

Therefore, research is needed to compare the performance of recycled marble by-products and other waste products used in finishes such as waste granite countertops and terrazzo. Finally, the analysis of the marble dosage effect in different states (i.e. powder and aggregate) and the combination of such byproducts in a mixture is of interest to propose mix design which maximizes the use of recycled content without affecting relevant properties of the mixture such as strength and workability.

Research Objective

The objective of this research is to evaluate the use of waste marble as a replacement for cement, sand and coarse aggregate, and to determine an optimum percentage of recycled materials that maximizes the sustainability of the concrete mixture without affecting its strength and workability. This research also compares the performance of waste marble with other materials used for similar applications such as recycled countertop granite and terrazzo.

Experimental Program

Materials

One virgin and three recycled types of aggregates were used in this study. The virgin aggregate was ¼" size crushed granite. The fine aggregate used in this study was a virgin manufactured granite sand, which had a fineness modulus of 2.9, specific gravity (SSD) equal to 2.65 and absorption capacity of 0.9%. The sieve analysis of the virgin aggregates is shown in Table 1:

Table 1. *Sieve Analysis of the virgin aggregates*

Sieve	3/8" Aggregate	Sand
3/8"	100	100
#4	51	99
#8	7	86
#16	2	66
#30	0	40
#50	0	16
#100	0	4

The recycled marble and recycled granite coarse aggregate were obtained by crushing disposed countertops and waste materials obtained from local subcontractors and recycling facilities in the San Francisco Bay Area. Each of the crushed materials were separated by sieve size (1/4", No. 4 No. 8 No 16) in order to create a blend that exactly resembles the sieve analysis of the original virgin aggregate. A sample of crushed terrazzo marble was also separated by size in order to compare its performance with the recycled marble.

The waste marble and granite countertops were crushed in smaller pieces using an electric hammer and then classified by size as shown in Figures 1(a) and 1(b).

Figure 1(a): Crushing process

Figure 1(b): Materials separated by size

In addition to the coarse aggregate, recycled marble was pulverized using a ball crusher, in order to create marble dust. The fine particles were separated in accordance to size (#100, #200, and smaller than #200). This dust was used to partially replace the Portland Cement Type II used in this study.

Figure 2: Ball crusher to pulverize marble

Mixture Design and Preparation

Four series of mixtures were produced as presented in Table 2. Series (V) consisted of four mixtures, and was focused on the effect of replacing cement with marble dust while using 100% virgin aggregate. The first mixture (V-0) in this series was the control mix, which was made exclusively with virgin aggregate and cement. The three remaining mixtures used marble powder to replace 5%, 10%, and 15% of the cement, and were identified as V-5D, V-10D, and V-15D, respectively. The marble powder used to replace cement was a combination of 20% retained on sieve #100, 40% retained on sieve #200, and 40% passing sieve #200.
The second series (RM) focused on the effect of replacing the virgin coarse aggregate with recycled marble, while keeping the cement dosage constant. The virgin aggregate was replaced using 15% and 30% of recycled marble, were identified as 15RM-0, and 30RM-0, respectively. As shown in Table 2, the recycled aggregate had the same particle size distribution as the virgin aggregate it replaced.

In the third series (RT), the combined effect of replacing coarse aggregate and cement was evaluated. Mixtures 15RT-0 and 30RT-0 had a 15% and 30% of coarse aggregate replacement by marble terrazzo and no marble dust (100% cement). The mixtures 15RT-5D and 15-RT-10D had a 15% coarse aggregate replacement and a replacement of 5% and 10% of the cement by marble dust, respectively. Such replacement of cement with marble dust, were selected in accordance to previous research by Ergun (2010) and Aruntas *et al.* (2010), while the recommended replacement of coarse aggregate and cement resembled the work by Gencela (2012) and Nepomuceno *et al.* (2012).

Finally, the effect of replacing virgin aggregate by recycled granite was evaluated on the fourth series (RG). As shown in Table 2, 15% and 30% of the virgin aggregate was replaced by recycled granite on the mixtures identified as 15RG and 30RG, respectively.

The water cementitious ratio for all mixtures was kept constant at 0.45, in order to strictly evaluate the effect of the aggregate and marble dust. It shall be noted that the calculation of the water cement ratio counts the dust marble as part of the cementitious materials. The type and quantity of virgin fine aggregate (sand) was kept constant for all mixtures. No chemical admixture was used in any of the of the mix design.

Each concrete mixture was prepared in a ball mixer by sequencing the addition of the components at different times. The first materials poured in the mixer were the fine and coarse virgin and recycled aggregates, blended for 60 seconds. Then the cement was added to the components in the mixer, and blended for 1-minute. Water was added afterwards, and the concrete was mixed for three minutes. After a 2-minute pause, the concrete was mixed for two additional minutes, before starting the fresh concrete tests.

Test Methods and Results

After completing the mixing process, the slump was measured in accordance to ASTM 143. The test results for each mixture are presented in Table 2.
Six 2” by 4” cylindrical specimens were prepared per mixture. The cylinder diameter was four times the maximum size of the coarse aggregate, as recommended by ASTM C31. Cylinders were filled in two layers; each layer was penetrated with a metal stick 25 times and lightly tapped by hand 10 times. Cylinders were then covered with plastic caps to prevent moisture loss. All of the specimens were de-molded and striped after 24 hours and placed in a curing room at 98% humidity for 7 or 28 days in accordance to ASTM C31.

Compressive strength tests were performed on sets of three cylinders at 7 and 28 days, using unbounded caps as specified by ASTM C 1231. Compressive strength results for each mixture at 7 and 28 days are shown in Table 2.

Table 2. *Experimental design and test results (1 yd^3)*

	Virgin Coarse				Recycled Marble		Recycled Terrazzo				Recycled Gravel	
ID	**V-0**	**V-5D**	**V-10D**	**V-15D**	**15RM-0**	**30RM-0**	**15RT-0**	**15RT-5D**	**15RT-10D**	**30RT-0**	**15RG-0**	**30RG-0**
Recycled Coarse Aggregate (%)	**0**	**0**	**0**	**0**	**15RM**	**30RM**	**15RT**	**15RT**	**15RT**	**30RT**	**15RG**	**30RG**
Recyled Dust (%)	**0**	**5**	**10**	**15**	**0**	**0**	**0**	**5**	**10**	**0**	**0**	**0**
Virgin Coarse Aggregate (lb)	1,165	1,165	1,165	1,165	990	816	990	990	990	816	990	816
RM #4 (lb)	-	-	-	-	85	170	-	-	-	-	-	-
RM #8 (lb)	-	-	-	-	77	153	-	-	-	-	-	-
RM #16 (lb)	-	-	-	-	13	26	-	-	-	-	-	-
TM #4 (lb)	-	-	-	-	-	-	85	85	85	170	-	-
TM #8 (lb)	-	-	-	-	-	-	77	77	77	153	-	-
TM #16 (lb)	-	-	-	-	-	-	13	13	13	26	-	-
RG #4 (lb)	-	-	-	-	-	-	-	-	-	-	85	170
RG #8 (lb)	-	-	-	-	-	-	-	-	-	-	77	153
RG #16 (lb)	-	-	-	-	-	-	-	-	-	-	13	26
Virgin Sand (lb)	1,451	1,451	1,451	1,451	1,451	1,451	1,451	1,451	1,451	1,451	1,451	1,451
MD #100 (lb)	-	9	17	26	-	-	-	9	17	-	-	-
MD #200 (lb)	-	17	34	51	-	-	-	17	34	-	-	-
MD Pan (lb)	-	17	34	51	-	-	-	17	34	-	-	-
Cement (lb)	856	813	770	727	856	856	856	813	770	856	856	856
Water (lb)	385	385	385	385	385	385	385	385	385	385	385	385
Slump (in)	6.25	5.75	5.25	5.25	6.00	8.25	3.50	5.75	6.50	6.75	7.75	8.00
f_{c7} (psi)	7,499	6,745	6,352	6,068	7,175	7,283	7,579	6,958	7,959	7,516	8,246	7,756
f_{c7} (psi)	9,985	9,687	9,217	9,477	10,335	9,968	10,608	9,847	9,824	10,091	10,018	9,948

Analysis of Results

Workability

The slump results for all V-series mixtures are shown in Figure 3. It can be seen that the control mixture (0% marble dust) had a 6 ¼" slump, which decreased to 5 ¾", 5 ¼", and 5 ¼" as 5%, 10% and 15% of the cement were replaced by marble dust. This behavior is consistent with the marble dust acting as fine particles in the mixture without the level of lubrication that cement particles can offer.

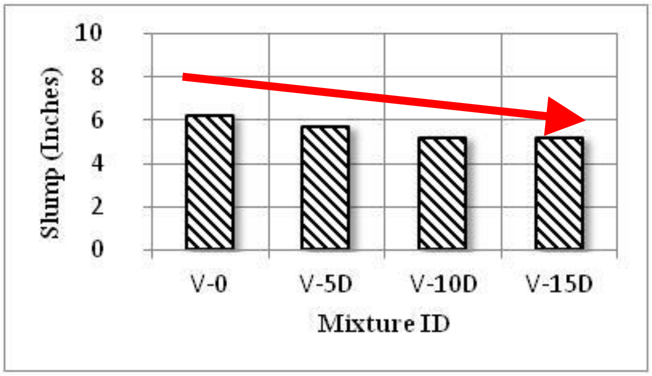


Figure 3: Slump vs. marble dust dosage

The effect of recycled aggregate on the slump can be observed in Figure 4. For the most part, the use of recycled aggregates or terrazzo did not significantly reduce the workability. One exception was 15RT-0, which had a significantly lower slump (and also a much higher compressive strength). All remaining mixtures had a workability which was close to or higher than the control mixture V-0. Mixtures with large contents of recycled marble and recycled granite had a slump that was on average 2" greater than the control mixture.

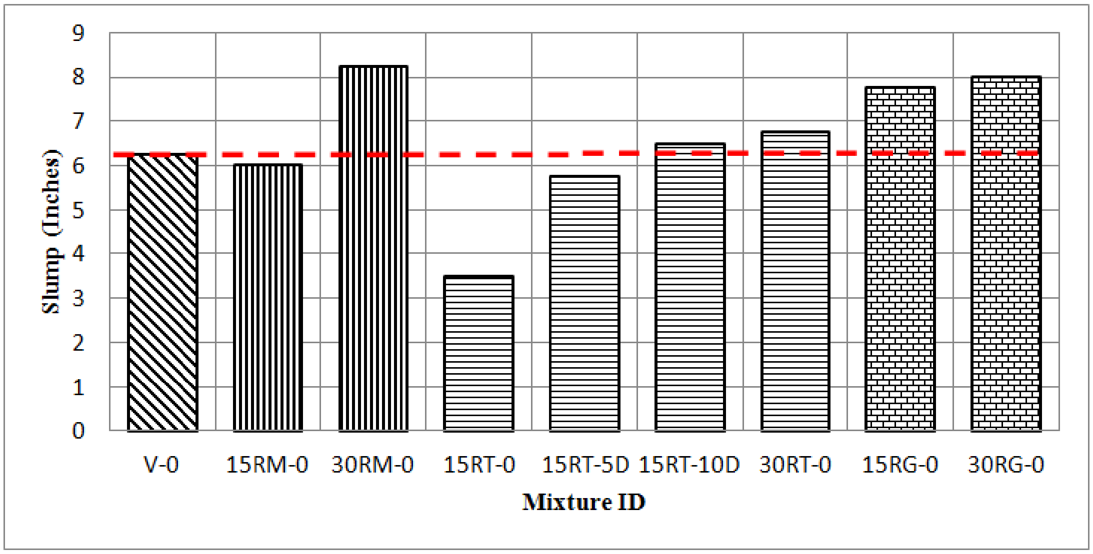
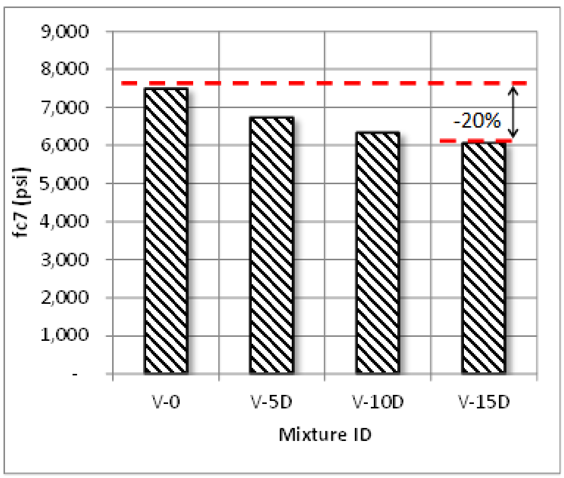


Figure 4: Slump variations in recycled aggregate mixtures

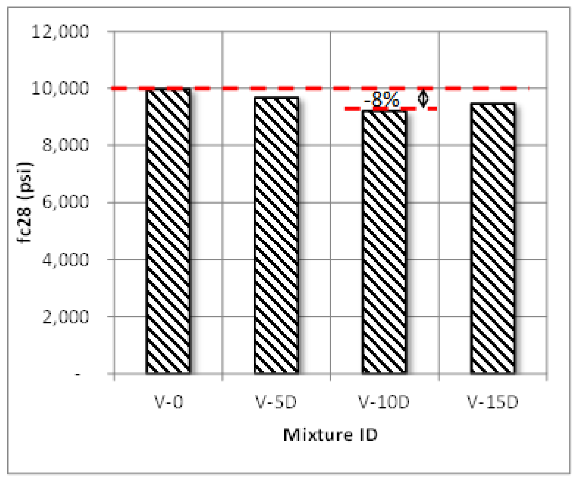
Compressive Strength

Figure 5 shows the effect of the marble dust replacement (5, 10, 15%) on compressive strength, as compared to the control mixture. It was observed that replacing cement with marble dust reduced the 7-day compressive strength by 10%, 15% and 19%, when 5, 10, and 15% of dust were used. While the effect at 7 days was quite significant, the reduction on the 28-day strength was only 3%, 8% and 5% for 5, 10, and 15% of dust replacement, respectively. The fact that the compressive strength reduction due to marble dust replacement at later ages is significantly smaller than at early ages suggests that the marble dust can have some positive effect on the cementitious matrix, albeit not at early ages.

The effect of marble dust on mixtures prepared with terrazzo aggregate is shown in Figure 6. The 7-day compressive strength was 8% lower for the mixture with 5% marble dust (15RT-5D), yet 5% higher for the mixture that had 10% marble dust (15RT-10D). The 28 days strength of the mixtures using 5% and 10% of marble dust was 7% lower as compared to the 0% dust mixture. Finally, the 28 day compressive strength of the mixture containing 15% marble dust was just 5% below the mixture without marble dust (15RT-0D). The 7-day strength of mixtures using 15% and 30% of terrazzo and no dust were virtually the same, which indicates that this material does not have a significant detrimental effect on the compressive strength of the concrete. Similar results were seen at 28 days where the mixture containing 30% of terrazzo was just 5% lower than the one with 15% of terrazzo aggregate.



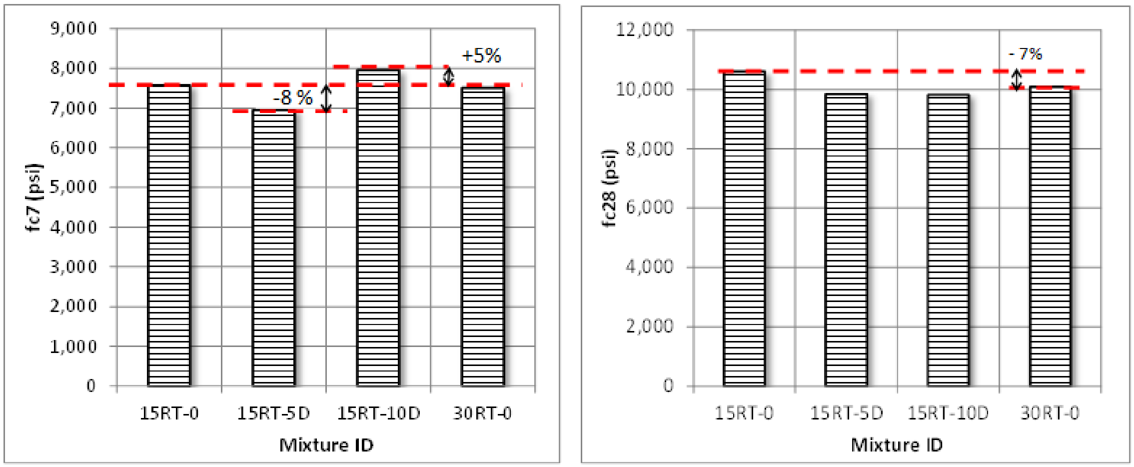
(a)



(b)

Figure 5: Effect of marble dust (MD) content on (a) 7 day and (b) 28 day compressive strength

The results reported in Fig. 5 and 6 indicate that marble dust can significantly reduce the compressive strength of a mixture at early ages. However, the reduction in 28 day compressive strength is much smaller reaching a maximum of 8%. The comparison between 7 and 28 days indicate that marble dust could be effectively used as a replacement of cement as long as the compressive strength reduction is taken into account when designing the mixture. Therefore, the authors suggest to increase the 28 day design strength by 8-10% for a mixture that will contain up to 15% of dust.



(a) **(b)**

Figure 6: Effect of marble dust (MD) in a terrazzo aggregate mixture (RT).

The effect of replacing virgin aggregate with different types of recycled aggregate is shown in Figures 7 and 8, for 7 and 28 days, respectively. Each recycled material (marble, terrazzo and granite) replaced 15 and 30% of the virgin aggregate; the results were compared with the control mixture (V0). The 7 day compressive strength of mixtures which had recycled materials was similar or greater than compared to the control mixture (V-0). For instance, recycled marble aggregate mixtures (15RM and 30RM) had a 7-day compressive strength that was just 4% lower than the control mixture, whereas terrazzo mixtures were equal to and recycled granite aggregate mixtures were 3% to 10% stronger than the control mixture, respectively. The compressive strength at 28 days followed a similar trend, as most mixtures using recycled aggregates were within 2% of the control mixture. The exceptions were mixtures 15RT-0 and 15RM-0 with a compressive strength that was 6% and 4% greater than the control mixture, respectively. The experimental results herein are consistent with previous research on recycled marble and granite by Binici *et al.*(2008).

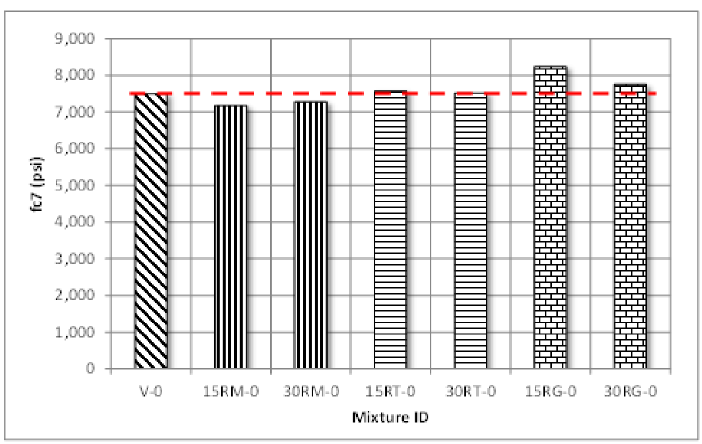


Figure 7: 7-day strength of recycle marble (RM), terrazzo (RT) and recycled granite (RG) mixtures.

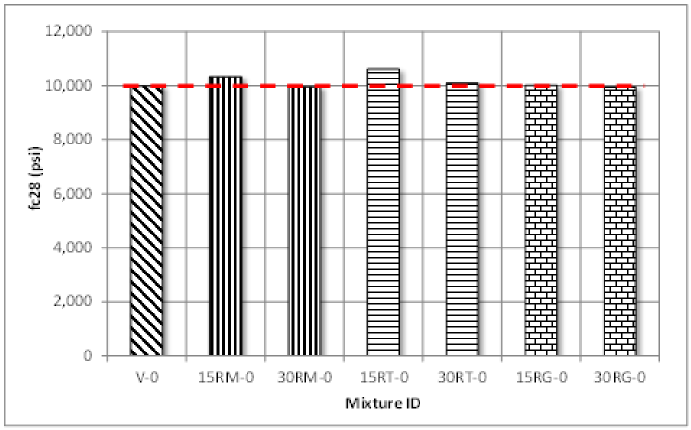


Figure 8: 28-day strength of recycle marble (RM), terrazzo (RT) and recycled granite (RG) mixtures.

Conclusions

This study has shown that marble, terrazzo and granite countertop waste from construction finishes activities can be effectively used as a replacement for up to 30% coarse and fine aggregate in concrete without negatively affecting the slump, the 7-day compressive strength or 28-day compressive strength. The use of such by-products in concrete, rather than disposing them in a landfill, significantly reduces the impact of such materials on the environment.

The use of marble dust as a replacement for cement shall be restricted to applications which do not require early age strength, since a significant decrease (19%) of 7-day compressive strength was found. Marble dust could be used for applications where 28-day compressive strength is specified, but the mixture design shall account for potential compressive strength reduction of up to 8%. Additionally, a larger dosage of water reducing admixture may be needed as the use of marble dust trends to reduce the slump of the concrete mixture.

This research indicates that the most practical, environmentally friendly, and cost efficient use of the recycled materials (marble, terrazzo and granite) in a project is as a partial coarse aggregate substitute. Coarse aggregate compromises the largest volume of the concrete, and therefore, replacing up to 30% of the virgin aggregate can significantly reduce aggregate extraction and landfill use. Additionally, the crushing process of the aforementioned materials to coarse aggregate size requires less energy as compared to sand and dust. Finally, the use of such recycled materials as coarse aggregate does not negatively impact the workability or mechanical properties of the concrete, which makes it a prime candidate for field implementation.

Acknowledgment

The authors gratefully acknowledge financial support from the California State University, East Bay Center for Students Research. The authors thank Ms. Megan White, Ms. Alana Guzzetta, and Mr. Jonathan Felts for their project support and technical advice.

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