Building Tomorrow's Society

Bâtir la Société de Demain

Fredericton, Canada

June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

RECYCLED GROUND OYSTER SHELL FOR USE AS FILLER IN SELF-CONSOLIDATED GROUT

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Abstract: In this paper, the mechanical properties of self consolidating grout with various levels of replacement of sand with ground oyster shell is investigated. The objective of this research is to determine the behaviour and structural capabilities of the alternate filler and determine its feasibility as an environmentally friendly and cost saving solution. Various levels of replacement of sand, namely 5, 10, 15, 20, 30 and 35% are investigated to find an optimal level. A base line grout without oyster shells was designed as a bench mark for strength and slump flow. One batch of mixes were designed with the same water content as the reference. The second batch was designed to have a similar slump flow as the bench mark by varying water content. Mixes consist of water, type N cement, mortar sand, superplasticizer, and ground oyster shells. Six grout cubes were prepared for each mix and were tested in compression at 38 days. Oyster shells were prepared by washing and drying followed by being passed through a jaw crusher twice and 4 minutes in a pulveriser. It was concluded that addition of all levels of ground oyster shells facilitated an increase in compressive strength. 20% replacement of sand with ground oyster shell provided the optimal compressive strength increase, with results 25% higher than the control.

1 INTRODUCTION

The production of concrete has a large negative impact on the environment. The cement production process emits significant amounts of carbon dioxide into the environment and the process consumes large amounts of water (Elyamanyet al. 2014; Pedersen 2004). Beyond simply adjusting the mixture proportions of a standard concrete mix, fillers can be added. Fillers are materials that can be added to the mixture in order to reduce the use or need for another more expensive or unsustainable material, or to vary other properties of the concrete or grout. The addition of fillers in concrete or grout mixes can help improve the sustainability, lessen the environmental impact as well as have an impact on physical properties. A very common use of fillers is in what is known as self-consolidating or flowable concretes and grouts in order to efficiently enhance the viscosity (Elyamany et al. 2014). Self consolidating concrete (SCC) and self consolidating grout or mortar (SCG or SCM) are a type of concrete and grout that has a high slump, eliminating the need for vibration to achieve good consolidation (Pedersen 2004). A few common environmentally friendly and recycled fillers include eggs shells, sea shells, lime stone rock, fly ash, stone dust, silicane fume and blast furnace slag (Elyamany, Abd Elmoaty, and Mohamed 2014; Pedersen 2004; Siffique 2008; Ye et al. 2007; Safi et al. 2015).

This paper will focus on the addition of waste sea shells, oyster shells in particular, to self consolidating grout. Safi et al. (2015) conducted a study to investigate the use of crushed sea shells as the fine aggregate in SCM and found that they could be used without negatively affecting the essential properties of mortar, causing only a small reduction in compressive strength. The study by Safi et al. made use of larger, sand sized crushed shells of various types but did not investigate the use of shells ground more finely than the sand. Yoon et al. (2003) conducted a study on the chemical-mechanical characteristics of crushed oyster shells. In this study they looked into the composition and characteristics of various sized crushed oyster shells as well as their effect when used in soil mortar, however; they did not specify which particle size distribution they used in their mixes. It was found that the compressive strength of their mortars decreased after 20% and 40% dosage ratio for cement/soil ratio of 0.2 and 0.1 respectively (Yoon et al. 2003). Olivia et al. (2015) investigated the mechanical properties of seashell concrete by partial replacement of the cement. The shells were filtered through a #200 sieve to ensure all particles were fine and conducted trial batches with 2,4,6 and 8% replacement of cement by weight. Olivia et al. concluded that the optimum compressive strength was 4% replacement, however; adding the seashells reduced all compressive strengths in comparison to the control with none.

2 EXPERIMENTAL PROGRAM

2.1 Test Matrix

The test matrix consisted of two main batches of grout with ground oyster shells replacing sand at various levels. A control mix with no ground oyster shell was used as a base line for both batches. The first batch was designed to have the same water to cement ratio as the control batch, only varying the amount of oyster shell at intervals of 5% replacement of the sand in comparison to the control. This allowed for a comparison and analysis of the effect of the filler on the workability and slump. The second batch was designed to have a similar slump as the control mixture, by varying the water to cement ratio along with the amount of oyster shell filler. This allowed for the effect on strength to be analyzed. As it is difficult to ensure the same slump every time, a range of ± 45 mm was allowed. Specimens were named based on the level of oyster shell in the batch (5-30) and whether they were water controlled (W) or slump controlled (S).

2.2 Material Properties

Both the masonry sand and the ground oyster shells were put through a sieve test to determine their gradation curves. The results of both tests are shown in Figure 1. Both the sand and ground oyster shells follow a similar gradation; however, the ground oyster shell is finer. This makes the ground oyster shell a good candidate to replace the sand in term of gradation.

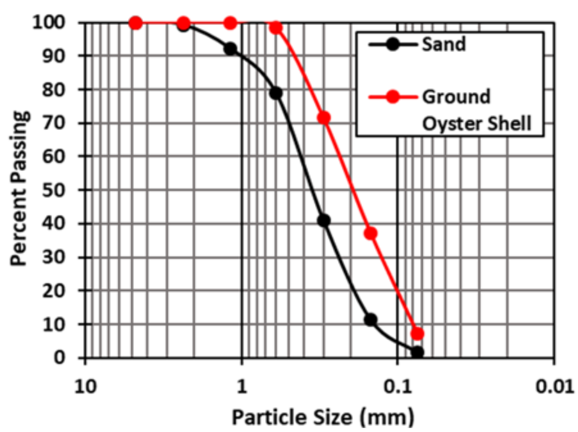

Figure 1: Gradation curve of sand and ground oyster shell

2.3 Specimen Fabrication

There were two main components to the fabrication of the test specimens. First the fresh oyster shells had to be prepared and finally the grout was mixed and cured. The oyster shells were collected from a beach in Brule Point, Nova Scotia. The shells were all empty and scoured by the tides and salt water. The oyster shells were then scoured and bathed in fresh water to remove as much salt and contaminants as possible. The shells were then placed in an oven at 70 degrees Celsius for approximately 24 hours. Once fully cleaned and dried, small 1 kg portions were sent through the jaw crusher twice each to break the full shells down into a size the pulverizer could manage. Next, in 1 kg size batches, the broken shells were placed in the pulverizer for 4 minutes until ground into a fine powder. This powder was collected and sieved in order to determine the particle size distribution. This process is shown in Figure 2.

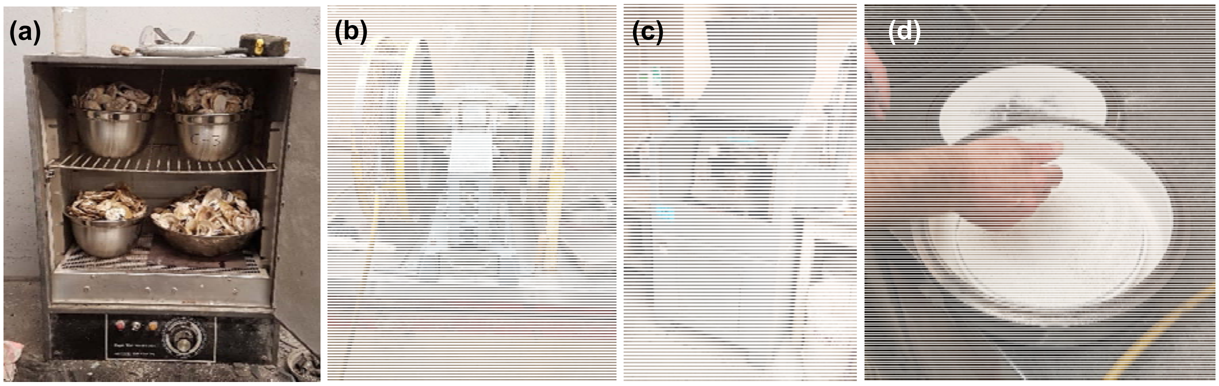

Figure 2: Ground oyster shell preparation: (a) shells are washed and dried; (b) shells are then put through jaw crusher twice; (c) shells are run through the pulverizer for 4 minutes; and (d) final oyster shell product

Once the ground oyster shell fines were prepared, the grout was mixed. All mixes contained water, superplasticizer, type N cement, masonry sand and the ground oyster shells. Depending on the batch of grout, there was a different variation of ground oyster shells, while maintaining the same quantity of fine aggregates, which includes the sand and oyster shells. To ensure a consistent mixture, the cement, fine aggregates and water were added in rotation and mixed with a power drill and paint mixer attachment. For each batch of grout, a modified slump test was conducted using a smaller tube (or cone) than the ASTM Standard for self-consolidating concrete to conserve material, ASTM 1611 (2009). A base line was set for this with the control mix. Three grout cubes were cast in 50x50x50 mm cubes for each batch of grout and cured for one day in lab before being removed from their molds and placed in the curing room. This process is shown in Figure 3.

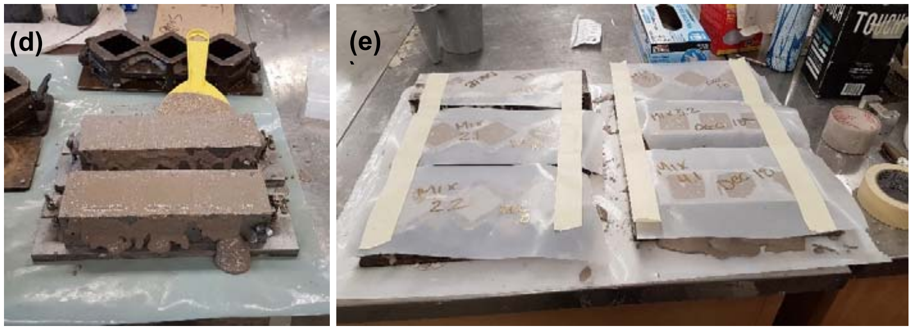

Figure 3: Specimen fabrication: (a) materials for the mix; (b) mixing materials; (c) modified slump test performed; (d) grout cubes prepared and; (e) grout cubes covered for one day of curing in lab

2.4 Test Setup

The test set up and procedure for the experiment was in accordance with ASTM C109 (2010). A spherical bottom fixture was used to minimize any accidental eccentricities. Final specimens were tested under compression using a universal testing machine with a constant strain loading rate of 1 mm/min. Load and stroke were recorded for all specimens until failure. Figure 4 below demonstrates the test setup.

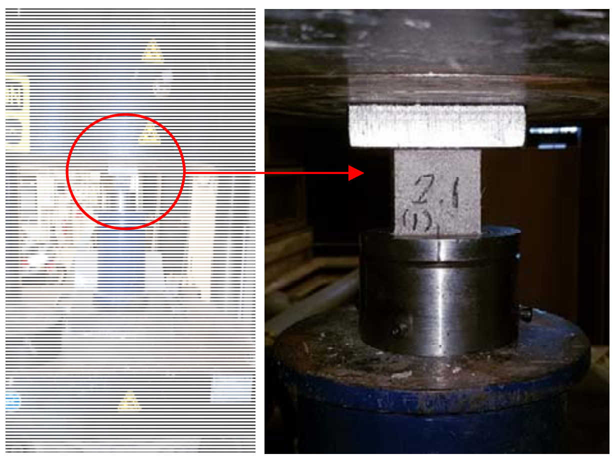

Figure 4: Test setup

3 RESULTS AND DISCUSSION

All specimens were tested under compression at 38 days after casting and their results are provided in Table 2. It should be noted that the control specimen and GO5-W were tested in compression, however only the peak load was recorded.

Table 2: Summary of test results

Specimen group ID	Mini slump flow (mm)	Compressive strength		
		Average (MPa)	Standard Deviation (MPa)	Coefficient of Variation (%)
Control	250	40.85	1.85	4.52
GO5-W	330	38.50	1.07	2.79
GO5-S	295	42.32	3.14	7.42
GO10-W	348	44.41	0.81	1.81
GO10-S	235	49.32	1.94	3.94
GO15-W	363	44.92	0.72	1.60

GO15-S	235	47.84	0.51	1.07
GO20-W	363	46.09	0.51	1.11
GO20-S	238	51.15	1.86	3.64
GO25-W	310	43.88	0.98	2.23
GO25-S	220	46.14	3.11	6.74
GO30-W	295	44.13	1.37	3.10
GO30-S	223	46.40	0.46	0.98

3.1 Slump Flow Behaviour

The control mix was designed to have a mini slump flow of 250 mm, which through trial and error was determined to be a reasonable slump for a self-consolidating mix. It should be noted that the mini slump flow was obtained from small volume of grout filled in a 50x100 mm cylinder. Initially when determining a reasonable mix design, full scale slump tests were conducted as well as the modified smaller test to ensure a fair comparison. When adding the same amount of water to each batch, the slump increased, as expected. For 25 and 30% addition of ground oyster shell the slump decreased in comparison to the addition of 5% to 20%, but still increased with respect to the control. The constant slump batch was designed to maintain a slump of ± 45 mm of the control. The results of the mini slump test for the constant water samples are provided in Figure 6.

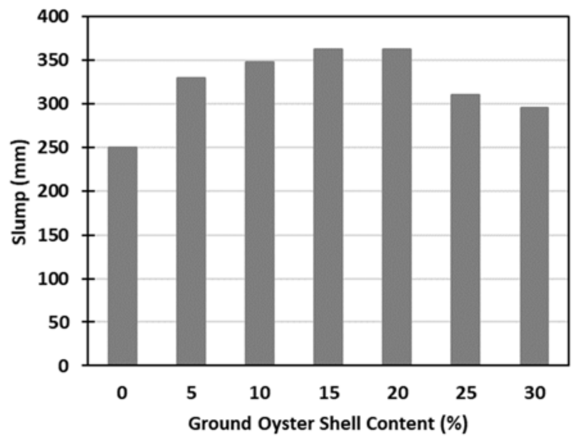

Figure 6: Variation of mini slump for constant water

3.2 Strength Behaviour

While maintaining constant slump, the results show an increase in strength in comparison to the control mix for all levels of oyster shell. The best strength results came from a 20% replacement of sand with oyster shell. The replacement of 20% of the sand corresponded to an increase in strength of almost 25% over the control. The 20% replacement was found to provide the highest strength increase for both constant slump and constant water, however; a lower strength increase was seen with constant water content. This is expected as more unnecessary water will lead to a weaker concrete; however, there is still an increase in the strength over the control mix in all but the 5% mix. The 5% ground oyster content mix, with constant water content appears to be off the trend when comparing it to the others. Figure 5 shows a compressive strength comparison for all ground oyster shell content levels tested.

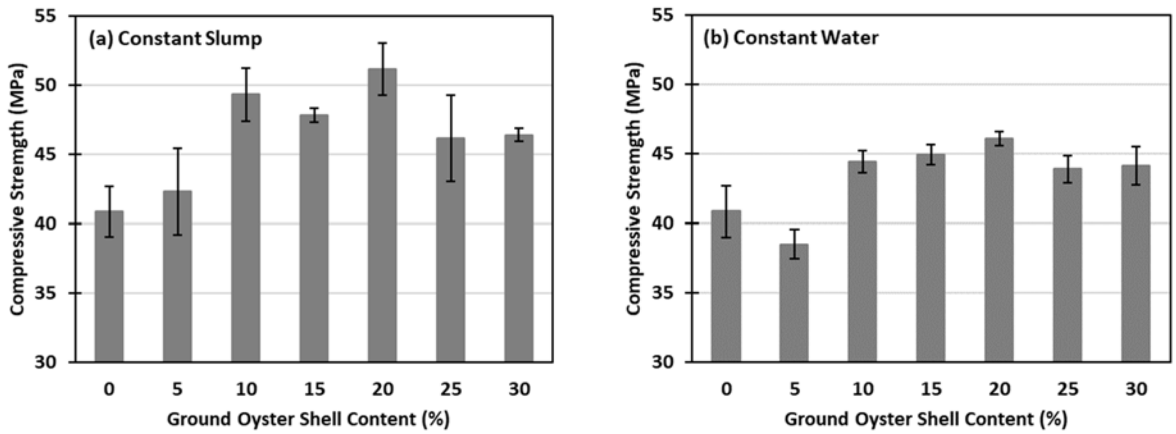

Figure 5: Variation of compressive strength: (a) constant slump mixes and (b) constant water mixes

Mix design proportions and details, for a cubic meter batch size, have been provided for the 20% ground oyster shell content mix with constant slump in Table 3.

Table 3: Mix proportions for 20% ground oyster content (by volume of sand)

Component	Quantity (1 m^3 batch)	
	Weight (kg)	Volume (m^3)
Water	170.5	0.170
Cement (Type N)	676.3	0.495
Masonry Sand	447.6	0.264
Ground Oyster Shell	60.0	0.066
Super Plasticizer	4.08	0.004
Mini Slump	238 mm	
28 Day Strength	51.15 MPa	

3.3 Load-Stroke Behaviour

Load and stroke were collected during the compression testing and the average curve for the three cubes of each constant slump batch is provided in Figure 7. Data from the 5% replacement batches has not been included as the discrepancies between the other data sets was too large. The cause of this discrepancy is unknown, however is likely due to an error in the mixing or curing stage. Further investigation is needed, including re casting and testing these specimens. Figure 7 shows that all variations followed a similar load-stroke shape, with the peak load and peak stroke varying slightly between specimens.

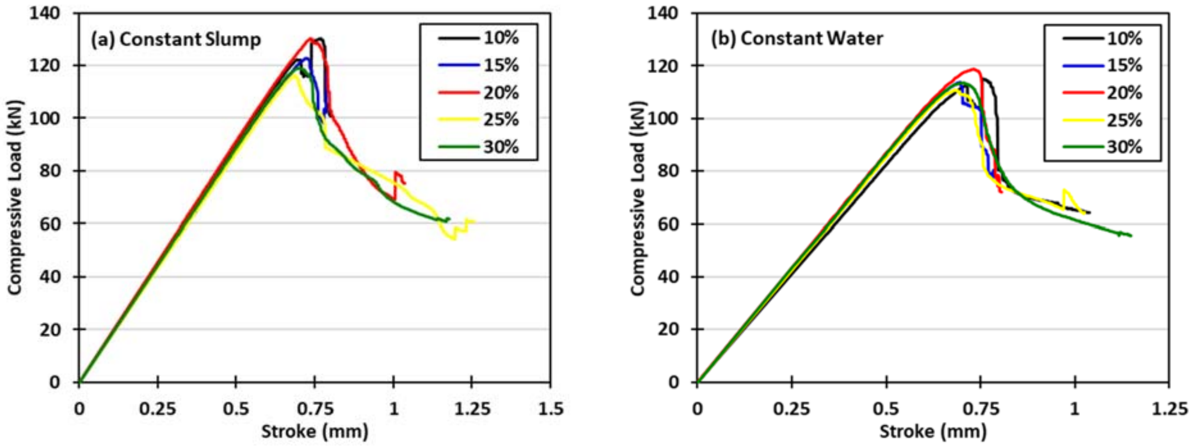

Figure 7: Comparison of load-stroke curves: (a) constant slump mixes and (b) constant water mixes

Table 4 gives the slope of the initial linear portions of these curves. It is seen that all constant slump specimens had a similar slope, with the average of all curves being 177.99 kN/mm. The constant water specimens had an average slope of 170.93 kN/mm.

Table 4: Initial slope of load-stroke curves

Ground Oyster Shell Content (%)	Average Initial Slope of Load-Stroke Curve (kN/mm)	
	Constant Slump	Constant Water
10	180.37	164.69
15	175.21	172.79
20	182.26	173.51
25	174.04	170.56
30	178.08	173.11
Average	177.99	170.93
Standard Deviation	3.07	3.28

4 CONCLUSION

Six variations of a control mix were designed to feature various levels of replacement of sand with ground oyster shell from 5-30%. Each level of replacement had two different batches, one with the same level of water as the control and the other with the same slump measurement as the control. All specimens were cast in grout cubes and tested in compression after 38 days of curing. It was found that for both controlled water and slump 20% replacement was the optimal design. 20% replacement of sand with ground oyster shell allowed for almost a 25% increase in strength over the control mix when slump was maintained. The next stage of this study will include mixing a larger batch of the 20% mix design to obtain the slump flow based on ASTM 1611 (2009). Further work on this topic will also include investigation into the particle size distribution of the ground oyster shell by conducting a hygrometer test on the fines. Various levels of replacement will be re-mixed in order to rule out any errors that may have occurred in the first round of mixing. Higher levels of replacement may also be considered, along with more levels of replacement between the 5-30% used in this study.

Acknowledgements

The authors acknowledge the financial support of Dalhousie University, the Nova Scotia Graduate Scholarship (NSGS) and the National Sciences and Engineering Research Council of Canada (NSERC). The aide of Dalhousie University's Mineral Engineering department with the crushing of the oyster shells was greatly appreciated. The authors also acknowledge the help of Jesse Keane for his help with testing and data acquisition.

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