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Partial Cement Replacement in Concrete with Gypsum Powder Recycled from Waste Drywalls

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Abstract: Construction industry is one of the most significant contributors to environmental issues in today's world. For this reason, sustainable approaches in building industry have always been sought by researchers in this domain. Cement manufacturing process, for example, emits considerable amounts of greenhouse gasses contributing to global warming. Replacing cement with other materials which have less environmental footprints has been considered a solution. Construction and demolition waste disposal, also, could cause environmental issues in landfills. Gypsum drywalls account for a considerable amount of construction waste which contains a noticeable amount of gypsum. Utilizing recycled gypsum from waste drywalls as a partial replacement for cement in concrete could address both problems regarding the impact of construction on the environment. In this study, recycled gypsum powder from waste drywall was used as a partial replacement for cement in concrete. Five concrete mix designs which include 0, 10 and 20% of recycled fine gypsum powder and whole gypsum were considered for this study. Since it has been proven that gypsum does not function well as the only partial replacement of cement, 50% of each mix design is dedicated to fly ash. Three cylindrical (100 mm x 200 mm) specimens of each mix design were tested at 7, 28, and 90 days. The results showed that the partial replacement of cement with recycled gypsum is a viable solution for more environmentally friendly concrete for our infrastructure.

1 INTRODUCTION

The negative impact of the construction industry on the natural environment is undebatable. Hereby, two of the most noticeable topics are discussed. First, the cement manufacturing process could result in carbon dioxide (CO_2) production, thereby contributing to climate change and global warming. Second, is the gypsum drywall disposal in landfills, which could result in soil degradation and the contamination of nearby water resources. Utilizing recycled gypsum as a partial replacement for cement in concrete structures could be considered as an approach to address both issues (Hansen and Sadeghian 2019 and Naik et al. 2010).

Cement manufacturing plants emit significant amounts of greenhouse gases (GHG) into the atmosphere. The emissions resulting from the cement industry account for up to 10% of artificial GHG emissions in the world (Nguyen et al. 2018 and Naik et al. 2010). Also, the cement industry alone is responsible for 7% of global CO_2 emissions (Malhotra 2010). Needless to say that CO_2 could have devastating impacts on the natural environment Since it is the major contributor to air pollution and global warming (Meyer 2009). Furthermore, the cement industry consumes a significant amount of energy annually for manufacturing the product (Nguyen et al. 2018). This could be an amplification for the production of GHGs resulting from cement manufacturing since a considerable amount of fossil fuels needs to be burned for sufficient energy to be provided for the cement manufacturing process Every year (Jing Ke et al. 2013). Nearly 3.4 billion tons of cement are produced as the major raw material for concrete manufacturing (Nguyen et al 2018). The costs of cement production and the huge volume of cement that is produced annually convinced Civil and environmental engineers to look for replacements for cement as the cementitious material in concrete.

Construction materials disposal at landfills is another noticeable issue in today's world. Each material could have different impacts on the natural environment depending on the material's chemical and mechanical properties. Gypsum wallboards (Also known as drywalls) account for a significant amount of residential construction waste (nearly 20 percent) (Naik 2010). As a result of drywall disposal, huge amounts of gypsum are accumulated in landfills, which will cause several environmental issues. Gypsum is capable of releasing hydrogen sulfide gasses which could result in soil degradation (Ahmed et al 2011). It is also a flammable gas that could be lethal in high concentrations (Chandara et al. 2009 and Hansen and Sadeghian 2020). Hydrogen sulfide could also penetrate the soil and cause water contamination in nearby areas (Hansen and Sadeghian 2020). Utilizing the accumulated gypsum resulting from drywall disposal is considered as an approach to address the issues resulting from cement manufacturing and gypsum drywall waste disposal (Hansen and Sadeghian 2020).

Using recycled gypsum from waste drywalls as a partial replacement for cement in concrete could reduce the demand for cement production and as a result, fewer GHGs would be emitted to the atmosphere. Also, it could be a rational approach to eliminate gypsum from our landfills and turn it into a resource. (Naik et al. 2010) used the combination of recycled gypsum powder and fly ash class C as a partial replacement for cement in concrete. According to the results, between 30- 60 percent of cement could be replaced by a gypsum-fly ash class C mixture. More importantly, concrete specimens containing 10 % gypsum as cementitious material are shown to have the same compressive strength as the conventional concrete after 28 days (Naik 2010). Hansen and Sadeghian (2020) attempted to replace a higher volume of cement with a gypsum-fly ash mixture (up to 70%). Gypsum could have negative impacts on the compressive strength of concrete in a short period after manufacturing. However, the concrete containing gypsum alongside fly ash and cement as the cementitious paste is proven to have higher compressive strength compared to the concrete mixture that has only cement and fly ash as the cementitious material (Hansen and Sadeghian 2020). Therefore, the application of recycled gypsum powder is acceptable, and utilizing this material in concrete manufacturing is feasible.

In a previous study by Hansen and Sadeghian (2020) and Naik (2010), only fine particles of the recycled gypsum from waste drywalls were used. To be more specific, the particles remaining on the sieve No 100, sieve no 200, and the pan during sieve analysis was separated and used in the concrete. This proportion accounts for only 38% of a certain sample of recycled gypsum. In other words, a considerable proportion of gypsum drywalls would remain as waste and would be dumped in the landfills again. Therefore, solutions are needed to be introduced in order to make this approach more sustainable. In this study, one more step has been taken in the domain of application of recycled gypsum in concrete, and the whole recycled gypsum is used as a replacement for cement in several concrete specimens. The main goal of this paper is to introduce an ultimate performance for the waste gypsum in our infrastructure.

2 EXPERIMENTAL PROGRAM

2.1 Test Matrix

Five total mix designs are considered for this study including one control batch, two batches that involve fine gypsum as a partial replacement for cement in different amounts (20% and 10%), and two batches that involve the whole gypsum as patrial replacements for 10% and 20% of cement in the concrete. Fly ash accounts for half of the cementitious material mass in all the batches and the other half is dedicated to cementing only for the control batch and the combination of cement and gypsum for other batches. The purpose of considering mixed designs with fine gypsum is to validate the results achieved by Hansen and Sadeghian (2020) making an appropriate comparison with this study. The detail for mixtures is presented in Table 1. Also, the proportion of each component of cementitious materials is demonstrated in Table 2 The capital letter G stands for the mixtures that involve the whole gypsum while FG stands for those in which only fine particles of gypsum are used. The letter C stands for control specimens. The number in front of each letter indicates the proportion of cement which s replaced by the corresponding gypsum (fine or whole amount). In order to make better comparisons considered the mix design for this study is the same as Hansen Sadeghian (2020).

Table 1: Mix design (the material quantities for 1 m^3 of concrete)

Material	Quantities
Water (kg)	187.9
Coarse Aggregate (kg)	1184.3
Fine Aggregate (kg)	574.6
Cementitious Materials (kg)	395.2
Superplasticizer (L)	0-1.6

Table 2: The contribution of each component of cementitious material in

Specimens ID	Cementitious Material (%)		
	Cement	Fly ash	Gypsum
C	50	50	0
G10	40	50	10
G20	30	50	20
FG10	40	50	10
FG20	30	50	20

2.2 Material Properties

Overall, three types of sand were available for this study; masonry sand, sand donated by local sources (Casey Metro, Halifax, NS, Canada) in previous years which was used by Hansen and Sadeghian, and sand donated by the same source recently. After sieve analysis, it was revealed that masonry sand is not falling into the ASTM parameters for making concrete. While both curves corresponding to the second and third sand are located between the ASTM top and bottom limit, they are not identical. The third type is decided to be used because of its availability for this study and later research related to this topic. The coarse aggregate donated by the same source is half-inch stone which is suitable for making concrete in terms of size distribution. The cement considered for this study is type GU Portland cement (CRH, Canada Group, ON, Canada). Fly ash used in the concrete was provided by local sources (Ocean Contractor Ltd, Dartmouth, NS, Canada). The recycled gypsum provided from waste gypsum drywalls was provided by USA Gypsum, Denver, PA, USA, which is the same gypsum used by Hansen and Sadeghian in the previous study. During Gypsum sieve analysis the fiber-like particles which were many courses than normal gypsum particles were observed on most of the sieves (all sieves but sieve No. 200 and pan) For mix designs that contain fine gypsum (the ID starts with FG) only the gypsum retaining on sieve 200 and pan is used. For other mixes, the whole gypsum was used without removing fiber-like and coarser particles. Figure 3 demonstrates the fine gypsum and whole gypsum particles.

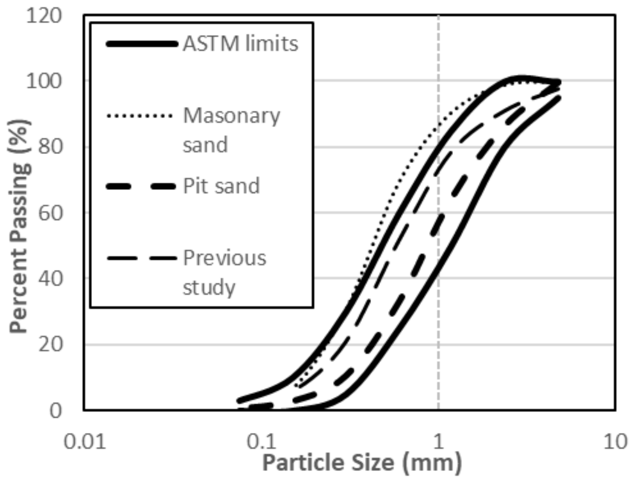

Figure 1: Fine Aggregate particle size distribution

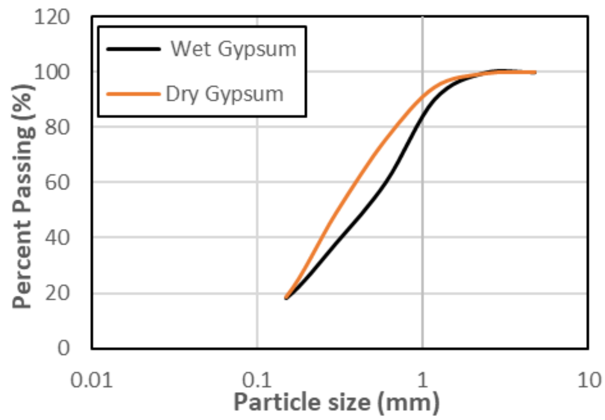

Figure 2: Gypsum Particle size Distribution

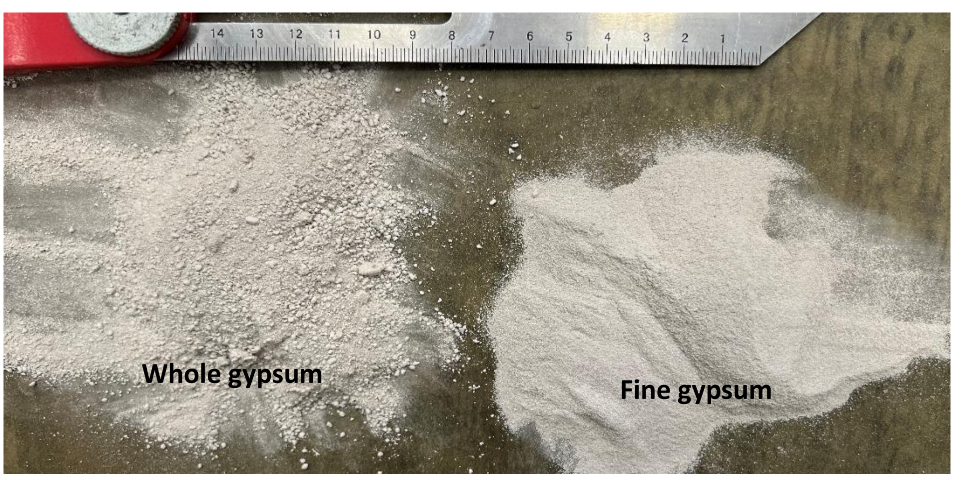

Figure 3: Fine gypsum and whole gypsum samples

After conducting sieve analysis on gypsum, some coarse fiber-like particles were witnessed on the sieve. These particles could be found on all the sieves except sieve No 200. In the previous research conducted by Hansen and Sadeghian (2019), these particles did not show up on sieve No 100. The main suspect of this contradiction was the effect of humidity. To test this hypothesis, sieve analysis was conducted on dry gypsum as well. A specific proportion of gypsum was oven-dried for 24 hours and afterwards, the sieve analysis was conducted on the dry sample. In this case, those fiber-like particles were no longer visible on sieve No 100. As can be seen in Fig 2, there are significant differences between the particle size distribution of the two types of gypsum. It is worth mentioning that the moisture content of gypsum turned out to be more than 22%, measuring the weight of the dry sample. This proportion of moisture could affect the sieve analysis results.

Figure 4: Gypsum concrete ingredients

Figure 5: Retaining gypsum powder on sieve No.100 after shaking. a) wet gypsum, b) dry gypsum

2.3 Specimen Preparation

Five batches are considered for this study. Three batches including control specimens are considered to validate previous studies regarding the impact of fine gypsum content as cementitious material on the compressive strength of concrete. The other two batches are considered to assess the impact of using the whole gypsum (fine particles and coarse particles) instead of fine gypsum in the concrete. A mini mixer was used for mixing all the ingredients of concrete. All the materials are added to the mixer in a certain order. The mixer was allowed to work until a homogenous mix is achieved. For those mix designs which involved gypsum, dehydration was witnessed in the mix. For this reason, a superplasticizer is used to make the mix workable and hydrated. For each mix design, three 100mm × 200mm molds are considered which are tested on day 7, day 28, and day 90. All the specimens are cured in the moisture room after being demolded (Figure 5).

Figure 6: a) Casting concrete in molds and preparing specimens. b) Capped specimens

2.4 Test Setup and Instrumentation

Specimens are removed from the moisture room and capped using sulfur compound after 24 hours. After another 24 hours, the capped specimens are tested at ages using the compressive test machine. The output is the maximum force that each specimen resists in pounds (lbs). After doing conversions and calculations the compressive strength is calculated in Megapascal (MPa).

3 RESULTS AND DISCUSSIONS

3.1 Compressive Test Results

Specimens were tested after 7, 28, and 90 days of curing in the moisture room. For each mix design, three specimens were tested on the testing day and the average compressive strength was determined in MPa. The tested specimens and the compressive test results corresponding to day 7, 28, and 90 tests are demonstrated in Figure 6, Figure 7, and Table 2.

Figure 7: Specimens after compressive strength test

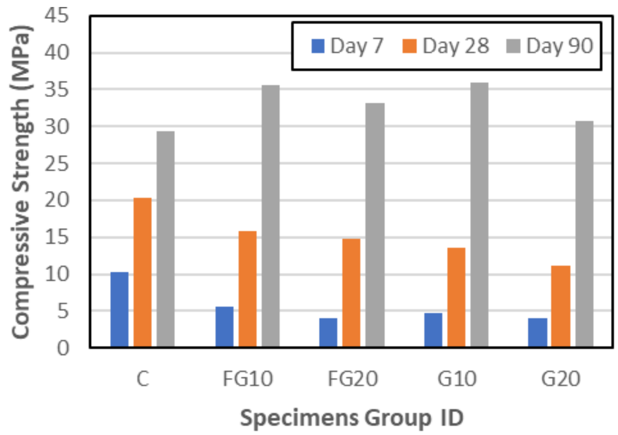

Figure 8: Compressive strength results

Table 3: Average Compressive strength of strength corresponding to each mix design

Specimen ID	Compressive Strength Day 7 (MPa)	Standard Deviation Day 7 (MPa)	Compressive Strength Day 28 (MPa)	Standard Deviation Day 28 (MPa)	Compressive Strength Day 90 (MPa)	Standard Deviation Day 90 (MPa)
C	10.2	0.49	20.4	1.98	29.4	3.1
G10	4.7	0	13.5	1.14	36.0	0.1
G20	4.1	0.43	11.1	0.71	30.8	1.99
FG10	5.6	0.13	15.8	0.33	35.5	1.89
FG20	4.0	0.25	14.7	0.85	33.2	3.4

3.2 The Impact of using Fine Gypsum and Whole Gypsum.

According to the compressive test results, the gypsum content could have a negative impact on the compressive strength of concrete. This strength reduction is more significant at early ages and became lower at later ages. In a longer period, however, the gypsum content had a positive impact on the compressive strength of concrete. Using fine gypsum could result in stronger concrete compared to the concrete which involves the whole gypsum in the mix design; however, according to the sieve analysis, almost 38% of the whole recycled gypsum would be used for making fine gypsum concrete. On the other hand, although the whole gypsum concrete is slightly weaker than fine gypsum concrete, the former is much more sustainable compared to the latter. Table 4 shows the comparison between whole gypsum, fine gypsum concrete, and control specimen in terms of compressive strength changes as a result of using gypsum in concrete.

Table 4: Compressive strength reduction and increase compared to

Specimen Type	10% Gypsum (Day 7)	20% Gypsum (Day 7)	10% Gypsum (Day 28)	20% Gypsum (Day 28)	10% Gypsum (Day 90)	20% Gypsum (Day 90)
Whole Gypsum	-53.9%	-59.8%	-33.8%	-45.6%	+22.4%	+4.8%
Fine Gypsum	-45.1%	-60.8%	-22.5%	-27.9%	+20.7%	+12.9%

3.3 Comparison of Previous Studies

Hansen and Sadeghian (2020) conducted a similar study in which fine gypsum concrete was evaluated. To make a better comparison, in this study both fine gypsum and whole gypsum concrete are considered. According to Table 3, the compressive strength of each mix design in this study is slightly different from that of the previous one although the same mix design and materials were used in both. Some parameters such as humidity, temperature, and the effect of superplasticizer could result in this difference. The impact of fine gypsum content followed a similar trend in both studies as can be seen in Table 4.

4 Conclusion and Recommendations

In this study, 5 batches with similar mix designs and different cementitious material compounds were considered. One control batch involved 50% cement and 50% fly ash as cementitious material, two batches with 10% and 20% of cement replaced with fine gypsum, and two batches in which 10% and 20% of cement were replaced with whole gypsum. To provide fine gypsum, only the retaining gypsum particles on sieve No. 200 and pan were used whereas for whole gypsum batches, specific proportions of gypsum were randomly added to the mix. 9 specimens were provided for each batch which are tested on day 7, day 28, and day 90. According to the tests on day 7 and day 28, the compressive strength of concrete reduces by increasing the proportion of gypsum by which cement is replaced. This strength reduction is more severe in early ages. The compressive strength even reduces to lower levels if the whole gypsum is used instead of fine gypsum as a replacement for cement. The promising point is that the strength reduction decreased significantly on the day 28 test. This could indicate that the negative impact of using gypsum in the concrete could become less noticeable or even negligible in the long-term period. According to day 90 test results, utilizing both fine and whole gypsum could increase the compressive strength of the concrete in the long-term period. Also, the slight difference between the compressive strength of whole gypsum concrete and fine gypsum concrete indicates that the whole gypsum concrete could be as practical in today’s life as fine gypsum concrete with higher sustainability features. Some contradictions have been witnessed between this study and the previous studies in this domain while similar mix designs were used in both. Some important factors could have contributed to this phenomenon including humidity rate, temperature, and the process of mixing materials and making specimens. It is highly recommended for further studies to consider the impact of gypsum content in concrete for a longer time period (more than 90 days). Furthermore, it is essential to seek solutions for addressing the issues regarding the lack of strength in the early ages of gypsum concrete. Also, it is worth mentioning that the durability of this type of concrete must be evaluated. For gypsum concrete to be fully functional in our infrastructure, it should be able to survive diverse environmental conditions.

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