CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

APPLICATION OF RECYCLED GYPSUM WALLBOARDS IN CEMENT MORTAR

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Abstract: Gypsum is a naturally formed mineral that is already known to be added to cement at small percentages in order to reduce the speed of reaction with water, however it seems that substantial technical research has not been done concerning larger proportions of gypsum. The primary objective of this study is to use recycled wallboard/drywall powder (hereafter is called gypsum) as a partial replacement for cement in cement mortar mixtures to introduce a more sustainable and environmentally friendly solution that lowers carbon dioxide (CO_2) emissions by using recycled materials, while maintaining adequate strength and durability. Used gypsum wallboard is often sent to landfills instead of being recycled, which can cause leachates with harmful environmental and health effects. Eight mixtures containing different combinations of cementitious material including cement, gypsum and fly ash were mixed with water and aggregates and placed in 50 mm mortar cube molds. After curing in a moist room, the mortar cubes were tested for compressive strength at the age of 3, 7, 28, and 56 days. Superplasticizers were used to regulate mixture consistency, as adding gypsum was found to dehydrate the mixture. Fly ash was also used, though requiring a longer initial setting time than cement. This study showed that mixtures containing only recycled gypsum and cement showed lower compressive strength at all ages, becoming increasingly weak with increased proportions of gypsum. However, combining gypsum and fly ash as partial replacement for cementitious material showed increased compressive strength, especially at later ages.

1 INTRODUCTION

It is well known that the production of cement releases large amounts of CO_2 into the atmosphere, causing negative impacts on our environment and contributing to global warming. Using a recycled material decreases the demand on producing virgin materials, ultimately reducing the CO_2 emissions, saving precious landfill space and keeping landfill sites unharmed. The construction industry produces roughly 33% of all solid waste in North America, with gypsum wallboard product comprising about 15% of this waste (Gratton and Beaudoin 2010). Currently, the majority of wallboard waste is disposed of in landfills, which is unsustainable and harmful to the surrounding environment. When exposed to rain and organic waste, landfill sites containing large volumes of gypsum have been shown to produce significant levels of hydrogen sulfide. This sulfide can be absorbed into the leachates or released into the air as a dangerous, flammable gas (Gratton and Beaudoin 2010). When absorbed into the leachates, the groundwater and consequently nearby ecosystems are vulnerable to its harmful effects. As the sulfate contained in gypsum drywall degrades in the landfill, it is also able to form complexes with other unstable metals or elements that are present in landfills, the most concerning being arsenic due to its high toxicity (Zhang et al. 2016). If the ability to use increased volumes of gypsum in cement is discovered to be successful, construction companies would likely be more inclined to recycle their gypsum waste to then be used in concrete applications, instead of producing or purchasing more. Having a sustainable use for recycled gypsum in concrete provides us with a safe and sustainable alternative by keeping the material out of landfills and decreasing CO_2 emissions during production, consequently lowering our environmental footprint.

Suarez et al. (2016) used life cycle assessment methodology to evaluate the environmental impacts of using natural and recycled gypsum in Portland cement production, but consideration was not given to the mechanical properties of concrete. A study by Naik et al. (2010) reported that replacing cement with up to 10% powdered gypsum wallboard did not adversely affect the properties of concrete, and better performance was observed when blending Class C fly ash and powdered gypsum with cement. Mineral additives such as fly ash have been reported to greatly enhance the durability of concrete and resistance to environmental impacts, as well as providing economic and ecological benefits. However, it is widely acknowledged that these by-products can reduce early strength of concrete (Wu and Naik 2002). Marlay (2011) considered that additional gypsum may be required to promote more desirable chemical reactions during concrete hydration when fly ash is used for cement replacement in high volumes. Despite a few research projects on recycled gypsum from drywalls, the effect of the material on the properties of concrete and cementitious products in general is not well-known. This paper reports the results of a preliminary study on the effects of recycled gypsum for use as partial replacement for cement in mortar cubes under compression.

2 EXPERIMENTAL PROGRAM

2.1 Test Matrix

The main test matrix consisted of five batches of mortar with varying proportions of gypsum for partial replacement by weight for cement, including a control mix containing no recycled gypsum. Additionally, three mixes containing fly ash were prepared and tested under compressive loading. To keep the consistency of the mix to a relatively similar level of workability, variable amounts of superplasticizer were added during mixing. The specimen’s batch proportions of are shown in Table 1.

Table 1: Test matrix and material quantities

Specimen Group ID	Gypsum Content (%)	Fly Ash Content (%)	Cement Content (%)	Water (mL)	Sand (g)	Gypsum (g)	Fly Ash (g)	Cement (g)	Super-plasticizer (mL)
0	0	0	100	514	2914.8	0	0	1060.6	0
1G	10	0	90	515	2915.2	106.2	0	954.3	1
2G	20	0	80	514	2915.4	211.8	0	848.3	1.5
3G	30	0	70	515	2914.9	317.9	0	741.8	2.5
4G	40	0	60	514	2914.0	424.4	0	635.9	3.5
5F	0	50	50	514	2915.2	0	530.1	530.2	3
25GF	25	25	50	515	2915.4	265.1	265.4	265.4	1
1G4F	10	40	50	515	2915.1	106.3	424.1	424.1	3

2.2 Material Properties

In this research, the gypsum was used as is from a drywall waste recycling company (USA Gypsum, Denver, PA, USA) that processes the material into an ultra-fine consistency with particle sizes ranging from 1/8 in. (3.175 mm) to dust. The cement used in all mixes was Type GU Portland Cement (CRH Canada Group, ON, Canada). Fly ash was available in the lab (Dalhousie University, NS, Canada). The sand was locally sourced (Casey Metro, Halifax, NS, Canada) and was used in air dried condition, so a level of moisture content was accepted. The gypsum and sand were both put through a sieve analysis to determine the particle size distribution curves, shown in Figure 1.

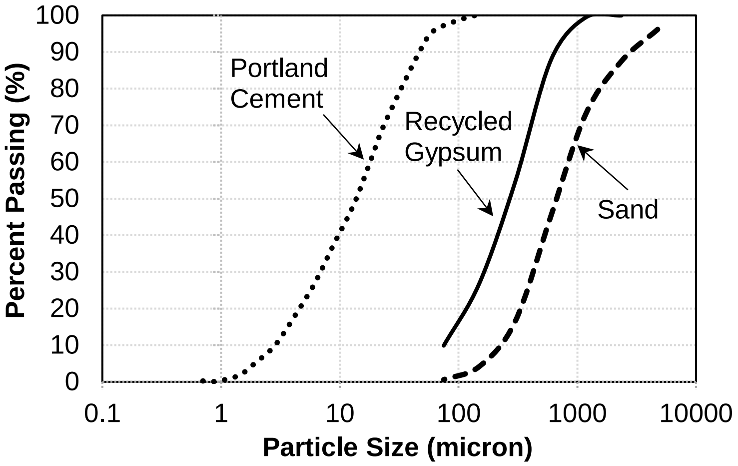

Figure 1. Particle size distribution of gypsum, sand and Portland cement. Note: Portland cement data retrieved from Sata et al. (2010)

During the sieve analysis, it was discovered that light-weight fibre-like particles attached together to create small bunches or clusters of material. To produce drywall, two outer sheets of paper contain the gypsum plaster, so it is assumed that these particles are made of paper that remained during the recycling process, however the actual chemical composition is unknown. These bunches tend to be larger and more loosely attached on the smaller number sieves (with larger openings), and more frequent and more tightly packed as the sieve size raises. Passed the No. 100 sieve, these clusters were no longer noticeable. Photos of various sieves retaining the recycled gypsum material are shown in Figure 2, including these particle bunches.

Figure 2. Gypsum retained of sieves (a) No. 16 (b) No. 30 (c) No. 50 (d) No. 100

2.3 Specimen Preparation

To prepare the specimens, ASTM C109 (2016) was followed for each of the mix designs. All material was slowly added to a tabletop electric mixer and then allowed to mix for 2-3 minutes until a uniform texture was accomplished. Adding gypsum to concrete, even at only 10% of cementitious material, was found to develop a dehydrated mix that had reduced workability. For this reason, the researcher visually and physically accessed each mix at this time and decided whether or not to add superplasticizer based on the workability of the mortar in comparison to the control mix. If needed, superplasticizer was added to the mixer in increments of 0.5 mL using a syringe and evenly distributing the liquid throughout and allowing to mix for another minute or so. The consistency of the mortar mix was then accessed again, and the process described above was repeated as necessary. After mixing, the 50x50x50 mm specimen molds, shown in Figure 3, were filled and hand tamped as required by the standard. The molds were removed after 24 hours and the specimens were then labelled and moved to a moist closet for curing.

Figure 3. Specimen molds

2.4 Test Setup and Instrumentation

Specimens were tested promptly after removal from the moist closet and tested at specified test ages. The procedure for the determination of compressive strength was in accordance with ASTM C109 (2016). The test setup is shown in Figure 4, where the maximum load is measured in pounds (lbs).

Figure 4. Compression test setup

3 RESULTS AND DISCUSSION

3.1 Compressive Behaviour

Specimens were tested under compressive loading after curing for 3, 7, 28 and 56 days. The average compressive strength was calculated by first converting the measured load from pounds (lbs) to Newtons (N), and then to megapascal (MPa), Table 2 provides the average results for compressive strength of specimens tested, taken from 3 mortar cubes per test.

Table 2: Summary of compressive strength results

Specimen Group ID	Day 3		Day 7		Day 28		Day 56	
	Average Strength (MPa)	Standard Deviation (MPa)	Average Strength (MPa)	Standard Deviation (MPa)	Average Strength (MPa)	Standard Deviation (MPa)	Average Strength (MPa)	Standard Deviation (MPa)
0	26.99	1.03	37.96	2.05	41.22	7.34	52.49	8.49
1G	25.50	0.51	28.17	1.36	27.73	0.93	30.10	0.68
2G	14.23	0.89	17.20	2.05	24.76	0.68	24.91	1.60
3G	13.34	0.89	16.61	1.36	21.50	0.68	21.20	0.68
4G	13.05	2.86	12.45	5.83	11.12	2.78	14.68	7.35
5F	20.31	2.19	26.84	0.26	55.75	9.26	51.15	12.53
25GF	8.16	0.68	18.09	1.68	43.59	1.18	49.52	6.31
1G4F	13.20	2.19	26.69	2.35	41.81	2.35	41.96	2.86

Typically, specimens subject to compressive loading failed by braking into an hourglass shape with larger pieces falling around the centre of faces not in contact with a surface. However, the specimens containing 40% gypsum broke more inconsistently and into smaller pieces that crumbled apart much easier than other specimens. The failure modes of various specimens after compression testing are shown in Figure 5.

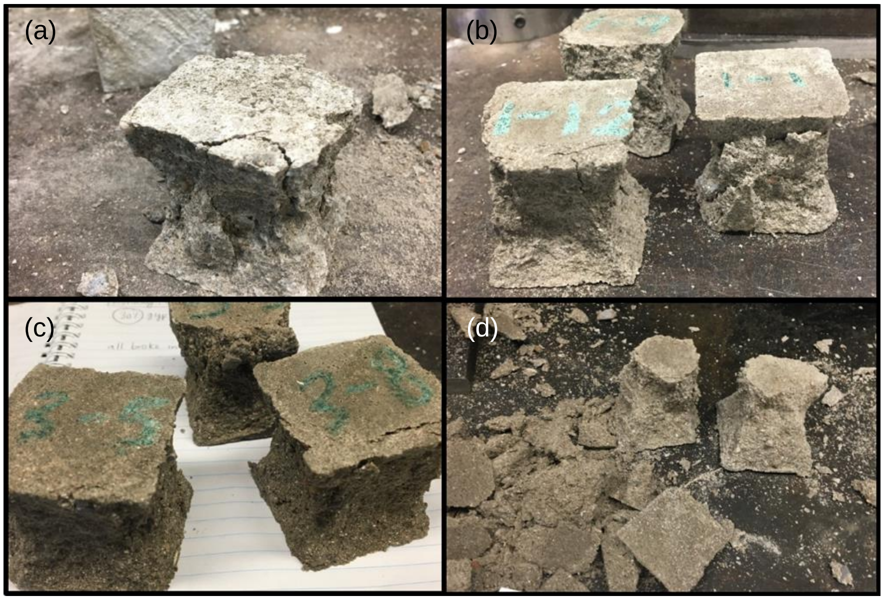

Figure 5. Compression testing on specimens (a) 0 (b) G1 (c) G3 (d) G4

3.2 Effect of Gypsum Content

It was detected that gypsum has a smaller density in mortar mixes when compared to cement, as the specimens' weight continually decreased with increasing gypsum content. The results shown in Table 3 are averaged from 3 cubes weighed on day 56, with the bottom row indicating the average difference (decrease) in weight compared to the control batch which contains no additional gypsum.

Table 3. Cube weight varying with gypsum content

Gypsum content (%)	0	10	20	30	40
Average weight (g)	300.30	289.47	287.93	286.83	278.30
Decrease from control (g)	0	10.83	12.37	13.47	22.00
Decrease from control (%)	0	3.74	4.30	4.70	7.91

Replacing varying percentages of cement with recycled gypsum powder as the cementitious material of the mix tends to decrease the compressive strength of specimens. This was expected, as similar results were observed by previous researchers. Figure 5 shows a comparison of the compressive strength at each test day in relation to the gypsum content, including error bars representing the standard deviation of test specimens. It was determined that as the gypsum content increases, a continuous decrease in the average compressive strength is seen in comparison to the control batch, at all ages. The largest decrease in strength is observed between 0-10%, and noticeably smaller variations are seen for batches containing 20% and 30% gypsum. When the cementitious material contains 40% gypsum, results are inconsistent with large error bars, and no significant strength gain is developed passed day 3.

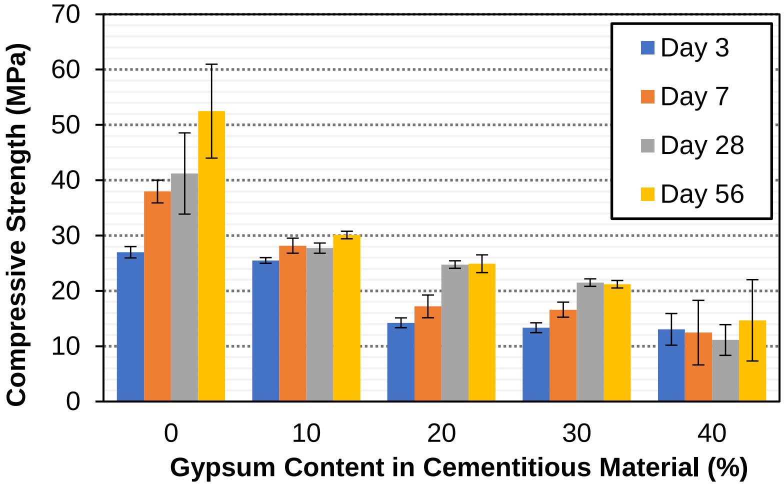

Figure 6. Compressive strength with varying gypsum content

Figure 6 was split up into separate graphs for each day in order to determine suitable trendlines for the compressive strength with increasing gypsum content. After assessing each of the individual graphs, the trends are generally best described by a negative logarithmic distribution. Table 4 highlights the results of the trendline analysis, including each trendline equation and coefficient of variation (R^2) found for each test day. It is accepted that an R^2 value equal to 1 indicates the best fit of the data to the model, so the model is less suitable at day 3. It was also determined that specimens allowed to cure for longer time periods showed a larger decrease in strength in comparison to the control batch. This can be seen in Table 4 as the negative slope of the logarithmic trendline continually decreasing from day 3 through 56.

Table 4. Trendline analysis at each test day

Trendline	Day 3	Day 7	Day 28	Day 56
Equation	$y= -10.12\ln(x)+28.31$	$y= -16.17\ln(x)+37.96$	$y= -16.61\ln(x)+41.17$	$y= -22.31\ln(x)+50.04$
R^2 value	0.846	0.972	0.938	0.963

3.3 Effect of Fly Ash

Three batches of mortar were mixed using fly ash as partial replacement in the cementitious material, one including only cement (5F), and two also including recycled gypsum powder (25GF and 1G4F). The average results from the compression tests for these mixes are presented in Figure 7. Significant strength development is observed between 7 and 28 days, however the strength development between 28 and 56 days is variable and considered insignificant. This differs from mixes containing only gypsum and cement shown in Figure 6, where the strength gain is less noticeable and more irregular.

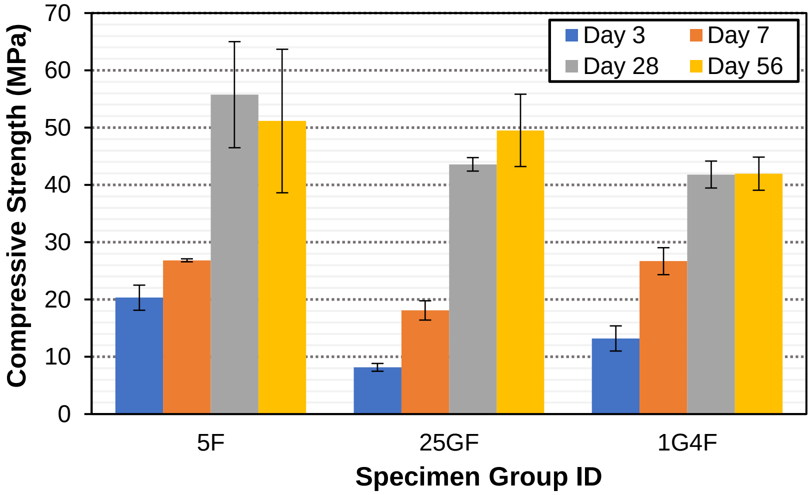

Figure 7. Compressive strength with varying gypsum and fly ash content

In order to compare the strength development of mixes containing fly ash to those without fly ash, Figure 8 was developed. Figure 8 (a) compares test results of mix “1G” containing 10% gypsum and 90% cement to mix “1G4F” containing 10% gypsum, 40% fly ash and 50% cement. Figure 8 (b) uses the average test results of mixes “2G” and “3G” to create “25G”, hypothetically containing 25% gypsum and 75% cement, to compare with mix “25GF” which contains 25% gypsum, 25% fly ash and 50% cement. These graphs show that mixing gypsum with fly ash and cement initially yields smaller compressive strengths at day 3, comparable results at day 7, and noticeably higher strengths after longer curation periods of 28 and 56 days. It can therefore be concluded that mixes containing fly ash require longer time periods to develop compressive strength, which coincides with the literature. This result also confirms previous research showing that fly ash is a very beneficial component for concretes long term strength when combined with gypsum as partial replacement of the cementitious material.

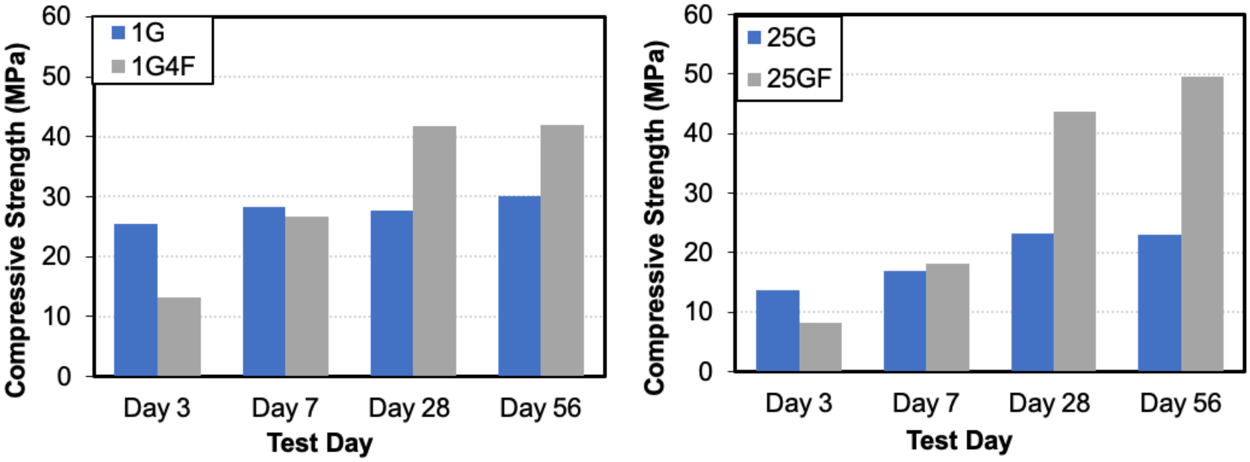

Figure 8. Compressive strength comparison with fly ash

4 CONCLUSIONS AND RECOMMENDATIONS

In this study, eight batches of cement mortar were cast in 50 mm cubes to then be tested under compressive loading after 3, 7, 28 and 56 days of curing. The cementitious content of these batches included one control batch with purely cement, four batches with recycled gypsum drywall powder replacing cement at 10, 20, 30 and 40%, one batch containing only cement and fly ash, and two batches containing cement, gypsum and fly ash. The results show that partially replacing cement with gypsum yields lighter weight specimens and consistently decreases the compressive strength at all ages in a negative logarithmic trend from 0-40% gypsum replacement. The deviation from the control mix was seen to continually increase with age, with the largest deviation at 56 days. Incorporating fly ash into the mixes with gypsum improved the compressive strength, especially at later ages. However, no mixes containing gypsum and fly ash as partial replacement for the cementitious material developed equivalent strength to the control mix, as has been documented in other literature. It is recommended that further investigation be continued using concrete cylinders with a larger variation of mix designs, in order to find an optimal mix that does not adversely affect the strength of concrete. Heavier consideration should be given to mixes containing fly ash due to its positive reaction with gypsum causing increased compressive strength, and less consideration will be given to mixes containing only cement with higher percentages of gypsum as partial replacement. To continue studying the effects of recycled gypsum in concrete, it would also be beneficial to consider other mechanical properties such as shrinkage/expansion and elastic modulus, as well as its resistance to environmental impacts.

ACKNOWLEDGEMENTS

The authors would like to thank Divert NS (Truro, NS, Canada) for their financial support of this project and USA Gypsum (Denver, PA, USA) for providing the recycled gypsum product. The authors would also like to thank Dalhousie University (Halifax, NS, Canada) for their resources and financial support.

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