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FURTHER EXPERIMENTATION ON THE UTILIZATION OF GASIFIER ASH IN MORTAR

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Abstract: Gasifier ash (GA) is a by-product of the gasification process of coal. Although GA is chemically similar to fly ash, it has never been used in concrete before. As such, GA may have the potential of serving as a partial cement or sand replacement in concrete. Incorporating GA in mortar and concrete can have several positive outcomes. First, this method will minimize the negative effects that cement production has on the environment by partially replacing cement with GA in concrete mixes. Second, using GA in concrete serves as a more sustainable alternative for the coal industry for the disposal of GA. A recent study conducted showed that GA can be a useful material if used as a partial sand replacement in regular cement mortars up to 10%. This paper presents a recent study conducted to investigate the effect of the water/cement ratio on the compressive strength of cement mortar. GA was incorporated in mortar cubes with varying percentages as both cement and sand replacement. The percentages water/cement ratios were then varied with respect to the best GA mortar mix. The results show that increasing the W/C ratio up to a certain limit can improve the compressive strength of GA mortar mix.

1 INTRODUCTION

Cement manufacturing is an unsustainable process that has a major contribution to the negative impacts on the environment. The huge amount of energy needed during the manufacturing process usually comes from the consumption so fossil fuels. In turn, a massive amount of greenhouse emissions is released in the air during this process. Due to the high demand of the construction industry for cement, millions of tons of cements are produced annually worldwide (Hanley 2004). For instance, about 85 million tons of cement were produced in the United States alone in 2016 (U.S. cement production 2017). As such, there is a persistent need to find alternative sustainable materials that can serve as a full or partial substitute of cement in concrete. Consequently, this will lead to a reduction in the amounts CO2 emissions associated with cement production.

The scavenging of useless materials qualified by the United States Environmental Protection Agency (USEPA) as waste and their incorporation in concrete and mortar mixes can have several advantages. First, it serves as a legitimate way for disposing the waste at a very low cost. This not only provides the needed protection to the environment but also assists in cleaning it. Second, the utilization of these wastes as full or partial cement replacement can minimize the demand for cement and the greenhouse gases emitted during its production. Also, some waste can lead to improvements in some of the characteristics of concrete and mortar if incorporated in the mixes. As such, the quest has been for a material that has chemical characteristics close to cement or other materials that have been proven to be effective when mixed with concrete. While previous research studies have investigated the effects of various alternative materials on the mechanical and chemical properties of concrete, there are still other materials that could be suitable for further investigation as partial cement replacements. For many years, the process of coal combustion has produced tons of fly ash that have already been extensively investigated and used in concrete. In a U.S.EPA report (1992), gasifier ash (GA) from the coal industry used to be classified as a special waste from the coal gasification process of refinement. However, it has been excluded from federal hazardous waste regulations recently according to the U.S. EPA.

The gasification of coal has become a popular approach in the conversion of coal and other carbon-based feeds into various usable energy (Hong et al. 1994; USDOE 2016). Gasification is merely one part of a major process that is commonly referred to as the Integrated Gasification Combined Cycle (IGCC). The IGCC is known for its cleaner coal combustion process compared to the traditional methods. IGCC combines gasification with traditional coal combustion. Such integration allows for carbon dioxide capturing and sequestration at lower costs as opposed to utilizing coal combustion alone (Maurstad 2007). The gasifiers used in this process may vary in the output temperature of the syngas, demand of oxidant, and feed size. This leads to a variation in the chemical composition of the GA generated from one plant to another.

The main benefit of the IGCC process is the reduction of the greenhouse emitted during coal combustion. When combustion coal, the emitted CO_2 can be captured and stored after the combustion process takes places whereas in IGCC the CO_2 capturing and storing (CCS) can occur before the combustion. This renders IGCC process more efficient due to its simplicity and the low energy consumed in the process (IPCC 2005). Post-combustion CCS is more difficult since flue gases from combustion contain other contaminants in combination with CO_2 (Wu 2016). While it is possible to remove the CO_2 from the combustion flue gases, there is a direct positive relationship between removal efficiency and the costs associated with its removal (IPCC 2005). By incorporating a gasification process before coal combustion, it is possible to have cleaner emitted gases which in turn would lead to a significant cost reduction for the process of CO_2 removal (Duke Energy 2016). The utilization of the waste materials of the gasification process in other industries, such as the construction industry, can be a potential venue for disposing this waste and reducing the carbon emissions resulting from other industries processes, such as cement production. None of the previous studies have investigated the effectiveness of the utilization of GA as a partial substitute for cement or sand in concrete and mortar mixes.

2 RESEACH OBJECTIVES AND METHODOLOGY

The objective of this research is to investigate the effect of the amount of the mixing water on the compressive strength of cement mortar made with GA. A previous study showed that replacing 10% of the sand in mortar cube by GA can lead to an increase in the compressive strength however the workability of the mix decreases (Abdel-Raheem et al. 2017). It is theorized that the incorporation of GA in cement mortar might need higher amounts of water to allow for the complete hydration of cement. As such, in this study the authors investigate the effect of varying the water/cement ratio on the compressive strength of cement mortars prepared with GA. Mortar mixes made with various percentages of GA replacing cement or sand were used to investigate the effect of different water/cement ratios on the compressive strength. The mortar cubes were prepared in accordance to the ASTM C109. The original W/C in this standard test is 0.48. Water/Cement ratios of 0.55 and 0.62 were also used in this study.

3 EXPERIMENTAL PROCEDURES

3.1 Materials

GA was obtained from the Dakota Gasification Company in North Dakota in the form of moist granular aggregate from the gasification of lignite coal (Dakota Gas. Co., 2015). For its incorporation into mortar mixes, GA was further processed by drying it at 105 °C to evaporate any moisture content. To use GA as sand replacement, dried GA was ground and sieved to particle size smaller than 4.75 mm (passing sieve # 4). To use GA as cement replacement, the dried GA was further ground and sieved to obtain fine particles passing sieve #200 (75µm). The density of the dried and sieved GA was 1,185 kg/m^3. Standard sand and cement were acquired from national supplier and qualified for their use in mortar. The density for the sand and cement used were 1,708 kg/m3 and 1,794 kg/m3, respectively.

3.2 Mix Design and Procedures

The replacement of cement and sand with GA were done volumetrically in varying percentages. The mix designs for cement and sand replacement mortar samples were prepared according ASTM C109, as shown in Tables 1 - 6. As per ASTM C109, sand/cement was 1:2.75. First, 8 mixes were prepared using Fine GA (< 75µm) as cement replacement with varying percentages – see Table 1. Another 8 mixes were prepared using Coarse GA (< 4.75 mm) as sand replacement with varying percentages – see Table 2. The W/C ratio for both sets of mixes (cement and sand replacements) was 0.48 in accordance with ASTM C109. However, to test the effect of water on the mix, the water/cement was varied between 0.48, 0.55, and 0.62 for the 0%, 10%, 30%, and 50% replacements only– see Tables 3-8.

Using a Hobart N50-60 mixer, water was poured into mixing bowl followed by cement (and replacement if needed), and mixed at low speed (139 rpm) for 30 s. Sand (and replacement if needed) was added over another 30 s periods while mixing. Mixing speed was increased to medium (285 rpm) and mortar mixed for another 30 s. After this, mixing stopped and the sides of bowl were scraped within 15 s and mortar allowed to sit covered for 75 s. Following the resting time, mortar was mixed again at medium speed for 60 s. Mortar was compacted into 50 mm cube molds and placed on vibrating table for 60 s. It should be noted that the incorporation of GA in the mix decreases the workability.

Table 1. Mix design of mortar prepared with Fine GA (75µm) as cement replacement (W/C 0.48)

2" Cube	**GC1a**	**GC2a**	**GC3a**	**GC4a**	**GC5a**	**GC6a**	**GC7a**	**GC8a**
% Replacement	0%	5%	10%	15%	20%	30%	40%	50%
Cement (g)	250.0	237.5	225.0	212.5	200.0	175.0	150.0	125.0
Sand (g)	687.5	687.5	687.5	687.5	687.5	687.5	687.5	687.5
Water (g)	121.0	121.0	121.0	121.0	121.0	121.0	121.0	121.0
Gasifier Ash (g)	0.0	8.3	16.5	24.8	33.0	49.6	66.1	82.6

Table 2. Mix design of mortar prepared with Coarse GA (< 4.75 mm) as sand replacement (W/C 0.48)

2" Cube	**GS1b**	**GS2b**	**GS3b**	**GS4b**	**GS5b**	**GS6b**	**GS7b**	**GS8b**
% Replacement	0%	5%	10%	15%	20%	30%	40%	50%
Cement (g)	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0
Sand (g)	687.5	653.1	618.8	584.4	550.0	481.3	412.5	343.8
Water (g)	121.0	121.0	121.0	121.0	121.0	121.0	121.0	121.0
Gasifier Ash (g)	0.0	23.9	47.7	71.6	95.4	143.2	190.9	238.6

Table 3. Mix design of mortar prepared with fine GA (75µm) as cement replacement (W/C 0.55)

2" Cube	**GC1a**	**GC2a**	**GC3a**	**GC4a**
% Replacement	0%	10%	30%	50%
Cement (g)	250.0	225.0	175.0	125.0
Sand (g)	687.5	687.5	687.5	687.5
Water (g)*	137.5	137.5	137.5	137.5
Gasifier Ash (g)	0.0	16.5	49.6	82.6

Table 4. Mix design of mortar prepared with fine GA (75µm) as cement replacement (W/C 0.62)

2" Cube	**GC1a**	**GC2a**	**GC3a**	**GC4a**
% Replacement	0%	10%	30%	50%
Cement (g)	250.0	225.0	175.0	125.0
Sand (g)	687.5	687.5	687.5	687.5
Water (g)*	155.0	155.0	155.0	155.0
Gasifier Ash (g)	0.0	16.5	49.6	82.6

3.3 Testing

After 24 hours of mixing, samples were removed from molds and placed in water for curing. Samples containing GA were cured separate from the control mix. All samples were tested for compressive strength after 7 days.

Table 5. Mix design of mortar prepared with coarse GA (< 4.75 mm) as cement replacement (W/C 0.55)

2" Cube	**GS1b**	**GS2b**	**GS3b**	**GS4b**
% Replacement	0%	5%	30%	50%
Cement (g)	250.0	250.0	250.0	250.0
Sand (g)	687.5	653.1	481.3	343.8
Water (g)*	137.5	137.5	137.5	137.5
Gasifier Ash (g)	0.0	23.9	143.2	238.6

Table 6. Mix design of mortar prepared with coarse GA (< 4.75 mm) as cement replacement (W/C 0.62)

2" Cube	**GS1b**	**GS2b**	**GS3b**	**GS4b**
% Replacement	0%	5%	30%	50%
Cement (g)	250.0	250.0	250.0	250.0
Sand (g)	687.5	653.1	481.3	343.8
Water (g)*	155.0	155.0	155.0	155.0
Gasifier Ash (g)	0.0	23.9	143.2	238.6

4 RESULTS AND DISCUSSIONS

The compression test was conducted according to the ASTM standards. The results – see Table 4 – show that both cement and sand replacements with RM can improve the compressive strength of cement mortars.

4.1 Fine GA (< 75µm) as Cement Replacement with Varying W/C Ratios

The results show that the utilization of Fine GA as cement replacement in mortar is not efficient using the standard W/C ratio of 0.48, as shown in Figure 1. As the percentage of Fine GA replacing cement increased, the compressive strength decreased. However, increasing the amount of mixing water improved the compressive strength of the mixes prepared with Fine GA slightly, as shown in Table 7 and Figure 2. The highest compressive strength was obtained with Fine GA as 10% cement replacement using W/C of 0.62.

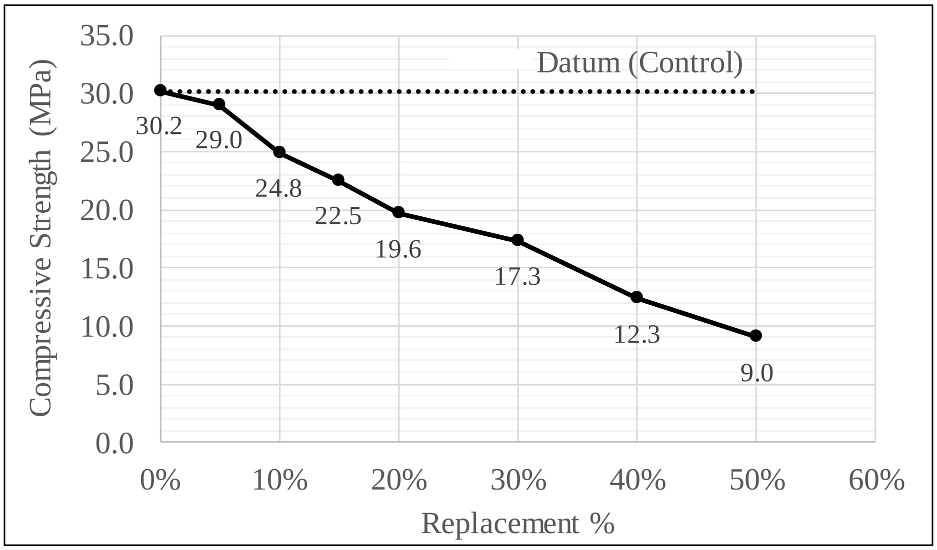

Figure 1. Compressive strength (MPa) of mortar cubes prepared with fine GA as cement replacement (W/C 0.48)

Table 7. Compressive strength (MPa) of mortar cubes prepared with fine GA as cement replacement using different W/C ratios

Comp. Strength (MPa) at Different W/C			
Replacement	**0.48**	**0.55**	**0.62**
0%	30.2	30.3	30.1
10%	24.8	28.8	31.2
30%	17.3	20.0	20.3
50%	9.0	16.2	13.8

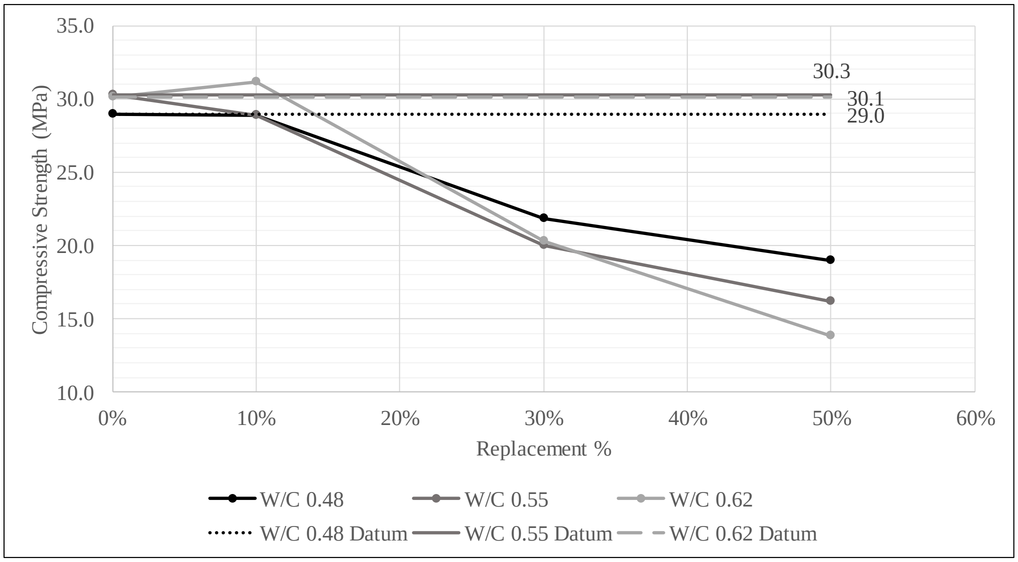

Figure 2. Comparison of Compressive strength (MPa) of mortar cubes prepared with Fine GA using varying W/C ratios

4.2 Coarse GA (< 4.75 mm) as Sand Replacement with Varying W/C Ratios

The utilization of Coarse GA as sand replacement in mortar is more efficient than cement replacement, as shown in Figure 3. The results show that replacing sand up to 10% with Coarse GA can improve the compressive strength of mortar using W/C of 0.48. However, increasing the percentage of replacement beyond this point will result in a drop of the compressive strength.

On the other hand, increasing the amount of mixing water used in the mixes prepared with Coarse GA had a negative impact on the compressive strength substantially, as shown in Table 8 and Figure 4. The highest compressive strength was obtained with coarse GA as 5% sand replacement using W/C of 0.48.

Although increasing the amount of water in the mixes prepared with coarse GA had a negative effect on the compressive strength, the results are inconclusive. By referring to Table 8, it can be noticed that there are enhancement in the compressive strength of the mixes prepared with Coarse GA of up to 30% and 50% when the amount of mixing water was increased. This means that maybe more water was needed to boost the compressive strength at these level of replacements.

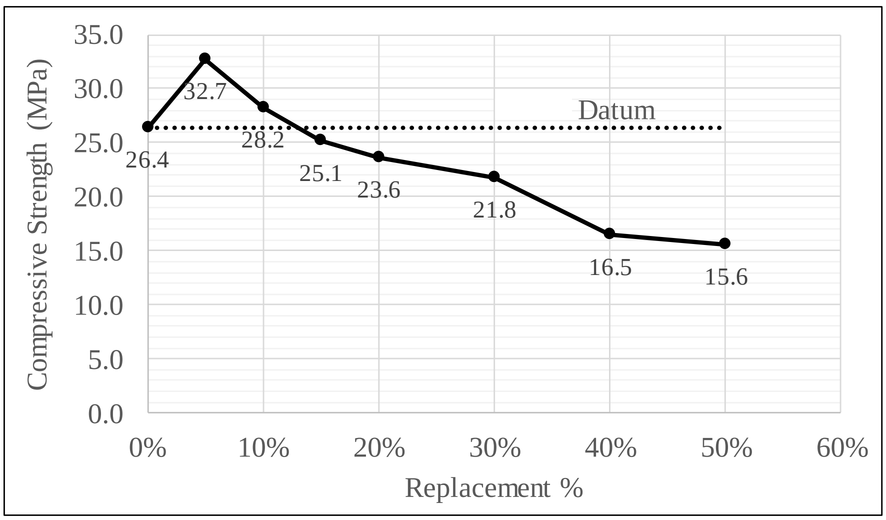

Figure 3. Compressive strength (MPa) of mortar cubes prepared with fine GA as sand replacement (W/C 0.48)

Table 8. Compressive strength (MPa) of mortar cubes prepared with fine GA as sand replacement using different W/C ratios

Comp. Strength (MPa) at Different W/C			
Replacement	**0.48**	**0.55**	**0.62**
0%	26.4	29.3	27.4
5%	32.7	27.2	28.2
30%	21.8	23.1	24.2
50%	15.6	26.7	23.1

5 CONCLUSION

The research presented in this paper discusses the effect of the amount of mixing water on the compressive strength of mortar prepared with GA. Different sizes of GA were used as cement and sand replacements.

In general, the results show that the amount of mixing water is a critical factor in determining the compressive strength of mortar made with GA. Fine GA used up to 10% cement replacement can increase the compressive strength of mortar with a W/C of 0.62. Increasing the amount of water in the mixes prepared with coarse GA enhanced the strength in mixes with higher replacements of sand. But, it had a negative effect on the compressive strength for the 5% replacement.

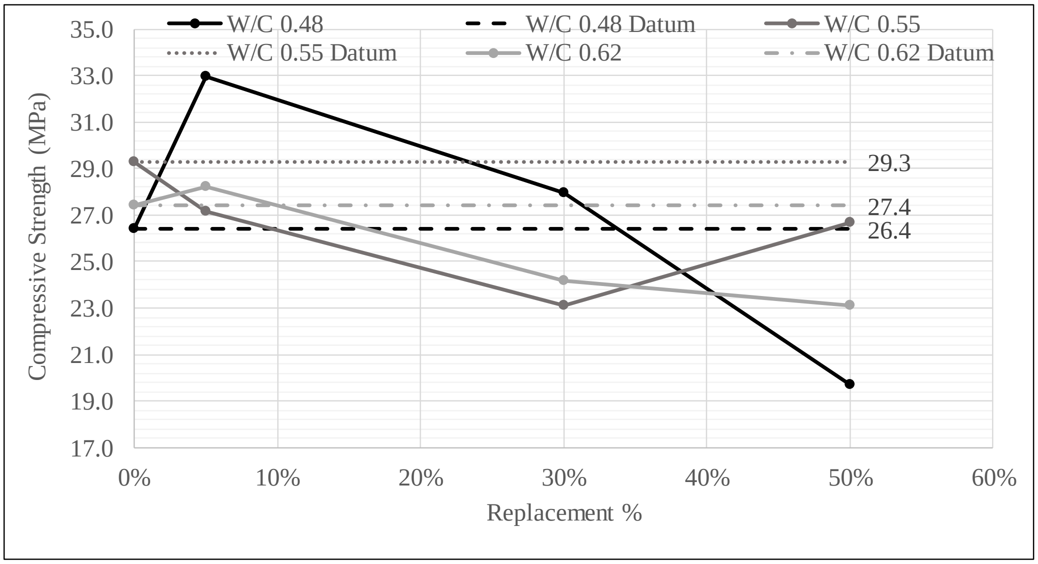

Figure 4. Comparison of Compressive strength (MPa) of mortar cubes prepared with Coarse GA using varying W/C ratios

6 FUTURE WORK

Further experimentation is needed to test the effect of GA replacement on mortar as well as concrete. The utilization of GA as a replacement of sand should be incorporated in concrete to set final conclusions about its effect on compressive strength. Since GA is similar in its chemical composition to fly ash, it might have better performance if mixed with alkaline activators. Finally, the effect of GA on other characteristics of concrete such as tensile and flexural strength will be assessed in future experimentations.

7 ACKNOWLEDGEMENTS

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