



PROPERTIES OF ALKALI ACTIVATED MORTAR INCORPORATING RECYCLED CONCRETE AND CERAMIC WASTE AS FINE AGGREGATE

Adesina, Adeyemi¹ and Soliman, Ahmed^{2*}

¹PhD Student, Department of Building, Civil and Environmental Engineering Concordia University, Montreal, Quebec Canada.

²Assistant Professor, Department of Building, Civil and Environmental Engineering Concordia University, Montreal, Quebec Canada.

*ahmed.soliman@concordia.ca

Abstract: Despite the development of alkali-activated composites to produce a greener composite for building purposes, the strain on natural sources of aggregates continues. The strain on these natural deposits of aggregates is as a result of high construction demand. To achieve a more sustainable alkali activated composite, it is essential to find more ways to replace the aggregates with waste materials. This experimental study was carried out to observe the possibility of using recycled concrete and ceramic waste as fine aggregate in an alkali-activated mortar. The binder used in this study was slag and activated with sodium silicate and hydroxide. Fine aggregates for the mortar was replaced with 25%, 50%, 75%, and 100% recycled concrete and ceramic waste. The sodium silicate to sodium hydroxide ratio was fixed at 2.5, and water to solid ratio in the range of 0.40 to 0.50 was used. The mechanical properties were explored to determine the optimum level to which fine aggregate in alkali-activated mortar can be replaced.

1 INTRODUCTION

The promising advantage of using alkali-activated materials (AAMs) over ordinary Portland cement (OPC) composite has been beneficial in terms of reducing the emission contribution of cement production. However, the strain on natural resources in terms of aggregates used still continues with increasing demand for mortar and concrete. As the construction industry gears towards having more sustainable materials, several areas of research have been explored with more focus placed on replacing cement in concrete. However, one of the areas getting attention recently is the use of waste materials in concrete.

The construction and demolition (C&D) waste have contributed by a large percentage of solid waste generated all over the world. The major composition of C&D waste is concrete and ceramic, with Germany producing about 60 million tons of C&D waste, the United Kingdom about 49 million tons, Netherlands about 20 million tons, and most of these wastes deposited in landfills (EAA, 2012; Tam, 2009). Therefore, finding ways to recycle these waste materials into a new mortar and concrete mixtures would be a step forward in achieving a more sustainable construction.

Aggregates represent about 60 to 75% by volume of the concrete (Taylor et al, 2007). As the demand for mortar/concrete increasing exponentially; the strain on natural deposits of aggregates continues. Therefore, the use of C&D waste to make mortar/concrete not only helps to have a greener construction material but

reduces the huge strain on natural deposits of aggregate. In addition, recycling C&D wastes in concrete and would help to conserve resources, manage waste, prevent groundwater contamination, and save land used for waste disposal. Also, the viability of these C&D wastes in new constructions would solve the shortage supply of natural aggregates in some part of the world (Cabral et al., 2010; Grdic et al., 2010). It should be noted that studies have been carried out on other waste materials to see the viability of using them as aggregate in concrete. Some of these waste materials that have been studied are; mine tailings (Thomas et al, 2013), and rubber tire (Thomas and Gupta, 2015).

Therefore, it is essential to find an alternative to the aggregates used so as to be able to meet the future demands of AAMs and conserve the natural deposits of aggregates. This study explores the viability of using two major types of construction wastes (recycled concrete and ceramic) as a substitute for natural sand used in mortar to produce alkali activated mortar. Also, the effect of different replacement levels and water to solid ratio on the properties of the mortar was explored.

2 EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Slag

Slag used was obtained from a plant in Ontario. The slag has Blaine fineness of 509m²/kg, with a specific gravity of 2.92, strength activity index of 97%, and chemical composition as shown in **Table 1**.

Table 1. Chemical composition of slag

Compound	Percentage (%)
Silicon Dioxide (SiO ₂)	32.40
Aluminum Oxide (Al ₂ O ₃)	14.96
Iron Oxide (Fe ₂ O ₃)	0.83
Sulphur Trioxide (SO ₃)	2.74
Calcium Oxide (CaO)	40.70
Magnesium Oxide	5.99
Total Alkali as Na ₂ O _{eq} , %	0.70

2.1.2 Ceramic waste

Ceramic waste used was obtained from a local producer of ceramic in Ontario. The initial shape of the ceramic was a rectangular prism, with an average dimension of 15cm x 5cm x 1.5cm. In order to use it as fine aggregate in mortar, the size of the ceramic waste was reduced to below 4.75mm by using baller miller, cone crusher, and pulverizer accordingly.

2.1.3 Recycled concrete

The recycled concrete used was obtained from a concrete dump site in Montreal. The recycled concrete obtained was a mix of both coarse and fine recycled concrete. Therefore, further sieving was done to obtain recycled concrete that has a maximum size of 4.75 mm.

2.1.4 Activators

Combined sodium silicate (SS) and sodium hydroxide (SH) solutions were used to activate slag. The sodium silicate used has 37.5% Na₂O + SiO₂ and 62.5% H₂O. 12M sodium hydroxide solution, obtained by dissolving 480g of sodium hydroxide pellets in distilled water, was used. The two activators were mixed together approximately 24 hours before using to allow the temperature of the solution to cool to room temperature. The ratio of SS to SH for all mixtures was 2.5.

2.2 Preparation, casting, and testing of specimens

Ceramic waste and recycled concrete are used at different replacement levels from 25% to 100% of the natural sand. The ratio of slag to aggregate was fixed at 1, and the ratio of water to solid ranges from 0.40 to 0.50. The mass of water is calculated as the total of the mass of water from the activators and additional water added. While the solid mass is the total mass of slag and solids from the activator. The mortars were produced by dry mixing the slag and aggregate for 45 seconds, after which half of the activator was added and mixed for 1 minute. This was followed by adding the remaining activator and mixing for an additional one minute.

Six cubic samples were made for each mixture. The compressive strength was determined according to ASTM C109/109M (Standard Test Method for Compressive Strength of Hydraulic Cement Mortars) at 14 days and 28 days. The density was also measured at 28 days. However, due to high absorption of ceramic waste, samples were not made for some mixtures due to poor workability as shown in **Table 2**.

Table 2: Details of experimental program

Aggregate	Mix ID	Natural sand replacement (%)	Water to solid ratio		
			0.40	0.45	0.50
Natural sand	NS	0	✓	✓	✓
Ceramic waste	CW25	25	✓	✓	✓
	CW50	50	x	✓	✓
	CW75	75	x	x	✓
	CW100	100	x	x	x
Recycled concrete	RC25	25	✓	✓	✓
	RC50	50	✓	✓	✓
	RC75	75	✓	✓	✓
	RC100	100	✓	✓	✓

✓ - samples made, x - samples not made due to very poor workability

3 RESULTS AND DISCUSSIONS

3.1 Workability.

As observed from Table 2, as the percentage of ceramic waste increase and water to solid reduces; it was impossible to make some mortar samples due to the high absorption rate of the ceramic waste. However, it was still possible to have up to 75% natural sand replacement with ceramic waste at the water to solid ratio of 0.50. However, at all replacement levels and water to solid ratio, it was possible to have up to 100% replacement level of natural sand with recycled concrete.

3.2 Density

The density of the alkali activator mortar samples is determined by dividing the mass of the specimens at 28 days by their corresponding volumes. From Figure 1, it would be observed that the density of alkali-activated mortar containing 100% natural sand reduces as the water to solid ratio increased. This trend was also observed when either ceramic waste or recycled concrete was used to replace natural sand at various replacement levels. This reduction in density would be as a result of dilution of the activators as more water is introduced, leading to less product formation (Cengiz et al., 2009; Jamieson et al., 2008; Phair and Van Denventer, 2002).

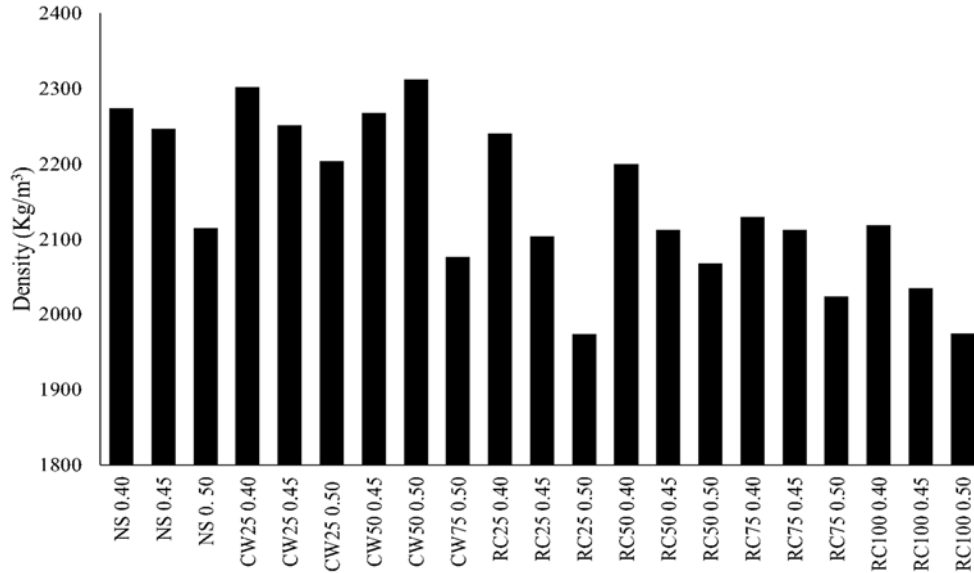


Figure 1: Density of alkali activator mortar with various replacement of sand with ceramic waste and recycled concrete

3.3 Compressive strength.

Compressive strength test is carried out on the cubic specimens to determine the effect of replacing natural sand on the strength of the mortar, and the results are presented in **Table 3** and the strength development with age for 25% replacement of natural sand is presented in **Figure 2**.

From **Table 3** and **Figure 3**, it would be observed that the strength of alkali-activated mortar decreases as water to solid ratio increased. This is as a result of the dilution of the activator. However, it would be observed from Figure 2 that 25% replacement of natural sand with ceramic waste is the optimum at all water to solid ratios considered. The increase in strength at 25% replacement level might be as a result of the activation of the ceramic waste by the activators leading to higher strength. Reig et al. (2017) were able to activate mortar with high ceramic content with sodium silicate and sodium hydroxide. However, as the percentage of natural sand replacement increases above 25%, there was a reduction in the compressive strength of the mortar. This might be as a result of high aluminosilicate source in the system compared to the available activator, leading to partial activation of the materials.

Results are shown in **Table 3** also show that samples with 100% natural sand achieve higher early strength compared to when it was partially replaced with recycled concrete and ceramic waste. This late gain in strength of samples with a natural sand replacement would be as a result of the activation of the ceramic waste and recycled concrete at later days.

Based on the limited results obtained for the replacement of natural sand with ceramic waste, it would be observed that the highest strength was achieved at 25% replacement of natural sand with ceramic waste at all water to solid ratio (**Figure 3**). Increasing the percentage to 50% led to a reduction in its compressive strength. It would also be observed that the compressive strength at 25% replacement with ceramic waste was higher than that for samples with 100% natural sand. The optimum water to solid ratio of natural sand replacement with ceramic waste in this study is concluded to be 0.40, as higher strength was obtained at this water to solid ratio regardless of replacement ratio. The decrease in the compressive strength with the increasing water to the solid ratio at all level is as a result of the dilution of the compressive strength with the increasing water to solid ratio at all level is as a result of the dilution of the activator, thereby leading to a reduction in the formation of products. A similar effect of increasing water to solid ratio was recorded by several earlier studies (Hardjito et al., 2004).

Table 3: Compressive strength of mortar samples at 7 days, 14 days, and 28 days

Mix ID	Water to solid ratio	Compressive strength (MPa)		
		7 days	14 days	28 days
NS	0.40	49.3	51.7	53.8
	0.45	53.8	68.6	75.8
	0.50	43.2	47.4	51.2
CW25	0.40	38.3	59.6	79.7
	0.45	46.2	60.8	74.3
	0.50	34.9	55.0	66.3
CW50	0.40	x	x	x
	0.45	41.5	47.3	55.8
	0.50	32.2	39.7	43.8
CW75	0.40	x	x	x
	0.45	x	x	x
	0.50	21.4	38.6	45.9
CW100	0.40	x	x	x
	0.45	x	x	x
	0.50	x	x	x
RC25	0.40	32.7	50.1	69.0
	0.45	17.8	29.0	43.2
	0.50	13.0	24.5	39.3
RC50	0.40	31.8	48.2	65.8
	0.45	19.4	32.9	45.3
	0.50	12.8	29.9	41.3
RC75	0.40	34.9	55.5	63.5
	0.45	19.7	28.7	40.8
	0.50	12.4	26.8	38.2
RC100	0.40	16.4	30.5	42.7
	0.45	14.7	29.6	39.6
	0.50	13.1	23.2	31.3

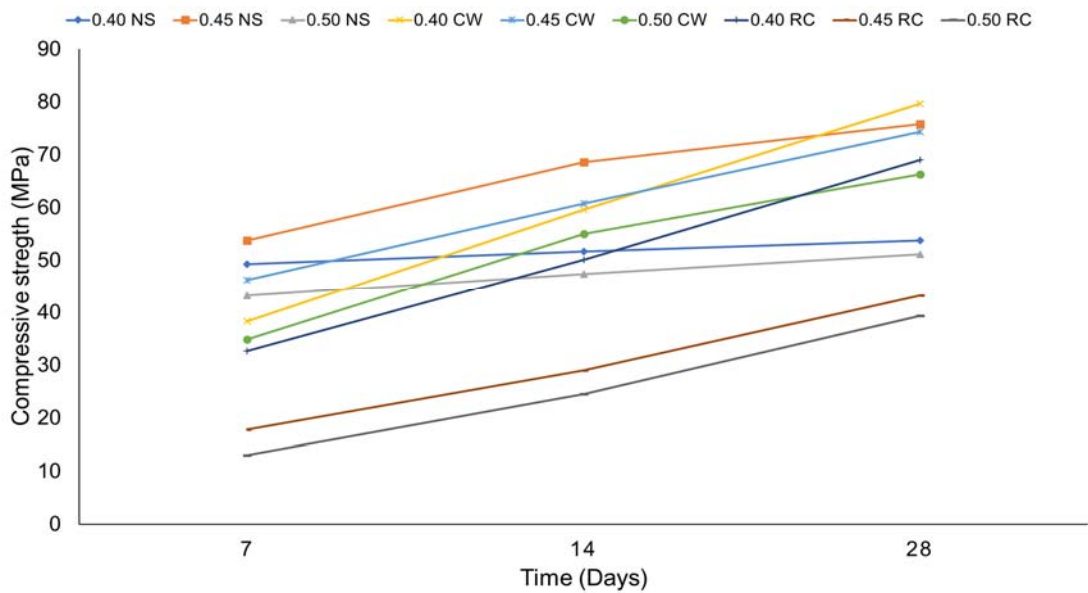


Figure 2: Compressive strength development at different replacement of natural sand

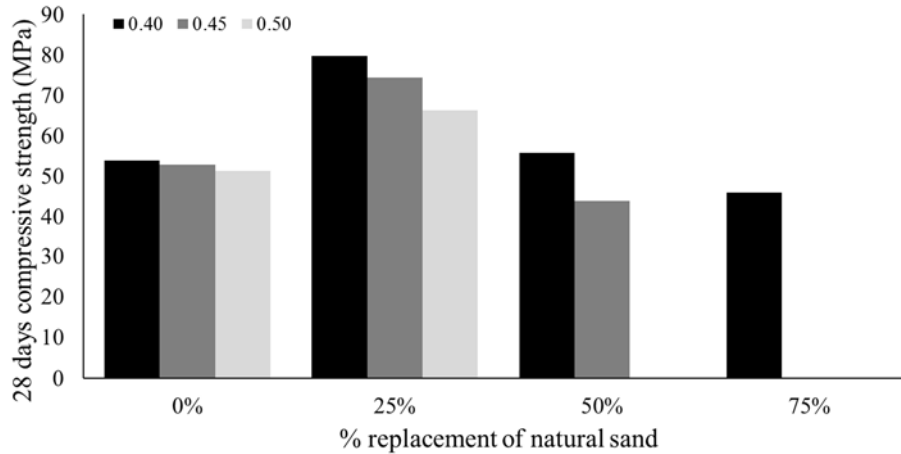


Figure 3: 28 days compressive strength of alkali activated mortar with different replacement levels of natural sand with ceramic waste

Also, there was a decrease in strength with increase in natural sand replacement with recycled concrete (**Figure 4**). However, mortar samples with 25% replacement of natural sand with recycled concrete had higher strength compared to the ones with 100% natural sand. There was a significant difference in the compressive strength at different water to solid ratios in samples with partial replacement of natural sand. For example, increasing the water to solid ratio from 0.40 to 0.45 resulted in 23MPa reduction in the 28 days compressive strength at 25% replacement level. The optimum replacement of natural sand with recycled concrete would be 25% at a water to solid ratio of 0.40, as this gave a higher strength compared to others.

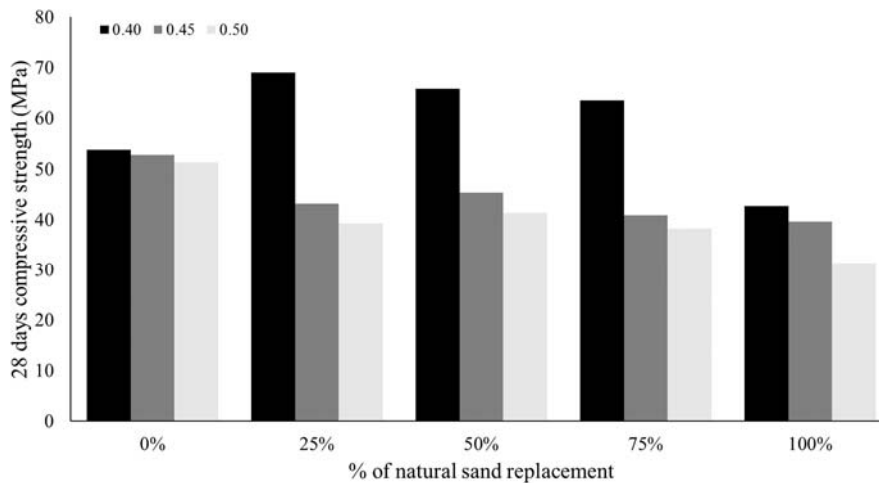


Figure 4: 28 days compressive strength of alkali activated mortar with different replacement levels of natural sand with recycled concrete

4 CONCLUSION

This study has shown the viability of using ceramic waste and recycled concrete as an alternative for natural sand in an alkali-activated mortar. This would reduce the strain on natural deposit of sand and would also prevent the contamination of groundwater and land use as a result of depositing ceramic wastes and

concrete wastes in landfills. Replacing 25% of natural sand with ceramic waste or recycled concrete would lead to higher strength.

However, despite replacement of natural sand with ceramic waste and recycled concrete at certain percentages resulted in high strength, an extensive study needs to be carried out so as to investigate long-term mechanical and durability properties. Also, calcium silicate hydrate (CSH) related to durability of concrete is introduced into the matrix with the use of recycled concrete as aggregate. Therefore, it is essential to strike a balance between strength, durability, and sustainability by exploring how the presence of CSH would affect the resulting mortar/concrete durability.

References

- Cabral, A., Schalch, V., Molin, D., and Ribeiro, J. 2010. Mechanical properties modeling of recycled aggregate concrete. *Constr Build Mater*, 24, 4, 421-430
- Cengiz, D., Cahit, B., Ozlem, C., and Okan, K. 2009 Influence of activator on the strength and drying shrinkage of alkali activated slag mortar. *Construction and Building Materials*, 23, 548-555.
- Duxon, P., Fernandez-Jimenez, A., Provis, J., Luckey, G., Palomo, A., and Van Deventer, J. 2007 Geopolymer technology: the current state of the art. *Journal of Material Science*, 42, 2917-2933
- European Aggregates Association. Annual review 2011–2012. Brussels, Belgium; 2012.
- Grdic, Z., Toplicic-Curcic, G., Despotovic, I., and Ristic, N. 2010. Properties of self-compacting concrete prepared with coarse recycled concrete aggregate. *Constr Build Mater*, 24, 7, 1129-1133
- Hardjito, D., Wallah, S., Sumajouw, D., and Rangan, B. 2004 On the development of fly ash-based geopolymer concrete. *ACI Material Journal*, 101, 467–472
- Jamieson, E., Jones, A., Guilfoyle, L., and Attiwell, S. 2008 Production and application of ReSand, Centre for Sustainable Resource Processing (CSRP) 2008 Conference, Brisbane Australia, 67-68
- Phair, J., Van Deventer, J., 2002. Characterization of fly ash based geopolymeric binders activated with sodium aluminate. *Ind. Eng. Chem. Res.* 41, 17, 4242-4251
- Reig, L., Tashima, M.M., Soriano, L., Borrachero, M.V., Monzó, J., Payá, J. 2013. Alkaline activation of ceramic waste materials. EMC, Universitat Jaume
- Tam, V. 2009 Comparing the implementation of concrete recycling in the Australian and Japanese construction industries. *J Cleaner Prod*, 17, 7, 688-702
- Taylor, P., Kosmatka, S., and Voigt, G. 2007 Integrated Materials and Construction Practicers for Concrete Pavement: A State of the Practice Manual. *FHWA-HIF-07-004*. FHWA, U. S. Department of Transportation,
- Thomas, C, Setién, J., Polanco, J., Alaejos, P., and Sánchez De Juan, M. 2013 Durability of recycled aggregate. *concrete Constr. Build. Mater.*, 40, 1054-1065
- Van Jaarsveld, J., and Van Deventer, J. 1999 Effect of alkali metal activators on the properties of fly ash-based geopolymer. *Industrial Engineering and Chemistry*, 38, 3932