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UTILIZATION OF RED MUD AS PARTIAL CEMENT REPLACEMENT IN MORTAR

Abdel-Raheem, Mohamed.[1,4], Martinez, Bilkis O.[2] and Santana, Lizeth G.[3]
[1,2,3] University of Texas Rio Grande Valley, Texas, U.S.A.
[4] mohamed.abdelraheem@utrgv.edu

Abstract: Red Mud (RM) is a hazardous waste produced during the alumina refining process. RM is very similar in its chemical composition to cement. This similarity has inspired researchers to investigate the possibility of utilizing RM as a possible partial replacement of cement in concrete and cement mortars. However, there are many discrepancies in the results obtained in previous studies conducted on RM in terms of 1) the usefulness of RM as a partial replacement of cement, and 2) the optimal replacement percentages concluded. One of the reasons for these discrepancies is the differences in the chemical composition of the RM used which varies with respect to the type of bauxite and the manufacturing process deployed. However, none of these studies utilized RM originated in the U.S.A. As such, it deems essential to carry out a further study to assess the performance of RM on the compressive strength of cement mortars using RM from the U.S.A. This paper presents the outcome of a recent research conducted to assess the effect of the utilization of RM as a partial cement and sand replacement in cement mortars. The preliminary results obtained show that the RM originated in the U.S. can be very useful if utilized in cement mortar as it improves the compressive strength.

1 INTRODUCTION

The continuous availability of Portland cement concrete is very critical to the construction industry. This has led to a dramatic increase in the production of Portland cement (Hanley, 2004). The manufacturing of cement is an unsustainable process that has serious negative impacts on the environments. First, it consumes large amount of energy which mostly comes from carbon fuel. Second, there are massive amounts of greenhouse emissions released in the air during the manufacturing process. The production of cement consumes large amounts of raw material as well which require high cost for mining, processing, and transportation. The production of these raw materials increases the greenhouse gas emission even more. As such, there is a need to minimize cement consumption. Since concrete is a vital material in the construction industries due to its multiple advantages, the focus has been on finding alternative material that can substitute Portland cement without compromising the quality of concrete significantly. Various industries produce billions of tons of industrial hazardous waste. Even with the legitimate methods of disposal- these wastes can still have a negative effect on the environment and high cost of disposal. The United States Environmental Protection Agency (USEPA) has issued a periodically-updated list of different wastes from many industries that are considered environmentally hazardous (USEPA, 1992). One of the wastes classified by the USEPA as hazardous material is the red mud (RM) produced during the alumina refining process.

RM is a special by-product waste formed during the process of refining alumina. In 2008, about 205 million tons were produced worldwide. The main contributors were Australia, China, Brazil, Guinea, India and Jamaica (Ribeiro et al., 2010).

There are several methods of disposing RM, such as: disposal via seawater discharge, lagooning, dry stacking, and dry disposal (Sahu and Patel, 2016). Lagooning is the most common method of disposal. In this method, clay-lined landfills are used to store the RM. Disposal in these landfills presents a serious problem as it led to polluting nearby water sources and raised concerns about humans and cattle health in the surrounding communities (Sahu and Patel, 2016). While the United States is not one of the main producers of bauxite, the large quantities of RM disposed come from the processing of the raw material imported and refined in various plants across the U.S.

Several studies have been conducted to investigate the effect of utilizing RM on the compressive strength of mortar and concrete when RM is used as a replacement of cement in concrete. However, there are many discrepancies in the results reported in these studies. For instance, a study concluded that the replacement of up to 10% of cement with RM did not affect the compressive strength of mortar (Rana et al., 2015). Other studies reported that RM can replaces cement for up to 20% (Bishetti, et al., 2015) and 25% (Rathod et al., 2012) without affecting the compressive strength of the mortar samples. These inconclusive results could be due to the differing chemical compositions of RM based on the origin of bauxite, the process used in refining, and the incorporation of other materials during the refining process. The different percentages of the main compounds that are typically found in RM are summarized in Table 1 (Snars and Gilkes, 2009).

Table 1. Minimum and maximum composition of oxides in red muds.

Oxide	Min%	Max %
Fe_2O_3	15.20	56.90
Al_2O_3	15.10	24.70
SiO_2	3.00	30.00
CaO	1.16	7.73
TiO_2	2.65	12.33

However, none of the previous studies conducted investigated the effect of utilizing the RM produced during the refining of the bauxite in the U.S in mortar or concrete. As such, it deemed essential to conduct a further study to assess the effect of the RM produced in the U.S. on the compressive strength of mortar and concrete when used in limited quantities as a partial substitute for cement and sand in the mixes .

2 RED MUD AS PARTIAL CEMENT REPLACEMENT

Although many studies have investigated the effectiveness of utilizing RM as a partial replacement of cement in mortars and concrete, none of these studies considered the replacement of sand with RM in mortar and concrete. One study showed that the addition of up to 2% red mud in self-compacting concrete (SCC) can increase the compressive strength while utilizing RM up to 4% may not have any negative outcome either (Khushwaha et al. 2013). This study presents two important findings. The first one is the utilization of RM as replacement of up to 2% of cement weight in SCC. The second finding is that SCC can be used as a safe venue for disposing RM without compromising the compressive strength of the mix. Four studies reported an enhancement of the compressive strength of concrete with addition of up to 15% RM as a cement replacement (Díaz et al. 2008, Ribeiro et al. 2013, Vangelatos et al. 2009, and Yogananda and Jagadish 1988). However, other studies reported that the maximum percentage of cement that can be replaced with RM to experience improvement in the compressive strength can be less or more than that (Bishetti et al. 2014, Rana et al. 2015, Rathod et al. 2012).

Other studies investigated the effect of RM on mortar and concrete when combined with other materials. Previous investigations have utilized RM as partial cement replacement along with the addition of amounts of lime and silica fume (Ashok and Sureshkumar, and Rana and Sathe 2015). The first study investigated the addition of 5% lime to concrete specimens with RM as 0%, 5%, 10%, 15% and 20 % partial replacement of cement. In this study, the concrete samples with 15% red mud and 5% hydrated lime obtained the highest compressive, tensile and flexural strength (Ashok and Sureshkumar). Rana and Sathe (2015) conducted a study on the effect of RM when combined with lime and silica in mortar. They prepared different mortar mixes with RM as 0%, 10%, 15%, 20% and 25% cement replacement with the addition of either lime or silica fume. Mortar cubes with 10% RM and 4% lime, and 10% RM and 20% silica fume (SF) had the highest compressive strength. Concrete samples were then made utilizing these mixture proportions. The results of this study showed that the compressive strength of the concrete samples with 10% RM and 4% lime and 10% RM and 20% SF had compressive strengths comparable to that of the control mix. Adversely, one study reported a continuous decrease in the compressive strength and workability of the mortar as the percentage of RM replacing cement increased (Senff et al., 2014).

Another study investigated red mud composites made without the use of cement (Gordon et al. 1996). In this study, cement was not used at all and instead it was fully replaced with a combination of red mud, hydrated lime, condensed silica fume, and limestone. The study showed that the composite samples reached a strength ranging from 18-22 MPa at 120 days (Gordon et al., 1996). Furthermore, some studies have even investigated the corrosivity effects of RM on reinforced concrete. These studies have concluded that RM is an effective inhibitor of corrosion of steel in reinforced concrete exposed to chlorides (Cabeza et al. 2005, Ribeiro et al. 2012).

As shown in the previous sections, there is a major contradiction on the effect of RM on the quality of mortar and concrete. Even the studies that showed improvement in the performance of the mortar and concrete made with RM encountered a discrepancy in the reported optimal percentage of RM that should be used in the mix. Also, the majority of these studies did not specify whether the replacement of cement were made volumetrically or by weight. This is absolutely important since the density of RM varies from one place to another.

The noted discrepancies and contradictions of the results reported in the literature regarding the effects of red mud when incorporated in concrete or cement mortars can be attributed to several factors, such as: the refining processes and the origin of the bauxite used. Another important reason for this inconsistency of conclusions is the size of the particles of the RM used. Some studies have reported different particle sizes of RM of 44 μm, 300 μm and 1.18 mm (Ashok and Sureshkumar et al., Rathod et al. 2012, Bishetti et al. 2014, and Sawant et al. 2012).

3 RESEACH OBJECTIVES

The objectives of this research is to investigate the effect of the RM produced during the alumina refining process in the U.S. on the quality of cement mortars and concrete. The RM has been incorporated in mortar and concrete mixes in varying percentages as cement and sand replacements. This paper reports the effect of RM on the compressive strength of mortar cubes only when utilized as a partial cement and sand replacement. Incorporating this material waste in mortar and concrete mixes can serve two purposes: First, it will reduce the negative effects of the current methods of RM disposal as well as the greenhouse emissions of the cement industry on the environment; second, it may improve or at least achieve the same quality of mortar and concrete using less cement. If proved useful, the incorporation of RM in mortar and concrete mixes will render the Red Mud mixes a sustainable material. First, it is considered regenerative material as it not only minimizes damaging the environment but also restores it. Second, it will contribute to the economy through the minimization of the cost of RM disposal as well as the cost of concrete as less cement will be needed. Finally, it will contribute to the well being of the society by eliminating a material that is considered hazardous to people's health.

4 EXPERIMENTAL PROCEDURES

4.1 Materials

Standard sand and cement were acquired from national supplier and qualified for their use in mortar. The dry density for the sand and cement used were 1,708 kg/m3 and 1,794 kg/m3, respectively. Red mud was obtained from the Alcoa plant in South Texas in a solid form in water; it was formed during the Bayer process. For its use in mortar, red mud was processed by first oven drying at 105°C to get rid of the moisture content. Then, it was further broken down to a smaller particle size by grinding and sieving to obtain fine particles passing sieve #200 (75µm). The dry density of the dried and sieved RM was 1,073 kg/m3. The chemical composition of the RM used is given in Table 2.

Table 2. Chemical Composition of the red mud used in this research

Oxide	% Weight
Fe_2O_3	30.40%
Al_2O_3	16.20%
TiO_2	10.11%
SiO_2	11.14%
CaO	0.00%
Na_2O	2.00%
other	30.15%

4.2 Mix Design and Procedures

The replacement of cement and sand with RM 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 and 2. As per ASTM C109, the water/cement was kept at 0.48 and sand/cement was 1:2.75. Using a Hobart N50-60 mixer, water was poured into mixing bowl followed by cement (and replacement, when needed) and mixed at low speed (139 rpm) for 30 s. Sand (and replacement, when 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 RM decreased the workability of the mix.

Table 2. Mix proportions for cement replacement mortar cubes.

RM/Cement Replacement								
Cube: 50 mm	**RC1**	**RC2**	**RC3**	**RC4**	**RC5**	**RC6**	**RC7**	**RC8**
% Replacement	0%	5%	10%	15%	20%	30%	40%	50%
Cement (g)	250.00	237.50	225.00	212.50	200.00	175.00	150.00	125.00
Sand (g)	687.50	687.50	687.50	687.50	687.50	687.50	687.50	687.50
Water (g)	121.00	121.00	121.00	121.00	121.00	121.00	121.00	121.00
Red Mud (g)	0.00	7.48	14.96	22.43	29.91	44.87	59.82	74.78

Table 3. Mix proportions for sand replacement mortar cubes.

RM/Sand Replacement								
Cube: 2 in.	**RS1**	**RS2**	**RS3**	**RS4**	**RS5**	**RS6**	**RS7**	**RS8**
% Replacement	0%	5%	10%	15%	20%	30%	40%	50%
Cement (g)	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Sand (g)	687.50	653.13	618.75	584.38	550.00	481.25	412.50	343.75
Water (g)	121.00	121.00	121.00	121.00	121.00	121.00	121.00	121.00
Red Mud (g)	0.00	21.60	43.21	64.81	86.41	129.62	172.83	216.03

4.3 Testing

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

5 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.

5.1 RM as Cement Replacement

The results of the compressive strength for the mortar samples with RM/Sand replacement showed an irregular behavior. First, the compressive strength decreased with increasing the RM replacement up to 20%. However, increasing the RM/Cement replacement up to 30% increased the compressive strength substantially. The continuous increase in the RM/Cement replacement led to a dramatic drop in the compressive strength for 40% and 50% replacements, as shown in Figure 1. The compressive strength of the control mix was 24.4 MPa. The highest compressive strength obtained was 25.6 MPa at 30% RM/Cement replacement with an improvement of 5% in the compressive strength of the mortar cubes.

Table 4. Compressive strength (MPa) of cement and sand replacement cubes red mud.

% Replacement	Cement Replacement	Sand Replacement
0%	24.4	24.4
5%	22.4	34.3
10%	22.2	27.8
15%	19.2	32.0
20%	23.9	42.6
30%	25.6	38.7
40%	15.5	3.5
50%	9.9	6.5

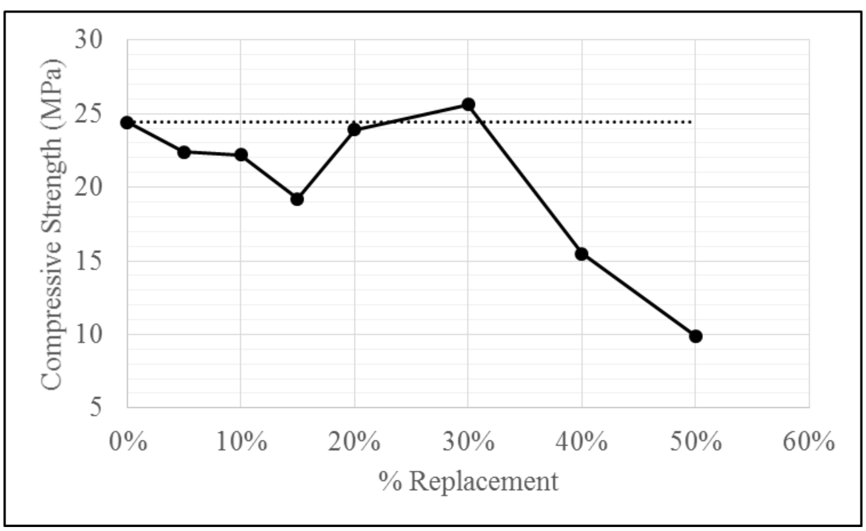

Figure 1. Compressive strength of mortar cubes with red mud as cement replacement.

5.2 RM as Sand Replacement

The results of the compressive strength for the mortar samples with RM/Cement replacement showed a more acceptable behavior than the RM/Cement samples. In general, it can be deduced that RM can improve the compressive strength of mortar cubes up to 30% replacement of cement. The continuous increase in the RM/Sand replacement beyond this point led to a dramatic decrease in the compressive strength for 40% and 50% replacements, as shown in Figure 2. The highest compressive strength obtained was 42.6 MPa at 20% RM/Cement replacement with an improvement of 75% in the compressive strength of the mortar cubes.

6 CONCLUSION

The results obtained are inconclusive regarding the performance of RM as a partial substitute for cement in mortar. There is no clear trend that can be used to establish facts. The compressive strength experienced a drop with an increase in the percentages of the RM replacements of cement up to 20% then a sudden increase in the compressive strength occurred at 30% followed by a major drop in strength for the 40% and 50%. As such, further experiments should be conducted to verify the effect of RM on the compressive strength of mortar when used as cement replacement. On the other hand, the compressive strength results of the mortar cubes made with RM/Sand replacements show a semi-regular behavior. The results obtained imply proportionality between the percentage of sand replacements and the increase of the mortar cube compressive strength of up to 30% replacement of sand. Incorporating RM as sand replacement can bring several benefits to the environment, the economy, the society, and the construction and alumina refining industries.

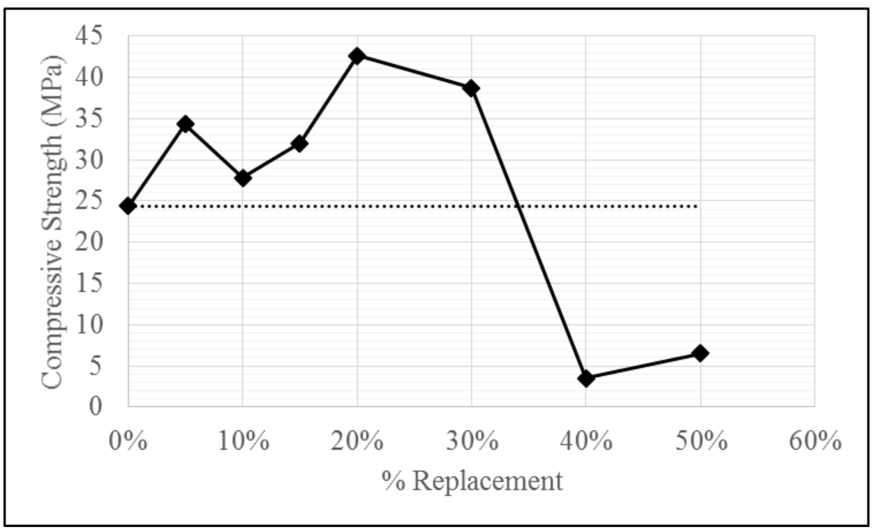

Figure 2. Compressive strength of mortar with red mud as sand replacement.

7 FUTURE WORK

Future work will include further experimentation of RM/cement replacement in mortar as well as in concrete. Concrete samples will be made using RM as a replacement of sand to draw final conclusions about its effect on compressive strength. New concrete mixes will be designed to test the performance of RM originated in the U.S. on concrete when used in combination with materials such as silica fume, lime and fly ash. The effect of RM on other characteristics of concrete such as tensile and flexural strength will be assessed in future experimentations.

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