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Effect of red mud as cement replacement on the properties of concrete

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Abstract- Indian aluminium industry generates significant amount of solid waste such as red mud. Red mud is produced during refining of alumina in Bayer's process. It is estimated that for production of 1 tonne of alumina, about 1.0 –2.5 tonne of red mud is generated. Annually, more than 4 million tonne of red mud is produced in India. As red mud contains some toxic elements, dumping of red mud contaminates the soil and water and also covers valuable land. By taking cementitious behaviour of the red mud into account, it can be used in mortar and concrete technology for construction practices by partially replacing cement. The use of red mud with partial replacement of cement proves to be economical because red mud, a by-product of alumina industry is available free of cost. The present study recapitulates the research on utilization of red mud as partial replacement of cement and its effect on mechanical and durability properties in mortar and concrete.
Keywords – Cement, Sustainable, Red mud, Concrete

I. INTRODUCTION

Aluminium plants are being set up rapidly throughout the world due to the increasing demand of aluminium as it is being used as a replacement of steel and other materials (Alam et al 2017). In Aluminium industry, red mud is one of the byproducts obtained when alumina is extracted from the bauxite ore through the Bayer process. To digest the bauxite ore, high concentration of sodium hydroxide (NaOH) solution is used at high temperature and pressure (Bayat et al 2018). India is considered to be 5th largest producer of bauxite which is the primary ore of aluminium in the world. In our country, the main producers of aluminium being National Aluminium Company (NALCO), Bharat Aluminium Company (BALCO), Hindustan Aluminium Company (HINDALCO) and Sesa Sterlite (now renamed as Vedanta). Mostly, the aluminium industries located closer to the sea dispose off the red mud into the sea thereby having an unfavourable effect on the aquatic plants and animals. In other cases, the residue which is in the form of slurry that is red mud (having a high solid concentration of 30-60% with a high ionic strength) is disposed off and dried in the large disposal area. Depending on the amount of bauxite and the type of process adopted in Aluminium industry, 1.0 – 2.5 tonne of red mud is generated for every one tonne of alumina produced (Bavani et al 2018). At present, 120 million tonnes of red mud is generated worldwide annually which is not being disposed off or recycled satisfactorily. Moreover, the disposing activities are becoming expensive and difficult. India contributes approximately 6.25% of the global red mud production that categorically consists of solid and metallic oxide impurities (Bavani et al 2018). Some researchers have found the potential use of red mud in the brick production and ceramic products (Dodoo-Arhin et al 2013 and Yang et al 2008). Red mud can also be used as catalyst and as adsorbent for removal of some valuable metals such as titanium and iron which can be recovered from the red mud (Kurtoğlu and Uzun 2016, Liu and Li 2015). Red mud has a high alkalinity (pH ranging from 9 to 14) due to which it becomes a hazardous waste material creating the problem of surface and ground water pollution. These environmental concerns have drawn considerable attention to investigating the feasibility of using red mud in various civil engineering fields. Red mud reduces the permeability thereby augmenting increase in the strength of the concrete. Red mud prevents the corrosion of reinforcement and it also acts as a good binding material (Bavani et al 2018). Therefore it can be used as a partial replacement of cement in mortar and concrete. Different researchers utilized the red mud in their studies to increase the strength of concrete and cement based materials and to improve the durability characteristics besides reduction in cost of concrete.

II. RED MUD PRODUCTION

The production of aluminium in China is more than 50% whereas India covers about 5% of the world's smelter production. Now days, more and more aluminium industries are being set up resulting in more production of alumina which in turn increases the production of red mud. As it is pertinent from Pie chart, China share in total world's production of Aluminium is more than 50% whereas our country's share is about 5% from the total world's production.

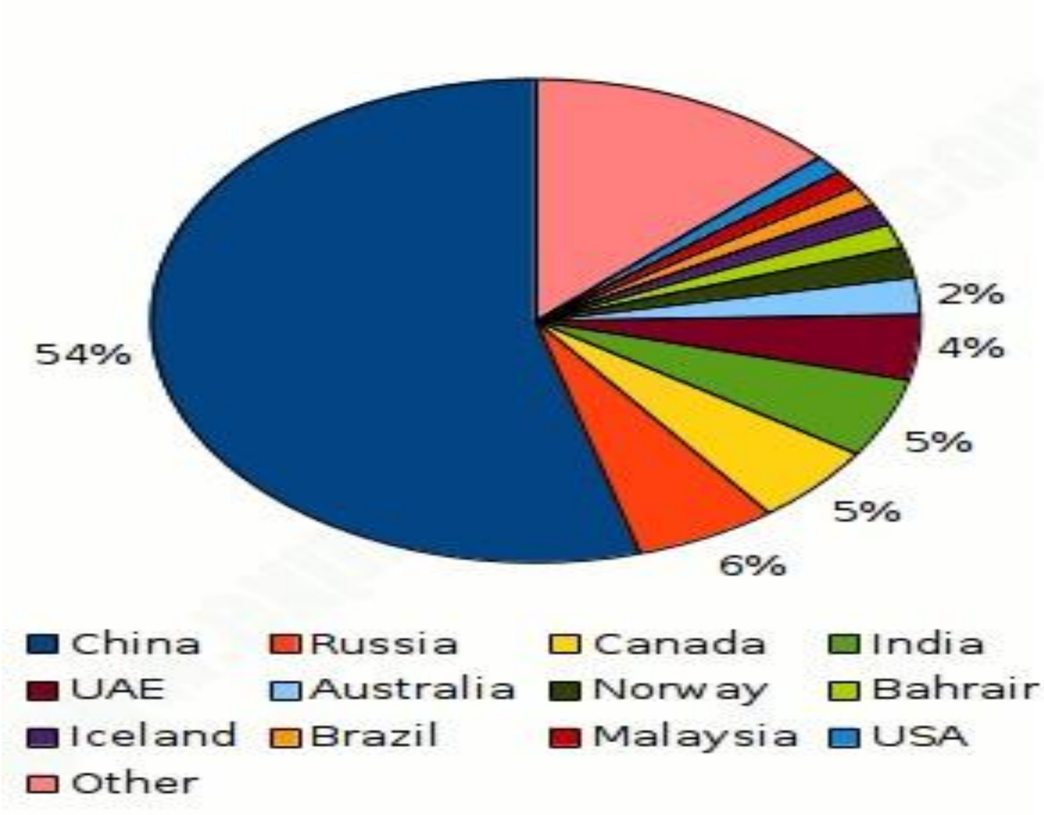

Fig.1 Pie chart indicating scenario of percentage of production of Aluminium in the world

III. USE OF RED MUD IN CEMENT PRODUCTION

The practicality of red mud in cement production has been studied by different researches all around the world. In India around two million tonne of red mud is used in cement production (Agrawal et al 2004). In Japan, red mud is used as raw material with other raw material such as clay and lime stone during the production of cement. The cement developed using red mud also meets with the specification of Standards.

Singh et al (1997) developed the new type of cements using different variations of red mud, lime, bauxite and gypsum. It was found that the compressive strength of these cements was comparable to Ordinary Portland Cement. The 28-day compressive strength of cement made with 50% lime, 30% red mud and 20% bauxite was around 10 MPa. The optimum firing temperature and firing time for the production of this cement was 1300^0C and 1.5 hour respectively. In another study, Singh et al developed the cement using red mud, lime, gypsum and bauxite. The maximum compressive strength of 25 MPa was achieved using 47.5% of lime, 7.5% of gypsum, 40% red mud and 5% bauxite. The optimum firing temperature and firing time for the production of this cement was 1250^0C and 1 hour respectively.

Tsakiridis et al (2004) found that the addition of red mud up to 3.5 % with raw material of clinker in cement production reduces the burning temperature of clinker. The mineralogical composition of red mud based clinker was similar to Portland clinker. The 90-day compressive strength of red mud based clinker was around 55MPa, which was more than the Portland clinker.

. IV. PROPERTIES

4.1 Physical Properties:

Specific gravity of red mud ranges from 1.96 to 3.25 and fineness ranges from 1000 to 3000 cm^2/gm. The density of red mud is 3.26 gm/cm^3 and the particle size is 14.8 µm. Red mud is basic in nature.

4.2 Chemical Properties:

The chemical properties of red mud such as MgO ranges from 1.13 to 1.7, K_2O ranges from 0.1 to 0.73 and MnO ranges from 0.078 to 0.1. The other chemical properties of red mud determined by different authors are given in Table 1.

Table 1 Chemical properties of red mud:

Oxide Composition / Research reported by Author(s)	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	TiO_2	LOI
Pujar and Prakash (2014)	9	22	47	3.50	3.5	12.4	19
Rathod et al (2014)	11.4	21.6	38.3	1.47	6.87	-	-
Metilda et al (2015)	11.53	14.14	48.50	3.96	7.50	5.42	-
Shinge and Pendhari (2015)	4.6	-	34.3	4.8	4.0	8.35	15
Shinge et al (2015)	19.497	22.522	34.752	0.503	10.684	3.58	-
Mahin Sha et al (2016)	12-15	20-22	40-45	1-2	4-5	1.8-2.0	-
Kumar and Sagar (2016)	18	6.31	12.38	35.3	2.71	-	-
Deepika et al (2017)	12-15	20-22	40-45	1-2	4-5	1.8-2.0	-
Nikbin et al (2015)	14.8	17.7	27.6	14.7	5.4	7.2	9.7
Syam Sai and Sukesh (2017)	12-15	20-22	40-45	1-2	4-5	1.8-2.0	-
Tharani et al (2017)	17	15	61	1	4	4	7
Singh et al (2018)	9.93	18.1	42.9	-	5.58	9.03	0.35
Tang et al (2018)	-	17.093	61.608	1.076	15.11	3.587	-
Bayat et al (2018)	13.26	15.41	20.54	19.87	5.87	4.97	16.3

V. MECHANICAL AND DURABILITY PROPERTIES

Pujar and Prakash (2014) examined the use of washed and unwashed red mud in concrete for the partial replacement of cement at 0% to 20% at an interval of 2%. Different tests such as compressive strength, flexural strength, split tensile strength, shear strength, water absorption and workability were conducted to determine the properties of concrete. It was found that the shear strength, compressive strength, flexural strength and split tensile strength increased with the increase of washed red mud upto 8% and unwashed red mud upto 2%, thereafter reduction in strengths was observed. Further, it was observed that water absorption and sorptivity decreased with the increase of washed red mud upto 8% and unwashed red mud upto 2%. The strength, workability and sorptivity of washed red mud was higher than the unwashed red mud.

Rathod et al (2014) replaced 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% of cement with red mud taking control mix with 0%. It was observed that the compressive strength and tensile strength decreased with the increase in the proportion of red mud. The optimum percentage of red mud to be replaced with cement was recommended as 25%.

Metilda et al (2015) studied the use of red mud in concrete in which the cement was partially replaced by red mud at 0% to 25% with an interval of 5%. Based on the experimental investigation, it was observed that the compressive strength, tensile strength and flexural strength increased with the increase in the percentage of red mud up to 15 % but beyond 15%, there was a reduction in the strength. Therefore, it was recommended to replace cement with red mud to the extent of 15%.

Shinge and Pendhari (2015) partially replaced cement by red mud at different proportions of 0%, 5%, 10%, 15% and 20%. It was found that the compressive strength decreased with the increase in the percentage of red mud. Also, it was observed that the tensile and flexural strength increased with the increase in the percentage of red mud. On the basis of experimental studies, it was suggested that 10% of red mud can be effectively used for partial replacement of cement without compromising the compressive strength.

Shinge et al (2015) encapsulated the use of red mud and rice husk ash in cement based materials (mortar). Proportions of red mud and rice husk ash used were 5%, 10%, 15% and 20%. The compressive strength at 0%, 5%, 10%, 15% and 20% of red mud was 36.72 N/mm^2, 36.10 N/mm^2, 34.33 N/mm^2, 30.33 N/mm^2 and 25.25 N/mm^2 whereas tensile strength was 3.00 MPa, 3.19 MPa, 3.43 MPa, 3.51 MPa, 3.66 MPa at 28 days implying that the compressive strength of red mud based mortar decreased while tensile strength increased with the increase in red mud proportion..

Yamuna (2015) investigated the use of red mud and quarry dust in cement mortar and concrete. Cement and fine aggregates were partially replaced by red mud and quarry dust. Different proportions of red mud such as 0%, 5%, 10%, 15%, 20%, 25% and 30% in cement mortar were used. From the compressive strength point of view, the optimum percentage of red mud in cement mortar was recommended as 20%. Keeping the red mud as 20% and replacing fine aggregates by quarry dust at proportions of 0%, 10%, 20%, 30%, 40%, 50% and 60%, tests were conducted to determine the split tensile strength. The split tensile strength increased up to 40% of quarry dust and then decreased.

Mahin Sha et al (2016) studied the effect of red mud concrete on workability, compressive strength and tensile strength. The replacement levels of cement by red mud such as 0% to 25% at an interval of 5% were used. Experimental study indicated that the compressive strength and the tensile strength decreased with the increase in the percentage of red mud whereas the workability of concrete increased with the increase in the percentage of red mud. Therefore, the optimum use of red mud as a cement replacement was recommended as 20%.

Kumar et al (2016) investigated the effect of red mud in cement mortar in addition to the effect of red mud and quarry dust for the partial replacement of cement and sand. Firstly, cement was partially replaced by red mud at different levels ranging from 0 to 30% at an interval of 5%. It was found that the compressive strength of cement mortar increased up to 20% followed by a subsequent decrease. Therefore, the optimum percentage of red mud was 20% for the partial replacement of cement. Secondly, this optimized percentage of red mud in combination with variable percentages of quarry dust was employed for the partial replacement of sand (from 0 to 60% with an increment of 10%). It was observed that the compressive strength and split tensile strength increased up to 40% of quarry dust and then reduced. So it can be concluded that the optimum percentage of red mud was 20% in cement whereas the optimum percentage of quarry dust was 40% in concrete.

Kumar and Sagar (2016) investigated the use of red mud and quarry dust in concrete. Red mud was used at different replacement levels such as 0, 5, 10, 15, 20 and 25% and quarry dust at 0, 10, 15, 20, 25, 30, 35 and 40% for the partial replacement of cement and sand. They witnessed a significant increase in the compressive strength and the flexural strength with respect to the upsurge in the percentage of red mud. On the contrary the strengths (compressive and flexural) were reduced with the increase in the percentage of red mud beyond 15% therefore it was established as an optimum percentage. Further at the optimum percentage of red mud (that is 15%), sand was partially replaced by quarry dust at different replacement levels and various tests were conducted to determine the mechanical properties. The compressive strength and the flexural strength increased with the increase in the percentage of quarry dust but there was a reduction in the strength beyond 30% of quarry dust. Therefore, it can be concluded that the optimum percentage of red mud and quarry dust for the partial replacement of cement and sand was 15% and 30%, respectively.

Liu and Poon (2016) studied the mechanical properties of self-compacting concrete using red mud. It was found that the 28 days compressive strength of red mud based self-compacting concrete was 38 MPa compare to 33 MPa of fly ash based self-compacting concrete. The elastic modulus and tensile strength of red mud based self-compacting concrete was also better than the fly ash based self-compacting concrete. Experiment was also done on the drying shrinkage and water permeability of self-compacting concrete based on red mud. Minimum drying shrinkage was observed in mix with 40% red mud as cement replacement. However the water absorption of concrete was increased with increase in red mud content due to high porosity. The internal curing of red mud was attributed to lower drying shrinkage, which consume the extra water within its porous structure.

Sowmyashreeet al (2016) studied the water absorption, acid resistance and carbonation of red mud based concrete. It was found that the compressive strength of concrete after acid treatment decreased with increase in red mud content while the water absorption of concrete increased with increase in red mud content. The carbonation resistance of different grades (M20 and M40) of red mud concrete was also investigated. In M20 grade of concrete after carbonation test, the compressive strength of 25% red mud and 30% red mud was decreased by 24% and 20% respectively. However for M40 grade of concrete the reduction of strength was lesser with 14% and 12% for 25% red mud and 30% red mud respectively. High grade of concrete was denser than lower grade of concrete, which reduces the penetration depth of CO_2 in the concrete. Due to less carbonation in M40 grade of concrete, compressive strength was better than M20 grade of concrete. Based on the study, the optimum percentage replacement of red mud with cement by weight was recommended as 30% both in case of M20 and M40 grade of concrete.

Deepika et al (2017) replaced cement by partially replacing with red mud at various proportions such as 0%, 10%, 15% and 20%. Different tests (such as compressive strength, tensile strength and flexural strength) were conducted to determine the mechanical properties of the red mud concrete. It was investigated that the compressive strength, tensile strength and flexural strength increased with the increase in the percentage of red mud.

Nikbin et al (2017) demonstrated the use of red mud in the concrete mixture. Different tests such as compressive strength, tensile strength, flexural strength, specific gravity and modulus of elasticity were conducted. It was determined that the compressive strength tends to decrease with the increase in red mud showing the reduction of strength of 3.5, 8.3, 15, 19.7 and 29.5% for specimens containing respectively 5, 10, 15, 20 and 25% red mud at the age of 28 days. The reduction in the compressive strength is due to the lower pozzolonic properties of red mud as compared to the cement. Since the particle size of red mud is smaller, therefore it has good filling capacity but this effect is not strong enough to compensate for lower chemical reactivity and hydration of red mud compared to cement and consequently compressive strength of specimens decreased as the red mud content increased. Similar trend was followed for the tensile strength, flexural strength, specific gravity and modulus of elasticity. The reduction in the modulus of elasticity of concrete is due to the fact that the addition of red mud leads to the decrease of aggregate volume in mixture which results in the lower stiffness of the concrete mixture.

Pateliya and Solanki (2017) investigated the use of red mud in mortar and concrete. Cement was partially replaced by red mud at different replacement levels such as 16% to 24% with an increment of 1%. Different tests were conducted to determine the mechanical (such as compressive strength, flexural strength and split tensile strength) and durability characteristics for three different grades of concrete (M20, M25 and M30). Experimental investigation showed that the compressive strength, flexural strength, split tensile strength and durability characteristics increased upto 18% and then decreased for all the three grades. Therefore, the recommended value of the optimum percentage of red mud was 18% for all the grades.

Syam Sai and Sukesh (2017) examined the effect of red mud (ranging from 0% to 20% at an interval of 5%) with 5% or without hydrated lime in concrete. Slump cone and compaction factor tests were used to determine the workability of concrete. It was found that the workability of concrete increased with the increase in percentage of red mud for M40 and M50 grade. Different tests were conducted to determine the mechanical properties such as compressive strength, flexural strength and split tensile strength for both the grades. Compressive strength and split tensile strength of the red mud concrete increased upto 10%, then decreased for both the grades with or without hydrated lime, although the strengths of red mud concrete with hydrated lime was higher than without hydrated lime. Flexural strength of the concrete decreased with the increase in the percentage of red mud. Finally, it was concluded to use 10% of red mud for concrete with or without hydrated lime.

Tharani et al (2017) examined the effect of red mud concrete in which the cement was partially replaced by red mud at 0%, 5%, 10% and 15%. The compressive strength of red mud concrete at replacement levels were 33.43%, 34.06%, 33.14% and 32.95% at 28 days. Results depict that the compressive strength increased up to 5% replacement level and then decreased. Further, the compressive strength of 10% replacement of cement with red mud was found at par with the conventional concrete. Therefore, the range of the optimum percentage of red mud was recommended as 5% to 10%.

Singh et al (2018) investigated that the red mud based geopolymer possessed very little compressive strength due to the less amount of silica, hence silica based materials such as ground granulated blast furnace slag, micro silica were added to maintain the Si/Al ratio. The highest strength of red mud based geopolymer was obtained at 30% for thermally cured samples with SiO_2/Al_2O_3 ratio at 5.1. Ambient cured samples exhibited better compressive strength results than the thermally cured samples. The optimum SiO_2/Al_2O_3 ratio was 4 for ambient cured samples which was lesser than the thermally cured samples. Therefore, the optimum use of red mud for both ambient and thermally cured samples was found to be 30%.

Tang et al (2018) examined the use of red mud on fresh and hardened properties of self compacting concrete (SCC). Fly ash was partially replaced by red mud at different replacement levels such as 12.5, 25 and 50% by weight. Different tests were conducted to determine the fresh, hardened properties and also the microstructural behaviour of self compacting concrete. It was depicted that the quantity of superplasticizer required to achieve SCC requirements increased with the increasing of red mud content as the flowability decreased with increase of red mud. Therefore, the red mud had negative effects on the fresh properties of SCC mixes. Also, it was observed from the experimental investigation that increase in the red mud content increased the compressive strength and elastic modulus but decreased the tensile strength.

Bayat et al (2018) influenced the use of red mud on the fresh and hardened properties of alkali-activated slag (AAS) paste and mortar. It was found that the cohesiveness increased while the fluidity, consistency and the consistency loss rates decreased with the increase in red mud content. The XRD, FTIR, SEM and TG/DTA results showed that after 28 days, the main crystalline minerals in the raw red mud (RM) and the thermally treated RM retained their nature in the gel and were incorporated by the gel structure. The optimum percentage of red mud was recommended as 20% providing the highest compressive strength while the flexural strength decreased with the increase of red mud content.

VI. CONCLUSIONS

1. The red mud generated in the production of alumina is a worldwide problem as it creates a nuisance. The production of red mud in India is more than 4 million tonnes while in world, it is 120 million tonnes. By partially replacing cement with red mud, problem of surface and ground water pollution can be reduced to a great extent.
2. The properties of red mud are analogous to the properties of cement, hence it can be effectively used as a partial replacement for cement which in turn decreases the production of cement followed by the subsequent decrease in the CO_2 emissions.

3. Compressive strength, tensile strength and flexural strength of red mud mortar/concrete goes on increasing up to 20% of red mud used for the partial replacement of cement and then it is decreased. Hence, we can say that the optimum percentage of red mud may be recommended as about 20%.

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