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Research Article

Red Mud, the Cutting Edge of Self Compacting Cement Concrete

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Abstract

Red mud is an undisposed industrial waste in Bayer's process during extraction of alumina from Bauxite. Accumulation of undisposed dry/wet red mud wastes of variant mineralogy pollutes air, soil, surface/ ground water and vegetation. Deterioration of the environment and its ecology has caused concern to the environment of the surroundings of Alumina industry. Efficacy of use of the red mud by partial replacement of cement and coarse aggregates in construction industry has brought revolution in research and development for last ten years. Engineers and scientists have conducted tests to ascertain the properties and the mechanical strengths by blending cement with red mud, fly ash and other admixtures at various proportions. Present research envisages the study of properties of self-compacting concrete and determining their mechanical strengths (Compressive, tensile and flexural) by replacing cement with red mud in the laboratory by using Digital Compression Testing Machine and the Universal Testing Machine (UTM) at various mixed proportions. The properties and strengths of blended concrete were found optimum and within safe limits when cement was blended with 20% neutralized red mud which can save the coming generation from catastrophe of the wastes of bauxites.

Keywords: *Blending, Concrete, compressive strength, Flexural strength, red mud, UTM*

1. Introduction

The red mud is a waste obtained from Bayer's process during extraction of aluminum from Bauxite ore. As per Mineral Commodity Summaries (2015), the worldwide Bauxite production is around 234 million metric tons (MMT), red mud (RM) $9x10^7$ MT in which India accounts for 19.3 MMT and RM of $2x10^6$ MT in 2014. The greatest producers of red mud in the world are Australia, Brazil, China, Greece, Guynea, Guyana, India and many other countries. The worldwide famous companies like ALOCA, ALCAN, RUSAL, BHP, CHALCO and many others contribute. Global production of red mud is amounting more than 120MMT out of which China shares about 60 MMT tons. W Liu,(2015. A picture of highest reserves of Bauxite in India/globe is in Table 1.

Huge quantity of red mud is received from Indian aluminum sector which was obtained in 2009 from Indian major industries NALCO (2.033 MMT), HINDALCO (1.654 MMT), VEDANTA (0.366 MMT), BALCO+MALCO (0.412 MMT), totaling to 4.465 MMT Chhada 2010 which is the undisposed waste of the industry. Red mud contains large number of compounds Fe_2O_3 (30-60%), Al_2O_3 (10-20%), SiO_2 (3-50%), Na_2O (2-10%), CaO (2-8%), and traces of TiO_2 (Sutar *et al*., 2014).

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This high alkaline slurry is practically a discarded waste due to it's high value of pH (10.5 to12.5), none uniform composition, polluting surface and underground water, requirement of vast disposing area, leaching properties, formation of sodium alumino-silicate, and deteriorating the adjoining vegetation. The world has not forgotten the adversity of 0.6 to 0.7 million cumec red mud sludge (2010) of the Ajkai Timfoldgyar plant of Hungary that affected the Bulgaria, Serbia, Ukraine and Romania and collapse of RM pond in Henan Province, China during Aug, 2016. The red mud is difficult to use with cement, as building materials, steel industries due to its rich soda content. In contrary, few of above mentioned oxides in RM are present in cement. Red mud can be used as a cementing material (Orient Cement which uses 2-4% RM of MALCO).

Accumulation of undisposed dry/wet red mud waste of variant mineralogy pollute air by dust, soda enriched soil, caustic leachate surface/ ground water and vegetation. Deterioration of the environment and its ecology has caused concern to the geomorphology. It's remediation and rehabilitation is highly essential by using a sizable quantity of red mud as soil amelioration, cement production, iron recovery, red Oxide manufacture, landfill restoration, road construction, building materials and many others.

Considering the threat to the environment, many researchers of the last decade have studied procedures to digest the red mud and use for human utilities after due processing.

Table 1: Statistics of bauxite ore, quantity of RM, in the globe, states of India

Name of the state	Cement productionn	Bauxite reserves	Bauxite mined	Red Mud	Bauxite		
	Kg/capita (2012)	MMT (2014)	MMT (2014)	MMT (2001)	India	Production MMT	Reserves (MMT)
Guinea		7400	19.3	15.7	Odisha	5.46	1810.5
Australia		6500	81.0	53.3	Andhra	0.0	615.3
India	191	3480	19.0	8.39	Gujarat	3.02	236.7
Brazil	353	2600	32.5	13.9	Chhattisgarh	1.82	171.0
Vietnam	560	2100	1.0	0.40	M.P.	0.82	146.8
Jamaica		2000	9.8	12.4	Jharkhand	2.01	146.3
Indonesia		1000	0.5	0.20	Maharashtra	1.97	174.9
Guyana		850	1.8	2.0	Tamilnadu	0.38	24.8
China		830	47.0	9.5	Karnataka	0.81	55.7
Greece		600	2.1	0.84	Goa	0.87	58.0
Suriname		580	5.0	2.0	UP	0.00	18.9
Others		2947	17.3	6.92	Kerala & others	0.00	20.7
Total		28000	234	125.46	Total	17.2	3479.6

Note: : Indian data from Ministry of Mines (GOI) and other data from USGS Minerals year book 2007, Mineral Commodity Summaries 2015, Meyer, 2004

Present study envisages the use of RM as concrete material replacing cement. Higher grade of concrete have been tested for different % of replacement but M20 is the common grade of concrete used in most populous and developing countries like India and china. The two countries have also ample reserve of bauxite ore.

Fig 1: The wet red mud pond at NALCO

2. Review of Literature

De Oliveira *et al*., (2012) and Vandhiyan *et al*., (2015) reported that the red mud can be used as coarse aggregate in cement concrete (CC). Optimum % of replacement of cement by red mud (15%) and copper slag was (40%) by Bishetti *et al* (2014), less than 20% for M25 concrete by Sha Mahin *et al*.,(2016), and 25% of cement by red mud in M25 concrete claimed by Rathod et. al.,(2014). Concrete of M30 grade was studied by replacing 10% red mud with 20% silica by weight can give equal results to that of conventional CC and saves in cost of concrete by 6.43%. Shetty et. al., (2014) have studied M25grade concrete by replacing cement by fly ash, red mud, and Iron ore tailings (IOT) as fine aggregate and the optimum compressive and flexural strength was obtained at 2% red mud with 10% IOT was replaced. Srivastav *et al*.,(2016) the optimum compressive strength and split tensile strength was obtained at 2% RM with 30% IOS substitution to cement. Garg *et al*.(2015), claimed bricks made of red mud can be used as light weight construction materials. Rao *et al*, 2016 reported AP in India has reserve of bauxite of 1000MMT but exploration not started yet. Patel et. al., (2015), the dry disposal is one of the better method and the wet red mud must be disposed or used after the processes like road based material, mining, building material and sintering. Treating red mud with methane, sulfidation process given by Iannicelli can be better treatment of hazardous red mud Ritter Stephen, (2014) A project from BHU, UP has optimized using neutralized red mud of HINDALCO as an additive to cement by 10% and the crushing strength was improved by 5 to 10% in concrete blocks. Similarly Orient cement reported improvement of properties of cement by adding 2-4% of red mud of MALCO. BHU (UP) and CGCRI with BALCO (Calcutta) and CECRI (Tamil Nadu), developed red oxide primer and some high strength red cements, by using red mud of HINDALCO, BALCO and MALCO and NALCO Fig 1.

Shendure *et al*, (2015), reported that replacing cement by 30%, 35% and 40% fly ash and 15% red mud after neutralization the concrete with 35% fly ash and 15% RM neutralized give optimum compressive strength. Soumyashree et. al., (2016) and Karthik Siddu *et. al.,(*2016) reported that concrete prepared by adding OPC, Red mud (30%), aggregates, hydrated lime and supper plasticizer Complast SP 430, make the concrete minimizes Greenhouse effect, ecofriendly and save energy during production OPC at reduced cost and compressive strength of M40 concrete increases.

Viscosity modifying agent (VMA) and super plasticizer (SP) were added to red mud by 2% each blended with concrete and the SCC properties were optimum Kushwaha *et al*., (2013). Davidson Emma (2014) found a correlation between the GDP growth and consumption of cement at global scenario.

Past literatures on cost saving of concrete reported that addition of RM in M30, M40, M50 grade NRM concrete with 15 % replacement was 7.48 %, 7.86 % and 8.17 % less than the conventional concrete with increase of compressive strength by 21.712 %, 16.412 % and 10.17 % respectively. Further the % of economy increased with higher grade of concrete but there was reduction in the compressive strength. The above conclusions induced for studying the optimum utilization of NRM in concrete as part replacement for cement.

3. Materials and methods

3.1.1 Red Mud (RM): The dry red mud from Bayer process of alumina extraction was collected from NALCO, Damanjodi in Odisha. This byproduct, called bauxite residue or "red mud", is produced in almost 1: 1 ratio to alumina when dry. The constituents of red mud, are iron as hematite (Fe_2O_3) orgoethite (FeOOH), while aluminum as gibbsite (Al_2O_3,$3H_2O$), diaspore (Al_2O_3,H_2O), cancrinite ($Na_6Ca_2(Al_6Si_6O_{24})$ $(CO_3)_2$, $2H_2O$) and katoite ($Ca_3Al_2(SiO_4)(OH)_8$). From the study made by NALCO, the average chemical composition of the red mud in 1000gms of specimen, Al_2O_3 , Fe_2O_3, CaO, SiO_2, TiO_2, Na_2O, H_2O(cry), Moisture are 18.76, 44.38, 11.88, 6.13, 5.54, 2.20, 9.77 and 1.00 respectively Chhadha (2010). NALCO employs modified closed cycle disposal system (CCD) to red mud ponds after counter current wash in six phases with sodium oxide @0.5gm/lit of return water from ponds and the chemical equation governed by

$$2NaOH + Al_2O_3, 3H_2O = Na_2O, Al_2O_3 + 4H_2O + R.M.$$

3.1.2 Cement: Cement used in the present study was Portland grey cement (OPC) 53 grade confirming IS 12269 (1987) having specific gravity 3.12, fineness value as retained on 90micron sieve is 4% and 320 m^2/Kg, soundness tested by LE-Chaelier's Apparatus found less than 10mm, Initial and final setting time 30 and 580 minutes respectively and satisfying the average compressive strength was tested as per IS code 4031 –part 6.

3.1.3 River sand (Fine aggregate): Local available dry sand (river) belonging to Zone II of IS code 383-1970 was used as fine aggregate with physical properties as specific gravity (2.61), fineness modulus 2.7 and % of water absorption was 1.5.

3.1.4 Hard Granite Chips (Coarse aggregate): Locally available crusher aggregates of black hard granite confirming to IS 383-1970 was used for the mix of green concrete having properties 10mm and 20mm aggregates Sp. Gr. 2.67, % of water absorption 1.5% each.

3.1.5 Water: Ordinary portable water was used for mixing (W/C ratio as 1: 0.50).and curing concrete confirming to IS -1984-(5).

3.2.1 Methodology: Neutralization and utilization of RM for its better waste management methods were suggested by different researchers like Bioremediation (Jain Surabhi and Dr S C Das 2014). The physical properties of the specimen well graded RM when tested in the laboratory was found of sp. gr. (2.85), density 3.05gm/cm^3, maximum dry density (1.53/cc, Fine ness 1200 cm^2 /gm optimum moisture content 33.5%, cohesive shear strength was found from triaxial test (0.123kg/ cm^2, CBR value 4.2 and Atter Berg's limit (13.2) indicating category as silt with low compressibility (MI) Jain et. al.., (2014). Neutralization of RM can be done by treating with acidic SPSs (spent pickling solutions) obtained during manufacturing of steel, CO_2 gas, sea water treatment and sintering. Rai *et al*,(2012).

3.2.1 Mix design: To determine the appropriate quantity of ingredients of concrete, methods adopted for the design mix can be Trial-Error Method, as per IS 456/2010 & IS 10262-2007, Indian Road Congress, IRC 44 Method, ACI Committee 211 Method and high strength concrete mix design. The design mix of the M20 concrete should have target strength for mix proportion (IS 456 – 2000) was as: $f'_{ck} = f_{ck} + 1.65S = 20 + (1.65 \times 4) = 26.6\ N/mm^2$ Where $f'_{ck} =$ Target av. compressive strength at 28 days, $f_{ck} =$ Characteristic compressive strength at 28 days, S = Standard deviation ($S = 4N/mm^2$).Present mix Proportions adopted in preparation of M20 concrete was cement =372 kg, water =186 kg, local river sand = 582 kg and black H.G. coarse aggregate = 1228 kg where the mix design ratio was C: FA: CA = 372: 582:1228 =1: 1.56: 3.3

3.2.2 Flexural Strength: The different dimensions of specimen beams were measured having width (b mm) and depth (d mm) by averaging two measurements for width and two measurements for depth. The measurements shall be taken at the failure plane to an accuracy of 1.3mm. The modulus of rupture is calculated as $(f_b) = {}^{3PL}/_{2bd^2}$, Where: f_b = Modulus of rupture in psi or MPa, P = Maximum applied load indicated by the testing machine in N, l = Span length in inches or mm, b = Average width of specimen in inches or mm, d = Average depth of specimen in mm

3.2.3 Self-compacting Concrete: "Self compacting concrete" (SCC) has high flow ability of concrete blended by pozzolanic materials, red mud, colloidal silica, admixtures and other materials that augment properties of concrete like strength, workability, low permeability, durability, resistance to segregation due to chemical action and other properties at lower cost. Shendure *et al* (2015) studied the SCC action of M50 NRM and optimized that concrete blended with fly ash (35%) and NRM (15%) and found the optimum properties of self-compacted concrete (SCC) and compressive Strength. As the light weight neutralized red mud pierce the voids and increases the density of the mix and the flow ability which add to the self-compacting property of the concrete.

Present study was conducted for Material tests, slump test for green concrete, compressive strength and flexural strength after 7days, 14days and 28days curing of the conventional concrete and the blended concrete of cubes, cylinders and CC beams.

Table 2: The test results: compressive strengths of concrete and red mud cubes (NRMC 00, NRMC10, NRMC20, NRMC30 and NRMC40)

Sl no	Comp. strength N /mm² (7curing days)			Comp. strength N/mm² after 14days			Comp. strength N/mm²after 28days			Remark
	days	Load (KN)	Comp. strength	days	Load (KN)	Comp. strength	Days	Load (KN	Comp strength	After 28days curing, M-20 (IS 456/2000) RMC00
Concrete NRMC00: M-20 conc. when prepared conventional concrete										
1	7	475	21.11	14	525	23.33	28	600	26.67	
2	7	450	20.00	14	530	23.55	28	600	26.67	
3	7	465	20.67	14	530	23.55	28	610	27.11	
Concrete NRMC10: M-20 conc. when Replaced with 10% red mud										After 28days curing, NRMC 00, NRMC10, NRMC20, NRMC30 & NRMC40
1	7	345	15.33	14	450	20.00	28	625	27.78	
2	7	355	15.77	14	475	21.11	28	635	28.82	
3	7	340	15.11	14	480	21.33	28	650	28.89	
Concrete NRMC20: M-20 conc. when Replaced with 20% red mud										
1	7	385	17.11	14	520	23.11	28	660	29.33	
2	7	400	17.77	14	500	22.22	28	655	29.11	
3	7	400	17.77	14	495	22.00	28	650	28.88	
Concrete NRMC30: M-20 conc. when Replaced with 30% red mud										
1	7	550	24.44	14	575	25.55	28	575	25.55	
2	7	540	24.00	14	565	25.43	28	580	25.77	
3	7	540	24.00	14	555	24.66	28	575	25.55	
Concrete NRMC40: M-20 conc. when Replaced with 40% red mud										
1	7	410	18.22	14	450	20	28	455	20.22	
2	7	415	18.44	14	425	18.88	28	460	20.44	
3	7	410	18.22	14	425	18.88	28	480	21.33	

4. Laboratory results

4.1.1 Compressive strengths of Cubes: The compressive strengths were studied for specimen cubes of conventional M20 concrete and concrete with replacement by neutralized red mud by 10%, 20% 30% and 40% by weight and cured for 7 Days, 14 days and 28 Days as per IS: 516-1959 specification.

(a)

(b)

Fig 2: (a) Universal testing machine (UTM) (b) Compression testing machine each of 1000MT capacity

45 cubes were casted for testing the compressive strength. The mixes designated were designated as NRMC10, NRMC 20, NRMC30 and NRMC40 and then tested on Compression Testing Machine (CTM) of capacity 1000kN compressive load Fig 2 (a) and Fig 2 (b). The test results of cube compressive strength are in Fig 3, Table 2.

The comparative results with conventional concrete M20 grade indicates that RMC10 and RMC20 satisfies the compressive strength criteria when the cement is replaced either by10% or 20% red mud Fig 3. During preparation of neutralized red mud concrete (NRMC) it was observed the initial setting time (30mnts) is same as that of conventional concrete as per (IS: 269-1976. But when the RM percentage is higher than 10%, the setting time of NRMC increases to 60-90mnts confirming to studies made by Sawant *et al.*, (2016).

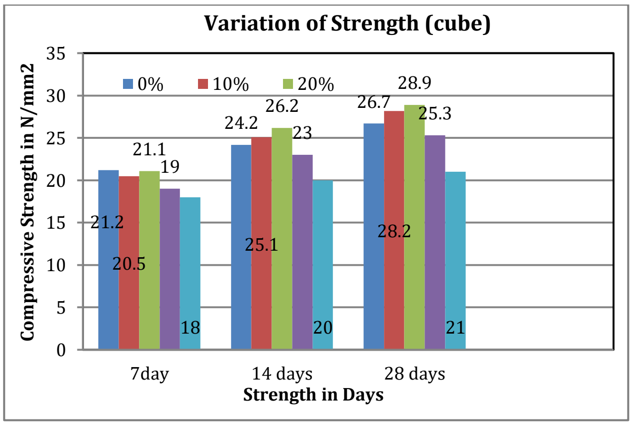

Fig 3: The test results: compressive strengths of concrete and red mud cubes

The initial setting time for the cement used in the present studies is 90 minutes. The initial setting time for 5% and 10% replacement by neutralized red mud gradually reduces whereas for 15% of replacement by neutralized red mud the initial setting is nearly the same as that of ordinary Portland cement. Future increase in neutralized red mud i.e. for 20% and 25% increases the initial setting time Fig 3.

4.1.2 Compressive strength of Cylinders

The compressive strength for specimen cylinders were studied of conventional M20 concrete and concrete with replacement of red mud by 10%, 20% and 30% by wt. at 7 Days, 14 days and 28 Days as per IS: 516-1959 specification 0.45 cylinders were casted for testing. The compressive strength of concrete cylinders should be within 80%-100% of cubes due to less slenderness ratio IS Code 10262 – 2009.

The compressive strength for specimen cylinders were studied of conventional M20 concrete and concrete with replacement of red mud by 10%, 20% and 30% weight when cured for 7 Days, 14 days and 28 Days as per IS: 516-1959 specification.

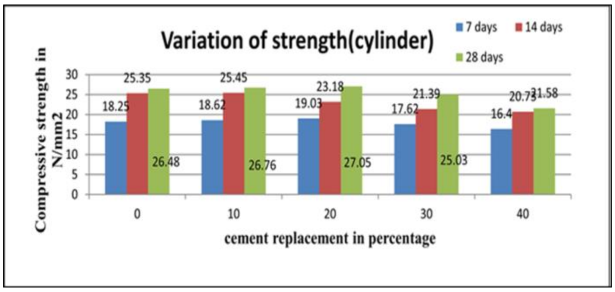

Fig 4: The test results: compressive strengths of concrete and red mud cubes (NRMC 00, NRMC10, NRMC20, NRMC30 and NRMC40)

45 cylinders were casted and the compressive strength with concrete and blended concrete are tested on Digital Compression Testing Machine (capacity 1000kN).The test results of cube compressive strength are in Fig 4 and Table 3.

Table 3: The test results: compressive strengths of conc. + red mud cylinders NRMC at different replacement

Sl no	Comp. strength N /mm^2 (7curing days)			Comp. strength N/mm^2 after 14days			Comp. strength N/mm^{2}after 28days			Remark
	days	Load (KN)	CompStrength	days	Load (KN)	Comp. strength	days	Load (KN)	Comp strength	After 28days curing, M-20 (IS 456/2000) NRMC00
Concrete NRMC00: M-20 conc. when prepared conventional concrete										
1	7	375	21.21	14	450	25.45	28	470	26.58	
2	7	400	22.62	14	450	25.45	28	470	26.58	
3	7	400	22.62	14	445	25.17	28	465	26.30	
Concrete NRMC10: M-20 conc. when Replaced with 10% red mud										After 28days curing, NRMC 00, NRMC10, NRMC20, NRMC30 & NRMC40
1	7	300	16.96	14	430	24.32	28	475	26.86	
2	7	325	18.38	14	450	25.45	28	475	26.86	
3	7	310	17.53	14	450	25.45	28	470	26.58	
Concrete NRMC20: M-20 conc. when Replaced with 20% red mud										
1	7	330	18.66	14	430	24.32	28	480	27.15	
2	7	345	19.51	14	400	22.62	28	475	26.86	
3	7	335	18.94	14	400	22.62	28	480	27.15	
Concrete NRMC30: M-20 conc. when Replaced with 30% red mud										
1	7	310	17.53	14	380	21.49	28	440	24.88	
2	7	315	17.81	14	380	21.49	28	450	25.45	
3	7	310	17.53	14	375	21.21	28	445	25.17	
Concrete NRMC40: M-20 conc. when Replaced with 40% red mud										
1	7	300	16.96	14	380	21.49	28	440	24.88	
2	7	285	16.12	14	360	20.36	28	450	25.45	
3	7	285	16.12	14	360	20.36	28	445	25.17	

4.1.3 Flexural Strength Test: Measure of the tensile strength of an unreinforced concrete beam or slab, the flexural strength to resist failure in bending is measured by loading (100 x 100mm) concrete beams with a span length at least three times the depth. The flexural strength is expressed as Modulus of Rupture (MR) in psi (MPa) and is determined by standard test methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading). The beam flexural strength was made as per the IS: 516-1959 specification, Concrete Grade M20 with different red mud percentages. For this study the concrete beams of size 100mm x 100mm x 500mm were prepared and optimum flexural strength was obtained when the replacement is adopted for the flexural tensile strength test. The results are tabulated as follows: 28days flexural strength for various proportion of blending is in Fig 6. The optimum compressive strength was obtained when the replacement was 20% for PCC beams.

Total 25 nos. of beams were prepared.. Beams were cured for 28 days; the beams were tested on the Universal Testing Machine (UTM). The optimum test result is shown in Fig 5. The beams were placed normal to the casting and Centre point system was adopted for the flexural tensile strength test. The results are given in Fig 6. 28days flexural strength for various proportion of blending is in Fig 6. The optimum compressive strength was obtained when the replacement was 20% for PCC beams.

SampleID	CUTM	TestDate	4/4/2016
Operator	Prabhudutta Panda Gui	Type	Flat
So(mm²)	[illegible] Mam	Size(mm)	500*100
Ls(mm)	500	Fbb(kN)	27.90
Rbb(MPa)	3	Fpb(kN)	/
Rpb(MPa)	/	Eb(GPa)	/
Type	Flat	U(J)	0.050

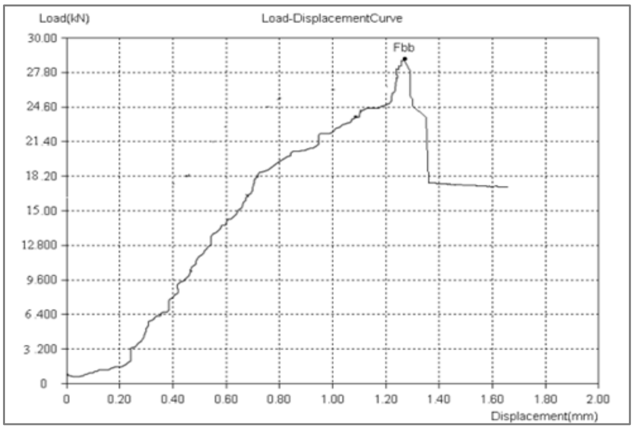

Fig 5: Flexural compressive strength of PCC beam (10% replacement of red mud) at 28days curing

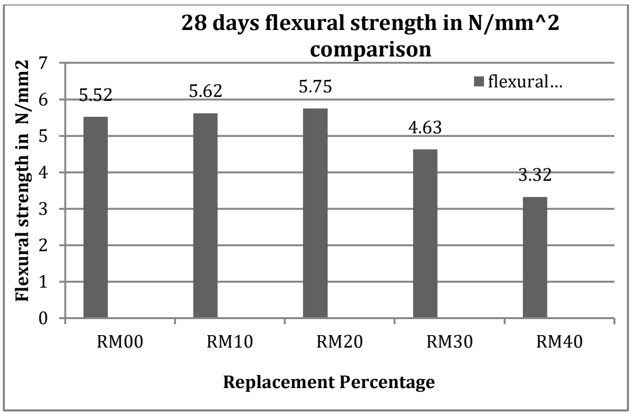

Fig 6: Flexural strength of concrete by different % of replacement of cement by RM

Conclusion

The partial replacement of cement by red mud resulted in producing Self Compacting Concrete, less permeable, anticorrosive, ecofriendly and cost effective concrete. At each replacement level of cement with red mud an increase in strength and self-compacting properties was observed up to 20% because of higher percentage of finer material. The concrete obtained is highly compact with smaller quantity of voids leading to higher strength, increased flowage and self-compacting.

In higher percentage of red mud, the concrete possess a very good early strength (7 days) but the rate of growth slows down as replacement in RM increases. Increase in flexural strength of red mud concrete is relatively more than the compressive strength. Although the optimum replacement for achieving desired compressive strength is 20%, it can be even more than 40% for the flexural strength.

This is the cutting edge in the direction of achieving strength of concrete by utilizing the environment alarming waste red mud to convert as ecofriendly self-compacting concrete.

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