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Optimized Structural Performance of Paver Blocks of Bajri Concrete: NRM Partly Substituting Cement

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Abstract: The discarded object dart during alumina extraction from bauxite ores in Bayers process is Red Mud. The solid/ liquid insoluble by-product dumped in exposed red mud ponds which are radioactive, highly alkaline and environmental contaminant to soil, surface water and ground water and possess disposal threats. Recent trend in increased urbanization and modernization has plenty of use of exterior flooring by concrete pavers block depending upon traffic load and volume. Present work is to know whether this red mud can be reused as a sustainable construction material to replace cement. The XRF spectroscopic advantage is taken to determine the composition identities between red mud and OPC cement. The study reveals the optimized percentage of red mud blend with cement after neutralization normalization. It cannot be disposed of easily. Attempt has been made to use bajri as the coarse aggregate instead of 12mm chips. The crusher by-product is having less use as construction materials. So the spare of cement by compensating with red mud and use of bajri shall be cost effective, environmentally sustainable and convenient disposal of the harmful waste. The mechanical characteristics like compressive, flexural, and split tensile strength etc., at 0%, 10%, 20%, 30% and 40% replacement of cement by red mud is found by using compressive testing machine (CTM) and universal testing machine (UTM) adhering to IS : 15658 (2006) and amended in 2011. The 20% OPC cement substitution by red mud is found to be adequate and will maintain sustainability.

Keywords: Mechanical Strength, Concrete, Red mud; Bajri, Pavers block.

I. INTRODUCTION

One of the major pollutant end products excreted from Bayer process in alumina production is red mud. The traditional method of throwing away of red mud (RM) is by ponding which has degradable environmental impacts. During rain, RM from the tank may spilled out or cause a breach and inundate nearby areas, contaminating the surface water by mixing, ground water by leaching processes. Disposal constraints of large quantities of ponded Red Mud (RM) poses space limitations as the RM is harmful due to its high pH value (11-13) and high alkalinity. Literature reveals, the RM from Damanjodi, Odisha (where the research sample is taken) contains six major oxides named CaO (1-2%), SiO_2(4-6%), Fe_2O_3(48-54%), Al_2O_3(17-20%), TiO_2(3-4%), and Na_2O (3-5%), Na_2O and small quantities of numerous minor elements and LOI (Loss on Ignition) is 10-14%, (Sutar et al, 2014[1]& Dodoo et al., 2017[2]). Presently researches are conducted by treating RM as cemetitous material after normalization. Cement is the most important material in structural constructions (mortar, CC or RCC) as the bonding materials used with stones, sand, bricks, blocks and paver blocks. Since cement manufacture involves high change in thermal energy associated with heavy atmospheric pollutants like CO_2 and other GHG gasses affecting the atmospheric sustainability Fig -1. The direct Bayer's trail RM exhibit radio activity Wyatt P. 2018[3].The waste red mud (RM) if conjoined to replace cement, then it will be cost effective, sustainable and energy conservation.

II. LITERATURE REVIEW

Sawant R. A. B. et al. 2012[4], Sarod D., et al, 2015[5], Gowsalya. R et al 2015[6] reported about red mud as partial replacement of Portland cement at different proportions and

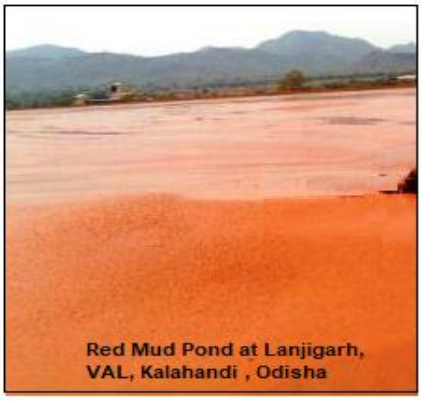

Fig. 1: Red mud Pond at Lanjigarh, Odisha

also with other ingredient like ultra-fines, fly ash etc. Bishetti P. N., et al., 2014[7], Pujar S. M. et al., 2014[8] reported that the Red Mud poses problems of disposal and environmental degradation. The high alkalinity (pH ranging from 10-13.5) red mud, which is caustic causes GW pollution during disposal, leading to health hazards.

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Cementous behaviour of the red mud proves to be befitting substitute for cement. Pujar et al, 2014[8]. Deepika et al., 2017 [9], Varghese M., 2017[10], have partly replaced cement by red mud in concrete for different fractions and estimated its impact on the mechanical strength and assessed its adaptability in concrete. Deelwal et al., 2014[11]have reported about the physical properties of RM like Sp. Gr., Particle size distribution, Atter Berg's limit, OMC and MDD, and recommended for its possible uses as geo-tech material.

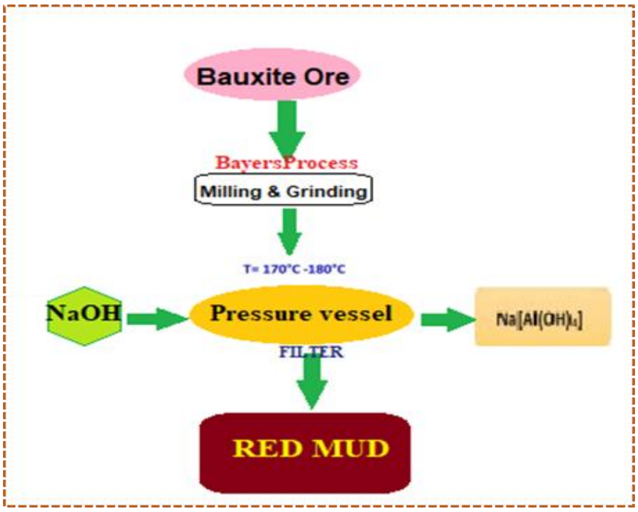
Red mud can have three fold benefits like waste disposal, raw material and added values when best used as building materials like colours, bricks, roads, benches, Krebs, sea defenses, litter bins, pipes, floor and tiles and many more (Tauber et al., 1971[12], Knight J. C. et al., 1986[13], Bhat et al., 2002[14], Lima et al., 2017[15]). Though not yet proved to be economical, researches are going on the metallurgical uses of red mud for extraction of iron, titania, as a ferriferous agglomerate and as a bentonite binding pellets in blast furnace and recovery of alkali, minor elements (Prasad P. M. et al, 1985[16], Kumar R., et al., 1995[17], and Dmitriev A., 2018[18]), The catalytic activity and other uses of red mud are as hydrogenation (organic compounds), catalysis of ceramics in manufacture of sanitary ware, pottery, special glazed tiles, ferrites and glasses, and de-chlorinating tetra-chloro-ethylene (Kara, et al, 1995[19], Snigdha et. al., 2008[20],Busto et. al., 2016[21]).

Velumaniet. al., 2017[22], mentioned that Paver blocks of CC with textile sludge as per IS 15658-2006 , have identical strength as that of M20 and M30 pavers block concrete by replacement of cement by red mud upto 35%. Blending by 10% of cement by red mud in the mortar of pavers block had high compressive strength and is cost effective Batham G., 2018[23]. Deshmukh et.al, 2014[24]reported that red mud convey improved resistance to chloride dissemination as it withstand RPC (rapid chloride permeability) Test. Kulkarni S 2018[25], have mentioned the industrial wastes like fly ash, RM, and GGBFS (ground granulated blast furnace slag) can bring green revolution concrete world. According to IS 15658: 2011 (modified), the non-traffic areas are without vehicular traffics and light-traffic areas have daily traffic < 150 numbers of commercial light vehicles above 30 kN laden weight.

Present Interest of investigation

Cement and its products are the leading usable construction materials which is energy intensive and producing 6% of the global CO2 emission (1.8GT/year assessed in 2005) as the 3rd largest source of Anthropogenic emission,of the globe next to water and earth(IEA GHG R&D programme, 200826], Sarod D., 2015[5]).Globally the production of CO2 in the years 2014, 2015 and 2016 were 1.51 ± 0.12 GtCO2,1.44 GtCO2and 1.46 ± 0.19 GtCO2respectively. The average CO2 level in atmosphere has raised from 250 ppm before industrial revolution to present as 407ppm. . It is high time to explore substitutes of cement to save our mother earth from climatic dogma of CC, RCC and cement mortar to wane cement production.

India being one of the largest producers of alumina, record of ~3 billion tones of red mud is available in waste ponds near alumina refining industries (after Bayer's Process) and adding @ 120 MT of red mud annually without any ore in red mud containing trace amount of heavy metals and radio nuclides, disposed in ponds, is contaminating the surface and ground water. It is found to be reuse Power et al., 2009[27]. The high alkalinity (pH: 11-13) are creating solemn threat to the water and environment and kills all vegetation's all around, Venkatesh S., 2019[28].A considerable work has been done to use this detrimental waste as to use this waste in manufacture of iron & steel, alumina, titania, and alkali, as building materials like brick, LWA (light weight aggregates), tiles manufacture for roofs and floors with cements, manufacture of pottery, bricks, sanitary ware, colored tiles , glasses, glazes, sanitary gadgets, and many others like



fertilizer, waste treatment and filler (Parekh et al, 1976[29], Prasad P.M. et al., 1985[16]). About 1 -2.5 MT of RM is evolved during production of 1MT of alumina depending upon the raw ore.

Fig. 2: How RM obtained from Bayers Process

Present study:

The designed uses of paving blocks are based upon the traffic and the loading pattern. It is decided by testing the compressive, tensile and flexural, shear forces on the concrete or mortar used to make the blocks/tiles. Before study, it is searched to identify the similar constituents between cement (OPC) and normalised Red mud (NRM) so that it can replace the former. Present study is a crack to the problem to find the % of partial substitute of red mud with cement used in construction of Paver Blocks. The present work includes collection of RM waste from NALCO, at Damanjodi, Odisha and normalising it for use. The blending of the NRM replacing as partial replacement of cement under various proportions and studying its physical, mechanical properties and laboratory properties as needed for paver tiles as per IS 15658 -2006 which are less studied **Fig -2.**

Neutralisation of Red Mud: The RM is highly alkaline and cannot be used directly. So it is neutralized by commercial HCl solution to reduce the pH value

Fig. 3: XRF spectroscopy for testing RM and cement

from 10-13 to <8.5 after grinding, powdered, and sieved by 1.18mm sieve to uniform grain size for use as cement replacement Gowsalya. R. et al., 2015[6].

XRF spectroscopy of NRM and OPC:

The distribution of particles size of the RM is almost identical to that of cement Varghese M. 2017[10]. The X-Ray Fluorescence spectrometer a non-destructive versatile tool is used for regular analyses of minerals, rocks, sediments and fluids of high atomic weight compounds or elements. It employs wavelength-dispersive spectroscopy, used to find the non-metals, metals, metalloids and rare earth metals directly either in % or ppm. The constituents of the RM sample and Portland cement (PC)and water samples were found by the XRF spectroscopy and the % of oxides of different metal, non-metals and radionuclide's in the XRF Spectrometer of CUTM are in **Table 2 and Fig-3**:

Table 2: Comparison of non-metals, metals and Radio nuclides in Cement and RM samples from Damanjodi, Odisha (XRF results)

Sl. No.	Oxides of non-metal, metals &radio nuclides		OPC Sample-1	NRM sample (Laxmi et al,2015)[30]	NRM Sample-II	Water sample	RM Average	Remarks
	Oxides of Heavy Metals present in OPC and NRM samples							
1	FeO			39.32				Ous form not in NRM
2	Na_2O			7.75				Not Present in NRM
3	Al_2O_3	%	2.958	22.84	15.463			Higher % in OPC than NRM
4	SiO_2	%	10.501	19.84	8.105	Si (%)	0.11	Lower % in OPC than NRM
5	CaO	%	79.212	1.24	2.352	Ca (ppm)	268.6	Less % in NRM than OPC
6	TiO_2	%	0.80%	7.87	4.748			Lower % in OPC than NRM
7	$Cr_2 O_3$	%	0.121		0.119			almost same %
8	Fe_2O_3	%	70.993		67.565	Fe (ppm)	25.8	almost same %
9	ZrO_2	%	0.308		0.254			almost same %
10	V_2O_5	%	0.202	0.68	0.194			almost same %
11	K_2O	%	0.156		0.517			Slightly less % in NRM
12	NiO	ppm	165		237.7			Slightly higher % in NRM
13	ZnO	ppm	202,3	0.45	208.4			almost same %
14	Cl_2	ppm	0.51		89	Cl_2(ppm)	319	Lower % in OPC than NRM
15	Ga_2O_3	ppm	182.1		149.6			Same ≈% in NRM
16	Rb_2O	ppm	657.9		137.4			Higher % in OPC than NRM
17	Nb_2O_5	ppm	194.7		158.7			Higher % in OPC than NRM
18	SnO_2	ppm	176.2		Nil	Sn (ppm)	52.6	Not Present in NRM
19	P_2O_5	%			0.431	P (ppm)	583.3	Not Present in OPC
20	MnO	ppm			939.3	S (ppm)	132.1	Not Present in OPC
21	SrO	ppm			29.8			Not Present in OPC
	REE/radio active of Heavy Metals present in OPC and NRM samples							
1	Bi_2O_3	ppm	514.5		106.7			Higher % in OPC than NRM
2	Yb_2O_3	ppm	270.3					Not present in NRM
3	Eu_2O_3	%	0.16		0.152			almost same %
4	HgO	ppm	68.5		10.7			Higher % in OPC than NRM
5	PbO	ppm	813.5		537.8			Higher % in OPC than NRM

The RM at Damanjodi has highest concentration (conc) of oxides of iron 67.565% among the Indian samples. The calcium content is less than the OPC sample whereas $Al_2 O_3$ conc. is less in OPC cement.

Paver blocks/tiles:

Paver blocks are pre-cast piece of cement concrete used in exterior landscaping, Railway surfaces, petrol pumps, patios, pool decks and driveways and airport or docks and many other decorative exterior and pavement applications. Square, rectangular, hexagonal, dumbbell, pentagonal, octagonal, are the shapes given to the blocks as per requirements and elegance. The factors that influence the size of coarse are WC ratio, grade/quality of cement, aggregate sizes, and methods of curing, air entrainment, size and shape of specimen, quality of concrete ingredients. Normal sizes of the paver blocks and their purpose of use at site are in **Table 3:**

Fig. 4: Split tensile stress of concrete Cylinder with NRM substitute CTM

Table 3: Paver blocks in different traffic categories, sub grade, and correction factors as per Pavers India (http://paversindia.com/iscode.html) (IS 15658-2006)

Sl.	Grade	Thick ness	Cor. Factor	Sub grade CBR %		Place of use
	Unit	mm	Plain/cham Fere din mm	Sub grade	Thick mm	
1	M 30	50	0.96/1.3	Blocks Sand bed WBM/WMM Coarse Sub base	60-80 20-40 250 200	Buildings & monuments, premises, slopes, levees foot paths, patios, gardens,
2	M 35	60	1.0/1.06	Blocks Sand bed WBM/WMM Coarse Sub base	60-80 20-40 250 200	Ramps, car parks, farm/ shop complexes, beach sites, tourist resorts, roads, low volume traffics,
3	M 40	80	1.12/ 1.18	Blocks Sand bed WBM/WMM Coarse Sub base	60-80 20-40 250 200	Arterial roads, city streets, utility cuts, medium low volume roads,
4	M 50	100	1.18/ 1.24	The placing of the paver blocks > 100mm thickness need special sub base preparation is needed as per underneath soil after up-holding OMC condition		Bus stand, Industrial &Mandi complexes, black cotton soils and service stations and factory floors
5	M 55	120	1.28/1.34			Mines area, ports, harbors and docks, airport and container terminals

III. MATERIALS

Recent trend in concrete industry emphasizes on mechanical properties like self-compacting concrete (SCC) instead of traditional concrete mix by introducing local available waste materials as constituents of CC and even with CRMs (cement replacement materials).The vibrator compaction era is gone. The possible ingredients used for SCC are Pumecrete, Majumdar and Mishra S. P. 2017[31], silica fume, RM and fly ash. Introduction of red mud with these cemetitous materials are SCC category which prevent segregation and permit the concrete to move easily under self-weight. The materials used for making concrete specimens are Cement, Fine aggregate, Plastic coated course aggregate, water. The code IS 15868: 2006 (amended in 2011) depicts about cement pavers blocks, slabs, bricks, squares, tiles used for civil construction.

Cement:

Grade of cement OPC43packed by Dec 2018 and used in Jan-2019, specific gravity of cement 3.14, fineness of cement 310 m²/Kg ,initial setting time 33min & final setting time 586min, Conforming IS Codes: IS: 8112 – 1989. According to manufacturer, the compressive strength of cement mortar after 28-days curing (IS 4031(6)-1988), is > 43 MPa.

Neutralized Red mud:

The red mud discussed for the study has specific gravity (sp. Gr) = 2.85, density (ρ) = 2187 kg/m3 and fineness modulus is >12000 cm^2/gm. The RM used is alkaline due to high pH and so neutralization is essential to deactivate by processes of neutralization like adding CO_2, adding seawater, bioleaching and the methods sintering to maintain pH value at 8.0 following the process adopted by Pujar et al 2014[8].

Corse Aggregates:

Course aggregates comprising a maximum size of (0-10) mm, locally called **Bazri**, having fineness modulus of 6.05, specific gravity of 2.67 as per the recommendations of IS: 15658 (2006) were used in saturated surface dry condition, water absorption is 1.5% is used for casting the pavers block and as per IS: 383-2016 (amended)

Fine Aggregate:

Fine aggregates used for preparation of M-30 grade specific gravity of 2.61, fineness modulus of 2.7 & water absorption 1.5% in saturated surface dry condition, from the test we can say that Fine Aggregate (Sand) is **Medium Sand.** It is conforming to **Zone III** grading as per IS: 383-2016, natural sand grain size**4.75-mm** maximum was used as fine aggregate.

Water:

College tap water was used in red mud substituted cement concrete with 38% water cement ratio ate a room temperature ranging 28^0C- 35^0. The water cement ratio was maintained.

Properties of SCC concrete:

After preparation of the concrete cubes for the paver blocks the different tests conducted are the compressive, flexural, tensile strengths, modulus of rupture, split tensile and the shear force of the blocks. All the tests were conducted either in Universal Testing Machine of Concrete Lab of CUTM, The UTM machine (Model BSUT- 100-ZE, Blue star design and manufactured in China), of maximum measuring range 0-1000KN of different cubes, cylinders and beams prepared in the Lab at different blending by RM. The concrete after placement due to its self-weight no compacting action like vibration is not needed and the concrete get compacted

Test for compressive strength; Specimen:

Compressive strength of CC is the structural capability to cart the loads on surface without crack formation, deformation or deflection. The tests for compressive strength of the blocks were done by compression testing machine (CTM) of capacity 100 KN **Fig -4**and so also by universal testing machine (UTM) of capacity 1000KN**(Fig -5)**as per the specification given in IS:516-1959 with 28days curing (as per IS code Page6, Table-3) is given as: Comp strength ≥ f_{ck}+0.825*accepted S.D. approximated upto 0.5N/m^2 and av. comp. strength (fc)= Load (P)/ compression area (A) where, P = applied maximum load (N)and cross section (CS)Area (A) in mm^2. The characteristic compressive strength should not be less than the design. According to standard practice the 7th day, 14th day and 28th day achievement of compressive strength should be 65%, 90% and 99% respectively. For M30 grade the CS should be after 7, 14 and 28 days should be 20, 27 and 30 N/mm^2 respectively (https://theconstructor.org/concrete/compressive-strength-concrete-cube-test/1561/

Test for Split tensile strength; Specimen:

The split tensile strength is considered as an indirect method of finding the optimum tensile strength of concrete cylinder that splits crosswise along the vertical diameter according to IS 5816 (1999). The test cylindrical specimens should have size of 100mm dia x 200mm length. The split tensile strength (f_{ct}) = 2P/π * dl, where P = the optimum applied load (N), l = the length of test sample (mm) and d = diameter test sample (mm) The split tensile strength is found by CTM but as per recommendation ASTM test methods C 39/C 39M with continuous application of load without shock at constant rate of range 0.7 to 1.4 MPa/minute (1.2 to 2.4 MPa/minute as per IS 5816 1999) until the specimen splits.

Test for flexural strength test; Specimen:

The Flexural strength or modulus of rupture (MOR) is the evaluation of tensile strength of un-reinforced beam or slab made of concrete to counterattack failure in bending. The Flexural strength (F_b) = $\frac{3PL}{2bd^2}$ where P = Maximum load (N), L = Length of the beam (mm) and d = Thickness of the beam (mm).(IS 15658:2006, page-16) used in the present procedure. The flexural strength test on CC is shown by means of either 3- point load test as per ASTM C78 or center point load test as per ASTM C293. The test is conducted the concrete shaft, beam or cantilever to access the property, quality of materials, the structural excellence, and to predict the durability, resistance of the entities by UTM. Flexural strength perceives the extent of stress/forces an un-reinforced slab; beam and other structures can survive at bending failures and depends of materials casted, proportion mix, size preparedness, handling and the curing. The MOR (f_r) is ~ 10% to 20% of the compressive strength provided by the concrete. The MOR (f_r) = 7.5 $\sqrt{f_c'}$ where f_r = is the MOR, and f_c' = compressive strength of concrete. The units of MOR is psi/ MPa which signifies the ability of unreinforced CC slab or beam to resist bending failure

Ingredients of concrete:

The characteristics of the materials used as ingredient of concrete are tested in the laboratory as per Kulkarni et al., 2018[25] and compared with their respective IS code and found that the materials are within permissible limits of the code provisions. The comparative statement is given in **Table-4**

Table 4: - Physiognomies of ingredients of concrete compared with IS code provision

Sl.	Ingredient	Tests conducted	Results of expt. conducted	IS: 12269-1987need
1	Cement(OPC-43 Grades) IS: 8112 – 1989	Specific Gravity: Cement- IS: 4031 (Part-11) –2005	Sp. gravity (3.14)	3.15
		Normal consistency test- IS: 4031 (Part-4) – 1999	Normal Consistency: 32.5%	30%-35%
		Initial and Final Setting Time: IS: 4031 (P-5) –1999	Initial -33mnts	>30
			Final:-586mnts	<600
		IS 4031-(1) (1996)	Fineness 310 m²/Kg	>225
2	Course Aggre-gate. (Bazri)	Coarse Aggt.:(Sieve Analysis)- IS: 2386(Part-1) –2016	Specific gravity 2.67	Is-383-2016(R) IS 15658 (2006)
3	Fine aggregate (the inert filler	IS: 2386 (Part-1) – 2016 Silt content - IS: 2386 (P-1) – 2016, Sp. Gr.: fine aggregate - IS: 2386 (P-3) -2016	River sand zone III Sp.gr.2.61	Is-383-2016 (R) 2016)
4	Normalized Red Mud (powered)	Physical properties of NRM	Wet density: 1.75, Sp. Gr.: 2.785, LL(%) 48.89, PL (%): 35.77 and PI: 13.12± 0.49	Tharani P et al., 2017[41],Feng& Wang 2018 [32]& lab results
		Red mud	Fineness 4,1%	

Methodology

The design mix was calculated according to traditional concrete mix design for M30 grade conforming to IS 10262: 2009. The M30 concrete mix design should have targeted strength (IS 456 – 2000) was as $f_{ck}' = f_{ck} + 1.65\,S$, where f_{ck}' = target average compressive strength after 28 days curing, f_{ck}= Characteristic compressive strength after 28 days curing and S = Standard deviation (S = 4N/mm²). The % of addition of red mud varied from 0%, 10%, 20%, 25%, 30% and 40% by weight of cement and the specimen was casted. The compression testing samples were cast in cubes of 70X 70 X 70 mm cast iron mould. The specimens were systematically placed in curing tanks after 24 hours for 7, 14 and 28 days respectively. For each given % of NRM nine cubes were casted with 0%, 10%, 20%, 30% and 40% of red mud was varied 10%-40% by weight of cement and the specimens like cubes, beams, cylinders and paver specimen were casted using M30 mix design. These paver samples casted square size of 150X150X80mm handmade in wood mould.

Fig. 5 : Flexural test by UTM (Model BSUT- 100-ZE, Blu star design and manufactured in China)

Casting of specimen:

The coarse aggregate (Bajri), the river sand and Cement, were taken as per mix design proportion 1:1.71:2.35 to prepare concrete of M 30 grade. Cement was substituted with red mud by 10, 20, 25, 30, and 40, % after the ingredients were homogeneously dry mixed. Later the water was added (@W/C= 0.362) and the mix was homogeneously variegated **Fig. 6(a) and Fig. 6(b).**

Fig. 6 (a): The trial specimen during casting

Fig. 6 (b): The trial specimen after 28days curing

This green concrete (after slump test and CF (compaction factor), was moulded as cubes, beams and cylinders and was compacted by hand compaction in 3-layers and later vibrated over the compaction table and kept for a day and later the remoulded cubes were wrapped by gunny bags placed in curing tank where allowed to tank curing for 7days, 14 days and 28 days. The water cured specimens were taken out for conducting the tests like. Mechanical strength properties (Compressive strength, Split tensile strength, Flexural strength test etc).

Universal Testing Machine (UTM):

Universal Testing Machine (UTM) of 100T capacity is used for testing tensile, compressive, torsion, bending and flexural tests. The metal slices, concrete cubes, cylinders and RCC beams can be tested for their mechanical properties by this machine. Present test is conducted in the Centurion University of Technology and Management Laboratory and the results/graphs are considered for technical uses. A result sample after 7days, 14days and 28days curing is given in Fig 7 (a), (b) and (C)

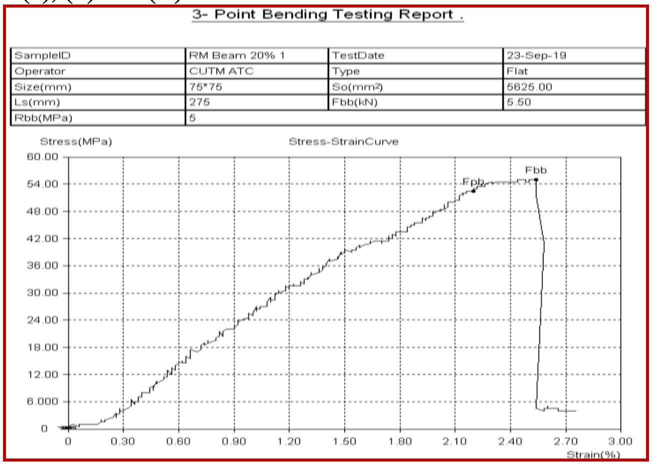


Fig 7 (a):Beam: 20% RM Substitute (7days curing)

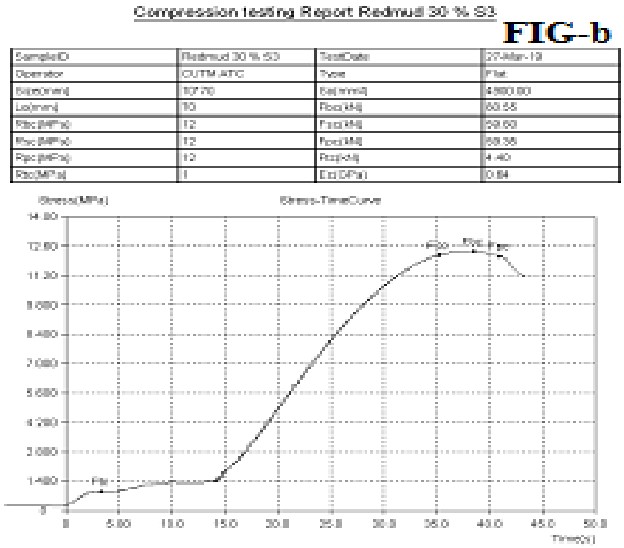


Fig.7(b):MortarCub:30% RM substitute(14 days curing)

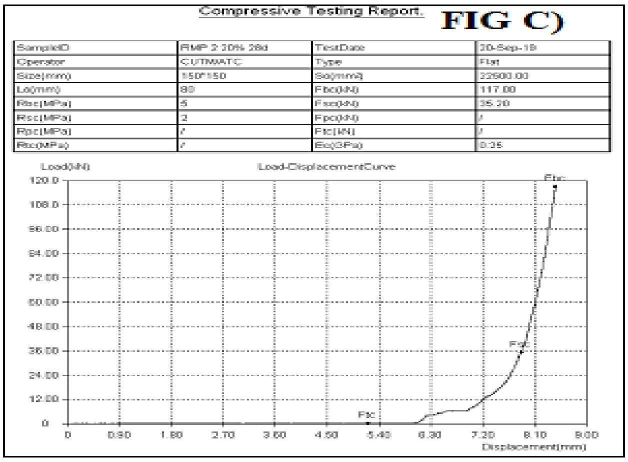


Fig7(c):Concc. Cube 20% RM substitute (28 days curing)

IV. RESULTS & DISCUSSIONS

The Chemical constituents of red mud and cement were checked by X-ray fluorescent spectrometer and it was found that there is low percentage of CaO present in the red mud in comparison to the same in the cement used. Deshmukh et al 2014[24] reported that the Cemetitous properties of red mud are less than cement. However the binding properties develops when the blended material react with water develop compressive strength due to formation of CSH (Calcium silicate hydrate).

Aspect ratio (L/T):

The concrete paver tiles prepared is of size 200mm x 200mm x 55mm, which has aspect ratio length/ thickness (L/T) = 200mm/55mm = 3.63 <4, hence the pavers block is within recommended dimensions prescribed by IS: 15658 -2006, page 5

Compressive strength (Only mortar cubes)

In order to compare the results obtained by adding 0%-40% varying amounts of red mud mixed with plain cement concrete and prepared a sample. The results of the compressive strength after 7 days ,14 days, and 28 days of curing are as presented in **Table:-5**

Compressive strength (with coarse aggregate as bajri)

Bajri is a crushed stone product of size < 10 mm obtained from crusher yards and has almost less utility in concrete making. The compressive strength of mortar added with the crusher Bajri has more compressive strength. Attempt has been made to replace 12mm chips by same amount of bajri to impart higher compressive strength to the pavers' tiles in low traffic areas. Concrete cubes were prepared and tested for the different mechanical strength of the specimen cubes and cylinder. The compressive strength is in Table 6

From the sets of determination of compressive strength of concrete cubes (bajri + sand +cement +NRM) it is observed that the compressive strengths of cubes are much higher than the cubes made up of cement mortar only. So can be concluded that bajri can be used for higher strength of low traffic paver tiles.

From the % of replacement of NRM by cement it can also be accepted that upto 20% replacement of normalised red mud in lieu of cement can resist better strength than that of mortar paver tiles to withstand loads of light traffic (Fig -9).

Table5: Cement mortar cubes of river sand, OPC cement with different % substitute by (NRM)

% Substitute	7days comp. strength by UTM				14 days comp. strength by UTM				28 days Comp. strength by UTM			
	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
	Sp- 1	Sp -2	Sp -3	Av.	Sp- 1	Sp -2	Sp -3	Av.	Sp- 1	Sp -2	Sp -3	Av.
0%	19.3	21.56	21.3	20.72	21.49	23.78	21.95	22.41	22.71	25.22	25.22	24.38
10%	16.86	21.77	16.43	18.35	21.49	22.15	18.37	20.67	23.2	26.22	20.94	23.45
20%	20.15	18.55	17.73	18.81	19.95	19.96	17.78	19.23	23.01	20.38	19.3	20.89
30%	15.71	6.53	12.16	11.47	16.89	8.48	10.39	11.92	14.96	14.76	8.9	12.87
40%	11.42	12.26	10.24	11.31	11.82	13.26	12.16	12.41	13.38	7.06	10.22	10.22
Sp: Specimen, UTM: Universal Testing Machine,												

From the trial results it is observed that up to substitution of the NRM by 20% the mortar can with stand load up to $21 N/mm^2$. The compressive strength is reduced comparatively when the replacement > 30%

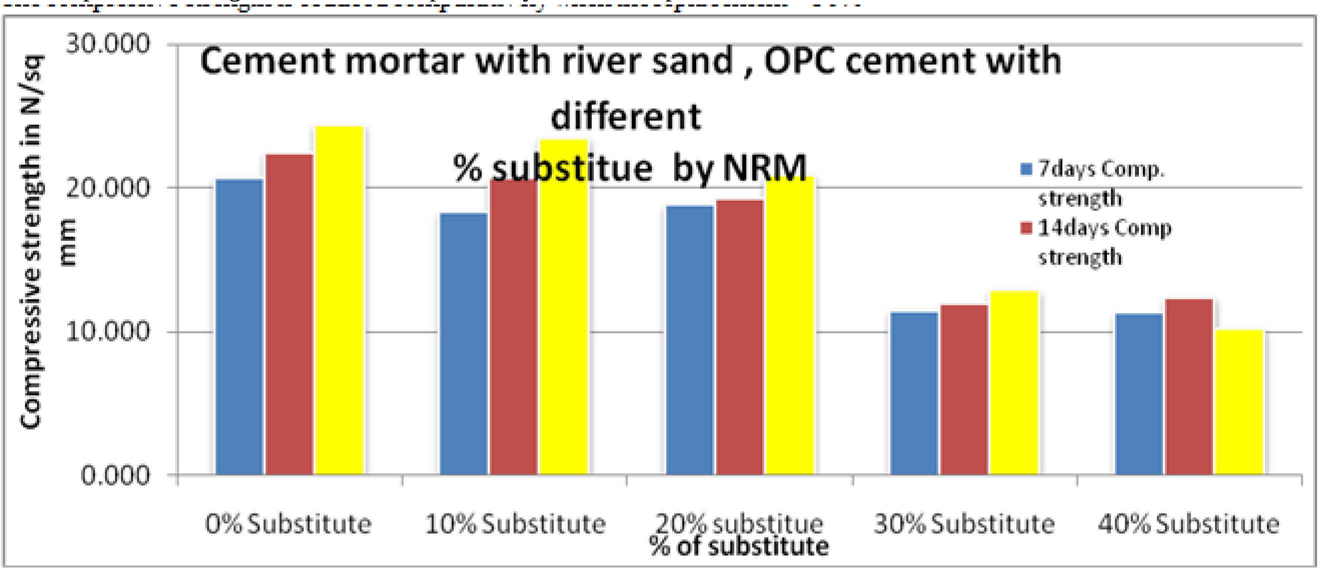


Fig 8: Compressive strength of cement mortar with different % of NRM replacement of cement

Table 6: Cement cube with bajri (<10mm), river sand and, OPC cement with different % substitute by Normalised Red Mud (NRM)

NRM substitute	7days comp. strength by UTM			Average	14 days comp. strength by UTM			Average	28 days Comp. strength by UTM			Average
	N/ mm^2	N/ mm^2	N/ mm^2	N/ mm^2	N/ mm^2	N/ mm^2	N/ mm^2	N/ mm^2	N/ mm^2	N/ mm^2	N/ mm^2	N/ mm^2
Test	Sp- 1	Sp -2	Sp -3	Av.	Sp- 1	Sp -2	Sp -3	Av.	Sp- 1	Sp -2	Sp -3	Av.
0%	21.08	20.02	20.64	20.58	23.3	23.57	23.33	23.40	26.77	27.09	26.67	26.84
10%	17.11	17.74	18.63	17.83	23.14	22.26	18.49	21.30	29.43	29.07	26.88	28.46
20%	15.3	15.75	15.14	15.40	20.03	21.15	21.3	20.83	27.75	28.8	28.85	28.47
30%	16.43	15.19	14.11	15.24	18.22	17.63	17.22	17.69	18.44	19.61	18.09	18.71
40%	12.73	11.48	13.27	12.49	14.45	14.64	15.37	14.82	16.82	15.64	15.77	16.08
Sp: Specimen, UTM: Universal Testing Machine,												

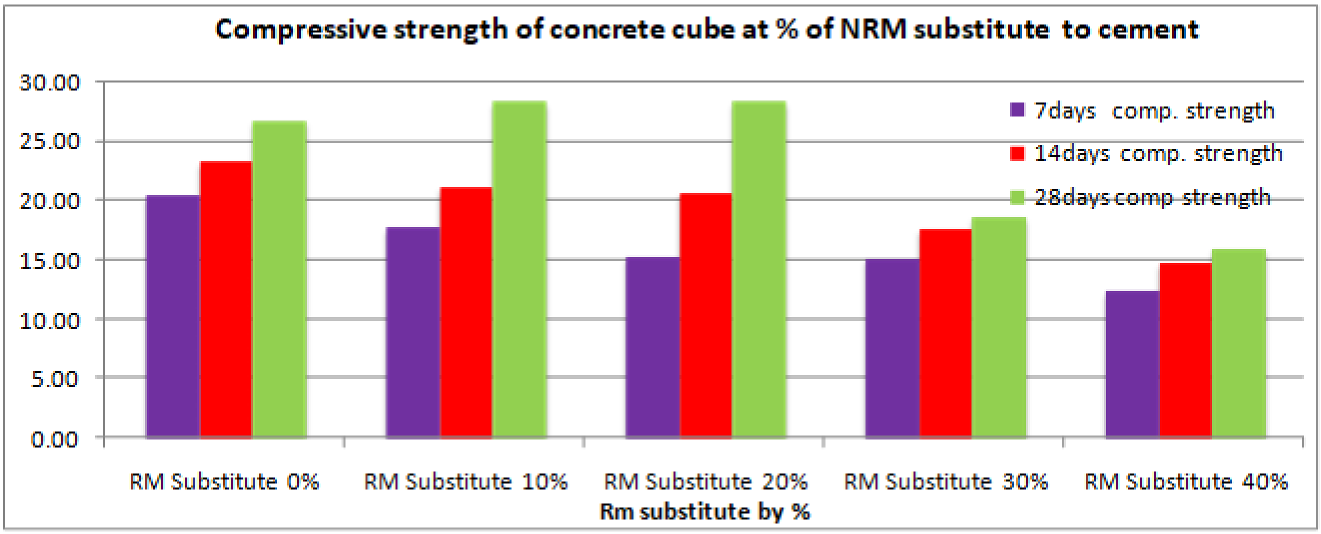


Fig 9 : Compressive strength of Bajri concrete cubes with different % of NRM replacing cement

Results of the flexural strength determination:

The beams of size 275mm x 75mm x 75mm is casted taking bajri as course aggregate, river sand, OPC cement and NRM at different percentages. The breaking load is found as per the IS- 15658:2006 (Annex –G, page -16) and the results are given in Table- 7 and fig- 10. The suggested breaking load for pedestrian/ residential paths allowed is 2KN and residential drive ways is 3KN. Different beams are casted with various % of NRM substation of cement and the breaking load (flexural strength) is obtained using UTM after 7days, 14 and 28days curing.

From the output results of UTM, it is observed that after 28days curing the cubes attain the flexural load satisfactorily. The breaking load is highest (4.30KN) when the paver's bajri concrete is admixed with 20% NRM replacing OPC. Hence it can be used for residential, public pedestrian pathways, light vehicles moving in residential approaches, petrol pumps etc comfortably.

Table 7: Breaking load for the concrete specimen for pavers block with % of NRM replacement

NRM substitute	7days comp. strength				14 days comp. strength				28 days comp. strength			
	KN	KN	KN	KN	KN	KN	KN	KN	KN	KN	KN	KN
Test	Sp- 1	Sp -2	Sp -3	Av.	Sp- 1	Sp -2	Sp -3	Av.	Sp- 1	Sp -2	Sp -3	Av.
0%	1.17	0.71	1.15	1.010	2.15	1.8	2.15	2.04	3.82	2.89	3.1	3.27
10%	1.04	1.13	2.12	1.430	1.83	2.1	2.89	2.27	2.73	3.79	4.1	3.54
20%	1.27	1.23	2.39	1.630	2.73	2.6	3.89	3.07	4.29	3.72	4.89	4.30
30%	1.16	0.07	0.11	0.447	2.1	0.9	1.67	1.55	2.56	1.7	3.18	2.48
40%	0.61	0.67	0.48	0.587	0.85	0.7	1.1	0.88	1.77	0.79	1.1	1.22
Sp: Specimen, UTM: Universal Testing Machine,												

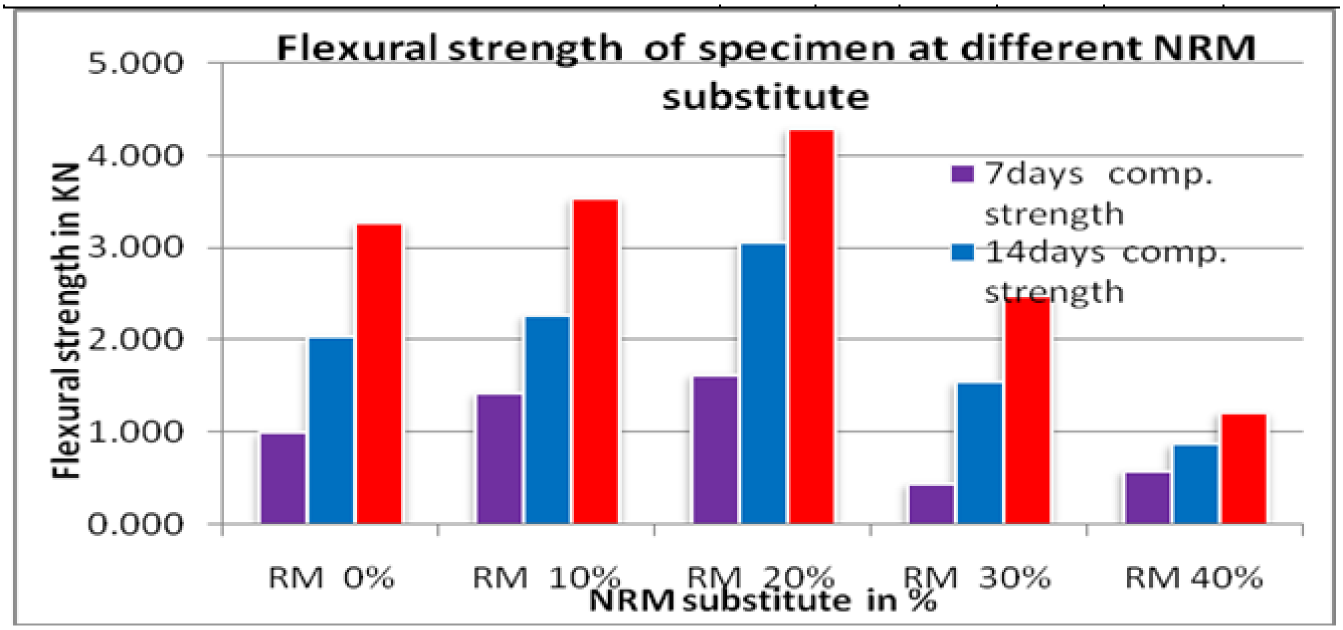


Fig 10: Flexural strength of concrete at various % of replacement by NRM

Table 8: Split tensile strength of the paver's concrete specimen tested by CTM

NRM subs-titute	7days comp. strength				14 days comp. strength				28 days Comp. strength			
	KN	KN	KN	KN	KN	KN	KN	KN	KN	KN	KN	KN
Test	Sp- 1	Sp -2	Sp -3	Av.	Sp- 1	Sp -2	Sp -3	Av.	Sp- 1	Sp -2	Sp -3	Av.
0%	4.81	5.02	5.13	4.99	5.12	5.8	5.98	5.63	6.32	6.67	6.88	6.62
10%	4.38	4.56	4.79	4.58	5.15	4.8	5.42	5.13	5.87	5.73	6.14	5.91
20%	3.89	3.51	4.03	3.81	4.62	4.3	4.12	4.34	5.37	5.01	4.25	4.88
30%	3.53	3.47	2.92	3.31	4.75	3.9	2.92	3.84	5.2	4.27	3.02	4.16
40%	3.11	3.42	3.14	3.22	3.18	3.5	3.15	3.27	3.29	3.97	3.2	3.49
Sp: Specimen, CTM: compressive Testing Machine,												

Split Tensile Test:

As per code IS 15658 -2011 the splitting strength (tensile) of the trial specimen should be 0.1 MPa; and failure load (F) to be approaching 10N/mm **Fig 11 and Table -8.**

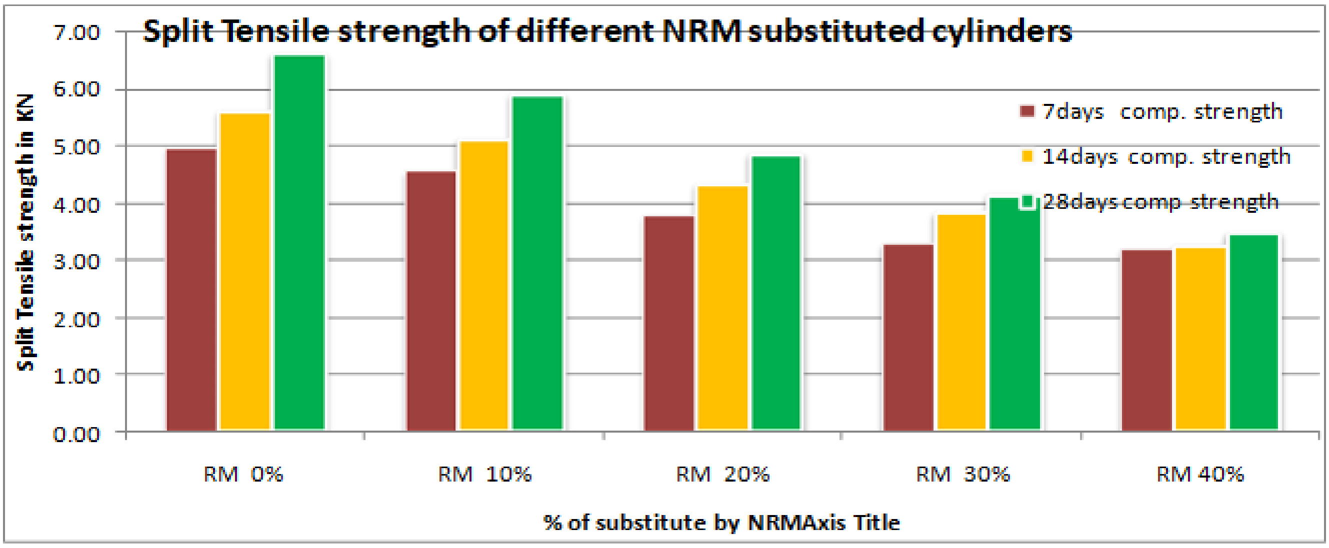


Fig 11: Split tensile strength of concrete at various % of replacement by NRM

It is found that the substitution of NRM give optimized result when cement is replaced by 20% of NRM. So paver blocks were casted of size 200mm x 200 mm x 55mm their compressive strength were tested by CTM. The comparative result is shown in Table 9

Table 9: The evaluation of the comp. strength of Pavers blocks after 7, 14, 24 days curing:

NRM substitute (%)	Comp. strength 7days curing	Comp. strength 14days curing	Comp. strength 28days curing	Average 28days curing
%	kN/mm^2	kN/mm^2	kN/mm^2	kN/mm^2
0% (T-1)	22.89	22.89	26.63	26.36
0% (T-2)	19.56	21.94	25.78	
0% (T-3)	20.67	22.61	26.67	
20% (T-1)	17.08	22.11	26.59	26.53
20% (T-2)	17.79	21.20	26.02	
20% (T-3)	17.79	21.50	25.97	

From the comparison of cement mortar cube with 0% substitute and 20% replacement of cement by normalized red mud indicates that the final strength is achieved by the 20% NRM substituted blocks. The compressive strength is equalized to the 20% NRM substituted paver blocks after 28days though it is comparatively less after 7days and 21days curing.

Discussion:

Table10: Studies made on partially replacing of neutralized Red Mud (NRM) by Cement

Sl.	concrete Gr./ mortar	Tests conducted	% replaced RM in concrete mix	Optimum replacement	Authors reference
1	M30	compressive strength, split tensile strength	5%,10%,15%,20%,25% ,30%,40%. RM	25% (equivalent to controld concrete)	Rathod et al., 2013[33]Venkatesh et al., 2019[28]
2	M-30 (NRM)	compressive strength, split tensile strength	0%, 5%,10%, 15%, 20%, 25%	20% NRM but less workability	Gowsalya. R et al 2015[6],
3	M-30 (NRM)	comp. strength split tensile strength, Flexure Strength Test	0%, 5%, 10%, 15%, 20% of RM & 5% of hydrated lime	15% NRM	Ashok P et. Al., 2014[34]
4	RM (MALCO)	Comp. strength split tensile strength, Tensile Strength Test	0%,10%, 15%, 20% RM + lingo sulphonates	15%NRM (WL dark/ brown complots mixture	Depika K et al., 2017[9]
5	RM (M-40, M-50)	comp. strength split tensile strength, Flexure Strength Test	0%,10%, 15%, 20% RM + (0%, 5%,	10% RM replacement	Sai S. P., 2017[37]
6	RM,M-20, M-25 and M-30	Comp. Strength, Splitting Tensile Strength, Flexural Strength	0%, 16%, 17%, 18%........24% RM	18% replacement in all three grades	Pateliya S., 2017[9]
7	M-30	Comp. Strength, Splitting Tensile Strength, Flexural Strength	0%, 5%, 10%, 15%, 20%, 25% RM	15% replacement	Metilda D. L., 2015[35]
8	M-20(NALCO)	Comp. Strength, Flexural Strength	0%, 5%, 10%, 15%, 20%, 30% , 40% RM	20% replacement	Nayak S & Mishra S. P et. Al, 2017[36]
9	M-30	Comp., split tensile, flexural strength	0%, 5%, 10%, 15%, 20%, 25%, RM	20%	Peter J., 2018[38]
10	M 40	Compression and split tensile test	0%, 10%, 20%, 30%, 40%	30% (replacing Machine sand)	Thangamani K, 2018[38]
11	M-25	compressive strength split tensile strength	0%, 5%, 10%, 15%, 20%, (RM)	15% (but mech. Prop.decline	Juned M. et. al., 2019[40]
12	M-30 with bajri as coarse aggt.	Comp. strength, split tensile, flexural strength and aspect ratio	0%, 10%, 20%, 30%, 40%	20% by NRM	Present work

Mechanical strengths of NRM substituted or other waste materials used for manufacturing paver blocks have been found by different researchers and the list of works is enlisted in Table 10.The present work is random testing of mechanical strength of pavers' concrete blocks with a replacement of 10, 20, 30% & 40% of NRM. To arrive at an optimized % of blending it is essential to have further studies 1% rise of RM substitute between 20%, 21%, 22%

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V. CONCLUSION

The constituents of NRM are analogous to cement as observed from the results X –Ray fluorescent spectroscopy, hence cement can be substituted by NRM and shall make it cost effective and achieve sustainability to the environment. But the quantity of Al_2O_3 and CaO is observed more in OPC than the NRM obtained from Damanjodi. The NRM has less cemetitous properties as it contains less % of CaO. But when the NRM react with cement and water, the cemetitous properties is built up due to increased process of hydration and gain strength in concrete. The compressive strength of light/no traffic floor is found to have high values of more than 25 MPa , when RM replacement is 20% and providing binder so that the new pavers can have sound strength for pedestrians and light vehicles. Since RM is a contaminant waste and bajri (local stone product) having less use in CC and RCC constructions, the cement can be replaced by 20% NRM and can be cost effectively used for manufacture of concrete paver blocks for pedestrians of no traffic or less traffic floors and pathways.

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