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Development of Red Mud Paver Blocks Prepared From Nuclear Power Plant

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Abstract : Red mud is a waste material generated by the Bayer Process widely used to produce alumina from bauxite throughout the world. The aim of the project is to say the possibility of replacing the Portland cement by red mud. Because it negatively affects the environment. To solve this problem, Portland cement was replaced up to 20% red mud by weight of cement. And evaluating its compressive strength of red mud paver tiles. This project examines the effects of red mud on the properties of hardened paver tile. The test results show that how its compressive strength becomes equivalent to normal paver tile without red mud content, it is concluded that optimum percentage of the replacement of cement by weight is found to be. By this percentage replacement we can have 15%strength is equal to the strength of normal paver tile.
Key words : Bayer process, Compressive strength, Water absorption, Red mud.

I Introduction

Aluminum is a light weight, high strength and recyclable structural metal. It plays an important role in social progress and has a pivotal contribution in transportation, food and beverage packaging, infrastructure, building and construction, electronics and electrification, aerospace and defense. It is the third abundant element in the earth‘s crust and is not found in the free state but in combined form with other compounds. The commercially mined aluminum ore is bauxite, as it has the highest content of alumina with minerals like silica, iron oxide, and other impurities in minor or trace amount. The primary aluminum production process consists of three stages: Mining of bauxite, followed by refining of bauxite to alumina by the Bayer process and finally smelting of alumina to aluminum. In the Bayer process, the insoluble product generated after bauxite digestion with sodium hydroxide at elevated temperature and pressure to produce alumina is known as red mud or bauxite residue. The waste product derives its color and name from its iron oxide content. As the bauxite has been subjected to sodium hydroxide treatment, the red mud is highly caustic with a pH in the range of 10.5-12.5. Bauxite posing a very serious and

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alarming environmental problem. About 1 ton of alumina is produced from 3tons of bauxite and about 1ton Aluminum is produced from 2tons of alumina. Depending on the raw material processed, 1-2.5tons of red mud is generated per ton of alumina produced. Red mud is a waste material generated by the Bayer Process widely used to produce alumina from bauxite throughout the world. The aim of the present project work was to investigate the possibility of the use of red mud. Because of storing issues, the waste negatively affects the environment. To solve this problem, Portland cement was replaced by 10%, 15% and 20 % RM by wt of cement by balancing its chemical composition [1]. Overall, the comprehensive utilization of red mud generated in the process of industrial production of alumina is still a worldwide problem. At current levels technology and practice, the capacity of consumption and secondary utilization is seriously insufficient. The secure stockpiling of red mud has to see a reduction of stockpiling costs and improvement of efficiency. So stockpiling is not a fundamental way to resolve the problems of red mud. Only through economical and viable comprehensive utilization can people resolve them effectively in the long term. As to the recovery of components from red mud, there are a lot of problems making for significant increases in recycling process costs and energy consumption, becoming serious impediments to industrial development. Therefore, we need to promote the industrialization of precious metal recovery processes, optimize complex processes and develop new ones. Although the added value is relatively low, the resources utilization of red mud is the most widely used way and the most effective way to resolve the red mud stockpiling problem. Red mud can also be used to produce other construction materials. A mature, relevant technology would greatly promote the consumption of red mud. Applying red mud as an environmental remediation material is a new hot point in terms of utilization. Due to the simple process, low cost, it is worth promoting its application in the field of environmental protection. However, there is a risk of introducing new contamination, and a difficulty of recycling it after the application. Therefore, more in-depth studies are needed and a comprehensive assessment of chemical and biological effects [2]. Different avenues of red mud utilization are more or less known but none of them have so far proved to be economically viable or commercially feasible. Experiments have been conducted under laboratory condition to assess the strength characteristics of the aluminum red mud. The project work focuses on the suitability of red mud obtained for construction. Five test groups were constituted with the replacement percentages 0%, 5%, 10%, 15%, 20% of red mud and 5% of hydrated lime with cement in each series. To achieve Pozzolanic property of red mud, hydrated lime was added. This paper points out another promising direction for the proper utilization of red mud. Red mud can be effectively used as replacement material for cement and replacement enables the large utilization of waste product. Red mud did not effect of the cement properties, rather improved the cement quality by way reducing the setting time & improved compressive strength. Used for road construction as an embankment landfill is an attractive option with a high potential for large volume reuse. Replacement of 20% OPC by calcined red mud is thus possible. Calcinations of redmud at 7000C leads to a pozzolanic material essentially reactive at early ages. In building material industry as a raw material in manufacture of building and pavement blocks and road surfacing. Dewatered (ferro alumina) as a raw material in cement manufacture. In ceramic industry as an additive to make special ceramics [3]. Rapid industrialization leads to the maximum discharge of waste products which in turn causing the environmental hazards. These wastes can be a substitute for conventional material, when utilized in a best way. Red Mud is a waste generated by the aluminium industry (an average of 3 million tons per year) in a Bayer's process and its disposal is a major problem for these industries as this is highly caustic and causes ground water contamination, leading to health hazards. By taking cementatious behavior of the red mud into account, an experiment was carried out to partially replace the cement by red mud in concrete for different percentages and also its effects on the strength and other properties of the concrete. For each percentage replacement up to 20% the compressive strength values of the red mud concrete coincides with that of conventional concrete. But beyond 20% there is reduction in the strength of conventional concrete. From the experimental work it was found that increase in red mud content (greater than 20%) decreases the compressive strength as well as tensile strength of concrete. Optimum percentage of the replacement of cement by weight is found to be 20%. By this replacement results got are nearly equal to the results of conventional concrete. We use mixture of red mud and cement for non-structural work. There is a future scope for the use of red mud concrete in structural point of view. Concrete prepared by using red mud is suitable in ornamental works and gives aesthetically pleasant appearance. Used for road construction as an embankment landfill is an attractive option with a high potential for large volume reuse. The above results show that the optimum utilization of Red mud in concrete is 20% as a partial replacement of cement. This study concludes that red mud can be innovative supplementary cementitious materials but judicious decision must be taken by expert engineers [4]. In India and worldwide, variety of waste is generated in different forms, shape and texture. These industrial wastes mostly possess threat to the environment and the society living nearby. Various researches has been done on this waste material to either degrade or to utilize it in some or the other way. One such hazardous waste generated by industry is red mud.

The result shows that the strength increases slightly for 4% Lime addition and there after strength decreases with increase in lime content. This can be explained by that the lime added may react with free reactive silica present in red mud and when the Silica gets exhausted, the extra lime added might have reacted with Alumina forming Calcium Aluminates (CaO.Al2O3) leading to more initial heat of hydration and thereby generating pores leading to decreased strength. The result gives that addition of silica enhances strength of mortar and for 10% red mud with 20% silica of red mud addition gives the same strength as that of only cement. Hence, it can concluded that 10% red mud can be utilized with addition of 20% Silica of Red mud without compromising the strength of Mortar and Concrete respectively. From the above two results it shows that compressive strength of the optimum red mud concrete increases by 4.6% and the tensile strength decreases by 8%. Overall it can be concluded that the results obtained for optimum red mud content shows that concrete can be used for R.C.C work after finding of other essential parameters of optimized concrete [5] It is envisaged that the utilization of red-mud bricks in urban housing and construction activities will lead to substantial reduction in the total weight of walls and partitions in multi-storied buildings, thus reducing the foundation costs and total building costs. The presence of all through tiny air filled cells provides excellent acoustic performance and they are highly suitable for partition walls, floor screens and panel material. The low thermal conductivity of red-mud bricks provides low thermal exchange between inner and outer atmospheric conditions. Hence, it helps in reducing the energy consumption. The lightness and irregular porous structure in the material increases resistance against earthquake and causing less chance of loss/damage to human lives. The utilization of red mud is of great significance from the point of view of resource conservation and sustainability of the aluminium industry. However, the reuse of red mud for any application should have four criteria of volume, performance, cost and risk [6]. The decrease in initial setting time at 5% and 10% may be due to the light weight of neutralized red mud and finer particles of mud which fills the voids of the cement by which there may be increase in the density of the mix. Beyond 10% of neutralized red mud cement initial setting time increases may be due to reduction in the density of mix. The effect of replacement of cement by neutralized red mud has been studied on design mix concrete of grade M50. The water-cement ratio 0.36 is kept constant for different percentage replacement of cement by neutralized red mud [7].

II. Aim of the Study

Development of paver blocks by partially replacement of red mud with cement .The study is mainly done to find the compression strength, corrosion resistance, abrasion loss, acid penetration, water absorption and flexural strength.

III .Experimental Investigation

3.1 Materials

Materials Used

3.1.1 Cement:

Ordinary Portland cement (OPC) 53 grade conforming to IS 8112 – 1989, and specific gravity of cement is found to be 3.15.The properties of cement given in Table 1.

Table 1 Properties of OPC Cement

Physical properties of cement	
Initial setting time(minutes)	53 mins
Final setting time(minutes)	257 mins
Standard consistency	31.0%
Specific gravity	3.15

Fineness of cement	10%
Chemical properties of cement	
SiO_2	20 - 21
Al_2O_3	5.3 - 5.6
Fe_2O_3	4.4 - 4.8
CaO	62 - 63
MgO	0.5 - 0.7
SO_3	2.4 - 2.8
Loss on ignition (LOI)	1.5 - 2.5

Table 2 Physical Properties of Fine Aggregates

Physical Properties	**Test Result**
Size	4.75mm
Specific Gravity	2.76
Water Absorption	0.80%

3.1.2 Fine aggregates:

Natural sand obtained from local river source is used as fine aggregate. Before mixing, the sand was air dried and free from foreign material. The grading of fine aggregate Conforms to Zone III of IS 383–1970 [6]. The physical properties are tabulated in

3.1.3 Course aggregates:

Crushed granite of size 10mm was used as coarse aggregate. The physical properties of coarse aggregate are tabulated in **Table 3. Which conforms to IS:2386-1,3&4[7].**

Table 3 Physical Properties of Course Aggregates

Physical Properties	**Test Result**
Size	10mm
Specific Gravity	2.87
Water Absorption	0.12%
Aggregate impact value	11.01%

3.1.4 Red mud

Red Mud is produced during the Bayer process for alumina production. It is the insoluble product after bauxite digestion with sodium hydroxide at elevated temperature and pressure. It is a mixture of compounds originally present in the parent mineral, bauxite, and of compounds formed or introduced during the Bayer cycle. It is disposed as a slurry having a solid concentration in the range of 10-30%, pH in the range of 13 and high ionic strength. The red mud as shown in Figure **1.**

Figure 1. Red Mud after Water Evaporation

The red mud is one of the major solid wastes coming from Bayer process of alumina production. For the present work it was collected from MALCO, at Mettur, Tamil Nadu. The physical and chemical properties are tabulated in Table 4 and Table 5

Table 4 Physical Properties of Red mud

Physical Properties	**Test Result**
Fineness	3000 cm^2 / kg
Specific Gravity	2.51
PH Value	10.5 to 12.5
Colour	Red

Table 5 Chemical Properties of Red mud

Ingredients	**Red Mud In%**
Fe2O3	38.3
Al2O3	21.6
SiO2	11.4
CaO	1.47
Na2O	6.87

IV. Experimental Procedure

Paver block with a Characteristic strength of 40MPa was designed. Four mixes were prepared by replacing 10%, 15%, 20% and 25% weight of cement by Red Mud and one Normal paver block was prepared as control mix without any replacement for cement. In order to study the strength comparison of Normal paver block–Red Mud Paver block and control mix. The mix proportions of Normal Paver–Red Mud Pavers are shown in Table 6. Totally 60 specimens were prepared and Paver of size 120mm x 240mm x 80mm were casted and cured in water. After 28 days of curing 15 paver block specimens were taken out and tested for compressive strength and also water absorption test, abrasion, flexural strength and corrosion test 45 paver block specimens were taken out and tested. The casting of paver block shown in Figure 2.

Figure 2. Casting of Paver Block.

Table 6. Mix Proportion of Normal and Red Mud Paver block

Materials	Normal Paver block	10%	15%	20%	25%
RM (kg)	0	0.63	0.945	1.26	1.57
Cement (kg)	6.3	5.67	5.35	5.04	4.75
FA (kg)	11.205	11.205	11.205	11.205	11.205
CA (kg)	7.9	7.9	7.9	7.9	7.9
H2O (lit)	2.55	2.55	2.55	2.55	2.55

Table .7 Compressive Strength in N/ mm^2

S. No	% of Red Mud	Compressive Strength in N/ mm^2
1	Control specimen	25
2	10%	37
3	15%	37.5
4	20 %	36.4
5	25 %	30

V. Result and Discussion

5.1. Compressive strength of concrete.

The test is carried out conforming to IS 516 -1959 to obtain compressive strength of concrete at the 28 days. The cubes are tested using 1400 tonne capacity HELICO compressive testing machine (CTM).The experimental set up arranged HELICO compressive testing machine as shown in Figure 3. Paver block strength shall be specified in terms of 28 days compressive strength. In case the compressive strength of paver blocks is determined for ages other than 28 days, the actual age at testing shall be reported. The average 28 days compressive strength of paver blocks shall meet the specified requirement. Individual paver block strength shall not be less than 85 percent of the specified strength. In case blocks of age less than 28 days are permitted to be supplied, correlation between 28 days strength and the strength at specified age for identified batch/mix of blocks shall be established.

Figure 3. Experimental Set up Arranged HELICO Compressive Testing Machine

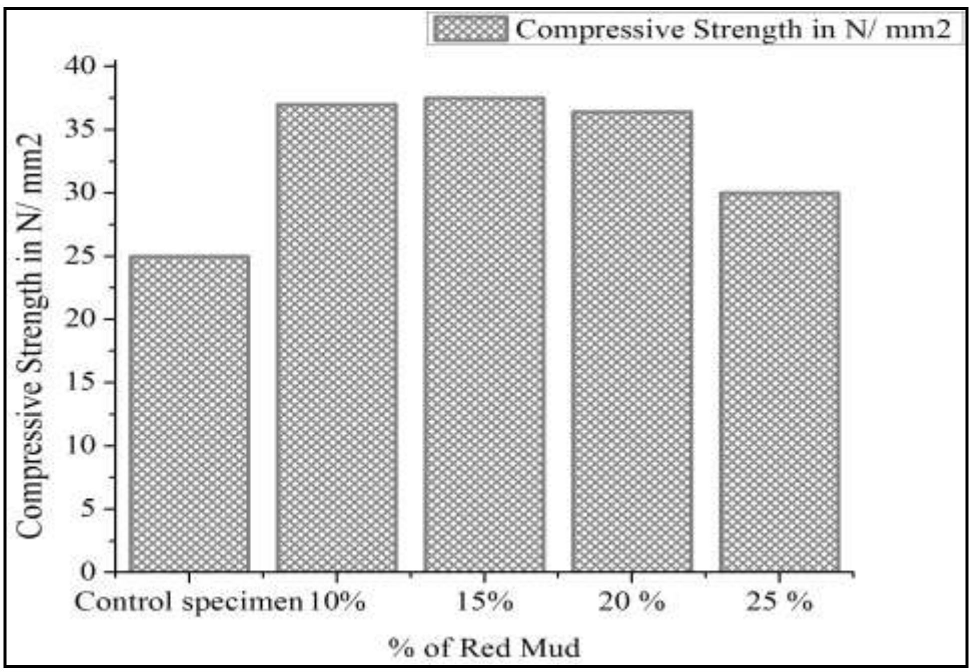

Figure 4. 28 Compressive strength of paver block in N/mm^2

The compressive strength result of Normal – Red mud paver mixes with 10%, 15%, 20% and 25% Red mud replacement with Cement were compared with control mix. It is observed that the compressive strength is increased by 94.5%, 91.9%,89.4% and 74% up on addition of 10%,15%,20% and 25% of Red Mud on 28 days curing respectively. Results of this test are show in Table .7 and Figure.4

5.2. Flexural Strength of paver block

The test is carried out conforming to IS 516 -1959 to obtain flexural strength of paver block at the 28 days are tested using loading frame 750 kN. The experimental set up arranged as shown in Figure 5.

Figure 5. Experimental Set Up Arranged flexural strength Testing Machine

The test procedure shall be the same as in 8 of IS 516, with the following modifications. The load shall be applied from the top of the specimen in the form of a simple beam loading through a roller placed midway between the supporting rollers, as shown in Figure 5. Loading of irregular-shaped specimens shall be as shown in Fig. 5. The load shall be applied without shock and increased continuously at a uniform rate of 6 kN/ min. The load shall be increased until the specimen fails, and the maximum load applied shall be recorded to the nearest N.

The flexural strength of the specimen shall be calculated as follows:

$F_b = 3PL / 2bd^2$

where

f_b = flexural strength, in N/mm^2

P = maximum load, in N

L = distance between central lines of supporting rollers, in mm

b = average width of block, measured from both Faces of the specimen, in mm; and

d = average thickness, measured from both ends of the fracture line, -in mm

The 28 days flexural strength of partially replacement of 10% and 15% of red mud with cement paver blocks are found to be 7.10% and 13.24 % more than the conventional paver block and partially replacement of 25% of red mud with cement paver blocks are found to be 13.99% flexural strength value decreased compare with conventional paver block. Partially replacement of 20 % of red mud with cement paver blocks are found to be more or less same compare with conventional paver block. Results of this test are show in Table .8 and Figure.6

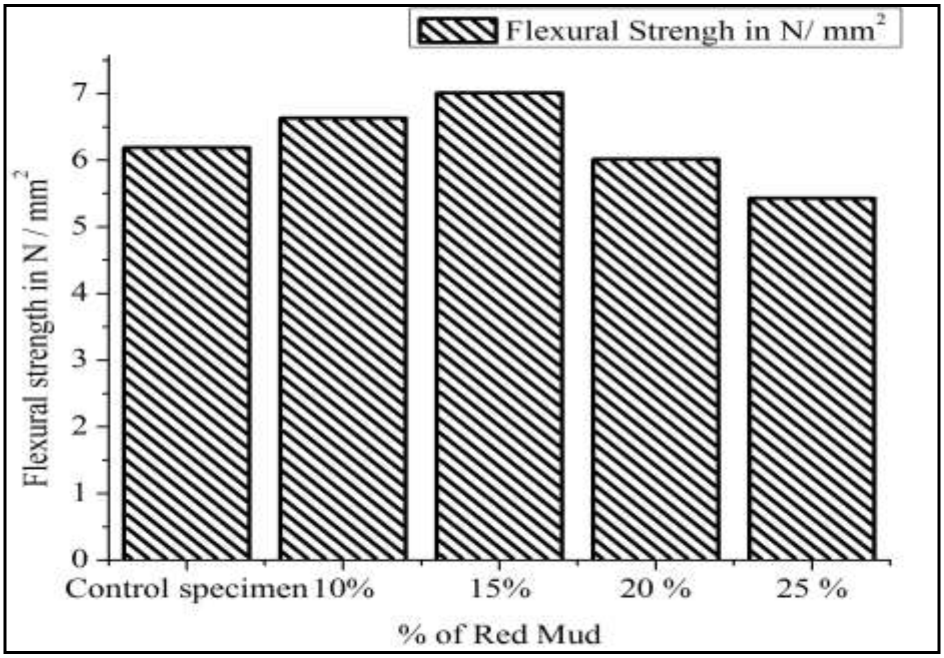

Figure 6. 28 Flexural strength of paver block in N/mm^2

Table 8. Flexural Strength in N/ mm^2

S. No	% of Red Mud	Flexural Strength in N/ mm^2
1	Control specimen	6.19
2	10%	6.63
3	15%	7.01
4	20 %	6.01
5	25 %	5.43

5.3. Water absorption test

The test specimen shall be completely immersed in water at room temperature for 24 +- 2 h. The specimen then shall be removed from the water and allowed to drain for 1min by placing them on a 10 mm or coarser wire -mesh. 'Visible water on the specimens shall be removed with a damp cloth.

The specimen shall be immediately weighed and the weight for each specimen noted in N to the nearest 0.01 N (W_W). Subsequent to saturation, the specimens shall be dried in a ventilated oven at 107 + 7°C for not less than 24 h and until two successive weighing at intervals of 2 h show an increment of loss not greater than 0.2 percent of the previously determined mass of the specimen. The dry weight of each specimen (W_d) shall be recorded in N to the nearest 0.0IN

The 28 days water absorption, the partially replacement of 20% and 25% of red mud with cement paver blocks are found to be 9.423 % and 19.34 % more than the conventional paver block and partially replacement of 10 % of red mud with cement paver blocks are found to be 7.955 % water absorption value decreased compare with conventional paver block. Partially replacement of 15 % of red mud with cement paver blocks are found to be more or less same compare with conventional paver block. Results of this test are show in Table .9 and Figure.7

Table 9. % of Water absorption

% of Red Mud	Wet Weight W (kg)	Dry Weight Wd (kg)	(%) of water Absorption
Normal	5.7680	5.5780	3.4062
10%	5.7540	5.5780	3.1552
15%	5.7940	5.6000	3.4642
20%	5.7050	5.5000	3.7272
25%	5.6320	5.4120	4.0650

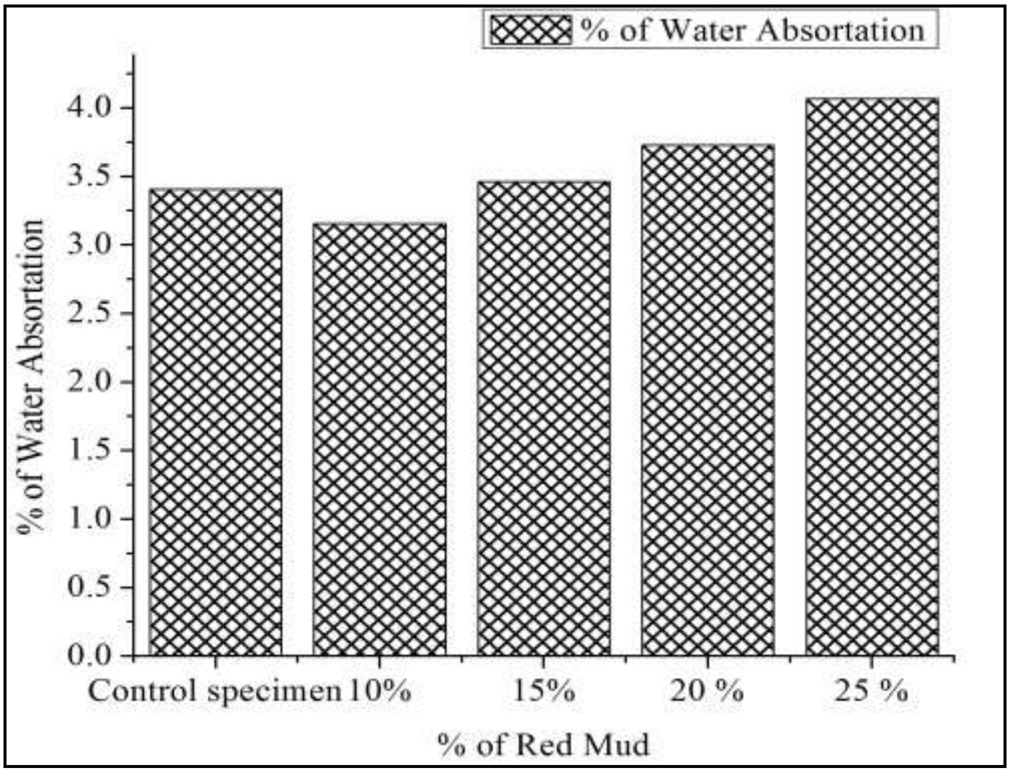

Figure 7. 28 % of Water absorption

% of Water absorption

% of water absorption = [(Ww – Wd) /Wd] x 100
Where,
Ww = weight of oven dried sample in air.
Wd = weight of surface dry sample in air after immersion in water.

5.4. Acid penetration test

This test is done as per procedure given in ASTM C 642-97 by oven-drying method. For this test 50mm x 50mm x 50mm cubes are cast. After 24 hours of remolding, the specimens are taken the initial weight (W1) after kept immersed in HCL (pickling solution). At the end of 28 days, the specimens are taken the finial weight (W2) is taken. The 28 days acid penetration of partially replacement of 25 % of red mud with cement paver blocks are found to be 66.67 % prevention of acid penetration compare with conventional paver block. Partially replacement of 10%, 15 % and 20 % of red mud with cement paver blocks are found to be more or less same compare with conventional paver block. Results of this test are show in table .10 and Figure.8

Table 10. % of Acid penetration

S. No	% of Red Mud	% of Acid penetration
1	Control specimen	6
2	10%	7.5
3	15%	7.9
4	20 %	8
5	25 %	10

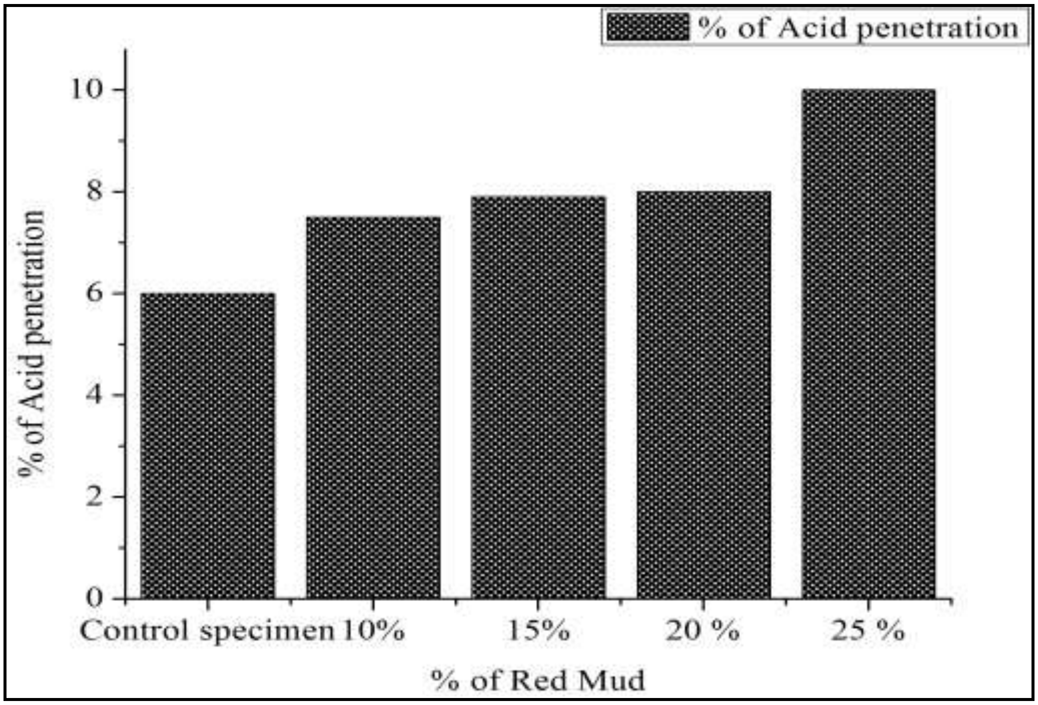

Figure 8. 28 % of Acid Penetration

5.5 Abrasion Test

The abrasion testing machine shown in Figure 9 . As per IS 1237 Square-shaped specimens measuring 71.0 x 71.0 mm shall be cut from the block specimens selected as per the sampling procedure in 8 and as per the number of specimens mentioned in Table 4. The contact face and the opposite face of the specimen shall be parallel and flat. For testing dry specimens, the specimens shall be dried to constant mass at a temperature of 105+ 5"C. The specimens shall be immersed in water for 7 days and wiped with a damp artificial sponge prior to each weighing so that all specimens appear equally damp.

Figure 9. Experimental Set Up Abrasion loss

The density of the specimen, PR shall be determined nearest to 0.1 g. The weight of the specimen shall be noted to nearest 0.1 g both prior to the abrasion test and after every four cycles conducted. In the case of two-layer specimens, the density of specimens taken separately from the wearing layer shall be determined.

The grinding path of the disc of the abrasion testing machine shall be evenly strewn with 20 g of the standard abrasive powder as per of IS 1237. The specimen shall be fixed in the holding device such that the testing surface faces the grinding disc. The specimen shall be centrally loaded with 294+3 N.

The grinding disc shall be run at a speed -of 30 rpm. The disc shall be stopped after one cycle of 22 revolutions. The disc and contact face after the specimen shall be cleaned of abrasive powder and debris. The specimen shall be turned 90° in the clockwise direction and 20 g of abrasive powder shall be evenly strewn on the testing track before starting the next cycle. When testing wet/saturated specimens, prior to each cycle, the track shall be wiped with a lightly damp artificial sponge and moistened before being strewn with the abrasive powder. From the start of the test, arrangement shall be made for drip-wetting of the central portion of the track, about 30 mm from the specimen (opposite to the direction of motion of the disc), by supplying water drops at the rate of 180 to 200 drops (13 ml) per minute. During this test, it should be ensured that the abrasive powder continuously returns to the effective area of the track.

The test cycle shall be repeated 16 times, the specimen being turned 90° in the clockwise direction and spreading of 20 g of abrasive powder on the testing track after each cycle.

The 28 days abrasive wear of partially replacement of 10% .15% and 20% of red mud with cement paver blocks are found to be 21.875 %, 14.70 % and 11.42% less than the conventional paver block and partially replacement of 25% of red mud with cement paver blocks are found to be 5.128 abrasive wear increased compare with conventional paver block. Results of this test are show in table .11and Figure 10.

Table 11. % of Abrasion loss

S. No	**% of Red Mud**	**Abrasion loss**
1	Control specimen	3.9
2	10%	3.2
3	15%	3.4
4	20 %	3.5
5	25 %	4.1

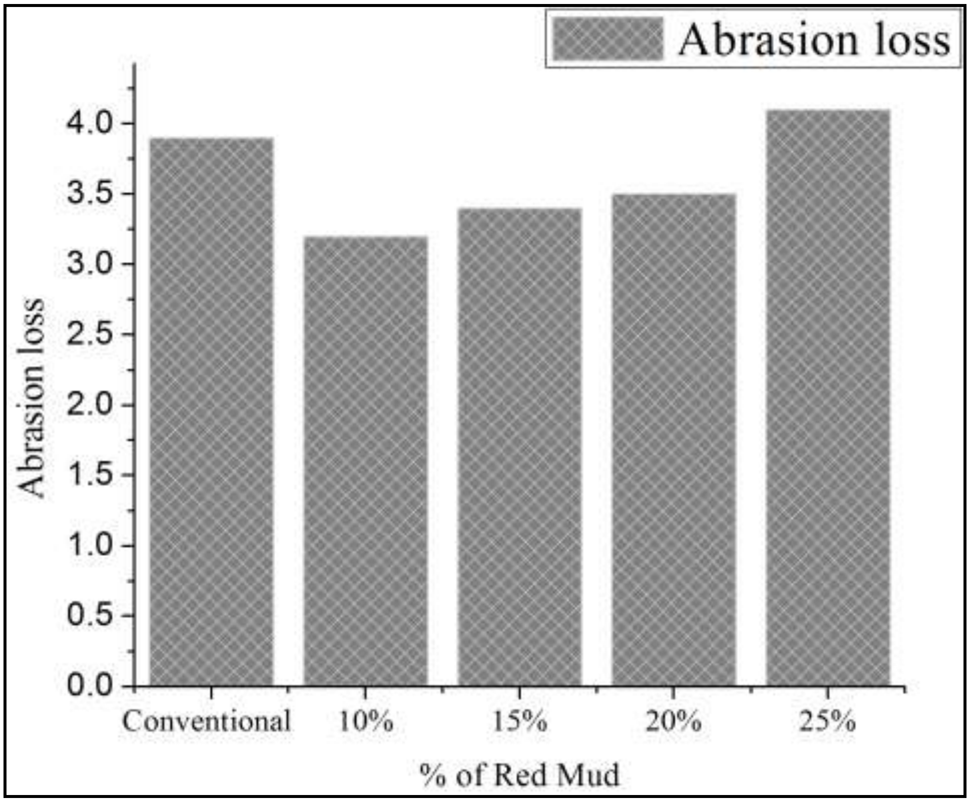

Figure 10 % of Abrasion loss

The abrasive wear of the specimen after 16 cycles of testing shall be calculated as the mean loss in specimen volume, ΔV, from the equation:

$\Delta V = \Delta m / PR$

Where:

ΔV = loss in volume after 16 cycle, in mm^3;

Δm = loss in mass after 16 cycles, in g; and

PR = density of the specimen, or in the case of two-layer specimens, the density of the wearing layer, in g/mm^3.

The abrasive wear shall be reported to the nearest whole number of 1000 mm3per 5000 mm^2.

VI. Conclusion

Addition of red mud leads to a significance increase in the characteristic strength and durability of paver block.

- The compressive strength is increased by 94.5%, 91.9%, 89.4% and 74% up on addition of 10%,15%,20% and 25% of Red Mud on 28 days curing respectively.
- The 28 days abrasive wear of partially replacement of 10% .15% and 20% of red mud with cement paver blocks are found to be 21.875 %, 14.70 % and 11.42% less than the conventional paver block.
- The 28 days acid penetration of partially replacement of 25 % of red mud with cement paver blocks are found to be 66.67 % prevention of acid penetration compare with conventional paver block.
- The partially replacement of 10 % of red mud with cement paver blocks are found to be 7.955 % water absorption value decreased compare with conventional paver block.
- The 28 days flexural strength of partially replacement of 10% and 15% of red mud with cement paver blocks are found to be 7.10% and 13.24 % more than the conventional paver block.

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