Advances in Concrete Construction, *Vol. 5, No. 6 (2017) 671-683*
DOI: https://doi.org/10.12989/acc.2017.5.6.671

Durability studies on concrete with partial replacement of cement and fine aggregates by fly ash and tailing material

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(Received July 13, 2017, Revised September 29, 2017, Accepted December 4, 2017)

Abstract. Commonly used concrete in general, consists of cement, fine aggregate, coarse aggregate and water. Natural river sand is the most commonly used material as fine aggregate in concrete. One of the important requirements of concrete is that it should be durable under certain conditions of exposure. The durability of concrete is defined as its ability to resist weathering action, chemical attack or any other process of deterioration. Durable concrete will retain its original form, quality and serviceability when exposed to its environment. Deterioration can occur in various forms such as alkali aggregate expansion, freeze-thaw expansion, salt scaling by de-icing salts, shrinkage, attack on the reinforcement due to carbonation, sulphate attack on exposure to ground water, sea water attack and corrosion caused by salts. Addition of admixtures may control these effects. In this paper, an attempt has been made to replace part of fine aggregate by tailing material and part of cement by fly ash to improve the durability of concrete. The various durability tests performed were chemical attack tests such as sulphate attack, chloride attack and acid attack test and water absorption test. The concrete blend with 35% Tailing Material (TM) in place of river sand and 20% Fly Ash (FA) in place of OPC, has exhibited higher durability characteristics.

Keywords: iron ore tailing; fly ash; compressive strength; chemical attack; durability

1. Introduction

In general, cement is the most important constituent of concrete. Production of cement involves an energy intensive kilning process and causes significant contribution to the green-house gas emission. A single industry accounts for around 5% of global carbon dioxide (CO_2) emissions. To ensure greener construction practice, it is essential to reduce the green-house gas contributions from cement production or to replace cement with other environmentally friendly and efficient by-product materials.

Behera *et al*. (2000), has attempted to develop and use Fly-Ash (FA) in activated form. 20%, 30%, 40% and 50% of Portland cement was replaced by FA. Different physical properties of the cement thus prepared have been examined. It was found that up to 35% FA in activated form can be used for manufacturing blended cement as per Indian Standards (IS 1489: Part 1 2015).

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http://www.techno-press.org/?journal=acc&subpage=7 ISSN: 2287-5301 (Print), 2287-531X (Online)

Currently several supplementary pozzolanic materials such as fly ash, blast furnace slag and silica fume are being researched over the past few decades (Mehta 1989). Fly ash is a by-product of coal-fired power plants and it is a pozzolanic material. When mixed with Portland cement, the products of fly ash-cement interaction are very similar to those formed by cement hydration (calcium silicate hydrate gel), but with a lower Ca/Si ratio (Escalante-Garcia and Sharp 2004).

Zhang *et al.* (2006) have reported the comprehensive utilization of iron ore tailings. The authors have shown that the utilization of iron ore tailings is efficient, socially beneficial and improves environment situation.

A case study was conducted by Yellishetty *et al.* (2008) on reuse of iron mineral wastes in civil engineering constructions in the tiny state of Goa. They examined the suitability of these wastes for use in construction. Laboratory experiments were carried out on the aggregate part of mine waste and physico-mechanical properties were obtained. The mean value of uni-axial compressive strength of concrete cubes was found to be of 21.93 and 19.91 MPa with mine aggregate and granite aggregate respectively.

Mahmood and Mulligan (2010) have attempted to explore the possibility of using hardened tailings as base materials for the construction of unpaved (temporary access) roads. Aruna and Kumar (2010) have also demonstrated the use of mine tailing waste material for manufacture of paver blocks. The utilization of iron ore tailing in the manufacture of bricks, paver blocks etc. have been studied by Aruna *et al.* (2012), Ravikumar *et al.* (2012).

Huang *et al*. (2013) studied feasibility of developing green ECC using iron ore tailings powder as cement replacement. Engineered Cementitious Composites (ECCs) are a unique class of high performance fiber-reinforced cementitious composites featuring high tensile ductility and durability. By adopting alternatives such as FA, brings down the need for larger cement production leading to reduced CO_2 emissions.

Sunil *et al.* (2015) have carried out studies to explore the possibility of utilizing mine tailing material as part replacement to fine aggregate and fly ash as part replacement to cement in concrete mixes. Replacement level of 20% OPC by fly ash has shown, about 5% increase in compressive strength as against control mix, for 28 days of water curing. The results of split tensile and flexural strength for 20% OPC replaced by fly ash have shown strengths equal to that of no replacement case (control mix).

Incorporation of fly ash as part replacement to cement shows reliable mechanical properties, e.g., compressive strength, flexural strength etc. in comparison to ordinary Portland cement (OPC) concrete (Siddique 2004). Durability properties including water absorption, permeability and chloride penetration indicate enhanced performance with cement replacement by fly ash (Malhotra 1990).

To address alternatives to shortage of natural aggregates, Yaragal *et al.* (2016), have reported processing of recycled aggregates from Construction and Demolition (C&D) waste adopting a rod mill for the first time. Parameters such as amount of C&D waste for processing, nature of charge and duration of processing time have been optimized for obtaining good quality recycled concrete aggregates (RCA). Performance of RCA based concrete and performance enhancement techniques of 50% RCA based concrete are discussed.

Further Yaragal *et al.* (2017), have reported performance enhancement of both 50% and 100% RCA based concretes by several innovative methods which all yielded compressive strength at-least equal to or more than no RCA based concrete (control concrete). They also have used Recycled Fine Aggregate (RFA) with appropriate modifications to serve as fine aggregate in mortar and concrete. The results are satisfactory for 100% replacement of river sand in mortars and concretes.

This study attempts to ascertain the right potential use of iron ore tailing and fly ash to develop durable concrete with part replacement of fine aggregate TM and part replacement of OPC by fly ash, to study its utilization for construction activity under different environmental conditions.

2. Materials and methods

2.1 Cement

The Ordinary Portland Cement (OPC) of 43 grade confirming to IS: 8112-2013 was used. Table 1 and 2 show the physical and chemical characteristics of cement.

Table 1 Physical properties of cement

Sl. No.	Physical properties of cement	Result	Requirements as per IS: 8112-1989
1	Fineness (m^2/kg)	334	Min 225
2	Specific gravity	3.10	3.10-3.15
3	Normal consistency (%)	29	-
4	Initial setting time (min)	120	Min 30
5	Final setting time (min)	440	Max 600

Table 2 Chemical characteristics of cement

Sl. No.	Properties	Result
1	pH	11.47
2	Electrical conductivity (ms/µs)	6.95
3	Silica oxide (SiO_2) (w/w) %	19.48
4	Iron oxide (Fe_2O_3) (w/w) %	2.00
5	Aluminium oxide (Al_2O_3) (w/w) %	8.25
6	Calcium oxide (CaO) (w/w) %	56.08
7	Magnesium oxide (MgO) (w/w) %	5.64
8	Loss on ignition (%)	4.77

2.2 Tailing material

Mine tailing is one of the waste materials generated from the mining industry and was collected from tailing dam, at Kudremukha, Karnataka, India. Tailing samples were taken at a depth of 0.90 m below the surface in the tailing dam and then transported to the laboratory in sealed bags. In laboratory, the tailing samples were air dried in shade and were then stored in non-corrodible bins for further investigation. From the particle size distribution curve (Fig. 1), it is observed that the fines percentage (silt and clay) is very less (about 5%). Further, it is noticed that the sand proportion is significant (about 95%). From the sieve analysis results, TM satisfied codal requirements confirming to zone III of IS: 383 2016.

2.3 Fine aggregate

The natural river sand was used as specified by the codal requirements confirming to zone II of IS: 383-1970. The river sand was washed and screened, to eliminate deleterious materials and over size particles. Fig. 1 shows the particle size distribution curves of fine aggregate and TM. From Fig. 1 it is observed that, the finer particles present in the sand is less then compared to TM. From the combined sieve analysis results show that, all the mixes mine tailings (TM)=30% and sand (S)=70% (TM30/S70, TM40/S60, TM50/S50 and TM60/S40) satisfied codal requirements confirming to zone II of IS: 383-1970. Table 3 show the physical characteristics of TM and river sand. Table 4 shows the chemical characteristics of TM.

Table 3 Physical characteristics of iron ore tailing material and river sand

Sl. No.	Particulars	TM	River sand
1	Specific gravity	3.27	2.64
2	Fineness modulus	2.69	3.51
3	Water absorption (%)	1.2	1.0
4	Bulk density: Loose (kg/m^3) Compact (kg/m^3)	 1684 1816	 1542 1650
5	Field moisture content (%)	9.56	-

Table 4 Chemical characteristics of iron ore tailing material

Sl. No.	Properties	Result
1	pH	7.45
2	Electrical conductivity (ms/µs)	145
3	Silica oxide (SiO_2) (w/w) %	62.06
4	Iron oxide (Fe_2O_3) (w/w) %	28.59
5	Aluminium oxide (Al_2O_3) (w/w) %	3.08
6	Calcium oxide (CaO) (w/w) %	0.073
7	Magnesium oxide (MgO) (w/w) %	0.017
8	Loss on ignition (%)	2.32

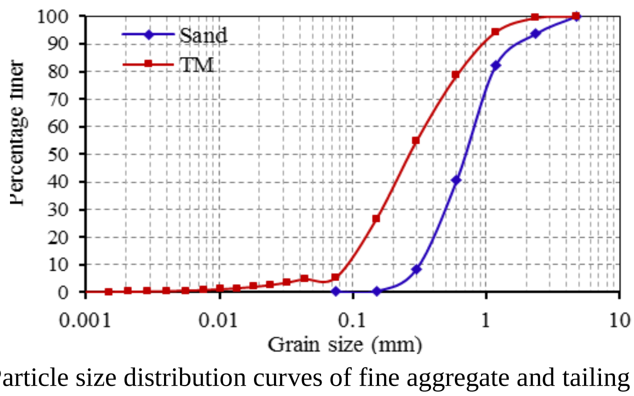

Fig. 1 Particle size distribution curves of fine aggregate and tailing material

2.4 Coarse aggregate

Nominal sizes of coarse aggregates (12.5 mm and 20 mm) as per IS 383-1970 were used in mix design. Table 5 shows the various physical properties of coarse aggregate used in this study.

Table 5 Physical properties of coarse aggregate

Sl. No.	Properties	Coarse aggregate	
		12.5 mm	20 mm
1	Specific gravity	2.75	2.68
2	Fineness modulus	3.23	3.11
3	Water absorption (%)	0.50	0.50
4	Compacted bulk density (kg/m^3)	1550	1420

Table 6 Physical properties and chemical properties of fly ash

Sl. No	Characteristics	Fly Ash
	Physical Property	
1	Specific gravity	2.07
2	Fineness (m^2/kg)	290
3	Bulk density (kg/m^3)	1100-1200
4	Colour (Visual observation)	Light grey
	Chemical Composition	
5	pH	10.21
6	Calcium oxide (CaO) (w/w) %	10.00
7	Silica oxide (SiO_2) (w/w) %	72.08
8	Aluminium oxide (Al_2O_3) (w/w) %	5.15
9	Iron oxide (Fe_2O_3) (w/w) %	0.57
10	Magnesium oxide (MgO) (w/w) %	4.04
11	Loss of ignition (%)	0.76

2.5 Fly ash

Fly ash is an industrial byproduct generated from Thermal Power Plants during combustion of coal. Particles are glassy, spherical ball bearings finer than cement particles. Sizes of particle are 0.1 μm-150 μm. Fly ash from M/s Raichur Thermal Power Station, Shakthinagar, Karnataka, has been used for the present investigation, which falls under siliceous based fly ash as per IS 3812-2013 (Part-1). Table 6 presents the physical and chemical properties of fly ash.

2.6 Water

Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. The water used was clean and free from deleterious matter.

2.7 Admixture

The high range water reducing and retarding superplasticizer confirming to ASTM C-494 Type G was used. The base of admixture used in this study was Sulphonated Naphthalene Formaldehyde. Super plasticizer used in the present investigation was between 0.4% and 0.65% by weight of cementitious materials.

2.8 Experimental study

Concrete mix of M40 was used for the experimental investigation. The mix design was done as per IS: 10262-2009 guidelines and final mix proportions was obtained as Water: Cement: Fine aggregate: Coarse aggregate=0.4: 1:1.55:2.57. Control concrete was proportioned using OPC alone as binder for the target strength of 48 MPa at the age of 28 days and a slump of 100 mm±25 mm was maintained. Superplasticizer Fosroc, conplast SP430 DIS, Sulphonated Naphthalene Formaldehyde was used to get the required slump. Final mix proportions were arrived based on trials. Table 7 below shows mix proportion of control concrete.

2.8.1 Mix proportions for replacement of natural sand by iron ore tailing material

Table 8 show the various trial mix proportions for replacement of sand by tailing material in concrete. Concrete mixes taken up for this study were proportioned with total cementitious content of 440 kg/m^3. For this cementitious content 5 set of concrete mixes were proportioned with 0%, 30%, 40%, 50% and 60% replacement of fine aggregate by tailing material. Water content was kept constant for all mixes.

Table 7 Mix proportion arrived from design mix

	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
1	176	440	681	1131

Table 8 Mix proportions for tailing replacement

Sl. No	Mix ID	TM (%)	Sand (%)	Mix proportion
1	TM0/S100	0	100	1.00:1.55:0.00:2.57
2	TM30/S70	30	70	1.00:1.09:0.57:2.57
3	TM40/S60	40	60	1.00:0.93:0.76:2.57
4	TM50/S50	50	50	1.00:0.78:0.95:2.57
5	TM60/S40	60	40	1.00:0.62:1.04:2.57

2.8.2 Mix proportions for replacement of fly ash with ordinary portland cement

Table 9 shows the various trial mix proportions for replacement of cement by fly ash in concrete.

2.9 Methodology

Specimen preparation and procedure for conduct of durability tests such as water absorption,

Table 9 Mix proportions for fly ash replacement

Sl. No	Mix ID	TM (%)	Sand (%)	Cement (%)	Fly ash (%)	Mix proportion
1	TM35/F0	35	65	100	0	1.00:0:1.68:2.57
2	TM35/F20	35	65	80	20	0.80:0.20:1.64:2.52
3	TM35/F30	35	65	70	30	0.70:0.30:1.63:2.49
4	TM35/F40	35	65	60	40	0.60:0.40:1.61:2.46
5	TM35/F50	35	65	50	50	0.50:0.50:1.59:2.44

sulphate attack and acid attack tests are detailed below,

2.9.1 Water absorption

150 mm concrete cubes were prepared for various mixes and water cured for 28 days. The specimen were then air dried for 24 hours. The dried specimen were weighed accurately to note the dry weight. The dried specimen were immersed in water. Weight of the specimen at pre-determined intervals of time were taken after wiping the surface with dry cloth. This process was continued for not less than 48 hours or up to extent of time till constant weight was obtained in two successive observations.

2.9.2 Sulphate attack

When concrete is exposed to environment containing aggressive chemicals, it leads to deterioration of concrete which can be assessed in terms of loss of weight of concrete. To study the acid resistance of concrete, the cube specimen were cured for 28 days. After 28 days, all specimens were kept in atmosphere for 2 days for constant weight. Subsequently, the specimen were weighed and then immersed in 3% Na_2SO_4 (pH=7, maintained using buffer) solution up to 28 days. After 28 days of immersion, the specimen were taken out and visually observed for the deterioration of the concrete due to sulphate attack. The specimens were weighed once again and the weight is compared with the normal control concrete weight in order to calculate the percentage of loss of weight and also the loss of strength. Figure 2 shows the concrete cubes after sulphate attack.

Fig. 2 Concrete cubes after sulphate attack

2.9.3 Acid attack

The concrete cubes of size 150 mm were prepared for various mixes and water cured for 28 days. After 28 days, all specimens were kept in atmosphere for 2 days for constant weight. Subsequently, the specimen were weighed and immersed in 5% sulphuric acid (H_2SO_4) solution (pH = 3.0) for 28 days. After 28 days of immersion, the specimen were taken out and kept in atmosphere for 2 days for constant weight. After drying, the changes in weight and the compressive strength of concrete cubes were found. Fig. 3 shows concrete cubes after sulphuric acid attack.

Fig. 3 Concrete cubes after acid attack

3. Results and discussion

3.1 Compressive strength variation

Compressive strength of control mix and modified mixes with 30%, 40%, 50% and 60% of sand replacement with TM was determined at 7, 28, 56 and 90 days. The maximum compressive strength is obtained for concrete mixes replaced with 30% & 40% tailing material; beyond that the compressive strength has reduced significantly (Fig. 4). The excessive free water content in the mixes with high TM content causes the particles of the constituents to separate leaving pores in the hardened concrete which consequently causes reduction in the concrete strength.

The highest compressive strength was achieved by 30% and 40% replacement of TM, which was found to be about 53 MPa compared to 49 MPa for the control mixture. This means that there is an increase in the concrete strength of almost 8% compared to the control mix. However, mixes with 50% and 60% replacement of sand by TM gave the lowest compressive strength around 45 Mpa which is almost 8% lower than the strength of the control mix.

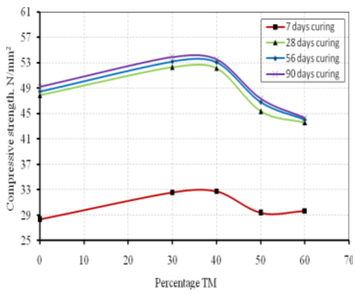

Fig. 4 Compressive strength V/s percentage TM

3.2 Water absorption

Table 10 shows the average water absorption test results for different blended mixes. A lower water absorption was noted for mixes TM35/F0 and TM35/F20 and a constant higher absorption was noted for the remaining three concrete mixes. This implies that inclusion of 35% TM and less than 20% fly ash will have beneficial effect of reduction in absorption characteristics and consequently enhancing the durability of the concrete. In this regard, FA in controlled amount will be suitable for inclusion in normal concrete. The bar chart in Fig. 5 is a pictorial relationship between water absorption and mix designation.

Table 10 Percentage of water absorption

Sl. No	Mix ID	Average Water Absorption (%)
1	TM35/F0	0.71
2	TM35/F20	0.76
3	TM35/F30	0.92
4	TM35/F40	0.90
5	TM35/F50	0.89

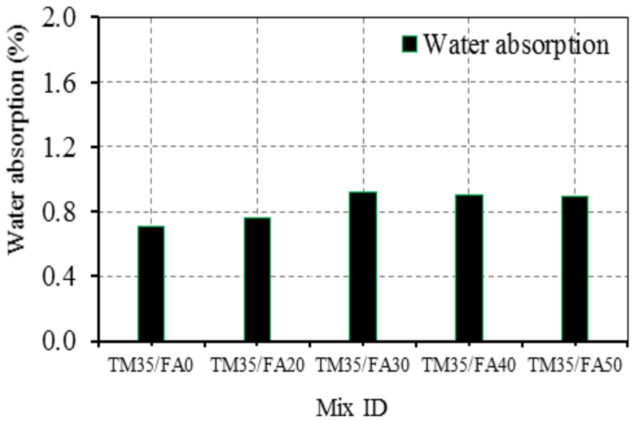

Fig. 5 Variation in water absorption for different blended concrete mixes

3.3 Sulphate attack

Tables 11 and 12 shows the sulphate attack test results of average % loss in weight and % loss in strength of concrete cube specimen for different blended mixes.

As per BS: 8110 Part 1, Clause 6.2.5.3, the total water soluble sulphate content of the concrete mix expressed as SO_3 should not exceed 4% by mass of cement in the mix.

Table 11 shows the percentage loss of weight of tailing and tailing fly ash concrete specimen immersed in sodium sulphate solution. Weight loss of TM35/F50 is not reported as it is not an optimized mix. Fig. 6 shows the loss of weight of the concrete cubes immersed in sodium sulphate solution at various curing periods. From Fig. 6, it is observed that weight losses are lesser in tailing fly ash concrete when compared to the tailing based concrete.

Table 11 Percentage Loss of weight due to sodium sulphate (Na_2SO_4) attack

Sl. No	Mix notation	Loss of weight (%)		
		Duration of curing (days)		
		7	28	56
1	TM35/F0	0.12	0.23	1.16
2	TM35/F20	0.08	0.20	1.01
3	TM35/F30	0.12	0.20	1.00
4	TM35/F40	0.08	0.20	1.06

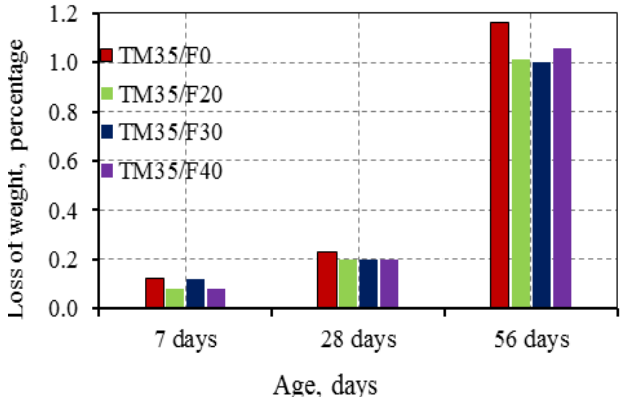

Fig. 6 Percentage loss of weight due to sodium sulphate (Na_2SO_4) attack

Table 12 Percentage increase in strength of specimens immersed in Na_2SO_4 solution

Sl. No	Mix notation	Increase in strength (%)		
		Duration of curing (days)		
		7	28	56
1	TM35/F0	0.34	2.08	4.48
2	TM35/F20	2.68	5.27	8.67
3	TM35/F30	2.76	5.05	7.13
4	TM35/F40	4.66	5.48	6.02

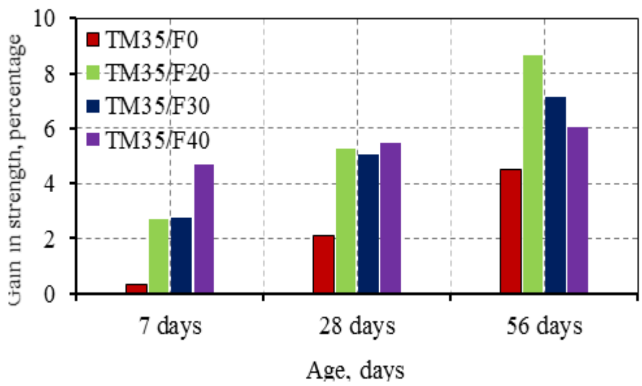

Fig. 7 Percentage increase in strength of specimens immersed in Na_2SO_4 solution

Table 12 shows the increase in strength due to sulphate attack after 56 days immersed in sulphate solution. Fig. 7, shows the percentage increase in strength of concrete cubes immersed in sulphate solution. The blended mix TM35/F20 shows good resistance to sulphate attack than control concrete.

3.4 Acid attack

Tables 13 and 14 show the acid attack test results of average % loss in weight and % loss in strength of concrete cube specimen of control concrete and different blended mixes when immersed in H_2SO_4 solution.

The results of percentage loss in weight of tailing fly ash concrete are shown in Table 13. Also, Fig. 8 shows the loss of weight of the concrete cubes immersed in sulphuric acid (H_2SO_4) solution at various curing periods. From Fig. 8, it is observed that weight losses are lesser in fly ash concrete when compared to the tailing concrete.

Table 13 Percentage loss of weight due to sulphuric acid (H_2SO_4) attack

Sl. No	Mix notation	Average percentage loss of weight Duration of curing (days)		
		7	28	56
1	TM35/F0	3.45	5.65	7.54
2	TM35/F20	3.08	5.48	7.35
3	TM35/F30	2.29	5.48	7.41
4	TM35/F40	1.64	3.93	6.47

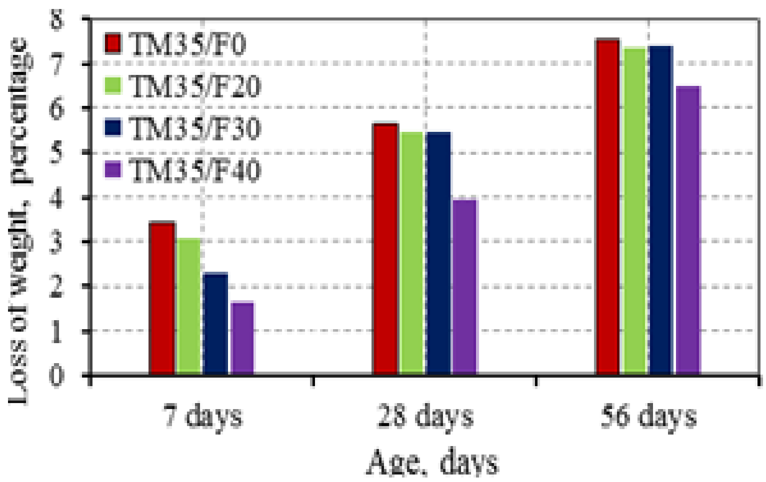

Fig. 8 Percentage loss of weight due to sulphuric acid (H_2SO_4) attack

The test results of loss in strength of tailing fly ash concrete immersed in H_2SO_4 solution are shown in Table 14. It is observed from Table 14 mix TM35/F20 shows good resistance to acid attack when compared with tailing based concrete. The results are also plotted in Fig. 9.

Table 14 Percentage loss of strength due to sulphuric acid (H_2SO_4) attack

Sl. No	Mix notation	Loss of compressive strength (%)		
		Duration of curing (days)		
		7	28	56
1	TM35/F0	17.11	23.72	28.82
2	TM35/F20	11.81	21.12	24.73
3	TM35/F30	19.07	23.24	28.96
4	TM35/F40	15.95	21.12	27.16

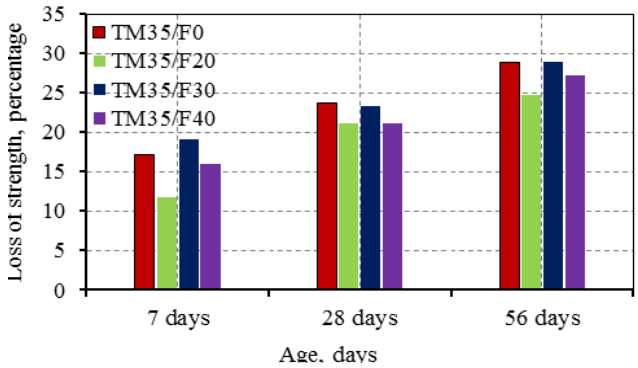

Fig. 9 Percentage loss of strength due to sulphuric acid (H_2SO_4) attack

4. Conclusions

The following conclusions were drawn from the study:

• Concrete with 35% TM showed higher compressive strength for 28 days curing. Further additions of TM caused reduction in the strength.

• It is recommended that 35% of TM having compressive strength of 53 MPa, can be used as replacement to river sand in order to obtain concrete with good strength properties.

• The concrete blended with 35% TM and 20% FA has exhibited higher durability characteristics (low water absorption-0.76%, sulphate attack-0.20% and acid attack-5.48%)

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