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Assessment of strength and durability of bagasse ash and Silica fume concrete

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Abstract. An alternative type of building system with masonry units is extensively used nowadays to reduce the emission of CO2 and embodied energy. Long-term performance of such structures has become essential for sustaining the building technology. This study aims to assess the strength and durability properties of concrete prepared with unprocessed bagasse ash (BA) and silica fume (SF). A mix proportion of 1:3:3 was used to cast concrete cubes of size 100 mm×100 mm×100 mm with various replacement levels of cement and tested. The cubes were cast with zero slump normally adopted in the manufacturing of hollow blocks. The cubes were exposed to acid attack, alkaline attack and sulphate attack to evaluate their durability. The mass loss and damages to concrete for all cases of exposures were determined at 30, 60, and 90 days, respectively. Then, the residual compressive strength for all cases was determined at the end of 90 days of durability test. The results showed that there was slight difference in mass loss before and after exposure to chemical attack in all the cases. Though the appearance was slightly different than the normal concrete the residual weight was not affected. The compressive strength of 10% bagasse ash (BA) as a replacement for cement, with 10% SF as admixture resulted in better strength than the normal concrete. Hence concrete with 10% replacement with BA along with 10% SF as admixture was considered to be durable. Besides solid concrete cubes, hollow blocks using the same concrete were casted and tested simultaneously to explore the possibility of production of masonry units.

Keywords: concrete; bagasse ash; Silica fume; compressive strength; durability; mass loss

1. Introduction

Several researches were carried out in the past decades and are still being conducted to study the performance of concrete prepared with BA. Use of BA as a pozzolanic material is hardly known and hence its uses are limited. Its commercial feasibility is not revealed and most of the BA is disposed off in the landfills as studied by Sivakumar *et al*. (2013). However, Guilherme *et al*. (2009) found that the pozzolanic reactivity of BA strongly depended on the incinerating temperature; a maximum reactivity occurred at around 500°C. The publications (Jayminkumar *et al*.2015, Kawade *et al*. 2013, Moises *et al*. 2007) also reported that the controlled burning of BA at

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800^{o}C-1000^{o}C increases the pozzolanic activity.

Generally, in almost all sugar industries, the bagasse was burnt in a power plant at very high temperature for attaining the required heat energy. The resultant ash from such power plants were in huge quantities and their disposal was a matter of concern. Hence the use of such BA in the manufacture of concrete was studied and the strength results were proven to be good when silica fume was added as an admixture. However, the strength alone was not the criteria for a sustainable concrete. According to Mehta (1999), the basic principle to attain the sustainability of concrete was through the conservation of primary materials, the fortification of the durability of concrete structures, and a holistic approach to the technology.

In the earlier period, the cement content and water cement ratio (w/c) specified to achieve a desirable strength was believed to be ample for durability. This led to the approach known as "Allen Compassing Prescriptive Approach" as described by Dhanya, B.S., and Manu Santhanam (2013). However ,Dhanya, B.S., and Manu Santhanam(2013) also observed when pozzolanic materials were incorporated into the concrete, the silica present in these materials react with the calcium hydroxide released during the hydration of the cement and formed additional calcium silicate hydrate (C – S – H)gel, which improved the mechanical properties of concrete and the durability .

Therefore durability plays an important role for sustainable development, as the failure of the structure would have several impacts on the environment. Ganesan *et al* (2012) have reported that at first, all the waste transforms into the environment from one form to another and second, natural resources get depleted for new construction. Further that might result in the loss in human existence.

This study aims to reuse BA obtained from burning of bagasse at high temperature of 1500^{o}C without any further grinding or processing as these may increase the expenditure. The reduction of cement by replacing it with BA in turn would reduce the green house emissions. The study also aims to develop new alternative building materials for construction. Concrete cubes were cast with zero slump and tested for its strength and durability properties. Finally, the weight, and appearance of such cubes were studied at various ages of 30, 60 and 90 days after chemical attack. Further, the residual compressive strength at the end of 90 days after acid attack was carried out. In addition the loss in mass and compressive strength was determined at all replacement level of BA.

2. Materials and methods

2.1 Ordinary Portland cement (OPC)

Commercially available Portland cement Type I conforming to ASTM C 150 specification (1997) was used in this study.

2.2 Bagasse Ash (BA)

The unprocessed BA from the Power Plant calcined at very high temperature of 1500 ^{o}C from a reputed Sugar Industry in Tamilnadu was obtained. The chemical properties of BA are presented in Table 1.

Table 1 Properties of bagasse ash

Sl. No.	Chemical composition	Content %
1.	Silicon dioxide (SiO_2) + Aluminium Oxide (Al_2O_3) + Iron Oxide (Fe_2O_3)	56.580
2.	Magnesium Oxide (MgO)	0.330
3.	Total Chlorides (Cl)	0.002
4.	Total Sulphur as Sulphur Trioxide (SO_3)	1.010
5.	Loss on ignition	2.430
6.	Calcium Oxide (CaO)	13.470
7.	Manganese Oxides (MnO)	1.140

Table 2 Properties of Silica Fume

Sl. No	Chemical composition	Content in %
1.	Silicon dioxide (SiO_2)	99.500
2.	Magnesium Oxide (MgO)	0.010
3.	Aluminium Oxide (Al_2O_3)	0.080
4.	Alkalies	0.290
5.	Loss on ignition	0.280
6.	Calcium Oxide (CaO)	0.010
7.	TiO_2	0.040
8.	Particle Size	800 μm

2.3 Silica Fume (SF)

Commercially available densified SF from Astra Chemicals, India Ltd, Chennai, having the properties shown in Table 2, was used.

2.4 Fine aggregate

In the present study, quarry dust was used as fine aggregate. The basic tests on quarry dust were conducted as per ASTM C136-06 and its specific gravity was around 1.95. Wet sieving of quarry dust through a 90 micron sieve was found to be 78% and the corresponding bulking value of quarry dust was 34.13%.

2.5 Course aggregate

Crushed stone of maximum size 12.5 mm, moisture content of 2.4%, Porosity of 48.8%(m%), unit weight of 1138 kg/m3, and specific gravity 2.64 confirming to ASTM C136-06 were used.

2.6 Water

Water conforming to as per ASTM C1602 / C1602M – 12 was used for mixing as well as curing of concrete specimens.

Table 3 Compressive strength of Hollow Concrete Block at 28 days in MPa

Samples No	Silica Fume in Percentage (%)	BA in Percentage (%)	Compressive Strength mean value
HB 1	0	Normal	9.42
HB 2	10	10	10.2
HB 3	10	20	6.93
HB 4	10	30	6.51

2.7 Preparation of samples

With the intention of using BA and SF concrete in the production of masonry units for construction, hollow blocks of size 400 mm × 100 mm × 200 mm were cast .This study was carried out in two phases. In Phase I, hollow concrete blocks were cast using the hollow block machine for concrete mix proportion of 1:3:3(1 part cement:3 parts quarry dust:3 parts crushed stone).The mix was prepared by replacing cement with BA by 0%, 10%, 20% and 30% along with 10% addition of silica fume on all proportions. The water/cement ratio was maintained 0.55 throughout the study. For each replacement, 8 hollow concrete blocks were cast. A total of 32 specimens were tested and its average compressive strength was determined at 28 days. Mixing, casting, and curing of all hollow masonry units were performed at the manufacturing plant following their standard commercial production procedure. The specimens were cured in water tank up to the testing age.

In Phase II, cubes of size 100×100×100 mm were cast with the same concrete mix proportion of 1:3:3. The average density of the concrete was 900 kg/m^3.The cubes were subjected to vibration using the table vibrator so as to maintain the zero slump as in commercial hollow block manufacturing. The mix and water/cement ratio were maintained the same as that of hollow concrete block. For each replacement, 8 cubes were cast with a total of 40 specimens and they were assessed for compressive strength at 7 and 28 days and further for durability. Then, the average compressive strength was found. All the materials used were batched by weight proportions. Immediately after casting, the specimens were covered with plastic sheets for 24Hrs to prevent the evaporation of water from the concrete. Then they were demoulded and cured in water under ambient temperature until they were tested for strength and durability.

3. Results and discussion

3.1 Compressive strength of hollow concrete block at 28 days

The compressive strength test of the hollow concrete blocks was carried out after 28 days as per the test procedure detailed in IS: 2185 Part-I (2005). The specimens were wiped to a surface dry condition upon removal from the curing tank just before the test. The tests were conducted for eight specimens and the average was taken for each mix proportion at all replacement level and the results are shown in Table 3.

From the above test results, it was observed that the compressive strength of cube was maximum at 10% of BA replacement with 10% of silica fume as admixture.

Table 4 Compressive strength of cube at different curing ages

Samples Designation	Silica Fume as admixture in Percentage (%)	BA as replacement to cement in Percentage (%)	Average Compressive Strength in MPa	
			7 days	28 days
LT187 F	0	0	18.30	36.63
LT187G	10	0	19.00	38.00
LT187H	10	10	18.95	37.20
LT187 I	10	20	14.65	33.40
LT187 J	10	30	12.24	29.40

Table 5 Durability results of cubes subjected to acid environment

Sample Name	Weight of cube in kg				Loss in weight at 90 days (kg)	Decrease in weight at 90 days %
	Initial	30 days	60 days	90 days		
LT187F	0.894	0.883	0.874	0.880	0.014	1.566
LT187G	0.908	0.891	0.889	0.899	0.009	0.991
LT187H	0.894	0.886	0.880	0.872	0.022	2.406
LT187 I	0.896	0.880	0.873	0.869	0.027	2.959
LT187 J	0.884	0.868	0.863	0.855	0.029	3.226

3.2 Compressive strength of cube at different curing ages

The specimens were wiped to a surface dry condition upon removal from the curing tank just before the test. The compressive strength tests of all cubes were carried out at various curing ages as per the test procedure detailed in IS: 516 (1959) in Universal Testing Machine. The tests were conducted for three specimens and the average was taken for each mix proportion at all replacement level and the results are shown in Table 4.

From the above results it can be seen that the compressive strength of cube was optimum at 10% of BA replacement with 10% of SF as admixture. Further it was seen that the SF as admixture increased the strength while the addition of BA decreased the strength to 37.2 MPa at 28 days. The same was also reported by Mahdi Mahdikhani and Ali Akbar Ramezanianpour (2014). This is due to the less pozzolanic nature of BA obtained at a high temperature of 1500^{o}C from sugar industry power plant. The studies (Subramani *et al*. 2015, Guilherme 2009) also reported that the pozzolanic reactivity of BA depended strongly on the incinerating temperature; a maximum reactivity occurred at around 500°C.

3.3 Durability results of cubes subjected to acid environment

As for durability of concrete, tests were conducted using concrete cubes .Two cubes each of size 100 mm×100 mm×100 mm were cast at mix proportions of 1:3:3 with various replacement level of cement by BA at 0%, 10%, 20% and 30% along with 10% addition of SF on all proportions. Total 10 cubes were cured for 28 days. After 28 days curing, cubes were taken out and allowed for drying for 24 hours and their compressive strength and weights were taken. Subsequently, cubes were immersed in acid for the required number of days.

For acid attack 5% hydrochloric acid was used. The cubes were immersed in acid solution for a period of 90 days. The acid solution was replaced periodically once in a week interval throughout 90 days so the concentration was maintained throughout this period. After 30, 60, and 90 days the specimens were taken from the acid solution and the surface of specimen was cleaned and weights were noted as in Tables 5. Further the appearance of cubes after acid attack was also studied.

The action of acids on concrete is the conversion of calcium compounds into calcium salts of the attacking acid. These reactions destroy the concrete structure. The replacement of silica fume is found to have increased the durability against acid attack as reported in Table 5. Amudhavalli N. K., Jeena Mathew (2012) also observed that this is due to the silica present in silica fume which combines with calcium hydroxide and reduces the amount susceptible to acid attack .Mostafa Jalal (2014), Luther (1989) also suggests that silica fume will increase the resistance of concrete to dilute acids and chemical attack through reduced permeability and through reduced content of calcium hydroxide.

b) Comparison of average weight of cubes subjected to acid environment at various curing ages

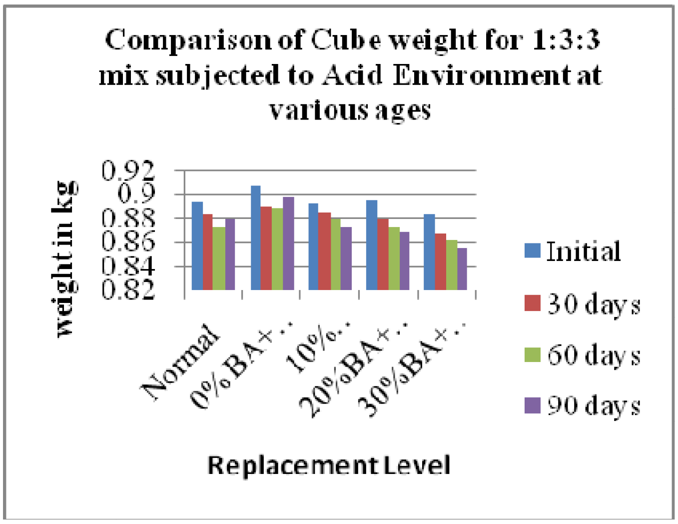


Fig. 1 Comparison of average weight of cubes subjected to acid environment at various ages

However, the average weight of cubes was found to be decreased at the end of 90 days on all replacement level of bagasse ash. Santosh kumar karri et. al (2015), Siddamreddy(2013) also observed the decreased strength of flyash concrete under HCl action .This is mainly due to the corrosive nature of HCl at all replacement levels. It is further observed that the loss in mass of concrete increases with increase in BA replacement at all replacement level .However 10% replacement of BA with 10% SF as admixture was found to be durable compared to the normal concrete.

Table 6 Durability results of cubes subjected to alkaline environment

Sample Name	Weight of cube in Kg				Loss in weight at 90 days (kg)	Decrease in weight at 90 days %
	Initial	30 days	60 days	90 days		
LT187 F	0.883	0.886	0.888	0.888	-0.005	-0.566
LT187 G	0.898	0.897	0.905	0.898	0.000	0.000
LT187 H	0.892	0.892	0.896	0.895	-0.004	-0.393
LT187 I	0.888	0.889	0.897	0.889	-0.002	-0.169
LT187 J	0.875	0.875	0.877	0.875	-0.001	-0.057

3.4 Durability results of cubes subjected to alkaline environment

Two cubes each of sizes 100 mm×100 mm×100 mm were cast for same mix proportion of 1:3:3 for various replacement level of cement with BA by 0%, 10%, 20% and 30% and with 10% addition of SF on all proportions. Total of 10 cubes were cast and cured for 28 days. After 28 days of curing cubes were taken out and allowed for drying for 24 hours and their weights and compressive strengths were taken. Subsequently, cubes were immersed in alkaline solution for required number of days.

For alkaline attack, 5% of NaOH solution dissolved in 1 litre of water was used. The cubes were immersed in NaOH solution for a period of 90 days. The alkali solution was replaced at an interval of once in a week throughout 90 days. But the concentration was maintained throughout this period. After 30, 60, 90 days the specimens were taken out from the alkaline solution and the surface of specimen was cleaned, weights were noted as in Table 6. Further, the appearance of cubes after alkaline exposure was also studied.

b) Comparison of average weight of cubes subjected to alkaline environment at various curing ages

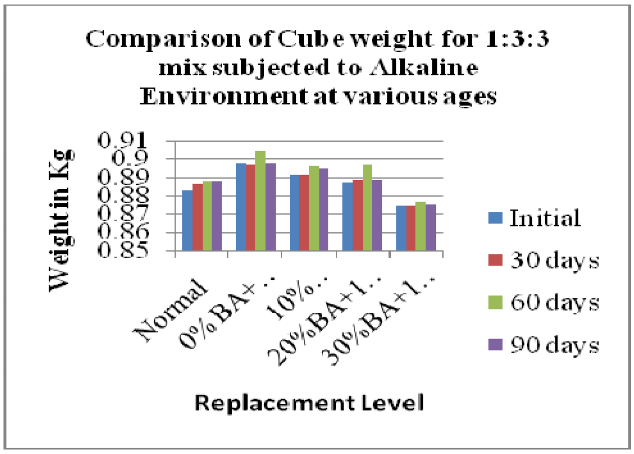


Fig. 2 Comparison of average weight of cubes subjected to Alkaline environment at various ages

Table 7 Durability results of cubes subjected to sulphate environment

Sample Name	Weight of cube in kg				Loss in weight at 90 days (kg)	Decrease in weight at 90 days %
	Initial	30 days	60 days	90 days		
LT187 F	0.896	0.896	0.893	0.900	-0.004	-0.446
LT187 G	0.909	0.909	0.903	0.912	-0.003	-0.330
LT187 H	0.899	0.898	0.897	0.901	-0.002	-0.223
LT187 I	0.892	0.892	0.890	0.893	-0.002	-0.168
LT187 J	0.887	0.879	0.885	0.887	-0.001	-0.056

The replacement of silica fume was found to have increased the durability against alkaline attack as reported in Table 6. The average weight of cubes was found to be increased at the end of 90 days on all replacement level of bagasse ash compared to the initial weight at 28 days. It was further observed that the loss in mass of concrete decreases at 10% replacement of BA with 10% SF as admixture compared to the normal concrete. Siddique, R., and Iqbal Khan, M. (2011) found that this is due to the alkalis from the cement and other sources, with hydroxyl ions and certain siliceous constituents leading to formation of distinctive gelatinous hydrates which expand as water is imbibed and exert pressure on surrounding matrix. This may lead to an increase in mass at 90 days.

3.5 Durability results of cubes subjected to Sulphate environment

Two cubes each of sizes 100 mm×100 mm×100 mm were cast at mix proportions of 1:3:3 for various replacement level of cement with BA by 0%, 10%, 20% and 30% and with 10% addition of silica fume on all proportions. Total of 10 cubes were cast and cured for 28 days. After 28 days of curing cubes were taken out and allowed for drying for 24 hours and their weights and compressive strength were taken. Afterwards, cubes were immersed in sulphate solution for required number of days. For sulphate attack 5% of $MgSO_4$ was dissolved in 1 litre of water and the cubes were immersed in this solution for a period of 90 days. The sulphate solution was replaced at an interval of once in a week throughout 90 days. But the concentration was maintained throughout this period. After 30, 60, 90 days the specimens were taken out from the sulphate solution and the surface of specimen was cleaned, weights were noted as given in Table 7. Further the appearance of cubes after sulphate exposure was also studied.

Similar to alkaline condition the weight of cubes subjected to sulphate attack increases with the addition of silica fume by 10% of cement. However, the increase in the replacement of BA to cement decreases the weight of cubes.

Sulphate attack of concrete occurs through both chemical and physical processes these being the reaction of sulphate ions with hydrated calcium aluminates forming ettringite, and the combination of sulphate ions with free calcium hydroxide forming gypsum. The first reaction is of more practical significance. Considerable increases in volume result from both reactions causing expansion and disruption of the hardened concrete was observed by Mangat, P.S., and Khatib, J.M (1993).This results in the increase in mass over 90 days.

b) Comparison of Average weight of cubes subjected to sulphate environment at various curing ages

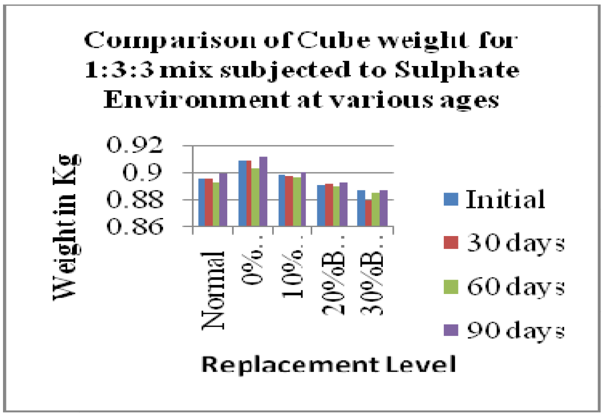


Fig. 3 Comparison of average weight of cubes subjected to sulphate environment at various ages

Further Sellevold and Nilsen (1987) also reported through their field studies of concretes with and without silica fume. They observed that even after 20 years' exposure to ground water containing 4g/L sulphate and 2.5-7.0 pH, the performance of the silica fume concrete was found equal to that of the concretes made with sulphate-resisting Portland cement. Lee *et al.* (2005) also observed that the total strength loss was greater in mortar specimens without silica fume compared to those with silica fume.

This shows that the silica fume concrete has better sulphate resistance than normal concrete. On the whole it was observed that the 10% BA replacement with 10% SF addition found to be more durable than the normal concrete as shown in Fig. 3.

3.6 Durability test Images of all mixes for different replacement level at various ages

From the above images at the end of 90 days the cubes subjected to acid exposure was found to have the colour of dark orange with many pores for normal concrete and dark yellow with pores at 10% BA placement and 10% SF as admixture. Hence, the 10% BA replacement was found to be good in appearance than normal concrete.

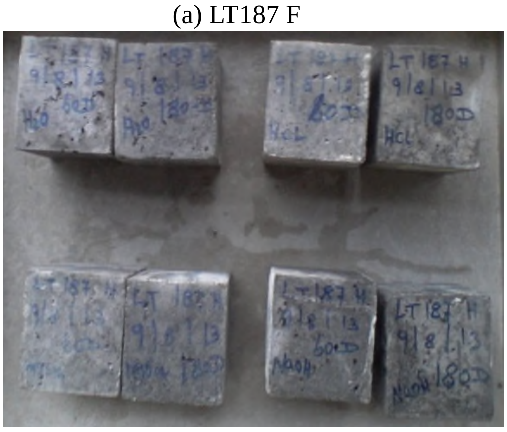
Similarly, a white coating was found in all mix subjected to alkaline and sulphate attack at all replacement level. Moreover, the same condition was seen in normal concrete subjected to such exposures. Further, it was observed that the formations of pores were found to increase with increase in BA replacement level, which showed the less pozzolanic nature of BA obtained at very high temperature of 1500^{o}C. Thus cubes subjected to alkaline and sulphate attack with10% BA replacement along with 10% SF as admixture was found to have good appearance than normal concrete.

3.7 Comparison of compressive strength of cube before and after durability studies

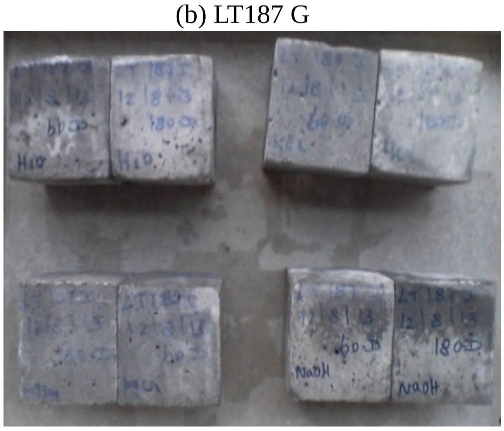
After exposing to various chemical attacks, finally at the end of 90 days the cubes were taken out, wiped, dried, and weighed .Then the specimens were tested in the Universal testing machine under a uniform rate of loading as per IS: 516. The strengths of specimens after acid, alkaline and sulphate attack were determined and tabulated in Table 8 on all replacement levels.

(a) LT187 F

(b) LT187 G



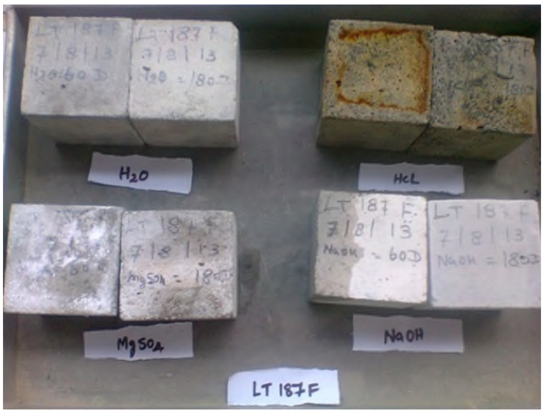
(c) LT187 H



(d) LT187 I

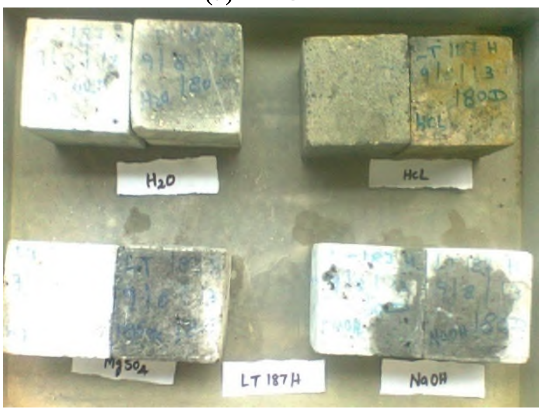
(e) LT187 J

Fig. 4 Durability Test Images of 1:3:3 mix for Different Replacement Level at 30 days on all exposures

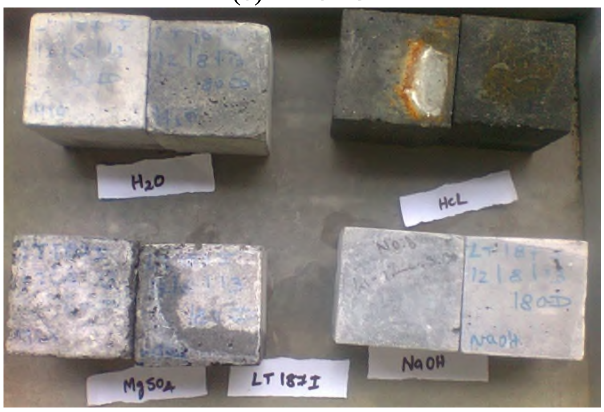


(a) LT187 F

(b) LT187 G



(c) LT187 H



(d) LT187 I

(e) LT187 J

Fig. 5 Durability Test Images of 1:3:3 mix for Different Replacement Level at 90 days on all exposures

Table 8 Comparison of compressive strength of cube before and after durability studies

Samples Designation	Average Compressive Strength in MPa			
	Initial at 28 days	Final at 90 days		
		At the end of Acid Test	At the end of Alkaline Test	At the end of Sulphate Test
LT187 F	36.630	21.200	34.200	35.550
LT187 H	37.200	23.200	34.750	36.450
LT187 I	33.400	16.000	32.700	31.500
LT187 J	29.400	10.000	31.450	25.200

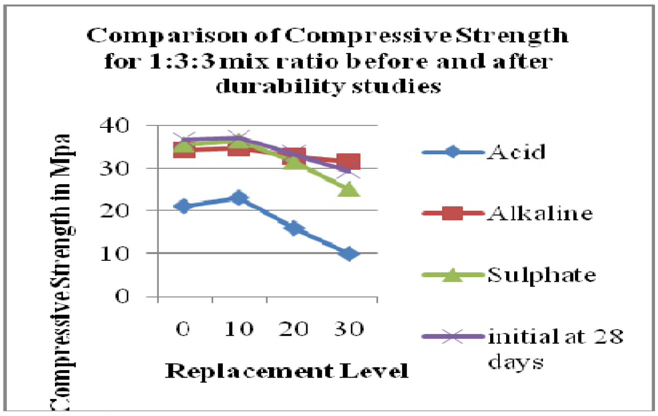


Fig. 6 Comparison of average compressive strength of cubes before and after durability studies

From Fig. 6 it was observed that the compressive strength of cube exposed to acid, sulphate and alkaline attack was optimum at 10% BA replacement .Further, the durability of cubes was found to be decreased with increase in the replacement of BA in the concrete. However, the 10% replacement of BA with 10% SF addition proved to be highly durable compared to normal concrete.

5. Conclusions

Based on the test results of the experimental investigations the following observations were drawn:

• The compressive strength of both hollow concrete block and cube was maximum at 10% BA replacement along with 10% SF as admixture compared to normal concrete. However, the compressive strength decreased with an increase in BA replacement.

• The addition of silica fume was found to increase the durability against acid, alkaline, sulphate attack. But increase in BA replacement decreases the durability of concrete. However with addition of silica fume the durability of BA concrete was found to be increased.

• The unprocessed BA obtained at 1500oC was found to be suitable and durable with silica fume as admixture and 10% replacement of BA with 10% addition of SF was found to be optimum in strength as well as in durability characteristics compared to the normal concrete.

• The residual compressive strength at the end of 90 days on all exposure conditions found to be optimum at 10% BA replacement along with 10% SF as admixture compared to normal concrete residual strength.

• Thus the utilization of the waste ash reduces the consumption of cement and thus reduces the possible green house emission. In addition, this would help in the reduction of waste ash disposal and health hazard problems.

• The manufacture of hollow concrete blocks requires simple manufacturing process.

However, a better perceptive view of the durability parameters relevant to mixes and test methods are needed. Further the durability of concrete at the site should also be determined to understand the real conditions and to associate the results with laboratory values.

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