USING ENVIRONMENT FRIENDLY FINELY DIVIDED MATERIALS IN BRITTLE MATRIX COMPOSITES

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1. ABSTRACT

Material engineers the world over are increasingly recommending the use of environment friendly efficient construction materials, which otherwise would have been classed as waste materials for improving the durability of concrete. Pakistan has been blessed by nature with huge natural resources of lime, and fly-ash is also becoming increasingly available with the induction of thermal power generation plants. To introduce the benefits of such concrete modifying materials to the engineering community in our country, an investigation has been carried out on the use of locally available powdered hydrated lime, fly-ash and their combinations in making concretes with a view to evaluate their strength, workability, durability and cost effectiveness. As such there is no documented data of local materials available on the topic in Pakistan. ACI (10) mentions powdered hydrated lime and fly–ash as finely divided admixtures which can be used to improve concrete properties at microstructure level. It is commonly believed by the engineers that the use of such materials is especially desirable for durability purposes. Moreover, lime when added in concrete absorbs CO_2 from the environment thus making it friendly flexible material.

The results of investigation are encouraging especially when the two were used in combination as some weight fraction of cement to make quality and environment friendly concrete.

Key Words: Concrete Lime, Fly–ash, Admixtures, Environment friendly, finely divided, Workability, Corrosion, Carbonation and Durability.

2. INTRODUCTION

It is well known that modification of construction materials always aims at some predetermined and carefully selected objective/(s). The choice of admixtures to be used also depends upon the objective/(s) of modification which may either be for strength, architectural finishes, concrete conveyance, placing, permeability, durability or a combination of these in addition to their availability(1,2)

As reported by ACI (10) titled "Guide for use of Admixtures in/ Concrete", finely divided mineral admixtures include hydrated powdered lime, fly-ash ground quartz, ground limestone, bentonite and talc. If concrete aggregates are deficient in fine particle sizes particularly those passing BS sieve 100 and 200, the use of finely divided mineral admixtures can reduce bleeding and segregation and increase in strength while reverse may also be true if these are used for concrete

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aggregate not deficient in fine aggregates in said range suggesting that its use should be made under supervision of a good material engineer.

Lime and fly-ash as independent admixtures and their combination has been used for modifying the concrete properties and a long term research has been conducted by the researchers to exploit the properties of locally available lime and fly-ash (1, 2). There are huge resources of natural lime available in Pakistan. Lime has been used in the construction industry since prehistoric period but its use in concrete as finely divided admixtures has explored its new properties and uses. There are many misconceptions about form of lime to be used in construction. For use in mortar/concrete, lime was produced by heating calcium carbonate (lime stone, chalk, shells and corals etc) in kiln to a temperature of approximately 900ºC-1100C^0 .At this temperature, CO_2 is driven off and calcium carbonate changes to calcium oxide (quick lime) due to calcinations process(6). When this calcium oxide (CaO) was slaked with water it formed calcium hydroxide or lime putty when excessive water was added. However if adequate amount of water was added with heat supplied it gave powdered hydrated lime of type S when crushed and screened through very fine sieves.

Powdered hydrated lime of type S is basically used in mortars and concrete to reduce the permeability of concrete by filling the pores in concrete. It improves cohesion and achieves economy through cement replacements. It can also be used in hot weather concreting. (7, 8, 14). In addition to mineral admixtures, synthetic polymers can also be used to improve durability and other properties of concrete (11, 12,13). The authors have also carried out research on this type of modified concrete and its details can be found else where (3, 4, 5)

3. FLY–ASH

Fly ash is a byproduct of burning finely divided coal in electrically generating power plants. It is captured from exhaust gases of power plants by electrostatic precipitation, which enables the relatively clean air to escape from smoke. Fly ash is rich in oxides of silica, alumina and iron. Chemically speaking, “FLY ASH LOOKS FOR LIME” when mixed with cement in presence of water. 100 kg of Portland cement when mixed with water liberates12-20 kg of free lime (CaO) during hydration. Fly ash with its chemically active silica and alumina readily reacts with this free lime to form additional cementitious compounds.

When used in concrete, fly ash acts like cement, and actually replaces a percentage of the Portland cement used. Fly ash generally replaces around 15% of cement in much of the concrete used today, but we can do much better by using it to replace up to 50% or more (17) to be known as High Volume Fly Ash Concrete (HVFAC)

Modification with Fly ash usually results in cement savings, increased workability, increased strength after 56 days, increased cohesion of mix, pore refinement, increased frost and chemical resistance and reduced permeability of concrete etc, which makes a high performance concrete. The above desirable properties are achieved because of its spherical shape and fineness. About 40% of fly-ash particles are under 10 microns while size of cement particle is 20 microns.

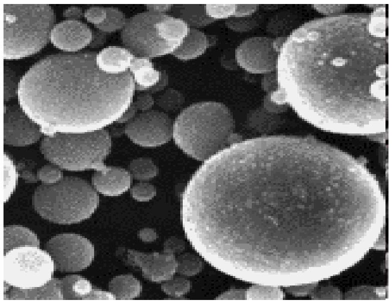

Fig (a) Fly-ash particles at higher magnification. Fig (b) Same at lower magnification

When fly ash is added to the mix, the silica in fly-ash reacts with these large crystals of $Ca(OH)_2$ and transforms them into a strong cement paste that binds concrete together.

$SiO_2 + Ca(OH)_2 \rightarrow CaO.SiO_2.H_2O$ (CSH- calcium silicate hydrate)

This eliminates the micro cracking and creates concrete that is much less permeable, and therefore more durable. Also, a reinforced cement concrete modified with fly-ash will be less prone to less corrosion as it decreases the ingress of water to a greater extent which actually causes the corrosion of rebars in reinforced concrete.

The fly-ash and lime are waste materials which may be a source of environmental concern if allowed to be spread near their place of manufacture. If used properly in construction, it would be an environmentally friendly efficient construction solution. The chemical composition of the fly-ask was a time consuming chemical process and therefore could not be done till the completion of this study.

4. USES OF LIME

There are many misconceptions about uses of powdered hydrated lime in construction industry and valuable research works all over the world and this material has proven to be an important mineral admixture in the construction industry. Lime can be used both in mortars and concretes for a number of useful purposes. Lime imparts a high water retentivity and reduces size of voids by accommodating itself in them. Some researchers have stated that bond strength also increases by using hydrated lime in concrete. Hydrated lime slightly decreases plasticity and workability of concrete. It imparts ease of re-tempering, high water retentivity, resistance against efflorescence, high sand carrying capacity and more flexibility under stress, more bond strength and autogenous healing to the mortars. Also lighter and colored mortars can be made by using hydrated lime along with a suitable pigment.

Uses of lime include soil modification and stabilization, specially in pavements, environmentally friendly construction, papermaking, production of chemicals (sodium alkalis, calcium carbide, calcium hypochlorite, citric acid, petro-chemicals, refractories, sugar refining, glass making, softening of drinking water, sewage treatment, agricultural fertilizers, fungicidal and insecticidal action, steel fluxing, bleaches, separation of cream from whole milk and in handling chicken litter etc.

5. USES OF FLY-ASH

Engineers have an interest in using fly ash on a routine basis to improve the quality of concrete and to increase cost effectiveness**.** Fly ash can compensate for fines not found in some sands and, thereby, enhance pumpability and concrete finishing. It results in a more predictable and consistent finished product which will ensure customer acceptance. It improves the flowability of concrete which translates into less wear and tear on the entire producer's equipment from batching facilities to trucks. Fly ash enables the producer to customize designs to each customer's needs, thus providing the producer who uses it with a competitive advantage. The addition of fly ash to the mix is a built-in insurance for later-age strength gain in concrete and ensures that the concrete will qualify as a durable building material. Fly ash contributes to the aesthetic appearance of the concrete. (15, 16). The workability of fly ash concrete generally ensures that the speed of construction is faster which translates into a quicker return on investment. Since fly ash concrete is not as vulnerable to deterioration or disintegration as rapidly as concrete without fly ash, it ensures low-maintenance buildings which will retain their value over the long-term. Fly ash definitely enhances quality of concrete construction and returns real benefits to every member of the building team.

6. CASTINGS

In order to study the parameters mentioned above for both normal (control), lime modified, fly-ash modified and combination of both lime and fly-ash concretes specimens were cast in both rich and lean concrete mixes i.e 1:1.5:3, 1:2:4and 1:2.5:5 concrete mix proportions by weight having net water-cement ratio (W/C) of 0.6 at a room temperature of 34^0C and relative humidity of 55 %. Locally available Haro sand with a fineness modulus of 2.60 on ASTM Sieve 100 (BS sieve 100) and Margallah crushed stone(lime stone or calcium carbonate) 3/4"or19.5mm down having a fineness modulus of 6.6 on sieve 100 were used. In the lime modified concrete, lime was added to the mixes of concrete of 1:1.5:3, 1:2.5:5 proportions as 10% by weight of cement ACI-211 [10]**.** Details of various types of modified concretes can be seen elsewhere [3, 4, 5)

On the similar lines, concretes were modified with fly-ash and specimens were cast using fly-ash equal to 10% of weight of cement. Mixes with a combination of fly-ash and lime (cocktail) were also cast (5 % lime and 5 % fly-ash) with a total of 10% as addition-not replacement) of weight of cement.

The castings included 100x100x100 mm (4"x 4"x 4 ") cubes and 150mm (6") diameter standard cylinders for compression testing and 50x50x50 mm (2"x 2"x 2") cubes for %age water absorption and durability tests. The coarse aggregates had an apparent specific gravity of 2.63. Coarse aggregates comprised crushed stone (3/4" or 19.5mm down) from Margallah Hills. Fine aggregates consisted of sand of river Haro sand having a fineness modulus of 2.6.Cement; lime and sand were mixed in a pan type mixer in laboratory in the presence of 50% water content to avoid their escape in form of dust. Then coarse aggregates and remaining water content was added. Total mixing time was about 4 minutes. Table 1and 2 give the bulk densities of constituent materials, their specific gravities while Tables 3,4 and 5 give workability test results.

Table No1:- Bulk Densities of Constituent Materials

Material	Loose State (Kg/m^3)/(Lbs/ft^3)	Rodded State(Kg/m^3)/(Lbs/Ft^3)
Haro/Lawrencepur Sand	1433.8 / 89.61	1586.0 / 99.12
Coarse aggregate (19 mm) down)	1418.3 / 88.64	1595.6 / 99.72
Cement	1435.4 / 89.71	Not Determined
Lime	649.8 / 40.61	do
Fly ash	933.58 / 58.31	do
Cocktail(lime+fly-ash)	799.25 / 49.92	do

Table No 2:- Specific Gravities of Constituent Materials.

Material	Specific Gravity
Crush	2.63
Sand	2.63
Cement	3.15
Lime	2.173
Fly-ash	2.562
Cocktail	2.515

Table No-3: Results of Workability Test for Lime Modified Concrete

Type of Test	Type of Mix	W/ C ratio	Normal Concrete	Modified Concrete
Slump Test (in)	1:1.5:3	0.6	2.5	3
	1:2.5:5	0.6	0	0
Compacting Factor Test	1:1.5:3	0.6	0.984	0.99
	1:2.5:5	0.6	0.802	0.763

Table No-4: Results of Workability Test for Fly-Ash Modified Concrete

Type of Test	Type of Mix	W/ C ratio	Normal Concrete	Modified Concrete
Slump Test (in)	1:1.5:3	0.6	2.5	0.5
	1:2.5:5	0.6	0	0
Compacting Factor Test	1:1.5:3	0.6	0.984	0.8
	1:2.5:5	0.6	0.802	0.7

Table No-5: Results of Workability Test for Fly-Ash and Lime Combination Cocktail Modified Concrete.

Type of Test	Type of Mix	W/ C ratio	Normal Concrete	Modified Concrete
Slump Test (in)	1:1.5:3	0.6	2.5	2.8
	1:2.5:5	0.6	0	0
Compacting Factor Test	1:1.5:3	0.6	0.984	0.99
	1:2.5:5	0.6	0.802	0.739

7. CURING OF SPECIMENS

For the first 24 hours after casting, the specimens were kept in moulds at 100% RH in the curing room maintained through showers. They were de-molded after 24 hours. Thereafter all the specimens were kept in water for 28 days. After that, they were taken out of water and kept at normal laboratory conditions and tested at specified ages. Tables 6, 7, 8 and 9 give the results of compressive strength of cylinders and cubes at different ages. Fig Nos 1 and 2 give the age-strength relationships of lime and fly-ash modified concretes.

Table No-6:-Comparative Results of Compressive Strength for Lime Modified Concrete

Mix Design	Lime Added	Size of Specimen	Crushing strength (Psi)			
			3 days	7 days	28 days	56 days
1:2.5:5	10% of cement	6”Φx 12” Cylinders	3137	3925	4713	--
1:2.5:5	10% of cement	4”x 4”x 4”	4838	5110	5600	7163
1:2.5:5 Control Mix	0% of cement	4”x 4”x 4”	2548	3030	3719	5373

Table No-7:- Comparative Results of Compressive Strength for Lime Modified Concrete

Mix Design	Lime Added	Size of Specimen	Crushing strength (Psi)			
			3 days	7 days	28 days	56 days
1:1.5:3	10% of cement	6"Φx 12" Cylinders	2634	2882	3684	-
1:1.5:3	10% of cement	4"x 4"x 4"	3395	4025	4550	6612
1:1.5:3 Control Mix	0% of cement	4"x 4"x 4"	2538	3101	3753	5785

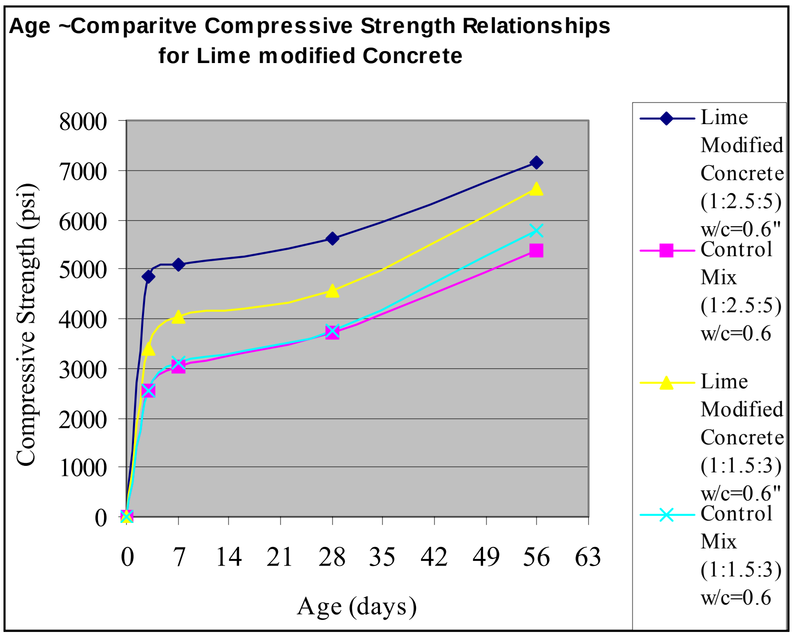

Fig .No. 1 Comparative Compressive strength- Age relationships of lime modified concrete

Table No-8: - Comparative Results of Compressive Strength for Fly-Ash Modified Concrete

Mix Design	Fly-ash Added	Size of Specimen	Crushing strength (Psi)			
			3 days	7 days	28 days	56 days
1:2.5:5	10% of cement	6"Φx 12" Cylinders	1830	2124	3071	--
1:2.5:5	10% of cement	4"x 4"x 4"	3271	3719	4133	4476
1:2.5:5 Control Mix	0% of cement	4"x 4"x 4"	2548	3030	3719	5373

Table No 9:- Comparative Results of Compressive Strength for Fly-Ash Modified Concrete

Mix Design	Fly-ash Added	Size of Specimen	Crushing strength (Psi)			
			3 days	7 days	28 days	56 days
1:1.5:3	10% of cement	6"Φx 12" Cylinders	2445	3407	4015	--
1:1.5:3	10% of cement	4"x 4"x 4"	3271	4375	5131	5650
1:1.5:3 Control Mix	0% of cement	4"x 4"x 4"	2341	3185	3753	5785

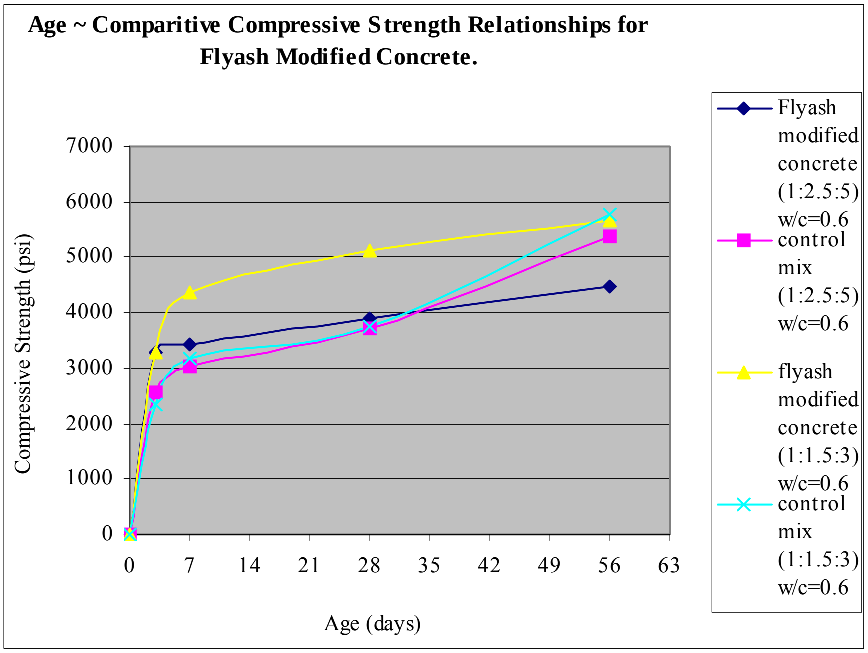

Fig No 2. Comparative compressive strengths of fly-ash modified concrete

Table No-10: Comparative Results of Compressive Strength for Fly-Ash and Lime Combination (cocktail) Modified Concrete

Mix Design	Fly-ash & Lime Combination Added	Size of Specimen	Crushing strength (Psi)			
			3 days	7 days	28 days	56 days
1:2.5:3	Each 5 % of cement	6"Φx 12" Cylinders	2546	2944	4056	--
1:2.5:3	Each 5 % of cement	4"x 4"x 4"	3185	4217	4787	5950
1:2.5:3 Control Mix	0% of cement	4"x 4"x 4"	2391	3255	4030	5373

Table No-11: Comparative Results of Compressive Strength for Fly-Ash and Lime

Combination Modified Concrete

Mix Design	Fly-ash & Lime Combination Added	Size of Specimen	Crushing strength (Psi)			
			3 days	7 days	28 days	56 days
1:1.5:3	Each 5 % of cement	6”Φx 12” Cylinders	2595	3049	4063	--
1:1.5:3	Each 5 % of cement	4”x 4”x 4”	3679	4511	5578	6825
1:1.5:3 Control Mix	0% of cement	4”x 4”x 4”	3376	4235	5062	6832

Tables No 10 Table and 11 give the strength-age relationships for cocktail modified concrete made in 1:2.5: and 1:1.5:3, W/c=0.6

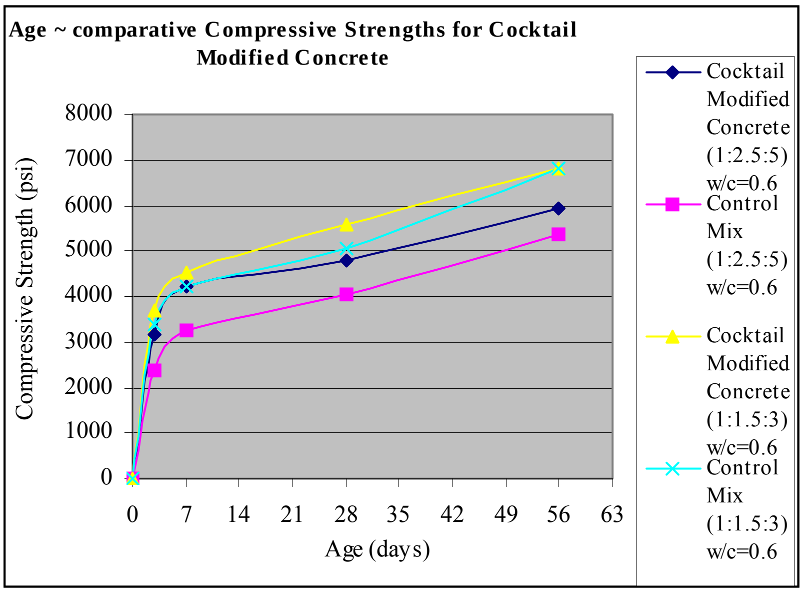

Fig No 3 Strength-age relationships of cocktail modified concretes.

8. CHEMICAL RESISTANCE OF NORMAL AND MODIFIED CONCRETES

Acid resistance test was performed on 2”x2”x2”(50x50x50mm) specimens cut from original 4”x4”x4”(100x100x100mm) cubes against N/2 solutions of HCl, HNO_3 and H_2SO_4. The procedure for making N/2 acid solutions is as follows.

1. Find the density of acid by using specific gravity flask/pycnometer.
2. Determine the percentage purity of acid from standard tables against density values either directly or by interpolation.
3. Find equivalent weight of acid i.e. by using formula,

Equivalent Weight = Molecular weight/number of hydrogen ions.

For example for H_2SO_4, the molecular weight is 98 (2 for H_2, 32 for S and 4x16=64 for O_4) divided by 2(number of hydrogen ions) equals 49.Compute density of 1N solution by following formula. **Density of 1N solution = (equivalent weight of acid x 100) / (density of acid x %age purity of acid)**

1. This density represents the amount of acid in grams to be added in water to make total volume as 1litre.
2. We can determine the volume of acid required by the following expression.
   Volume = Weight / Density

9. TEST PROCEDURE:

The specimens were immersed in acid solution, an immediate reaction took place and after one week, the solution became weaker and was changed. This was repeated four times during 28 days cycle and pH changes were monitored during this cycle by means of pH sticks or by uusing pH meter. After 28 days weight loss indicated degree of vulnerability or indirect durability as per recommendations of international literature (12). The results of acid resistance are given below.

Table No 12- Acid Resistance Test Results 1: 1.5: 3, W/C= 0.6

Acid	Sample	Initial Weight	Weight after 28 Days	% Weight Loss
HCl	lime	292.52	277.6	5.10
	fly-ash	270.72	261.75	3.31
	cocktail	266.62	257.32	3.48
	control	250.17	236.18	5.59
H_2SO_4	lime	270.61	255.94	5.42
	fly-ash	288.65	273.19	5.35
	cocktail	318.58	303.71	4.66
	control	293.8	273.34	6.96
HNO_3	lime	269.6	249.08	7.61
	fly-ash	325.54	287.97	11.54
	cocktail	311.55	291.77	6.34
	control	296.22	285.63	3.57

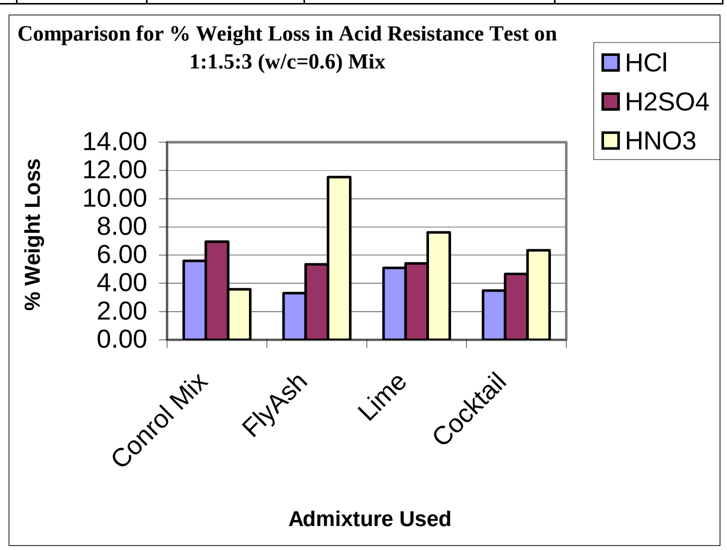

Fig 4 **Results of acid resistance tests on control, lime, fly-ash and cocktail modified concretes of 1:1.5:3.0, w/c = 0.6 concrete**.

Table No. 13:- Acid Resistance Test 1:2.5:5, W/C=0.60

Acid	Sample	Initial Weight	Weight after 28 Days	% Weight Loss
HCl	lime	279.15	269.44	3.48
	fly-ash	277.81	264.08	4.94
	cocktail	260.23	247	5.08
	control	291.85	280.76	3.80
H_2SO_4	lime	319.75	307.7	3.77
	fly-ash	274.22	261.07	4.80
	cocktail	297.84	288.5	3.14
	control	288.36	275.3	4.53
HNO_3	lime	264.56	245	7.39
	fly-ash	272.86	252.08	7.62
	Cocktail	273.12	253.23	7.28
	Control	282.91	263.18	6.97

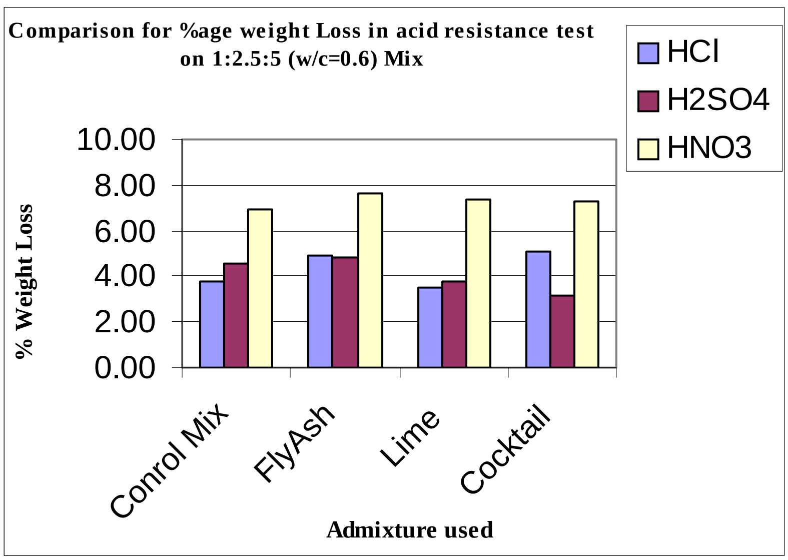

Fig 5. Acid resistance test results on 1:2.5:5.0, w/c=0.6 concrete.

10. DISCUSSION

From the behavior of fly-ash it appeared to be of class F accor4ding to ASTM classification because for class C fly-ash Bulk density is usually low. Increase of workability due to addition of lime may be attributed to its fine-ness and no water demand compared with fly-ash modified concrete in which workability reduces due to water demand of fly-ash. Addition of lime and fly-ash increases the strength of lime and fly-ash modified concretes. This may be understood to be the fact due to "packing effect" of the voids in the products of hydration. Lime and fly-ash modified concretes present variable results for the both mixes against three acids and no well defined conclusion may be made. Against HCL and H_2SO_4 control concrete gives more weight loss while for HNO_3 control concrete gives least weight loss.

11. CONCLUDING REMARKS

1. Use of fly-ash and lime in concrete results in economical-high performance concrete.
2. The results are only for the materials and mix proportions used. For other mix proportions, same results may not be applicable.
3. Compressive strength of concrete increase with an increase in %age of this type of fly-ash and lime as an addition of some percentage of cement in concrete at early ages
4. Permeability, durability and cohesion of concrete in general are improved with the addition of mineral admixtures studied.
5. Workability of concrete is increased when fly ash is added to it but situation is reverse with lime.
6. For better results, it is recommended that lime and fly-ash should be batched on volume basis for mixing in concrete. If taken as a weight percent of cement, lesser percentages may give still better results.
7. From acid resistance tests on cut specimens, it became clear that acids attack severely the coarse aggregates (lime stone). The attack on the paste was that serious for N/2 normality.

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