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An Experimental Investigation on FaL-G Paste

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Abstract: FaL-G is the product name given to a cementitious mixture composed of **F**ly **a**sh (Fa), **L**ime (L) and **G**ypsum (G). It is low-cost and environmental-friendly material very useful in rural housing industry. Since it is manufactured using industrial wastes and by-products, the environmental impacts are mitigated. This paper addresses the technology of making compressed FaL-G paste blocks with low-calcium (Class F) dry fly ash procured from Raichur Thermal Power Plant, Karnataka and sponge iron plant Malur. The cardinal aim is to study the setting and strength characteristics of FaL-G paste. Its applicability as controlled low strength material is also ascertained. The FaL-G paste compressed cylinders were prepared without the use of conventional cement. The compressive strength of FaL-G cylinders were tested with different parameters. It was noticed that the strength of FaL-G paste increases with age and adequate to use it in making deferent composites. FaL-G paste can also be used as controlled low strength material as it has good relative flow area and adequate strength development with age.

Keywords: fly ash, lime, Gypsum, paste, CLSM, compressive strength.

INTRODUCTION

In recent times the emission of carbon dioxide into the air is being increased day by day due to various reasons. This weakens the heat–trapping blanket that surrounds the planet, causing global warming.

Various alternatives can be considered to protect the planet. The rapid increase in the capacity of thermal power generation has resulted in the production of a huge quantity of fly ash. The prevailing disposal methods are not free from environmental pollution and ecological imbalance.

On the other hand, the production of each ton of cement releases an equal amount of carbon dioxide to the atmosphere. The usage of cement can be reduced by using the other possible cementing materials without compromising the strength and durability.

The most basic building material for construction of houses are the usual burnt clay bricks and concrete blcoks. A significant quantity of fuel is utilized in making the bricks. Also, continuous removal of topsoil, in producing conventional bricks creates environmental problems. Cement concrete blocks need conventional cement and not a sustainable material.

There is strong need to adopt cost effective sustainable technologies using local materials and appropriate/intermediate technologies using materials with efficient and effective technology inputs. Different methods are adopted to produce the building blocks using cement, lime-fly ash, lime-slag bindings etc. There is a need to develop simple and highly effective technologies for producing the building blocks.

This is in considering the short supply, increasing cost, energy and environment considerations for traditional and conventional materials. The possibility of using innovative building materials and technologies, using waste material like fly ash has been considered. There is a need to adopt cost-effective and environmentally appropriate technologies by upgrading of traditional technologies, as also using local materials. Building materials is an area where enormous amount of innovation for cost reduction can be achieved.

FaL-G is the product name given to a cementitious mixture composed of **F**ly **a**sh (Fa), **L**ime (L) and **G**ypsum (G). It is low-cost and environmental-friendly material very useful even in rural housing industry. FaL-G in certain proportions, as a building material, is an outcome of innovation to promote large-scale utilization of fly ash by Bhanumathidas and Kalidas **[1]**. It gains strength like any other hydraulic cement, in the presence of water, and is water resistant when hardened.

Large amounts of gypsum and fly ash are available at phosphoric acid manufacturing plants and thermal power plants, respectively. These materials can be used to source sulphate and silica alumina. Gypsum contains impurities of phosphate, fluoride, organic matter and alkalies which prevent its direct use as building material. It is one of the calcium sulphate's rich residues. Phosphogypsum is an important by-product of phosphoric acid fertilizer industry.

It consists of $CaSO_4.2H_2O$ and contains some impurities such as phosphate, fluoride, organic matter and alkalies. Approximately 5 million tons of phosphogypsum is produced each year in India **[2]**. Cementitious binder, FaL-G, finds extensive application in the manufacturing of building components and materials such as bricks, hollow bricks and structural concretes. FaL-G technology enables production of bricks with a simple process of mixing and water curing.

Due to such appropriate technology apart from economy, conservation of energy and pollution control are also

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Vol. 2, Issue 3, March 2015

achieved **[3].** The FaL-G specimens like 50:40:10(flyash:lime:gypsum) with different combination were casted and air dried. The samples were kept for curing under the condition of room temperature . The specimens are cured for 7, 28, 56 and 90 days. The FaL-G material can also be recommended as CLSM i.e., controlled low strength material.

The range of RFA (relative flow area) and Strength development is quite considerable implying that number of trials would be involved in arriving suitable combinations. Since the strength development is influenced by several factors such as type of fly ash, lime, age and characteristics of materials.

FaL-G technology contributes to the conservation of energy and reduces environmental degradation. Since it is manufactured using industrial wastes and by-products of industry, the environmental impacts are mitigated. FaL-G plants have the advantage of continuous year-wide operation and hence provide year-long employment opportunity to skilled artisans.

It creates self-help livelihood opportunities for the people. In certain cases, where by-product lime is not available in adequate quantity, ordinary Portland cement is used as the source of lime, producing the same quality of bricks and blocks.

Scope of research

FaL-G is relatively economical material derived from base materials like fly ash, lime and gypsum. The research reported till date speaks about the random use of the material without any rational approach. The report on proportioning, strength development in FaL-G paste is very less.

This forms the basic of any FaL-G product. Also there is large scope for the development of FaL-G compressed blocks made from mortar. In this paper the study of physical, chemical, setting characteristics and compressive strength of different proportions of FaL-G paste at different ages are studied. The suitability FaL-G as controlled low strength material is also examined.

Materials and Methods

Dry fly ash was procured from Raichur Thermal Power Plant Karnataka (FA1)and sponge iron plant Malur (FA2) The processed fly ash (FA3) used was procured from DIRK company, Nasik. Two different limes were used in the research viz lime Slaked lime(L1) and Readymade lime(L2).

The physical and chemical properties of fly ashes used in this investigation are indicated in **Tables 1 and 2**.Chemical properties of slaked lime, commercially available lime and gypsum are indicated in **Tables 4,5 and 6.**

The chemical composition of fly ash samples FA1 and FA3 are almost same except the particle size. Whereas the sample FA2 is significantly different as the source is different. The major change in the composition is in Al_2O3 and SiO_2. The ratio of SiO_2 and Al_2O_3 of the ashes FA1, and FA3 is around 2 suitable to use for making low CO_2 cements, These fly ash samples satisfy the requirements of IS: 3812[172].

The ash sample FA2 was particularly used to study the impact of chemical and physical composition on the properties of FaL-G paste.

There is variation in the specific gravity and grain size distribution of the ashes. The fly ash FA1 is finer compared to other two types of ashes as there are no particles less than 45 microns.

This can also be confirmed by SEM images as in **Figs 1,3 and 5**. SEM images of the ash indicate that almost all the particles in fly ash are spherical and smooth. The X- ray diffraction (XRD) spectra showed that all the fly ash samples have large diffuse peak at about 20-40^o ($2\theta_{max}$) as indicated in **Figs 2,4and 6**. The study confirms the presence of crystalline phases of Quartz and Mullite in matrix of alumino silicate glass.

Table 1 Chemical Properties of fly ash

Binder	Chemical Composition in percentage							
	Al_2O_3	Fe_2O_3	SiO_2	MgO	SO_3	Na_2O	Total Chlorides	CaO
FA1	31.36	1.5	61.25	0.75	0.53	1.35	0.06	3.20
FA2	57.14	2.1	37.14	1.66	0.4	1.2	0.056	0.3
FA3	30.531	3.91	59.51	1.96	1.091	1.211	0.039	1.74

Table 2 Physical Properties of fly ash

Binder	Specific Gravity	Percentage Finer than 45μ	Fineness, m^2/Kg	Loss on Ignition	Lime reactivity, Mpa
FA1	2.40	0.00	1134.1	0.9	7.23
FA2	2.55	2.46	356	22.85	4.7
FA3	2.40	16.12	350	1.2	5.4

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Vol. 2, Issue 3, March 2015

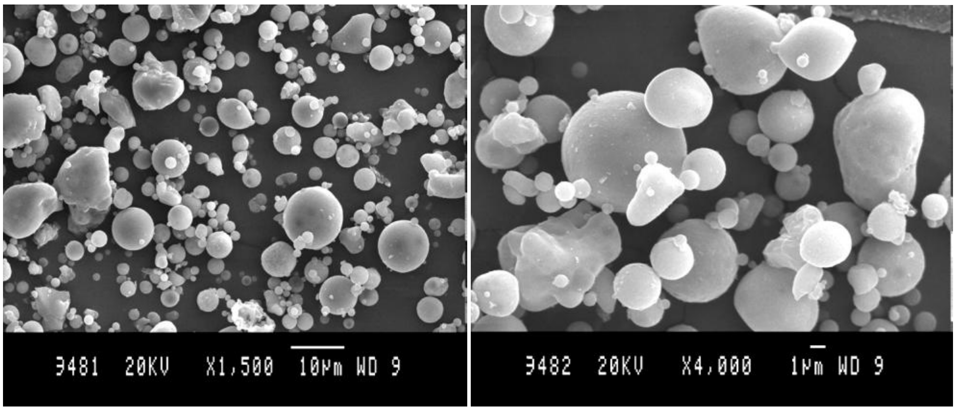
Specific Gravity	Chemical Composition in percentage						
	Al_2O_3	Fe_2O_3	SiO_2	MgO	SO_3	Na_2O	CaO
2.83	0.56	0.2	1.23	3.71	---	-----	94.3

Table 4 Chemical properties of Readymade lime (L2)

Specific Gravity	Chemical Composition in percentage							
	Al_2O_3	Fe_2O_3	SiO_2	MgO	SO_3	Acid insoluble ash	Other acid	CaO
2.77	0.87	0.56	2.79	---	---	5.89	4.41	85.48

Table 5 Chemical properties of Gypsum

Specific Gravity	Chemical Composition in percentage				
	Al_2O_3	Fe_2O_3	SO_3	Na_2O	Other chemical
2.3	0.56	0.05	69.73	1.59	41.9



Magnification 10um Magnification 1um

Fig 1. SEM images of Fly Ash - FA1

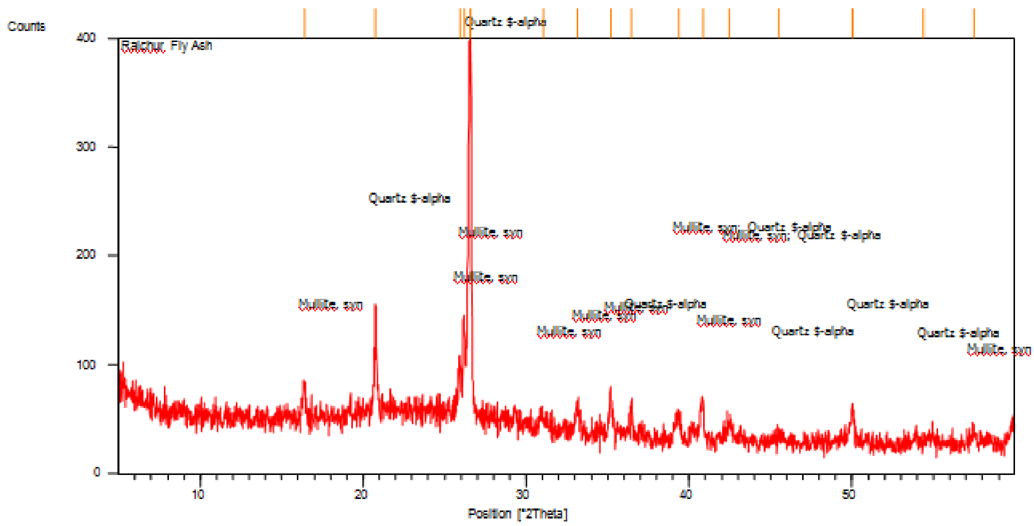


Fig2. X- Ray Diffractogram of fly ash - FA1

ISSN (Online) 2393-8021
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Vol. 2, Issue 3, March 2015

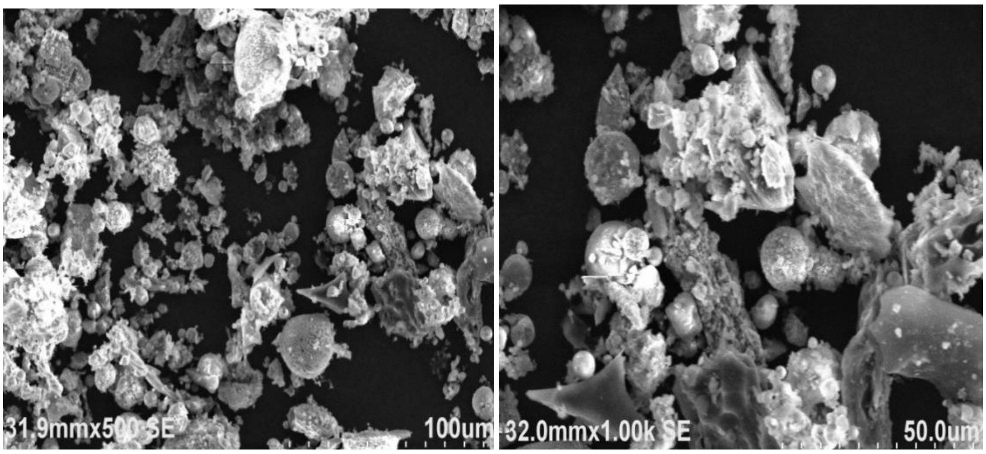


Fig 3. SEM images of Fly Ash – FA2

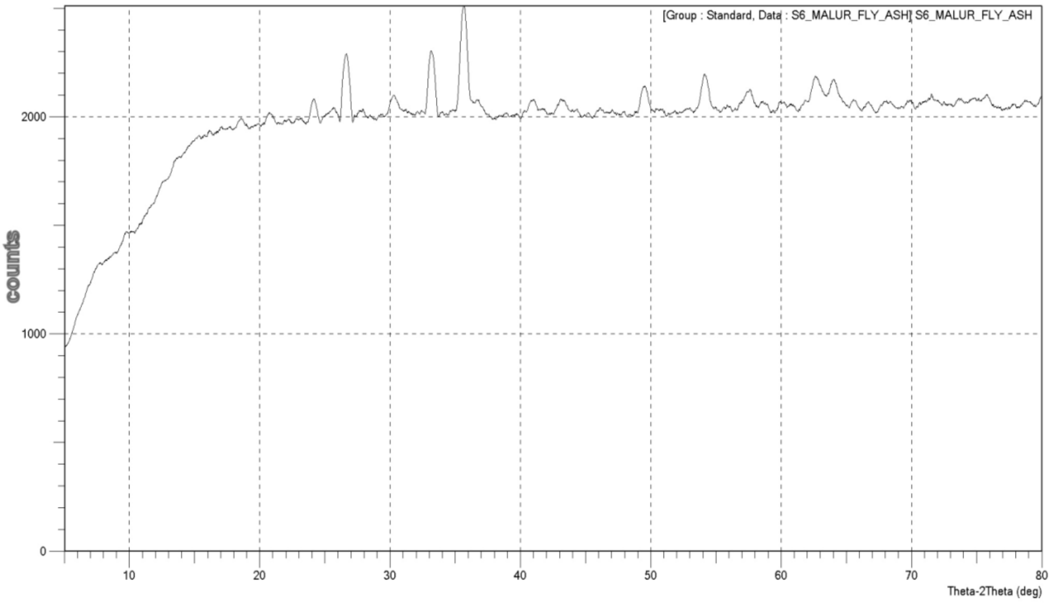
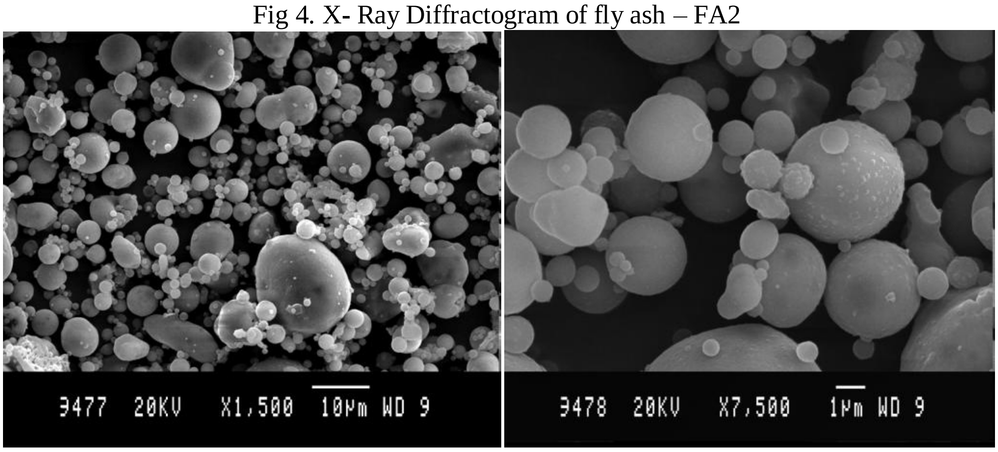


Fig 4. X- Ray Diffractogram of fly ash – FA2



Magnification X1, 500 10um Magnification X7, 500 1um

Fig 5. SEM images of Fly Ash –

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Vol. 2, Issue 3, March 2015

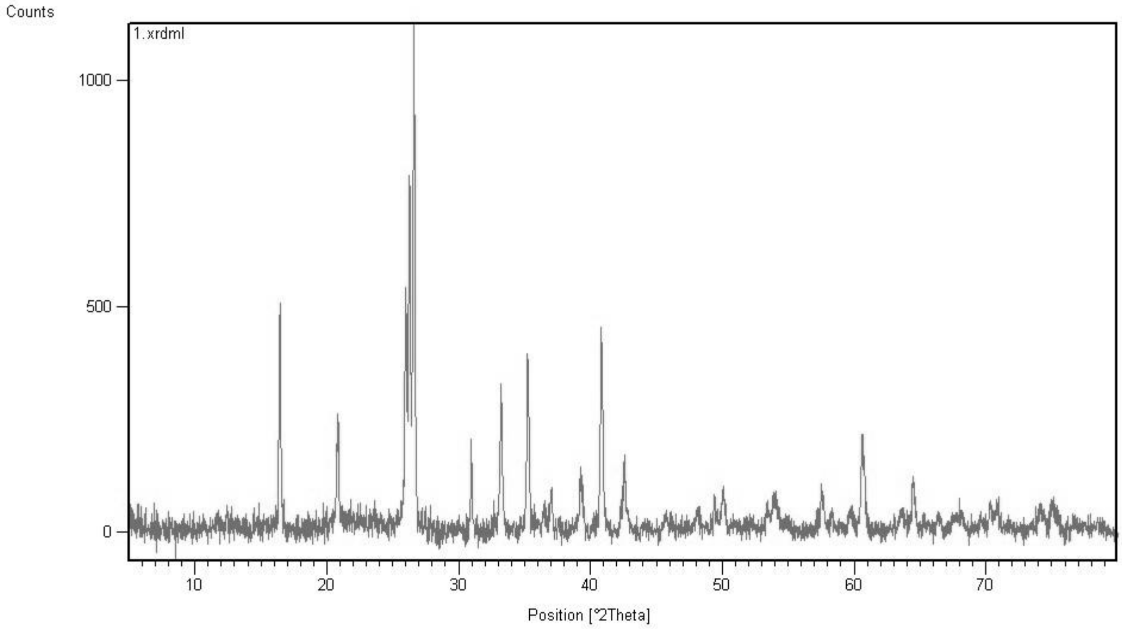

Fig 6.X- Ray Diffractogram of fly ash – FA3

A standard normal consistency test was conducted on FaL-G paste and the water content for the normal consistency was determined. The procedure adopted was the same which is used for conventional cement. FaL-G paste blocks were prepared from base materials fly ash, lime and gypsum. Tap water was used to mix the ingredients. The static compaction device was used to cast the compressed cylinders of diameter 38mm and height 76mm, the volume being 86190 mm^3. This process compresses the wet mix into a specified size and to the required density. The compressed FaL-G cylinders were cured in wet cloth for 28days or till the age of testing whichever is earlier. The cylinders were tested for compression at various ages. FaL-G paste was used to make low strength material. Flow and strength characteristics were determined.Different proportions of FaL-G paste are tabulated in **Table 6.** The paste proportions used in standard consistency test along with different types of lime are tabulated in **Table7**

Table 6. Proportioning of FaL-G paste

Sl no	Specimen ID	Proportions			Water/FaL-G binder ratio
		Fly ash	Lime	Gypsum	
1	FA1	45	45	10	0.2
2	FA1	50	40	10	0.2
3	FA1	55	55	10	0.2
4	FA1	60	30	10	0.2
5	FA2	60	30	10	0.2
6	FA2	70	20	10	0.2
7	FA2	75	15	10	0.2
8	FA3	50	40	10	0.2
9	FA3	55	35	10	0.2

Table 7. FaL-G paste proportions used in standard consistency test

Designation	Proportion of FaL-G	Fly ash type	Lime type
P1	45:45:10	Un-processed Raichur thermal power plant FA1	Slaked lime L1
P2	50:40:10		
P3	55:35:10		
P4	60:30:10		
P5	60:30:10	Un-processed Malur sponge iron plant FA2	Ready Made L2
P6	70:20:10		
P7	75:15:10		
P8	50:40:10	Processed FA3	
P9	55:35:10		

Results and Discussion

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Vol. 2, Issue 3, March 2015

Standard consistency, Initial setting time and Final setting time of FaL-G paste are tabulated in **Table 8** and represented in **Fig 7**. The normal consistency of FaL-G binder is almost same as cement sample. The initial and final setting time is slightly more in slaked lime (L1)when compared to ready made lime(L2).

Table 8 .Standard consistency and setting time of FaL-G paste

Designation	Proportion of FaL-G	Normal consistency %		Initial setting time (hr:min)		Final setting time (hr:min)	
		L1	L2	L1	L2	L1	L2
P1	45:45:10	29	29	2:40	2:15	25:10	24:30
P2	50:40:10	29	30	2:50	2:20	25:15	24:35
P3	55:35:10	30	30	2:55	2:30	25:20	24:40
P4	60:30:10	30	31	2:55	2:35	25:25	24:45
P5	60:30:10	_	30	_	2:05	_	23:35
P6	70:20:10	_	29	_	2:05	_	23:40
P7	75:15:10	_	29	_	2:15	_	23:55
P8	50:40:10	_	30	_	2:05	_	24:10
P9	55:35:10	_	30	_	2:15	_	24:15

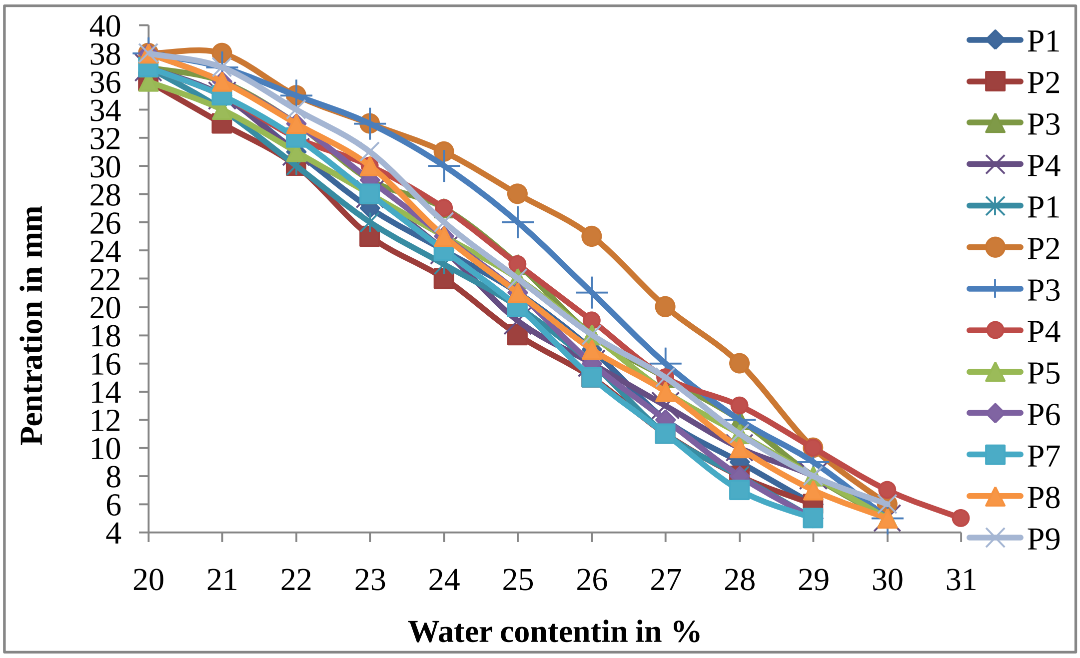

Fig 7.Standard consistency test for different paste proportions in FaL-G

COMPRESSIVE STRENGTH OF FaL-G PASTE

The results of compressive strength of FaL-G paste cylinders was determined at different ages are tabulated in **Table 9.**

It was noticed that FaL-G paste samples made with FA2 developed cracks for different water ratio 0.125, 0.15, 0.175, and 0.2. Hence they were not considered for the strength development study. It was noticed that at constant water-to-FaL-G ratio of 0.2, as strength is higher for the FaL-G samples made from FA1 and FA3 fly ash.

There was gradual increase in strength development for different age in days with different proportions of FaL-G with different fly ash (FA1and FA3) and with lime (L1andL2) as shown in **Figs 8 and 9**. It was noticed that strength development with use of lime (L2) was slightly higher than lime (L1) and airline cracks were observed for FaL-G samples of fly ash (FA2). FA3 fly ash sample in FaL-G specimen has slight increase in strength than FA1 samples

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ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 3, March 2015

Table 9 Compressive strength of FaL-G paste at different age

Designation	Proportion of FaL-G	Compressive Strength in Mpa							
		7days		28 days		56 days		90 days	
		L1	L2	L1	L2	L1	L2	L1	L2
P1(FA1)	45:45:10	0.61	0.68	5.463	6.012	12.914	12.914	14.91	15.283
P2(FA1)	50:40:10	0.726	0.757	5.883	6.189	12.889	13.502	15.515	16.195
P3(FA1)	55:35:10	1.234	1.375	6.342	6.645	13.84	14.277	16.62	16.9
P4(FA1)	60:30:10	0.596	0.726	5.731	5.922	12.545	12.791	15.089	15.21
P8(FA3)	50:40:10	_	0.893	_	6.178	_	13.548	_	16.32
P9(FA3)	55:35:10	_	1.168	_	6.583	_	14.257	_	16.994

NOTE: For P5,P6,P7 of FA2 Malur sponge iron plant fly ash cylindrical specimens casted with static compaction device were observed with air line cracks on the surface of the specime

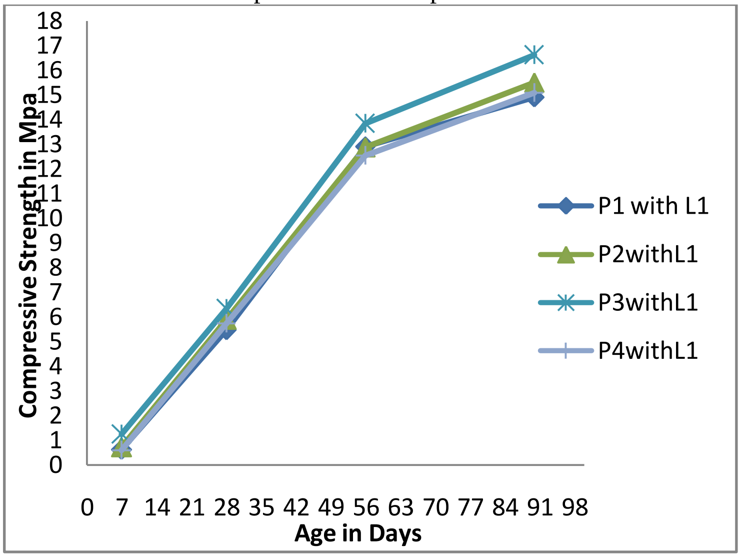

Fig.8 variation of compressive strength with Age

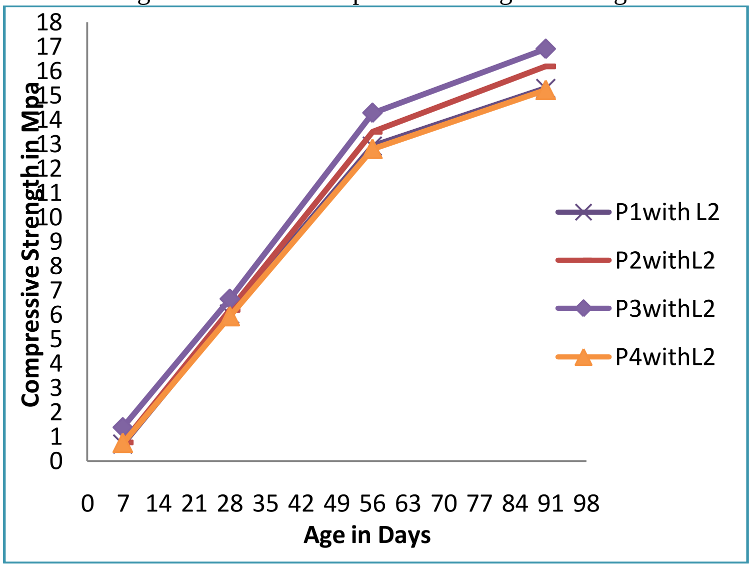

Fig 9 variation of compressive strength with Age

CONTROLLED LOW STRENGTH MATERIALS (CLSM)

It can be seen in **Table10 and 11** that in all the cases of FaL-G the relative flow area increases with increase in water content. In turn the strength decreases with increase in fluid ratios. The range of RFA (relative flow area) and Strength development is quite considerable implying that number of trials would be involved in arriving suitable combinations. Since the strength development is influenced by several factors such as type of fly ash, lime, age and characteristics of materials

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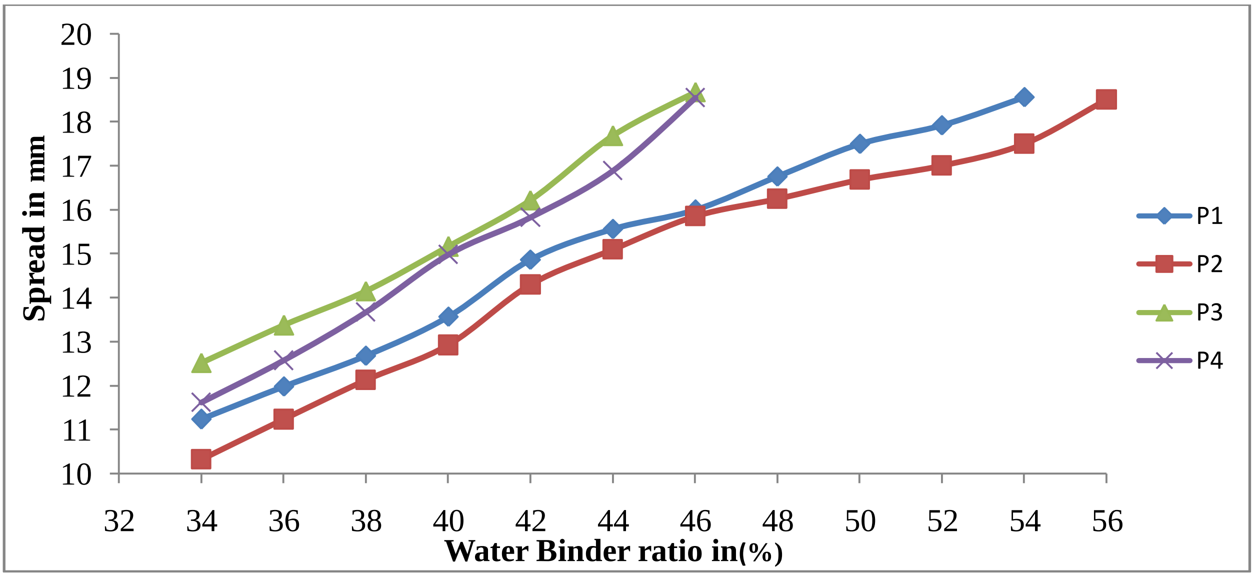
International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 3, March 2015

Table 10 Length of spread

Fly ash	FA1			
Lime	L2			
Designation	P1	P2	P3	P4
Water/Binder ratio	spread in mm			
34	11.23	10.32	12.52	11.62
36	11.98	11.23	13.37	12.57
38	12.68	12.12	14.15	13.67
40	13.57	12.92	15.16	14.98
42	14.86	14.3	16.22	15.82
44	15.56	15.1	17.68	16.89
46	15.99	15.85	18.68	18.54
48	16.76	16.25		
50	17.5	16.68		
52	17.92	17		
54	18.56	17.5		
56		18.5		



variation of spread with water content

Table 11 RFA and Average strength development values at 3, 7, 28 days for different proportions

Designation	Water binder ratio in %	Normalized values			
		RFA(relative flow area)	Avg. Strength in days in Mpa		
			3	7	28
P1	54	5.123	0.417	0.617	5.67
P2	56	5.091	0.481	0.689	6.012
P3	46	5.203	0.519	1.084	6.125
P4	46	5.112	0.435	0.665	5.512

CONCLUSIONS

Based on the experimental works reported in the research, the following conclusion can be made.

- Standard consistency of FaL-G paste decreases with increase in lime content.
- Setting time of FaL-G paste is longer compared to Portland cement.Compressive strength of FaL-G paste increases with age.
- strength development of FaL-G paste varies with proportion. Raichur fly ash (FA1) shows little lesser strength compare to processed fly ash (FA3).

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Vol. 2, Issue 3, March 2015

- Strength gain of FaL-G composites is very slow compared to cement composites.Strength of FaL-G varies with percentage of fly ash content, lime content.
- Micro structural studies show the densification of paste with the age.
- FaL-G paste as CLSM results in good relative flow area (RFA) i.e a reflection of workability and the development of strength with age increases.
- From the above studies and test results it can be concluded that non-cementitious paste can be produced from industrial waste materials like fly ash, lime and gypsum (FaL-G) that can be used as a building material in civil works.

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