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An Experimental Study on Effect of Silica Fume & Fly Ash in Slag Concrete

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ABSTRACT

Concrete is the most versatile construction material because it can be designed to withstand the harshest environments while taking on the most inspirational forms. Engineers are continually pushing the limits to improve its performance with the help of innovative chemical admixtures and supplementary cementitious materials. Nowadays, most concrete mixture contains supplementary cementitious material which forms part of the cementitious component. These materials are majority byproducts from other processes. The main benefits of SCMs are their ability to replace certain amount of cement and still able to display cementitious property, thus reducing the cost of using Portland cement. The fast growth in industrialization has resulted in tons and tons of byproduct or waste materials, which can be used as SCMs such as fly ash, silica fume, ground granulated blast furnace slag, steel slag etc. The use of these byproducts not only helps to utilize these waste materials but also enhances the properties of concrete in fresh and hydrated states. Slag cement and fly ash are the two most common SCMs used in concrete. Most concrete produced today includes one or both of these materials. For this reason their properties are frequently compared to each other by mix designers seeking to optimize concrete mixtures. Perhaps the most successful SCM is silica fume because it improves both strength and durability of concrete to such extent that modern design rules call for the addition of silica fume for design of high strength concrete. To design high strength concrete good quality aggregates is also required. Steel slag is an industrial byproduct obtained from the steel manufacturing industry. This can be used as aggregate in concrete. It is currently used as aggregate in hot mix asphalt surface applications, but there is a need for some additional work to determine the feasibility of utilizing this industrial byproduct more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture. Replacing all or some portion of natural aggregates with steel slag would lead to considerable environmental benefits. Steel slag aggregate generally exhibit a propensity to expand because of the presence of free lime and magnesium oxides hence steel slag aggregates are not used in concrete making. Proper weathering treatment and use of pozzolanic materials like silica fume with steel slag is reported to reduce the expansion of the concrete. However, all these materials have certain shortfalls but a proper combination of them can compensate each other's drawbacks which may result in a good matrix product with enhance overall quality.

INTRODUCTION:

Concrete is a mixture of cement, sand, coarse aggregate and water. Its success lies in its versatility as can be designed to withstand harshest environments while taking on the most inspirational forms. Engineers and scientists are further trying to increase its limits with the help of innovative chemical admixtures and various supplementary cementitious materials SCMs [1].

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Early SCMs consisted of natural, readily available materials like volcanic ash or diatomaceous earth. The engineering marvels like Roman aqueducts, the Coliseum are examples of this technique used by Greeks and Romans. Nowadays, most concrete mixture contains SCMs which are mainly byproducts or waste materials from other industrial processes [2].

SUPPLEMENTARY CEMENTITIOUS MATERIAL:

More recently, strict environmental – pollution controls and regulations have produced an increase in the industrial wastes and sub graded byproducts which can be used as SCMs such as fly ash, silica fume, ground granulated blast furnace slag etc. The use of SCMs in concrete constructions not only prevent these materials to check the pollution but also to enhance the properties of concrete in fresh and hydrated states.

The SCMs can be divided in two categories based on their type of reaction : hydraulic and pozzolanic. Hydraulic materials react directly with water to form cementitious compound like GGBS. Pozzolanic materials do not have any cementitious property but when used with cement or lime react with calcium hydroxide to form products possessing cementitious prosperities.

Ground granulated blast furnace Slag: It is hydraulic type of SCM.

Ground granulated blast furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag ,a by-product of iron and steel making from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder [3].

Ground granulated blast furnace slag (GGBFS) has been utilized for many years as an additional cementitious material in Portland cement concretes, either as a mineral admixture or as a component of blended cement. Granulated blast furnace slag typically replaces 35–65% Portland cement in concrete. The use of GGBFS as a partial replacement of ordinary Portland cement improves strength and durability of concrete by creating a denser matrix and thereby increasing the service life of concrete structures. It has a higher proportion of the strength-enhancing calcium silicate hydrates (CSH) than concrete made with Portland cement only, and a reduced content of free lime, which does not contribute to concrete strength [4].

Fly ash: It is pozzalanic SC material.

Fly ash is one of the residues generated in the combustion of coal. Fly ash is generally captured from the chimneys of coal-fired power plants, and is one of two types of ash that jointly are known as coal ash; the other, bottom ash, is removed from the bottom of coal furnaces. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO). Fly ash is classified as Class F and Class C types [7].

The replacement of Portland cement with fly ash is considered to reduce the greenhouse gas "footprint" of concrete, as the production of one ton of Portland cement produces approximately one ton of CO_2 as compared to zero CO_2 being produced using existing fly ash. New fly ash production, i.e., the burning of coal, produces approximately twenty to thirty tons of CO_2 per ton of fly ash [5].

Since the worldwide production of Portland cement is expected to reach nearly 2 billion tons by 2010, replacement of any large portion of this cement by fly ash could significantly reduce carbon emissions associated with construction.

It has been used successfully to replace Portland cement up to 30% by mass, without adversely affecting the strength and durability of concrete. Several laboratory and field investigations involving concrete containing fly ash had reported to exhibit excellent mechanical and durability properties. However, the pozzolanic reaction of fly ash being a slow process, its contribution

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Silica Fume: It is also a type of pozzolanic material.
Silica fume is a byproduct in the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Silica fume consists of fine particles with a surface area on the order of 215,280 ft²/lb (20,000 m²/kg) when measured by nitrogen adsorption techniques, with particles approximately one hundredth the size of the average cement Because of its extreme fineness and high silica content, silica fume is a very effective pozzolanic material particle [6].

Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance. These improvements stems from both the mechanical improvements resulting from addition of a very fine powder to the cement paste mix as well as from the pozzolanic reactions between the silica fume and free calcium hydroxide in the paste. Addition of silica fume also reduces the permeability of concrete to chloride ions, which protects the reinforcing steel of concrete from corrosion, especially in chloride-rich environments such as coastal regions .When silica fume is incorporated, the rate of cement hydration increases at the early hours due to the release of OH ÿ ions and alkalis into the pore fluid. The increased rate of hydration may be attributable to the ability of silica fume to provide nucleating sites to precipitating hydration products like lime, C±S±H, and ettringite. It has been reported that the pozzolanic reaction of silica fume is very significant and the non-evaporable water content decreases between 90 and 550 days at low water /binder ratios with the addition of silica fume.

During the last decade, considerable attention has been given to the use of silica fume as a partial replacement of cement to produce high-strength concrete.

STEEL SLAG:

The Steel slag, a byproduct of steel making, is produced during the separation of molten steel from impurities in steel making furnaces. This can be used as aggregate in concrete. Steel slag aggregate generally exhibit a propensity to expand because of the presence of free lime and magnesium oxides that have not reacted with the silicate structure and that can hydrated and expand in humid environments. This potentially expansive nature (volume changes up to 10 percent or more attributable to the hydration of calcium and magnesium oxides) could cause difficulties with products containing steel slag, and is one reason why steel slag aggregate are not used in concrete construction. Steel slag is currently used as aggregate in hot mix asphalt surface applications, but there is a need for some additional work to determine the feasibility of utilizing this industrial by-product more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture. Most of the volume of concrete is aggregates. Replacing all or some portion of natural aggregates with steel slag would lead to considerable environmental benefits. Steel slag has high specific gravity, high abrasion value than naturally available aggregate apart from the drawbacks like more water absorption, high alkalis. Therefore with proper treatments it can be used as coarse aggregate in concrete [8].

The production of a HSC may be hampered if the aggregates are weak. Weak and marginal aggregates are widespread in many parts of the world and there is a concern as to the production of HSC in those regions. Incorporation of silica fume is one of the methods of enhancing the strength of concrete, particularly when the aggregates are of low quality.

MATERIALS AND METHODOLOGY

Silica Fume

Silica fume is a byproduct in the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Silica fume consists of fine particles with a surface area on the order of 215,280 ft²/lb (20,000 m²/kg) when measured by nitrogen adsorption techniques, with particles approximately one hundredth the size of the average cement Because of its extreme fineness and high silica

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Steel Slag

Steel slag is the residue of steel production process and composed of silicates and oxides of unwanted elements in steel chemical composition. Fifty million tons per year of LD slag were produced as a residue from Basic Oxygen Process (BOP) in the world.

In order to use these slags in cement, its hydraulic properties should be known. Chemical composition is one of the important parameters determining the hydraulic properties of the slags. In general, it is assumed that the higher the alkalinity, the higher the hydraulic properties. If alkalinity is> 1.8, it should be considered as cementitious material [10].

Investigations were carried out also on the usability of steel slag as construction material under laboratory and practical conditions. For this application, the required properties are high compression strength, wear strength and resistance to climatic conditions. The most important criterion is volume stability, in which free CaO and MgO contents of the slag play an important role. Both oxides can go into reaction with water. Hydration causes volume expansion and affects stability of volume. This is one reason why steel slag aggregate are not suitable for use in Portland cement concrete b. But at the moment, most steel slag being used as unbound aggregate for ashphalt concrete pavement in many countries.

XRD Analysis of Steel slag.

From XRD Analysis of steel slag we can find what type Alkalis present. These are tabulated in Table No 3.5.

Table No.3.5

Chemical Compound	Visible	Ref-Code	Score
Na_2O	Yes	03-1074	10
K_2O	Yes	77-2176	10

From above table we can conclude that some amount of Alkalis present in steel slag.

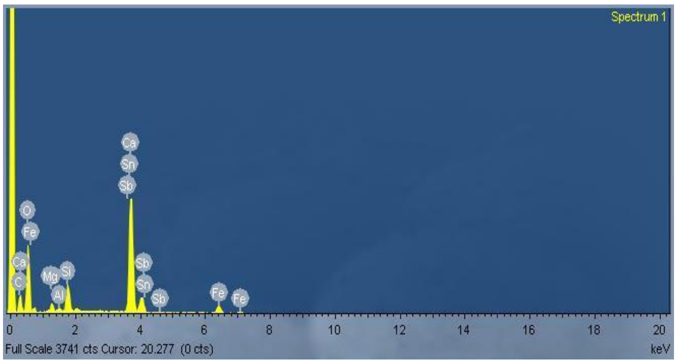

Figure 3.1 XRD Analysis of Steel Slag

Fly ash cement

Fly ash, which is largely made up of silicon dioxide and calcium oxide, can be used as a substitute for Portland cement, or as a supplement to it. The materials which make up fly ash are pozzolanic, meaning that they can be used to bind cement materials together. Pozzolanic materials, including fly ash cement, add durability and strength to concrete [11].

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Fly ash cement is also known as green concrete. It binds the toxic chemicals that are present in the fly ash in a way that should prevent them from contaminating natural resources. Using fly ash cement in place of or in addition to Portland cement uses less energy, requires less invasive mining, and reduces both resource consumption and CO2 emissions [12].

SLAG CEMENT

Slag cement has been used in concrete projects in the United States for over a century. Earlier usage of slag cement in Europe and elsewhere demonstrates that long-term concrete performance is enhanced in many ways. Based on these early experiences, modern designers have found that these improved durability characteristics help further reduce life-cycle costs, lower maintenance costs and makes concrete more sustainable. For more information on how slag cement is manufactured and it enhances the durability and sustainability of concrete.

SAND

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. The most common constituent of sand, in inland continental settings and non-tropical coastal settings, is silica(silicon dioxide, or SiO2), usually in the form of quartz which, because of its chemical inertness and considerable hardness, is the most common mineral resistant to weathering.It is used as fine aggregate in concrete [13].

METHODOLOGY

TEST PROCEDURE:

The Experimental programme was carried out in two stages

Stage 1: Experimental work were conducted on mortar mixes by using different binder mix modified with different percentages of silica fume.

Stage2: Experimental works were conducted on steel slag concrete mixes by using different binder mix modified with different percentages of silica fume.

Stage 1: This experimental investigation was carried out for three different combinations of slag cement and fly ash cement. In each combination three different proportion of silica fume had been added along with the controlled mix without silica fume [15].

Binders being used were different combinations of slag cement, fly ash cement in the proportions 1:0, 0:1 and 1:1 hence total three combinations. Further in each type of combination of binder mix 0%,10 % and 20 % percentage of silica fume had been added. Hence total 12 sets of mortar of 1:3 proportion were prepared by mixing one part of binder mix and three parts of naturally available sand.

Stage2: Here concrete is prepared with three different types of binder mix with silica fume.

A: DETERMINATION OF STRENGTH OF CONCRETE OF 1:1.5:3 MIX PROPORTION BY USING FLY ASH CEMENT + SILICA FUME AS BINDER MIX ,SAND AS FINE AGGREGATE AND STEEL SLAG AS COARSE AGGREGATE.

In this phase concrete of mix proportion 1 : 1.5 : 3 will be prepared by using fly ash cement + silica fume as binder mix with different proportion of silica fume, sand as fine aggregate and steel slag as coarse aggregate. The different proportion of silica fume in the concrete mix will vary from 0%, 10%, and 20%. The concrete mixes will be tested for following strengths.

- Compressive strength after 7 days,28 days, 56 days
- Porosity test after 28 days and 56 days
- Capillary absorption test after 28 days and 56 days
- Wet - dry test after 26 days and 56 days

Compressive strength by Rebound hammer method.

B: DETERMINATION OF STRENGTH OF CONCRETE OF 1:1.5:3 MIX PROPORTION BY USING SLAG CEMENT+SILICA FUME AS BINDER,SAND AS FINE AGGREGATE AND STEEL SLAG AS COARSE AGGREGATE

In this phase concrete of mix proportion 1 : 1.5 : 3 will be prepared by using slag cement + silica fume as binder mix with different proportion of silica fume ,sand as fine aggregate and steel slag as coarse aggregate. The proportion of silica fume in the concrete mix will vary from 0% , 10% and 20 % of the blend. The concrete mixes will be tested for following strengths.

- Compressive strength after 7 days,28 days, 56 days
- Flexural strength after 28 days, 56 days
- Compressive strength by Rebound hammer method.
- Porosity test after 28 days and 56 days
- Capillary absorption test after 28 days and 56 days
- Wet - dry test after 28 days and 56 days.

C: DETERMINATION OF STRENGTH OF CONCRETE OF 1:1.5:3 MIX PROPORTION BY USING FLY ASH CEMENT+SLAG CEMENT + SILICA FUME AS BINDER MIX ,SAND AS FINE AGGREGATE AND STEEL SLAG AS COARSE AGGREGATE.

In this phase concrete of mix proportion 1 : 1.5 : 3 will be prepared by using fly ash cement + slag cement + silica fume as binder mix with different proportion of silica fume, sand as fine aggregate and steel slag as coarse aggregate. The different proportion of silica fume in the concrete mix will vary from 0%,10%, and 20%. The concrete mixes will be tested for following strengths.

- Compressive strength after 7 days,28 days, 56 days
- Flexural strength after 28 days, 56 days
- Porosity test after 28 days and 56 days
- Capillary absorption test after 28 days and 56 days
- Wet - dry test after 26 days and 56 days
- Compressive strength by Rebound hammer method.

RESULTS AND DISCUSSIONS

EXPERIMENTAL STUDY ON MORTAR.

Here we prepared mortar with ratio 1:3 from different types of cement + silica fume replacement as binder mix and sand as fine aggregate. Then its physical properties like capillary absorption consistency, compressive strength and porosity was predicted. These test results both in tabular form and graphical presentation are given below.

Normal Consistency for Mortar.

Normal consistency of different binder mixes was determined using the following procedure referring to IS 4031: part 4 (1988):

- 300 gm of sample coarser than 150 micron sieve is taken.
- Approximate percentage of water was added to the sample and was mixed thoroughly for 2-3 minutes.
- Paste was placed in the vicat"s mould and was kept under the needle of vicat"s apparatus.
- Needle was released quickly after making it touch the surface of the sample.
- Check was made whether the reading was coming in between 5-7 mm or not and same process was repeated if not
- The percentage of water with which the above condition is satisfied is called normal consistency.
- Normal consistency of different binder mixes were tabulated below in Table No. 4.1.

Table No.4.1

Mix	Description	Cement (grams)	Silica fume (gram s)	Consistency (%)
SC0	SC	300	00	31.5
SC10	SC with 10% SF	270	30	35
SC20	SC with 20% SF	240	60	40.5
FC0	FC	300	00	37.5
FC10	FC with 10% SF	270	30	47
FC20	FC with 20% SF	240	60	55.5
SFC0	SC:FC (1:1)	150 each	00	36.5
SFC10	SC:FC (1:1) with 10% SF	135 each	30	41.5
SFC20	SC:FC (1:1) with 20% SF	120 each	60	47.5

Where, SC = slag cement FC = fly ash cement
SF = silica fume
SFC = slag and fly ash cement
SC0 = Slag cement with 0% silica fume replacement.
SC10 = Slag cement with 10% silica fume replacement.

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From the above table we can conclude that water requirement increases with increase in percentage of replacement by silica fume and fly ash cement consumes more water due to its fineness. Water requirement or normal consistency of a binder mix increases with increment in percentage of silica fume replacement.
Water requirement in case of fly ash cement binder mix is more because it is finer when compared to slag cement.

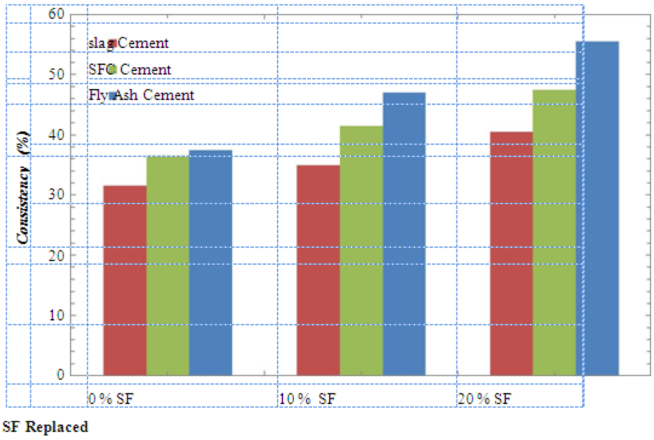

Figure.4.1 Consistency of Mortar.

From the above graph we can conclude that water requirement increases with increase in percentage of replacement by silica fume and fly ash cement consumes more water due to its fineness. Water requirement or normal consistency of a binder mix increases with increment in percentage of silica fume replacement.

EXPERIMENTAL STUDY ON CONCRETE CUBE.

Here we prepared concrete with ratio 1:1.5:3 from different types of cement + silica fume replacement as binder mix, sand as fine aggregate and steel slag as coarse aggregate. Then its physical properties like capillary absorption, water/cement ratio, compressive strength, porosity, flexural strength, and wet-dry test was predicted. These test results both in tabular form and graphical presentation are given below.

Water /Cement Ratio and Slump.

The water cement ratio and slump of steel slag concrete with different binder mix with silica fume replacement is given below.

Table No. 4.6

Type of cement	% of SF Replaced	W/C Ratio	Slump in (mm)
Fly ash cement		0.51	52
	0		
		0.58	52
	10		
		0.591	58
	20		
Slag cement	0	0.47	63
	10	0.518	50
	20	0.581	55
Slag and fly ash	0	0.489	60
cement blend (1:1)			
	10	0.543	53
	20	0.544	52

From the above table we concluded that W/C ratio increases with increase in silica fume replacement. Because silica fume consumes more water.

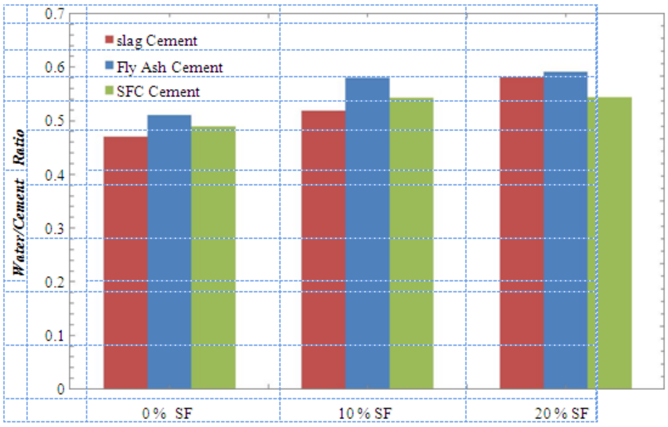

Figure.4.8 Water Cement Ratio for steel slag concrete

CONCLUSION

From the present study the following conclusions are drawn:

1.Inclusion of silica fume improves the strength of different types of binder mix by making them more denser.

2.Addition of silica fume improves the early strength gain of fly ash cement whereas it increases the later age strength of slag cement.

3.The equal blend of slag and fly ash cements improves overall strength development at any stage.

4.Addition of silica fume to any binder mix reduces capillary absorption and porosity because fine particles of silica fume reacts with lime present in cement and form hydrates dancer and crystalline in composition.

5.The capillary absorption and porosity decreases with increase dose up to 20% replacement of silica fume for mortar.

6.Addition of silica fume to the concrete containing steel slag as coarse aggregate reduces the strength of concrete at any age.

7.This is due to the formation of voids during mixing and compacting the concrete mix in vibration table because silica fume make the mixture sticky or more cohesive which do not allow the entrapped air to escape. The use of needle vibrator may help to minimize this problem.

8.The most important reason of reduction in strength is due to alkali aggregate reaction between binder matrix and the steel slag used as coarse aggregate. By nature cement paste is alkaline. The presence of alkalis Na2O, K2O in the steel slag make the

concrete more alkaline. When silica fume is added to the concrete, silica present in the silica fume react with the alkalis and lime and form a gel which harm the bond between aggregate and the binder matrix. This decrease is more prominent with higher dose of silica fume.

9.Combination of fly ash cement and silica fume makes the concrete more cohesive or sticky than the concrete containing slag cement and silica fume causing formation of more voids with fly ash cement. Therefore the concrete mixes containing fly ash and silica fume show higher capillary absorption and porosity than concrete mixescontaining slag cement and silica fume.

10.The total replacement of natural coarse aggregate by steel slag is not recommended in concrete. A partial replacement with fly ash cement may help to produce high strength concrete with properly treated steel slag.

11.The steel slag should be properly treated by stock piling it in open for at least one year to allow the free CaO & MgO to hydrate and thereby to reduce the expansion in later age.

12.A thorough chemical analysis of the steel slag is recommended to find out the presence of alkalis which may adversely affect to the bond between binder matrix and the aggregate.

REFERENCES

[1]. Thanongsak, N., Watcharapong, W., and Chaipanich. A., (2009), “Utilization of fly ash with silica fume and properties of Portland cement–fly ash–silica fume concrete”. Fuel, Volume 89, Issue 3, March 2010, Pages 768-774.

[2]. Patel, A, Singh, S.P, Murmoo, M. (2009), “Evaluation of strength characteristics of steel slag hydrated matrix” Proceedings of Civil Engineering Conference-Innovation without limits (CEC-09), 18th - 19th September‟ 2009.

[3].Li Yun-feng, Yao Yan, Wang Ling, “Recycling of industrial waste and performance of steel slag green concrete”, J. Cent. South Univ. Technol.(2009) 16: 8−0773, DOI: 10.1007/s11771-009-0128-x.

[4]. Velosa, A.L, and Cachim, P.B.,” Hydraulic lime based concrete: Strength development using a pozzolanic addition and different curing conditions” ,Construction and Building Materials ,Vol.23,Issue5,May2009,pp.2107-2111.

[5]. Barbhuiya S.A., Gbagbo, J.K., Russeli, M.I., Basheer, P.A.M. “Properties of fly ash concrete modified with hydrated lime and silica fume”, aCentre for Built Environment Research, School of Planning, Architecture and Civil Engineering, Queen‟s University Belfast, Northern Ireland BT7 1NN, United Kingdom Received 28 January 2009; revised 1 June 2009; accepted 3 June 2009. Available online 15 July 2009.

[6]. Gonen,T. and Yazicioglu,S. “ The influence of mineral admixtures on the short and long term performances of concrete” department of construction education, Firat University, Elazig 23119, Turkey.2009.

[7]. Mateusz R.J. O. and Tommy N. “ Effect of composition and Initial Curing Conditions of Scaling Resistance of Ternary(OPC/FA/SF) concrete”, Journal of Materials in Civil Engineering © ASCE/October 2008, PP 668-677.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

[8]. Chang-long,W QI, Yan-ming,He Jin-yun, "Experimental Study on Steel Slag and Slag Replacing Sand in Concrete", 2008, International Workshop on Modelling, Simulation and Optimization.

[9]. Jigar P. Patel, "Broader use of steel slag aggregates in concrete", M.Tech.thesis, Cleveland State University, December, 2008.

[10]. N.P. Rajamane *, J. Annie Peter, P.S. Ambily," Prediction of compressive strength of concrete with fly ash as sand replacement material". Cement and Concrete Composites, Volume 29, Issue 3, March 2007, Pages 218-223.

[11]. Abdullah A. Almusallam, Hamoud Beshr, Mohammed Maslehuddin, Omar S.B. Al-Amoudi,, "Effect of silica fume on the mechanical properties of low quality coarse aggregate concrete", Cement & Concrete Composites 26 (2004) 891–900.

[12]. Turkmen.I," Influence of different curing conditions on the physical and mechanical properties of concrete with admixtures of silica fume and blast furnace slag", Materials Letters 57 (2003), pp.4560-4569.Article/ View Record in Scopus/Cited by in Scopus(9).

[13]. Tasdemir,C," Combined effects of mineral admixtures and curing conditions on the sorptivity coefficient of concrete", cement and concrete research 33(2003), pp. 1637-1642.

[14]. Thomas , M. D. A. and Shehata, M. H. " Use of ternary cementitious systems containing silica fume and fly ash in concrete "; cementand concrete research 29 (1999).

[15]. Bijen, J. " Benefits of slag and fly ash " construction and building materials , vol. 10, no.5, pp. 309-314, 1996.