Experimental investigation of Low-Calcium Fly Ash-Based Geopolymer Concrete Reinforced with steel fibers

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I. Introduction

Concrete usage around the globe is second only to water. An important ingredient in the conventional concrete is the Portland cement. The production of one ton of cement emits approximately one ton of carbon dioxide to the atmosphere. Moreover, cement production is not only highly energy-intensive, next to steel and Aluminium, but also consumes significant amount of natural resources. In order to meet infrastructure developments, the usage of concrete is on the increase. Do we build additional cement plants to meet this increase in demand for concrete, or find alternative binders to make concrete? We have conducted some research on the manufacture and behavior, of "Low-Calcium Fly Ash-Based Geopolymer Concrete Reinforced with steel fibres". This concrete uses no Portland cement; instead, we use the low-calcium fly ash from a local coal burning power station as a source material to make the binder necessary to manufacture concrete. This study is aimed to know the compressive strength of concrete using the basic materials like Fine Aggregate, Coarse Aggregate and the binder material as fly ash the flexural strength study between the geopolymer concrete with and without steel fiber. Various properties like Workability, Initial setting time, compressive strength and Split tensile Strength has been studied are to be compared with geopolymer concrete with and without steel fibre.

LITERATURE REVIEW

Various journals, articles and conference papers related composite construction, materials used in the construction, etc. have been referred for the purpose of developing ideas for the research work. Data from websites of the kind of informative types, advertisement types, blogs, groups, etc. have been considered and incorporated in the report work as well. Some of the informative data collected from certain journals and conference papers are summarized and given below.

DEVELOPMENT OF FLY ASH-BASED GEOPOLYMER CONCRETE:

PROGRESS AND RESEARCH NEEDS

Djwantoro Hardjito and B.Vijaya Rangan

Research on low-calcium fly ash-based geopolymer concrete, sometimes called 'concrete with no cement', has been attracting significant attention. Geopolymer concrete offers a solution for the need of 'greener' construction material in the midst of the environmental concern on the production of ordinary Portland cement (OPC). In the last five years, numerous reports on geopolymer concrete have been published. This paper reviews the progress of development, discusses the present status, and explores the research needs

MICROSTRUCTURE AND FLEXURAL PROPERTIES OF GEOPOLYMER MATRIX-FIBRE REINFORCED COMPOSITE WITH ADDITIVES OF ALUMINA (Al_2O_3) NANOFIBRES BORTNOVSKY

In 1979, when Davidovits first introduced the term ''geopolymers'' to designate a new class of three-dimensional alumino-slilicate materials, geopolymers have attracted the interest of scientists due to their excellent mechanical and thermal properties, low density, low cost, as well as chemical and fire resistance [1-3]. The aim of this study is an investigation and comparing the influence of alumina (Al_2O_3) nanofibres additives on flexural strength (_f),flexural modulus (Ef) and relative deformation (A) of geopolymer composites reinforced with unidirectional fibres. Microstructural observations have been carried out by means of scanning electron microscopy (SEM) and energy-dispersive X-ray analysis (EDX).

. PERFORMANCE OF GEOPOLYMERIC CONCRETE REINFORCED WITH STEEL FIBERS

Susan, Bernal; Ruby, De Gutierrez, Silvio, Delvasto, Erich, Rodriguez

The purpose of this paper is to present the results of the development of fracture toughness to early ages of geopolymeric concrete (GEOCONCRETE) reinforced with steel fibers, based in a Colombian granulated blast furnace slag (GBFS) activated with waterglass ($Na_2SiO_3.nH_2O$ + NaOH). The concrete mixes with 400 kg of binder were prepared and fibers in proportions of 40 kg and 120 kg by m^3 of concrete were incorporated. The compressive and splitting tensile strength were determined; likewise fracture toughness parameters, pull-out curves and KIC in samples after 7, 14 and 28 days of curing were calculated. Additionally, durability properties as porosity and capillary suction were reported. The mechanical testing results obtained indicate that the incorporation of steel fibers in Geo-Concretes reduces the compressive strength at early ages. On the contrary, the splitting tensile strength, the flexural strength and the toughness increase significantly. The strengths and the toughness of Ordinary Portland

Cement Concretes (OPCC) with the same proportion of binder and fibers were lesser than the Geo-concretes reinforced with steel fibers. The results shown the elevated performance of the properties exhibited by the geopolymeric cements with and without reinforcement.

FRACTURE TOUGHNESS OF GEOPOLYMERIC CONCRETES REINFORCED WITH BASALT FIBERS

Dylmar Penteado Dias, Clelio Thaumaturgo

The purpose of this work was to investigate the influence of the volumetric fraction of the fibers on the fracture toughness of geopolymeric cement concretes reinforced with basalt fibers. The values of fracture toughness, critical stress intensity factor and critical crack mouth opening displacement were measured on 18 notched beams tested by three-point bending. The a0=h (notch height/beam height) ratio was equal to 0.2 and the L0=h (distance between the supports/beam height) ratio was equal to 3. According to the experimental results, geopolymeric concretes have better fracture properties than conventional Portland cement. They are also less sensitive to the presence of cracks._ 2004 Elsevier Ltd. All rights reserved.

A REVIEW ON THE UTILIZATION OF FLY ASH

M. Ahmaruzzaman

Fly ash, generated during the combustion of coal for energy production, is an industrial by-product which is recognized as an environmental pollutant. Because of the environmental problems presented by the fly ash, considerable research has been undertaken on the subject worldwide. In this paper, the utilization of fly ash in construction, as a low-cost adsorbent for the removal of organic compounds, flue gas and metals, light weight aggregate, mine back fill, road sub-base, and zeolite synthesis is discussed. A considerable amount of research has been conducted using fly ash for adsorption of NOx, SOx, organic compounds, and mercury in air, dyes and other organic compounds in waters. It is found that fly ash is a promising adsorbent for the removal of various pollutants. The adsorption capacity of fly ash may be increased after chemical and physical activation. It was also found that fly ash has good potential for use in the construction industry. The conversion of fly ash into zeolites has many applications such as ion exchange, molecular sieves, and adsorbents. Converting fly ash into zeolites not only alleviates the disposal problem but also converts a waste material into a marketable commodity

GEOPOLYMER CONCRETE: THE NEXT DECADE OF CEMENT CONCRETE

(Raiji wala D.B., Patil H. S.)

This paper presents the progress of the research on making Geopolymer concrete using the Thermal Power Plant fly ash, (Ukai) Gujarat, India. The project aims at making and studying the different properties of Geopolymer concrete using this fly ash and the other ingredients locally available in Gujarat. Potassium Hydroxide and sodium Hydroxide solution were used as alkali activators indifferent mix proportions. The actual compressive strength of the concrete depends on various parameters such as the ratio of the activator solution to fly ash, morality of the alkaline solution, ratio of the activator chemicals, curing temperature etc. In recent years, Concrete usage around the world is second only to water. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. The amount of the carbon dioxide released during the manufacture of OPC due to the calcinations of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and aluminum. Attempts to reduce the use of Portland cement in concrete are receiving much attention due to environment-related. Fly ash-based Geopolymer concrete is a 'new' material that does not need the presence of Portland cement as a binder. The role of Portland cement is replaced by low calcium fly ash. Geopolymer is an inorganic alumino-Hydroxide polymer synthesized from predominantly silicon (Si) and aluminum (Al) materials of geological origin or byproduct materials such as fly ash. The term Geopolymer was introduced to represent the mineral polymers resulting from geochemistry. The process involves a chemical reaction under highly alkaline conditions on Si-Al minerals; yielding polymeric Si-O-Al-O bonds in amorphous.

GEOPOLYMERIZATION: A REVIEW AND PROSPECTS FOR THE MINERALS INDUSTRY

(Kostas Komnitsas, Dimitra Zaharaki)

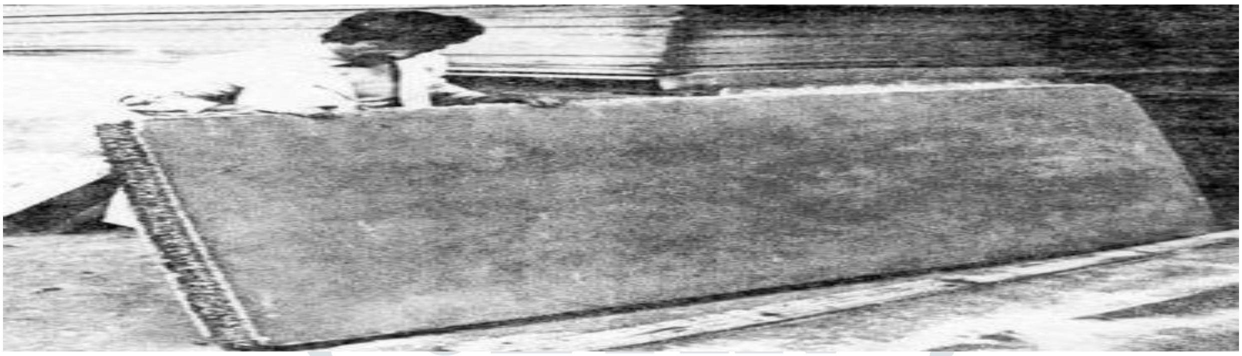
Inorganic polymers , more commonly referred to as "geopolymers", are allumino-silicates materials which exhibit excellent physical and chemical properties and a diverse range of potential applications , including precast structures and non structural elements , concrete pavements and products, containment and immobilization of toxic , hazardous and radioactive wastes, advanced structural tooling and refractory ceramics ,and fire resistant composites used in buildings , aero planes ,shipbuilding, racing cars and the nuclear power industry. The current paper presents a brief history and a review of geopolymer technology, summarizes and critically analyses the most important research findings over the last 25 years, attempts to elucidate chemistry and reaction mechanisms for the most important categories of materials involved, identifies the gaps in the existing body of knowledge and underlines the reasons why this promising technology after all these years of research has not become widely accepted by the industry. Finally the paper proposes further research and development topics and suggests steps forward to improve the potential of geopolymerisation , focusing on the utilization of mining and metallurgical wastes and by-products , the synthesis of geopolymers with advanced properties and the stabilization of hazardous wastes. It is strongly believed that geopolymerisation, when established as a viable technology and recognized by the industry, will contribute to the sustainable development of the minerals sector.

ADMIXTURE

Historical view of geopolymer concrete

Geopolymers are inorganic polymeric binding materials, firstly developed by Joseph Davidovits in 1970, which is applicable since 1972 in France, Europe, and USA. Its chemistry concept was invented in 1979 with the creation of a non-for profit scientific organization. This application shows genuine geopolymer products having brilliantly withstood 25 years of use and that are continuously commercialized.STEEL FIBERS

Commercially available steel fibers are manufactured from drawn steel wire from silt sheet or by the melt extraction processes which produces fibers that have crescents-shaped cross section. . This fibers have equivalent diameter of 0.5mm and length 20mm. Aspect ratio of steel fibers is 40. Steel fibres have been used in conventional concrete mixes, shotcrete and slurry- infiltrated fibres concrete. Typically, content of steel fibers ranges from 0.25% to 2.0% by volume. Fibers contents is excess of 2.0% by volume generally result in poor workability and fibers distribution, but can be used successfully where the paste content of the mix is increased and the size of coarse aggregate is not larger than 10mm.



Sl. no	**Materials**	**68%**	**70%**	**72%**	**74%**	**76%**
1.	Coarse aggregate (70%-10mm) **kg/m^3**	1223.75	1220.62	1255.62	1243.2	1325
2.	Fine aggregate (4.75mm-30%) **kg/m^3**	407.5	406.875	418.125	532.8	438.75
3.	Fly ash **kg/m^3**	511.875	465	433.75	462.2	360
4.	Sodium Silicate **kg/m^3**	178.125	161.875	151.25	115.47	138.125
5.	Sodium Hydroxide **kg/m^3**	77.5	70.625	65.625	46.2	60
6.	Fiber **kg/m^3**	100	100	100	100	100

ALKALINE LIQUID:

Sodium silicate and sodium hydroxide has been used in GPC and the combination of this solution is called as alkaline liquids. Instead of sodium silicate and sodium hydroxide, potassium silicate and potassium hydroxide can also be used. For this project, we have got the sufficient sodium silicate from micro fine chemicals.

MIX DESIGN INTRODUCTION

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of the ingredient of concrete is governed by the required performance of the concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of the workability, therefore, becomes of vital importance.

RESULTS

Table 6.1 **Compressive strength for 8M NaOH in 70% of combined aggregate**

Mix no	Fiber	Liquid/ flyash	Materials (Kg / m³)					Extra water (ml)	Slump (mm)	Sample	Weight Kg	Load N	Area mm^2	Stress N/mm^2
			Fly ash	S.S	S.H	C.A	F.A							
1	0.60	0.45	7.69	2.41	1.05	19.5	6.5	200	1.5	1	8.04	240000	22500	10.66
										2	7.40	200000	22500	8.88
										3	8.28	290000	22500	12.88
										4	7.86	250000	22500	11.11
2	0.60	0.5	7.44	2.59	1.13	19.5	6.5	200	5	1	8.20	370000	22500	16.44
										2	8.20	420000	22500	18.66
										3	8.84	380000	22500	16.88
										4	8.30	280000	22500	12.44
3	0.60	0.55	7.19	2.76	1.2	19.5	6.5	200	12	1	8.21	200000	22500	8.88
										2	8.42	210000	22500	9.33
										3	8.10	300000	22500	13.33
										4	8.42	210000	22500	9.33
4	0.60	0.6	6.98	2.92	1.27	19.5	6.5	200	23	1	8.14	200000	22500	8.88
										2	8.15	190000	22500	8.44
										3	8.32	200000	22500	8.88
										4	8.02	100000	22500	4.44

Table 6.2 **Compressive strength for 10M NaOH in 70% of combined aggregate**

Mix no	Fiber	Liquid/ flyash	Materials (Kg / m³)					Extra water (ml)	Slump (mm)	Sample	Weight Kg	Load N	Area mm^2	Stress N/mm^2
			Fly ash	S.S	S.H	C.A	F.A							
1	0.60	0.5	7.44	2.59	1.13	19.5	6.5	200	12	1	7.81	600000	22500	26.66
										2	7.60	700000	22500	31.11
										3	8.20	710000	22500	31.55
										4	7.65	830000	22500	36.88
2	0.60	0.55	7.19	2.76	1.2	19.5	6.5	200	5	1	9.14	300000	22500	13.33
										2	8.62	500000	22500	22.22
										3	9.16	460000	22500	20.44
										4	8.83	470000	22500	20.88
3	0.60	0.6	6.98	2.92	1.27	19.5	6.5	200	20	1	8.33	520000	22500	23.11
										2	8.34	540000	22500	24.00
										3	8.62	330000	22500	14.66
										4	8.00	360000	22500	16.00

Table 6.3 **Compressive strength for 12M NaOH in 70% of combined aggregate**

Mix no	Fiber	Liquid/ flyash	Materials (Kg / m³)					Extra water (ml)	Slump (mm)	Sample	Weight Kg	Load N	Area mm²	Stress N/mm²
			Fly ash	S.S	S.H	C.A	F.A							
1	0.60	0.5	7.44	2.59	1.13	19.5	6.5	200	3	1	8.74	430000	22500	19.11
										2	8.87	240000	22500	10.66
										3	8.26	28000	22500	12.44
										4	8.72	31000	22500	13.77
2	0.60	0.55	7.19	2.76	1.2	19.5	6.5	200	10	1	8.09	340000	22500	15.11
										2	8.52	340000	22500	15.11
										3	8.48	380000	22500	16.88
										4	8.69	300000	22500	13.33
3	0.60	0.6	6.98	2.92	1.27	19.5	6.5	200	17	1	8.11	380000	22500	16.88
										2	8.12	180000	22500	8.00
										3	8.83	310000	22500	13.77
										4	8.33	300000	22500	13.33

Table 6.4 **Compressive strength for 8M NaOH in 72% of combined aggregate**

Mix no	Fiber	Liquid/ flyash	Materials (Kg / m³)					Extra water (ml)	Slump (mm)	Sample	Weight Kg	Load N	Area mm²	Stress N/mm²
			Fly ash	S.S	S.H	C.A	F.A							
1	**0.60**	**0.5**	**6.94**	**2.42**	**1.05**	**20**	**6.69**	**206**	5	1	8.65	70000	22500	3.11
										2	8.73	210000	22500	9.33
										3	8.49	300000	22500	13.33
										4	8.31	310000	22500	13.77
2	0.60	0.55	6.72	2.57	1.12	20	6.69	206	22	1	8.35	230000	22500	10.22
										2	7.85	130000	22500	5.77
										3	8.84	280000	22500	12.44
										4	7.95	80000	22500	3.55
3	0.60	0.6	6.51	2.72	1.18	20	6.69	206	24	1	7.94	70000	22500	3.11
										2	7.68	200000	22500	8.88
										3	8.42	200000	22500	8.88
										4	8.2	80000	22500	3.55

Table 6.5 **Compressive strength for 10M NaOH in 72% of combined aggregate**

Mix no	Fiber	Liquid/ flyash	Materials (Kg / m³)					Extra water (ml)	Slump (mm)	Sample	Weight Kg	Load N	Area mm²	Stress N/mm²
			Fly ash	S.S	S.H	C.A	F.A							
1	0.60	0.5	6.94	2.42	1.05	20	6.69	206	3	1	8.26	260000	22500	11.55
										2	8.37	230000	22500	10.22
										3	8.68	290000	22500	12.88
										4	8.22	90000	22500	4.00
2	0.60	0.55	6.72	2.57	1.12	20	6.69	206	4	1	8.12	290000	22500	12.88
										2	8.69	240000	22500	10.66
										3	8.14	280000	22500	12.44
										4	8.31	230000	22500	10.22
3	0.60	0.6	6.51	2.72	1.18	20	6.69	206	20	1	8.66	200000	22500	8.88
										2	8.67	410000	22500	18.22
										3	8.41	180000	22500	8.00
										4	8.31	350000	22500	15.55

Table 6.6 **Compressive strength for 12M NaOH in 72% of combined aggregate**

Mix no	Fiber	Liquid/ flyash	Materials (Kg / m³)					Extra water (ml)	Slump (mm)	Sample	Weight Kg	Load N	Area mm²	Stress N/mm²
			Fly ash	S.S	S.H	C.A	F.A							
1	0.60	0.5	6.94	2.42	1.05	20	6.69	206	1	1	8.02	100000	22500	4.44
										2	8.36	330000	22500	14.66
										3	8.33	260000	22500	11.55
										4	8.35	220000	22500	9.77
2	0.60	0.55	6.72	2.57	1.12	20	6.69	206	16	1	8.67	240000	22500	10.66
										2	8.47	90000	22500	4.00
										3	8.6	290000	22500	12.88
										4	8.09	360000	22500	16.00
3	0.60	0.6	6.51	2.72	1.18	20	6.69	206	17	1	8.7	310000	22500	13.77
										2	8.49	300000	22500	13.33
										3	8.38	270000	22500	12.00
										4	8.22	260000	22500	11.55

Table 6.11 **Compressive strength for 12M NaOH in 76% of combined aggregate**

Mix no	Fiber	Liquid/ flyash	Materials (Kg / m³)					Extra water (ml)	Slump (mm)	Sample	Weight Kg	Load N	Area mm²	Stress N/mm²
			Fly ash	S.S	S.H	C.A	F.A							
1	0.60	0.5	5.95	2.07	0.9	21.2	7.1	220	16	1	8.67	220000	22500	9.777
										2	8.54	190000	22500	8.444
										3	8.32	200000	22500	8.888
										4	8.47	390000	22500	17.333
2	0.60	0.55	5.76	2.21	0.96	21.2	7.1	220	10	1	8.11	300000	22500	13.333
										2	8.48	150000	22500	6.666
										3	8.83	130000	22500	5.777
										4	8.38	200000	22500	8.888
3	0.60	0.6	5.58	2.33	1.01	21.2	7.1	220	14	1	8.18	180000	22500	8.000
										2	8.53	200000	22500	8.888
										3	7.99	250000	22500	11.111
										4	8.15	190000	22500	8.444

REQUIREMENTS OF CONCRETE MIX DESIGN

The requirements which form the basis of selection of proportioning of mix ingredients are:

The minimum compressive strength required from structural consideration.The adequate workability necessary for full compaction with the compacting equipment"s available.Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site condition.Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

CONCLUSION

Geopolymer concrete

To match with the Indian standard concrete Mix of IS10262 (recommended guidelines for concrete mix design) (i.e.) Compressive strength to be obtained as per standard.

To study the Fresh and harden properties of the concrete

Fresh concrete

Slump cone

Flow table

Vee-bee consistometer

Compaction factor

Harden Concrete

Compressive strength

Modulus of rupture

Tensile strength

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