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EXPERIMENTAL INVESTIGATION ON MECHANICAL PROPERTIES OF SUGAR CANE BAGASSE ASHES BASED GEOPOLYMER CONCRETE

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ABSTRACT
In the modern era, global warming becomes a critical environmental issue. Each passing year, the amount of greenhouse gas emission to the atmosphere is in an increasing trend. Carbon dioxide (CO2) remains the ace greenhouse gas which cause significant influence on global warming. CO2 contributes about 82% of the total greenhouse gas emission. Cement industries are one of the major emitters of CO2. India is the world's second-largest cement producer next to China to reduce the utilisation of cement in concrete. In the prospects and perspectives of waste reutilization and eco- sustainable concrete production, the feasibility of total replacement of cement with fly ash and partial replacement of fly-ash with SCBA in geo-polymer concrete was investigated in this project. Usage of this type of concrete can reduce the usage of cement and also the CO2 emission. The molarity of sodium hydroxide 10M and partial replacement of Fly-ash with Sugar Cane Bagasse ashes (SCBA) with various percentages of 2.5%, 5.0%, 7.5% and 10.0%. A comparative study was conducted on the performance of mechanical properties of heat (600C & 800C) and ambient cured (7, 14, 28 days) SCBA based geopolymer concrete. It was observed that higher compressive strength (28 days ambient curing) was attained for the eco-friendly concrete up to 5.0% replacement of fly- ash with SCBA.
Key words: Fly ash, 10M, SCBA(Sugar Cane Bagasse ashes), SCBA based geopolymer concrete.

I.INTRODUCTION

1.1 GENERAL

Concrete is construed as a globally preferred building material and it plays an inevitable role in the construction arena. Though concrete comprises of several ingredients, cement is considered as a key ingredient in the concrete which gives binding property. In recent years, the cement production has grown very rapidly all over the world due to the huge requirement of cement for multi-various construction purposes. Worldwide the Portland cement production increases 9% annually. India stands second in the world cement production and produces 6.9% of world's cement output. One tonne of cement production emits equal amount of CO2 to the atmosphere. Carbon dioxide is a primary greenhouse gas which contributes to global warming. Cement industries are the third largest source of CO2 emissions and they account for 8% of the total greenhouse gas emissions to the atmosphere. Greenhouse gas emission causes a serious threat to the environment (Asokan 2005; Bednarik et al. 2000). In World, nearly 12 billion tonnes of concrete are produced for construction every year. Owing to the huge requirement of concrete this quantity may increase in the forthcoming years. Over- exploitation of natural resources and unused waste industrial by-products generation causes serious jeopardy to the environment. So, an alternate technology should be used in construction which reduces the usage of cement in concrete. Geopolymer concrete is an appropriate technology to utilize the industrial by-products and also the usage of cement can be completely eliminated.

Power generation in India predominantly depends on coal-based power plants. In thermal power plants, during the production of power, high heat is generated through the burning of coal; due to this process, enormous quantity of fly ash and bottom ash is produced as waste by-products. Yearly 131 million tonnes of fly ash are produced and only 60% of total production is used for other purposes. Remaining is unutilized. Similarly, ample quantity of bottom ash is also formed during the coal combustion. Fly ash is obtained in fine powdery form and bottom ash as coarser ash particles. Improper disposal of fly ash and bottom ash in open spaces causes environmental pollution.

Over exploitation of river sand for construction activities results in natural resources depletion. In order to maintain the sustainable development, it is necessary to find alternative material for the conventional concrete ingredients (Raijiwala & Pat 2010; Rangan 2008). Pozzolanic property of fly ash and grain size of bottom ash and M-Sand gives a greater scope to use these by-products as an alternative material for cement and river sand in concrete.

Geopolymer concrete is predominantly made by utilizing industrial by-products such as fly ash or Ground Granulated Blast Furnace Slag (GGBS). Due to abundant quantity of fly ash, it is the most preferred pozzolanic material to produce geopolymer concrete. In this research an attempt has been made to investigate the feasibility of utilization of fly ash as an alternate to cement, M-Sand and bottom ash as

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substitute materials for River sand to produce geopolymer concrete.

1.2 AN OVERVIEW OF GEOPOLYMER CONCRETE

In 1908, a German Engineer and chemist Kuhl is first patented his research work on alkali activated based binder materials. Later, Chemistry Professor Davidovit found the geopolymers to exemplify the class of inorganic polymers that endure polycondensation, which remains stable at temperatures up to 1250˚C and are non-inflammable. In 1972, a novel approach was established on the geosynthesis of kaolinite which reacted with sodium hydroxide (NaOH) and poly condenses to Hydro sodalite at a temperature of 100oC to 150˚C. In 1973 – 1976, by using this technology building product of fire- resistant chip board panel was developed and later prolonged to ceramic applications in 1978. Even though, it has excellent thermal and mechanical properties, the research work was restricted due to poor water absorption.

Geopolymer concrete is predominantly made by utilizing industrial by-products such as fly ash or ground granulated blast furnace slag (GGBS). Enormous quantity of fly ash is produced as a by-product from thermal power plants, proper utilization of fly ash is essential to reduce waste dumping and pollution. Due to abundant quantity, fly ash is the most preferred pozzolanic material to produce geopolymer concrete. Geopolymer concrete consist of two major constituents" viz., source material and alkaline activating solution. The source material should be rich in silicon and alumina. The alkaline activator is sodium or potassium-based liquids that are soluble alkali metals. The most common alkaline activator is sodium hydroxide (NaOH) and sodium silicate (NaSiO2) (Juenger & Winnefled 2011; Rangan 2008). Schematic representation of polymerization of geopolymer concrete is shown in Figure 1.1.

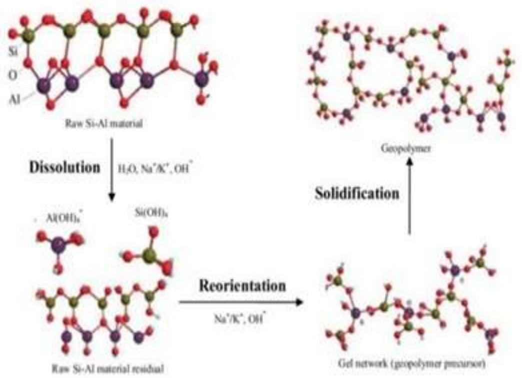

Figure 1:Reaction mechanism of Geopolymerization

1.1 SOURCE MATERIALS FOR GEOPOLYMER CONCRETE

Fly Ash

In the recent decades, one of the main sectors which have high increase in the production of waste, specifically ash, are the hydro-electric power plants producing electricity to provide the requirements of the continuously increasing population. Coal ash is the material remaining the after the burning of coal at a temperature of 1500oC in suspended state and it together produces fly ash and bottom ash as by products. Bottom ash is collected in the boiler and whereas fly ash is collected in the chimney. From the year 2000, the coal ash has been shifted to "waste material" from the group of "hazardous industrial waste". It has become an accessible commodity.

Scenario of Fly Ash in India

The ash content present in Indian coal is up to 30 – 40% and its imported coals has 10 – 15% of ash content. It was found that, among the total cash generated only 80% of fly ash and 20% of bottom ash has been used and remaining has been dumped in open yard as landfills. The generation of fly ash increased year by year due to the electrical power requirement of the society. The awareness of utilizing Fly ash in construction industry is high when compared to bottom ash. In huge parts of coal ash, only the fly ash has been accepted as a basic material for production of geopolymers while the usage of bottom ash is less because of its maximum carbon content (Djwantoro Hardjito 2010; Si Hwan Kim et al. 2012; Singh & Siddique 2013).

Sugar Cane Bagasse ashes

Sugar Cane Bagasse Ash (SCBA) is a fine mineral residue produced during the combustion of sugarcane bagasse in sugar industries. Sugarcane bagasse ash is obtainable from the boiler or the cogeneration unit of sugar industry. This ash is normally collected in the filter bag, wet scrubber or electrostatic precipitator. The discrepancy of ash resulting from the boiler and cogeneration unit depends on the method of burning and temperature prevailing in the units. The temperature plays a most significant role in determining the pozzolanic nature and mineral constituents of ash.

The characteristic of this ash varies depending upon the chemical content, calcining conditions, source and nature of the raw material and several other factors (Biruk Hailu 2011). Though the research on sugarcane bagasse ash as a cement replacement material has been initiated in India, it would take years to utilise the large quantity of Bagasse Ash (BA) as a valueadded product.

II.LITERATURE SURVEY

2.1 HISTORY OF GEOPOLYMERS

During early 1940"s due to frequent damages in Europe due to high amount of fires, there was search begun to find better fire resistant material. In this attempt alkali activated alumino-silicate materials was one of the discovery made by the scientists. In 1950"s Glukhovsky first discovered alkali activated alumino-silicate material, however, not until the French scientist Joseph Davidovits introduce the term "geopolymer" in 1979 for his binder, this new binding material does not come into the limelight. Davidovits in 1988, for the first time, suggested the potential use of inorganic alumino-silicate binders in the construction industry.

2.2 TERMINOLOGY AND CHEMISTRY

Davidovits (1994) theorized that an alkaline liquid had the potential to react with the aluminium (Al) and silicon (Si) located in a source material of geological origin or in by- product materials such as fly ash and blast furnace slag to create binders. This reaction of alkaline liquid with aluminium and silicon is termed as polymerization process. These alumino-silicate polymers with an amorphous microstructure, which are formed in alkaline environment, are termed as geopolymers. The activation mechanism of alumino-silicate materials was proposed by Glukhovsky in 1959. This mechanism was broadly divided into three steps: (a) destruction–coagulation, (b) coagulation–condensation, and
(c) condensation–crystallization.

In 1979, Davidovits proposed geopolymer chemistry concept, and the properties of this new binder material. The term poly (sialate) was also suggested by him, wherein sialate is an abbreviation form for silicon-oxo-aluminate (Davidovits 2008). The chemical structure of polysialates which exists in three different features based on silicon and aluminum proportions is shown in Figure 2.1. The poly (sialate) network consists of Si+4 and Al+3 ions in IV-fold coordination, sharing oxygen ions and ranges from amorphous to semi-crystalline (Davidovits 1989, Sakulich 2011). Poly (sialate) has an empirical formula of: Mn (-(SiO2) z –AlO2) n, wH2O, where „M‟ is the alkali element that is used; „n‟ is the degree of polymerization, „z‟ value lies in between 1and 3 depending on the chemistry of the reaction, and „w‟ depends on the extent of hydration reaction completed.

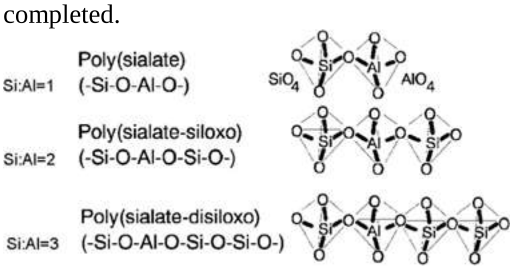

Figure 2.Structure of poly (sialate) in three different features (Davidovits 1979)

III.OBJECTIVE AND METHODOLOGY

3.1 OBJECTIVES

The present work aims at evaluation of the response of ambient and heat cured geopolymer concrete in terms of its mechanical properties. The main objectives of the present project work are as follows.

1. To study the compressive strength development of ambient and oven cured geopolymer concrete by replacing 2.5, 5.0, 7.5 and 10.0% fly ash by sugar cane bagasse ashes (SCBA).
2. To compare the mechanical properties of the SCBA based geopolymer concrete (SGPC) cured under oven and in ambient conditions.

Fly ash samples are collected from NTPC Ramagundam, Telangana. Flyash and SCBA were used as cementitious material in the replacement cement in concrete. River sand was used as fine aggregate. Coarse aggregate was obtained from locally available sources. Combination of sodium hydroxide and sodium silicate solution was used as alkaline activator. In the experimental investigation, the evaluation mechanical properties include compressive strength, indirect flexural strength and indirect split tensile strength of GPC.

3.2 METHODOLOGY

1. Collect the SCBA and sieved from IS Sieve 75microns. The passed from IS Sieve 75microns SCBA was collected and used for this project work.
2. The design mix methodology of OPC – M30 mix design as per IS 10262-2019. The same mix design converted in to M30 to G30 by fully replacing cement with fly-ash and alkali solution additionally added to improve the binder properties in fly-ash.
3. The fly-ash (class F), SCBA prepared at laboratory with manual incineration process, locally available river sand (ZONE - II) and coarse aggregates (NMAS 20) was used for this investigation.
4. The GPC, was cured with oven (600C & 800C) and ambient cured 7,14, 28days.

Table 3.3: Quantities of materials for 1cube with G30

Mix No	QD – TW (%)	Water absorption (%)
M1	0 - 0	2.2
M2	50 - 0	2.0
M3	50 – 10	2.6
M4	50 -20	2.8
M5	50 – 30	3.0
M6	50 – 40	3.3
M7	50 - 50	3.8

Table 3.4 Mix Proportions for GPC with fly ash replacing with SCBA

Replacement of SCBA (%)	Fine aggregate (gm)	Coarse aggregate (gm)	Fly ash (gm)	SCBA (gm)	Alkali liquid		Super plasticizer (ml)
					NaOH (ml)	Na_2SiO_3 (ml)	
0%	2620	4838	1485	0	154	307	14.8
2.5%			1447.87	37.125			
5.0%			1410.75	74.25			
7.5%			1373.62	111.375			
10.0%			1336.5	148.5			

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IV.EXPERIMENTAL INVESTIGATIONS

4.1GENERAL

The experimental part of the Project consists of a preliminary study for fundamental and primarily thorough a detrimental study. The former preliminary study consists of studying the strength development of G30 grade Geopolymer concrete containing SCBA as a partially replaced material for fly ash. The replacement levels of fly ash with SCBA consisted of 0% (control) to 10.0%. The later detrimental one consists of studying the feasibility of using SCBA based GPC with up to 10% replacement of fly ash. The workability, strength and Structure as the three-dimensional characteristics of concrete are considered.

4.2MATERIALS

The constituent materials were planned for use both in the preliminary and primary investigation for the development of SCBA based geo polymer concrete.

In the present study, one of the source materials used in making geopolymer concrete was Class F fly ash (Low calcium fly-ash). It was collected from NTPC Ramagundam, Telangana, India.

Figure.3 Fly ash

The river sand is sieved using 4.75 mm sieve and the particles passing through 4.75mm sieve and retained on 75 micron sieve is defined as fine aggregate.

Figure. 4 River sand

SCBA is a by-product generated from sugar cane juice point, Maisammaguda. SCBA used in this study was obtained from the manual incineration of sugar cane waste, Maisammaguda. The calcination temperature at which SCBA produced was very high of about 1500oC. Specific gravity of SCBA was 1.9.

The total of Silicon dioxide (SiO_2) + Aluminium Oxide (Al_2O_3) + Iron Oxide (Fe_2O_3) of SCBA used in the present work was found to be 56.58%. Loss on ignition of SCBA was observed as 2.43. The properties of SCBA used in this investigation are presented in Table 4.2.

Figure. 5 SCBA

Aggregates are the major ingredients of concrete. It constitutes the total volume, provide a rigid skeleton structure for concrete, and act as economical space fillers. Aggregates contribute to both the weight and stiffness of concrete. Generally coarse aggregate are derived from rock. Their properties depend on the mineralogical composition of rock, the environmental exposure to which the rock has been subjected and the method of crushing employed to get different sizes. The physical, chemical and thermal properties of aggregates substantially influence the performance of concrete. The dimension between 20mm to 4.75mm termed as coarse aggregate.

Figure. 6 Coarse aggregate

Water is an important ingredient to make concrete. The purpose of adding water to concrete is, to distribute the cement evenly, react with cement chemically to produce calcium silicate hydrate gel and provide workable one. Small amount of water is needed to hydrate cement. Additional water is required to lubricate the mix. Excess water leads to bleeding stage ultimately creation of pores. Quantity of water is controlled by the w/c ratio. The water used must be free from oil, acid and alkali, salts and organic material. It should be potable.

Locally available SCBA was the primary material used in this experimental work. The river sand, SCBA and crushed stone granite coarse aggregate (college labortary) were used. Physical properties of fly ash, river sand, SCBA, coarse aggregates were determined and were shown in Table 4.1.

Table 4.1 Physical properties of materials

Material	Property	Test result	
Fly-ash	Specific gravity	2.19	IS: 12269-1987
	Fineness modulus	2%	
SCBA	Specific gravity	1.9	
	Fineness modulus	2%	
Fine Aggregate (sand)	Specific gravity	2.56	IS: 2386 (Part-I) - 1963
	Fineness modulus	2.71	
	Water absorption	1.1%	
Coarse Aggregate	Specific gravity	2.72	IS 383 – 1987
	Maximum size	20mm	
	Fineness modulus	5.1	
	Water absorption	1.8%	

Table 4.2 Chemical composition of SCBA by XRF (mass %) K, Radhika [12]

Chemical composition	Silicon dioxide + Aluminium Oxide + Iron Oxide	Magnesium Oxide (MgO)	Total Chloride (Cl)	Total Sulphur as Sulphur Trioxide (SO_3)	Loss On Ignition (LOI)	Calcium Oxide (CaO)	Manganese Oxides (MnO)
Content in %	56.58	0.33	0.002	1.01	2.43	13.47	1.14

Table 4.2 Chemical composition of fly ash by XRF (mass %) Venkateswara Rao, J. [11]

S. No.	Oxide	Mass (%)	S. No.	Oxide	Mass (%)
1	SiO_2	58.132	16	Co	0.007
2	Al_2O_3	32.546	17	Ni	0.009
3	Fe_2O_3	4.044	18	Cu	0.012
4	CaO	1.41	19	Zn	0.013
5	Na_2O	0.17	20	Ga	0.006
6	K_2O	0.96	21	Ge	0.001
7	TiO_2	1.156	22	Rb	0.007
8	MgO	0.714	23	Sr	0.023
9	P_2O_5	0.474	24	Y	0.006
10	SO_3	0.125	25	Nb	0.004
11	Zr	0.046	26	Ba	0.035
12	Cr	0.015	27	Nd	0.021
13	Cl	0.021	28	Tl	0.001
14	Ti	1.156	29	Pb	0.008
15	Mn	0.029	30	Th	0.006

V.RESULTS AND DISCUSSIONS

This chapter presents the results obtained from the tests (discussed in Chapter 4) conducted on geopolymer concrete specimens and their composites. First of all, the results of mechanical properties of GPC (100% fly ash) and GPC with Fly ash replacing with SCBA (F100S0, F97.5S2.5, F95S5, F92.5S7.5 & F90S10) specimens on mechanical properties and physical properties was presented.

5.1 Physical properties of Geopolymer concrete

Table 5.1 Physical properties of GPC cubes

Mix No.	RS - QD (%)	Shape and size test	Colour test	Structure test
M1	$F_{100}S_0$	For all cubes are cube shaped with sharp edges and size of 15 cm x 15 cm x 15 cm	All the cubes having the uniform colour for entire structure	There are no flaws, cracks or holes present on that broken face then that is a good quality
M2	$F_{97.5}S_{2.5}$			
M3	$F_{95}S_5$			
M4	$F_{92.5}S_{7.5}$			
M5	$F_{90}S_{10}$			

5.2Fresh properties of Geopolymer concrete

The Slump cone test results of the Geopolymer concrete for the replacement of fly ash with SCBA by 0, 2.5, 5.0, 7.5 and 10.0 % are shown in table 5.2 and graphically represented in Fig 5.1.

Table 5.2 Slump cone test results

Mix No.	Fly ash - SCBA (%)	Slump value (mm)
M1	$F_{100}S_0$	85
M2	$F_{97.5}S_{2.5}$	90
M3	$F_{95}S_5$	94
M4	$F_{92.5}S_{7.5}$	100
M5	$F_{90}S_{10}$	104

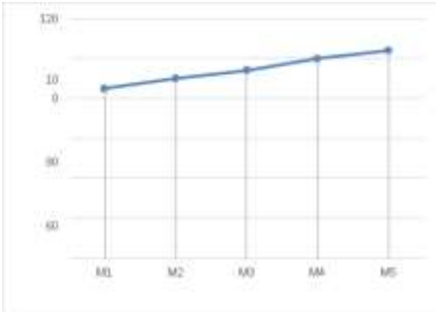

Figure 7 Slump test results graph

It is observed that there is increase in the workability of the Geopolymer concrete when the fly ash is replaced with SCBA. Based on the observations, all of the slump values are in the low to medium workability range.

5.3Harden properties of Geopolymer concrete

Oven curing

The compressive strength by oven curing under 600c and 800c results of the Geopolymer concrete for the replacement of fly ash with SCBA by 0, 2.5, 5.0, 7.5 and 10.0 % are shown in table 5.3 and graphically represented in Fig 5.2.

Table 5.3 Compressive strength test results (Oven curing)

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Mix No.	Fly ash - SCBA (%)	Average Compressive strength (Mpa)	
		60^0c	80^0c
M1	$F_{100}S_0$	22.4	35
M2	$F_{97.5}S_{2.5}$	24	37.5
M3	$F_{95}S_5$	26	39.2
M4	$F_{92.5}S_{7.5}$	20.5	34.1
M5	$F_{90}S_{10}$	18	30.2

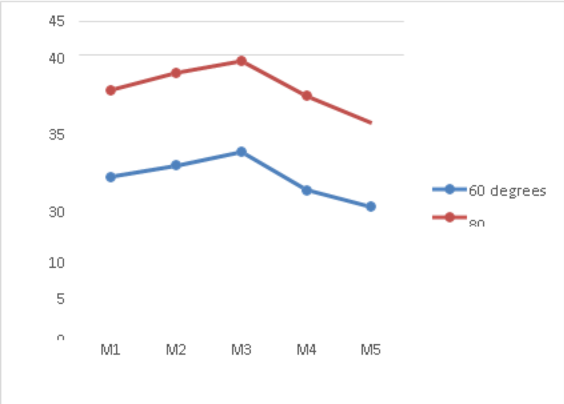

Figure 8: Compressive strength test results graph (Oven curing)

It is observed that there is increase in the compressive strength of the geopolymer concrete when the Flyash was replaced with SCBA. Based on the observations, all of the compressive strength values are higher for SCBA replacement. The highest compressive strength gains for 800c as compare to the 600c. The optimum dosage of Fly ash replacement in SCBA was 5.0%.

Ambient curing

The compressive strength by ambient curing under 7, 14 and 28 days results of the Geopolymer concrete for the replacement of fly ash with SCBA by 0, 2.5, 5.0, 7.5 and 10.0 % are shown in table 5.4 and graphically represented in Fig 5.3.

Table 5.4 Compressive strength test results (Ambient curing)

Mix No.	Fly ash - SCBA (%)	Average Compressive strength (Mpa)		
		7days	14 days	28 days
M1	$F_{100}S_0$	28.5	38.9	45
M2	$F_{97.5}S_{2.5}$	27.5	43	47.4
M3	$F_{95}S_5$	28	42.24	48.6
M4	$F_{92.5}S_{7.5}$	27.54	40	46.3
M5	$F_{90}S_{10}$	25.2	38.6	45.2

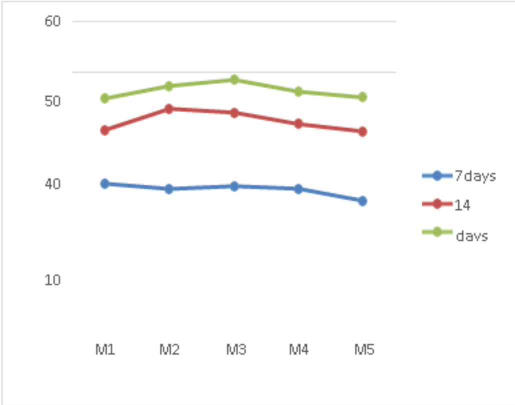

Figure 9: Compressive strength test results graph (Ambient curing)

It is observed that there is increase in the compressive strength of the geopolymer concrete when the fly ash was replaced with SCBA. Based on the observations, all of the compressive strength values are higher for SCBA replacement. The optimum dosage of Fly ash replacement in SCBA was 5.0%.

Comparison of curing based strength

It is observed that there is increase in the compressive strength of the geopolymer concrete when the fly ash was replaced with SCBA. Based on the comparison of oven and ambient curing, the compressive strength higher for 28days ambient curing as compare to the oven curing.

For 28days ambient curing of geopolymer concrete, the percentage increase of compressive strength value for 2.0%, 5.0%, 7.5% and 10.0% replacement of fly ash with SCBA was 5.5%, 8%, 2.83% and 0.44%respectively.

Table 5.5 Compressive strength test results comparison

Mix No.	Fly ash - SCBA (%)	Average Compressive strength (Mpa)		
		80^0c	60^0c	28 days
M1	$F_{100}S_0$	22.4	35	45
M2	$F_{97.5}S_{2.5}$	24	37.5	47.4
M3	$F_{95}S_5$	26	39.2	48.6
M4	$F_{92.5}S_{7.5}$	20.5	34.1	46.3
M5	$F_{90}S_{10}$	18	30.2	45.2

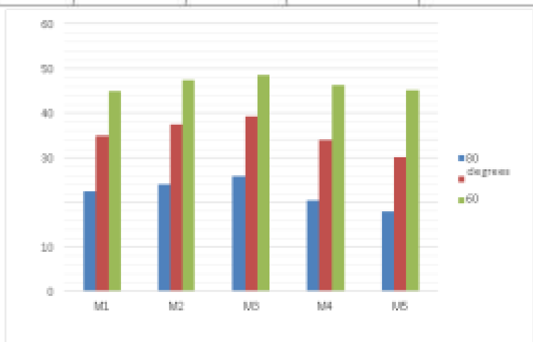

Figure 10: Compressive strength test results comparison graph

VI.CONCLUSIONS

The aim of the present investigation is to evaluate the mechanical properties of oven and ambient cured geopolymer concrete as well as to examine their partial replacement of fly ash with SCBA. Totally 5 mixes of geopolymer concrete namely F100S0, F97.5S2.5, F95S5, F92.5S7.5 & F90S10 were considered. The conclusions were;

1. With the increase in sugar cane bagasse ash (SCBA) content, the workability of the geopolymer concrete is found to be increasing from low to medium slump.
2. With the increase in sugar cane bagasse ash (SCBA) content, the compressive strength of the geopolymer concrete is found to be increasing. It is evident from the results of compressive strength of geopolymer concrete at 7, 14, 28 days cured under ambient conditions and 800c, 600c at oven curing for 24 hours.
3. Compressive strengths of SCBA based geopolymer concrete with 5.0% replacement of fly ash with SCBA at the age of 28 days respectively under ambient conditions are better than corresponding compressive strengths of SCBA based geopolymer concrete under oven curing.
4. For 28days ambient curing of geopolymer concrete, the percentage increase of compressive strength value for 2.5%, 5.0%, 7.5% and 10.0% replacement of fly ash with SCBA was 5.5%, 8%, 2.83% and 0.44% respectively.
5. The optimum dosage of SCBA replacement in fly ash in the G30 based geopolymer concrete was 5.0%.

SCOPE FOR FUTURE STUDIES

Based on the knowledge and experience gained during the experimental studies the following can be identified for further research.

- Ambient cured geopolymer concrete composites by partial replacing of fly ash with other cementitious materials (GGBS, Marble dust, MSWA etc.) investigated.
- Ambient cured geopolymer concrete with various molarities of NaOH can be investigated based on compressive strength.
- Influence of elevated temperatures on the ambient cured geopolymer concretes with partial replacing of fly ash with OPC can be investigated.
- Shrinkage and creep characteristics of ambient cured geopolymer concretes can be investigated.
- Durability tests on geo-polymer concrete can be investigated.
- This study limited for Replacement of flyash, it will be extended for replacement of fine aggregates and coarse aggregates.

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