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Analysis of Adding GGBS and Fly Ash in Self Compacting Geo - Polymer Concrete for Structures

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Abstract In the olden days, some eco-friendly and easily accessible materials such as mud, lime, and egg mixer were used in the building constructions. However, these materials are not sufficient to construct huge and more buildings. For this, the researchers preferred the cement as the main binding material used in the concrete mixture. The cement manufacturing companies are releasing more CO_2 during cement production, which leads to the environmental pollution in the earth. To overcome the problem of the ecological system, this work proposed the Self Compacting Geo- Polymer Concrete – SCGPC, which is not a normal cement concrete. The SCGPC is used to fill cavities easily and rapidly without any compaction. The industrial wastes like fly ash, GGBS - Ground Granulated Blast - furnace Slag, metakaolin kaolinite, clay, iron ore, silica fume and limestone can be used as the substitute materials for cement. This work mainly concentrates on the effects of two specific mechanical properties such as split tensile and compressive strength of SCGPC by adding fly ash and GGBS. These factors were evaluated with the Alkaline Activator Solution (AAS) to fly ash and GGBS ratio, the ratio of Na_2SiO_3 solution to the NaOH solution, the dosage of superplasticizer, rest period and temperature degree. The proposed SCGPC (8M, 10M and 12M) has analyzed both split tensile and compressive strength in three sets (7, 28 and 56 days). At last, the analyzed results were compared with conventional concrete. Based on the comparison, while the increase of curing temperature, both mechanical properties of SCGPC have reduced.

Keywords Compressive Strength, Ground Granulated Blast- furnace Slag, Split Tensile Strength, Fly Ash, Self-Compacting Geo Polymer Concrete

1. Introduction

Basically, the concrete is a main component in all structural works. The concrete mixer consists of aggregate, sand, water and cement. In the above concrete mixer, cement as an important binding material can be prepared from factories, and other material are naturally available in the world [1]. The concrete is a flexible material which can be mixed simply to reach a several range of needs and designed to any shape effectively. The concrete has many advantages such as simply to be cast, cheap material, durability, fire-resistant and on-site manufactural component. However, the low tensile strength and low ductility are the disadvantages of concrete [2]. The general properties of new concrete is following: workability, segregation, setting time, reliability, draining, unit weight and regularity. The normal concrete mixing time must be adequate to yield a uniform concrete. The mixing time is based on the type of mixer and properties of new concrete. Normally, the method of condensing concrete contains the removal of entrapped air which can be attained by the use of vibrators and tamping [3-5]. After compaction, the concrete must be cured to improve the strength. The curing processes are used for helping the hydration of cement, control of temperature and the travel of moisture within the concrete. There are many types of concretes available in existing days like Plain or Ordinary Concrete, High-Density Concrete, Reinforced Concrete, Ready Mix Concrete, Light – Weight Concrete and Air Entrained Concrete etc. [6]. For ready mix concrete type, the constituents are hosted into a mixer truck and they can be mixed during transportation to the site. In concrete, Portland cement is the main binding material to construct the structural components [7-10].

The PCC- Portland Cement Concrete is a necessary constituent of concrete, which is not an environmentally friendly material. The manufacturing of cement factories is the 3rd largest factory of pollution source in the world which emits nearly 5,00,000 tons per year of carbon monoxide, nitrogen oxide and sulphur dioxide [11]. The emission gases are intoxicating greenhouse gases, which trap to heat the atmosphere and warm the globe. But the improving of infrastructure or surrounding ecosystem is the main challengeable task of any developing countries. In recent days, a large population of developing countries used the thermal power stations to produce the power [12-14]. A large amount of fly ash material comes from the power stations. Blast Furnace Slag is also one of the waste materials coming from the steel plant. Many researchers have focused their work to replace the conventional materials by adding some industrial waste materials in order to ensure ecological development. The practical applications of SCGPC are more corrosion and resistant, both compressive and tensile strengths getting quickly and curing process also takes less time.

1.1. Motivation

In modern days, the Geo-Polymers may be an attention for reinforcing and their worldwide forthcoming needs of construction area to improve the sustainable growth. The SCGPC – Self Compacting Geo Polymer Concrete is a new method of concrete technology. It does not require any kind of compaction, which can be produced by the removal of ordinary PCC. When compared to PCC, the SCGPC also reduces the CO_2 - carbon dioxide emission and makes as an environmental friendly structural material. The GPC – Geo Polymer Concrete has special good characteristics like sulphate resistance, low shrinkage, provides good strength, chloride penetration, corrosion resistance and freeze-thaw resistance [15-18]. Geo-Polymers are the manufacturing of alkali activation of an Alumino silicate (Al_2O_5Si) source. Normally there are many raw materials used as an Alumino silicate source like fly ash, metakaolin, silica fume, slag, and rice husk ash [19]. From which the GGBS - Ground Granulated Blast- furnace Slag and fly ash are considered as an important source for the production of Al_2O_5Si geo-polymers because it's getting easily from the industrial wastes and steel plants. These are used to supply sources of Aluminum-Al, and Silicon-Si which are melted in Alkaline Activator Solution (AAS) and to make a strong binder [20].

1.2. Objectives

The Geo-Polymers are manufactured by mixing of AAS solution which encloses of NaOH - Sodium Hydroxide solution, some dosage of superplasticizer, Na_2SiO_3 - Sodium Silicate solution. These high-alkali GPC binders do not make any alkali-aggregate reaction. The main objective of this research work is to evaluate the mechanical strength properties of SCGPC mixer concrete by adding some additional waste materials to AAS such as GGBS and fly ash. The proposed work has mainly concentrated on the analysis of mechanical strength properties of proposed SCGPC on the basis of curing age and temperature degree. The proposed SCGPC (8M, 10M and 12M) has analyzed three sets like 7, 28 and 56 days split tensile and compressive strength. After that, the analyzed strength results of proposed SCGPC were compared with the normal concrete.

1.3. Research Methodology

The main purpose of this research work is to estimate the mechanical strength properties (split tensile and compressive) of proposed SCGPC by adding GGBS and fly ash and analyzed based on the curing age and temperature. In order to achieve the goal of the research work, some of the steps have been followed:

(i) Initially, check the chemical or mineral composition of additional raw materials (GGBS and fly ash),
(ii) Ensure the grain size analysis of the coarse and fine aggregate.
(iii) Measure the slump flow values for workability action,
(iv) Prepare the mix design of SCGPC (8M, 10M and 12M),
(v) Make the cubes and cylinders for proposed SCGPC (8M, 10M and 12M)

Conduct the experiment for analyzing the mechanical properties of proposed SCGPC at 7, 28 and 56 days vs curing temperature

1.4. Organization of the Paper

In existing, many researchers have done the Geo-Polymer concrete related work by adding additional materials to the binding material of concrete in order to improve the strength. Some of the researches have investigated by replacing of some chemical components to the AAS for the binding solution and analyzed the strength of the modified concrete. To enhance this research work, many existing Geo Polymer Concrete related papers were reviewed and found the benefits and disadvantages. The structure of this research paper includes with following: chapter 1 as the introduction section which contained with background, motivation, objectives, research methodology and organization, chapter 2 as the Literature review section which described the overall survey of existing GPC design, techniques, methods and materials used, chapter 3 described the experimental methodology of work which includes with mineral composition, grain size analysis, slump values, mix design of SCGPC, cubes and cylinders preparation, Chapter 4 explained the experimental results of proposed SCGPC analysis and the chapter 5 as the last section that concluded with the future extension work.

2. Experimental Method

The proposed work has been done to make in terms of analyzing the mechanical strength properties of every mixture after particular curing periods which includes the following steps. i) identify optimum GGBS and fly ash in concrete mixture through an experimental study; ii) analyze the coarse and fine aggregate; iii) prepare the mix design of different grades of SCGPC; iv) measure the slump flow values; v) prepare the cubes and cylinders; vi) cure the cubes and cylinders at 7, 28 and 56 days with different degree temperature; vii) analyze the mechanical strength properties of different grade of SCGPC.

2.1. Mineral Composition of GGBS and Fly Ash

In this proposed work, first take the raw materials as GGBS and fly ash for preparing new concrete mixture. Both raw materials contain different percentages of chemical composition with Al_2O_3 - Alumina, SiO_2 - Silica, Lime - CaO, Sulphur Trioxide -SO_3, Magnesia - MgO, Fe_2O_3 - Iron Oxide, Titanium Oxide - TiO_2, and loss on Ignition. Table 1 shows the Mineral composition of GGBS and fly ash.

Table 1. Mineral composition of GGBS and fly ash

Mineral Composition (%)	Fly Ash	GGBS
Silica	65.2	30.65
Alumina	28.2	16.3
Iron Oxide	3.01	0.59
Lime	1.01	34.49
Magnesia	1.01	6.80
Titanium Oxide	0.50	-
Sulphur Trioxide	0.21	1.86
Loss on Ignition	0.3	2.10

2.2. Analyze the Coarse and Fine Aggregate

For construction activities, the sieve analysis is one of the necessary process to get the soil particle sizes which is also known as mechanical straining. For example, in fine aggregate grade analysis, first took 1 kg of fine aggregate, then arranged the set of sieves (10mm to 0.15mm sieves) in descending order. Taken aggregates have placed in to the top sieve, after that the set up arrangement has preserved on the sieve shaker to vibrate. After vibrated, measured the retaining percentage of fine aggregate and percentage of passing. The same procedure will have applied for the coarse aggregate sieve analysis with 12.5mm sieves to 2.36mm sieves. To regulate the particle size circulation of taken fine and coarse aggregate which helps to identify the aggregate engineering properties. Tables 2 and 3 show the particle size analysis of coarse aggregate with 12.5mm and fine aggregate respectively.

Table 2. Grain size analysis of Coarse Aggregate

Sieve size (mm)	Weight of retained (gm)	Retained Percentage	Cumulative retained percentage	Cumulative % of passing
				Coarse Aggregate
12.5	20	0.41	0.41	99.59
10	2812	56.98	57.39	42.61
4.75	1834	37.16	94.55	5.45
2.36	264	5.35	99.9	0.9
PAN	5	0.1	100	0

Table 3. Grain size analysis of Fine Aggregate

Sieve size (mm)	Weight of retained (gm)	Retained Percentage	Cumulative retained percentage	Cumulative % of passing
				Fine Aggregate
10	0	0	0	100
4.75	15	1.5	1.5	98.5
2.36	40	4	5.5	94.5
1.18	130	13	18.5	81.5
0.6	370	37	55.5	44.5
0.3	295	29.5	85	15
0.15	145	14.5	99.5	0.5
PAN	5	0.5	100	0

Table 4. Slump values of SCGPC

Mix No	Molarity (M)	Slump flow (mm)	T50 Slump flow (sec)	V- Funnel (sec)	L-Box ratio (h2/h1)
M1	8	685	3.41	9.51	0.96
M2	10	676	3.75	10.23	0.94
M3	12	665	4.22	11.20	0.93
SCGPC acceptance criteria as per EFNARC {1&2}					
Minimum		650	2	6	0.8
Maximum		800	5	12	1

2.3. Measure the Slump Flow Values

The slump test is used to examine the reliability or workability of the SCGPC mix prepared at the lab yard. It is used to gage the horizontal free flow of SCGPC without obstructions. The slump flow test was initially established in Japan for the use of underwater concrete construction. Normally, in this flow test, have to prepare 6 liter of concrete which is required to proceed with the experiment. Take the base plate and placed it into the slump cone at the midpoint hold down firmly. After that, fill the slump cone with the concrete with the help of scoop. Strike off the SCGPC concrete level simply without compaction using the trowel. Then eradicate all excess concrete from the surrounded places of the slump cone. After that remove the slump cone in a vertical position and let the SCGPC concrete flow freely. Finally check the final diameter of the SCGPC in two upright ways and estimate the average of the two diameters. Also, it was carried out to check the same quality of SCGPC during building construction. In general, the concrete slump value is used to measure the workability which specifies the water content ratio. Also it includes the properties of different materials, methods of mixing, dosage and admixtures. The calculation of SCGPC slump value is shown in Figure 1. The slump values of M8, M10 and M12 SCGPC are given in Table 4.

Figure 1. Calculation of SCGPC Slump value

2.4. Mix Design of SCGPC

The mix design of SCGPC has been made with the help of Rangan's method and EFNARC. Based on the guidelines given by European Federation of National Associations Representing for Concrete - EFNARC guidelines and Rangan's method, the following ranges were designated for the particular ingredients of the mixtures.

- The GGBS and fly ash with the Class of "F" included with little calcium were taken for the Geo Polymer binders and are permanent at 50:50 ratios by mass. The combined aggregates viz., the aggregates of coarse and fine was generally in the rate of 70 to 80%, by mass. In this study, the mass of combined aggregate can be taken as 73% of the mass of concrete.
- In this combined aggregate, in order to meet the necessities of standard grading curves, the coarse aggregates (45%) of 12.5 mm and fine aggregate (55%) of sand were taken. The alkaline activator solution (AAS) was taken as a mixture of Na2SiO3, Na2O = 13.7%, H2O = 55.9% and SiO2 = 29.4% by mass and NaOH in the form of pellets with the range of 97%-98% pureness.
- The ratio of Na2SiO3 to NaOH solution was generally in the range of 0.4 to 2.5, by mass. In this study, it was fixed at 2.5. The different molarities of NaOH solution were used in the making of AAS such as 8M,10M and 12M. The ratio of AAS to propose SCGPC binders (GGBS and fly ash) was preserved at 0.45. The ratio of water to Geo Polymer solids was taken as 0.33.

The 2% dosage of superplasticizer by mass for the Geo - Polymer binder was applied in order to achieve the necessary workability characteristics of SCGPC. The proposed SCGPC mix ratios are given in Table 5.

Table 5. Mix ratios of proposed SCGPC

Materials	Mass (kg/m^3)		
	8M	10M	12M
Coarse Aggregate	786.33	786.33	786.33
Fine Aggregate	961.08	961.08	961.08
Fly ash	225	225	225
GGBS	225	225	225
Sodium silicate solution	144.66	144.66	144.66
Sodium Hydroxide solution	18.51	23.14	27.77
Alkaline solution/ (FA+GGBS) (by mass)	0.45	0.45	0.45
Na_2SiO_3/NaOH	2.5	2.5	2.5
Water/ Geopolymer Solids (by mass)	0.33	0.33	0.33
Super Plasticizer	9	9	9

2.5. Preparation of Concrete Cubes and Cylinders

After the mix design procedure, the required quantity of fine aggregate, coarse aggregate, GGBS, fly ash, Sodium Hydroxide solution, Sodium silicate solution, Alkaline solution, Water, Na_2SiO_3/NaOH, and Super Plasticizer have taken to prepare the SCGPC cubes and cylinders for testing. The SCGPC cubes and cylinders have prepared in the laboratory, for each trial took 3 cylinders and cubes. Totally prepared 135 cubes and 135 cylinders in the laboratory using concrete mixture machine. The average time taken for the concrete mixture is around 7 minutes. The sample size of cubes is 15x15x15cm (length x width x depth) and the sample size of cylinders for testing is 15x30cm (diameter x length). The SCGPC cubes and cylinders have been prepared periodically and cured in a hot oven based on the required curing temperature. After curing of SCGPC, did the experimental analysis of strength properties. Then the SCGPC strength properties like 8M, 10M and 12M based on Table 5 has taken. The sample of SCGPC cubes and cylinders is given in Figure 2.

Figure 2. Sample of SCGPC cubes and cylinders

3. Experimental Results

The results of the concrete have been analyzed with the mechanical properties which have been discussed in this section. After the preparation of cubes, the mechanical strength properties of SCGPC have been checked. For compressive mechanical strength checking, 1 set of 3 cube specimens has been subjected to several raised temperatures in the range of ambient temperature to 200^{0}C, with the increment range of 50^{0}C, in a thermostat controlled electrical furnace. The SCGPC gains about 55-65% of the entire SCGPC- compressive resistive strength within 7 days. The 7, 28 and 56 day SCGPC - compressive strength vs temperature is given in Figures 3, 4 and 5 respectively.

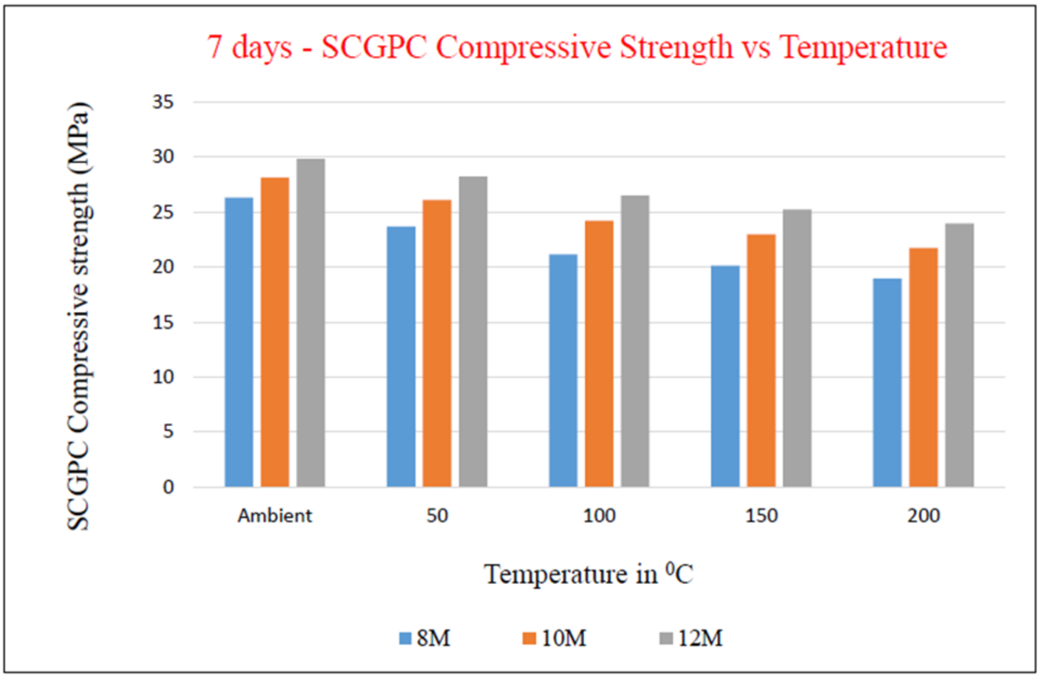

Figure 3. 7 days – SCGPC Compressive Strength vs temperature

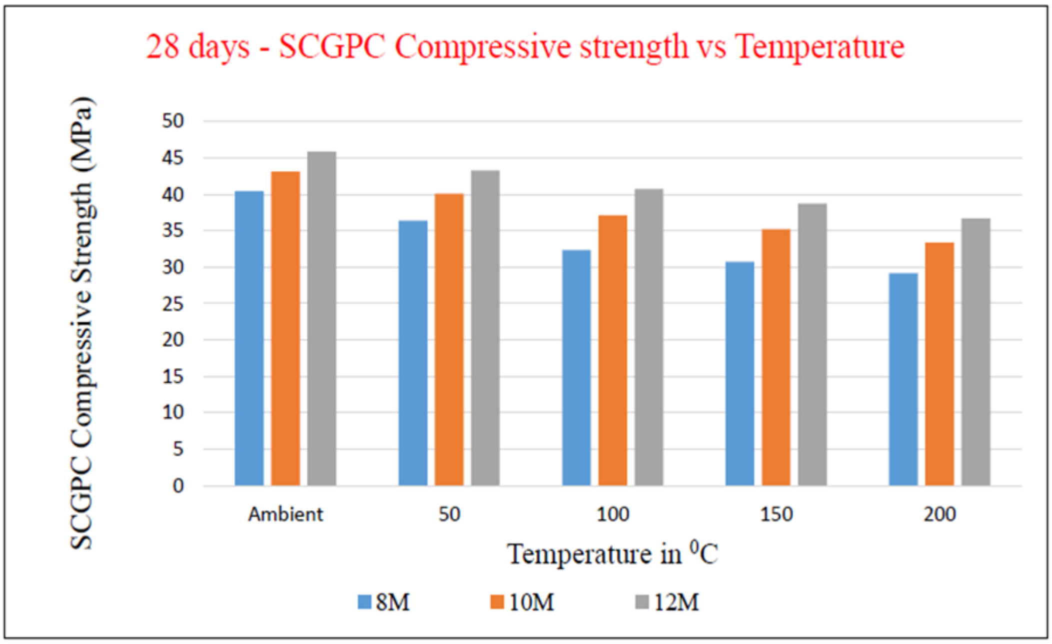

Figure 4. 28 days – SCGPC Compressive Strength vs temperature

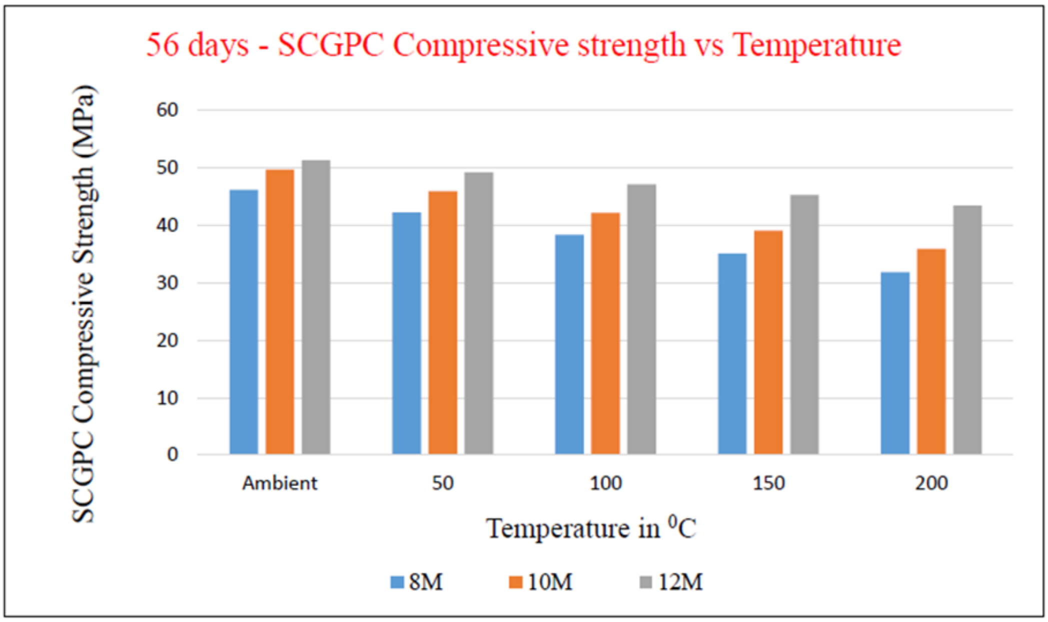

Figure 5. 56 days – SCGPC Compressive Strength vs temperature

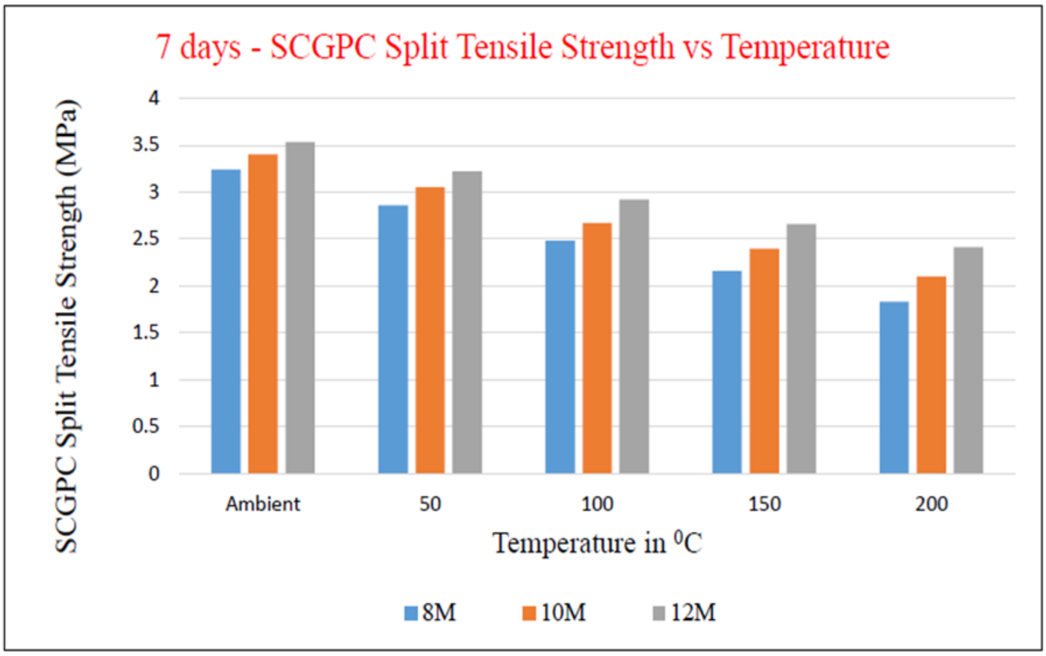

Figure 6. 7 days – SCGPC Split Tensile Strength vs temperature

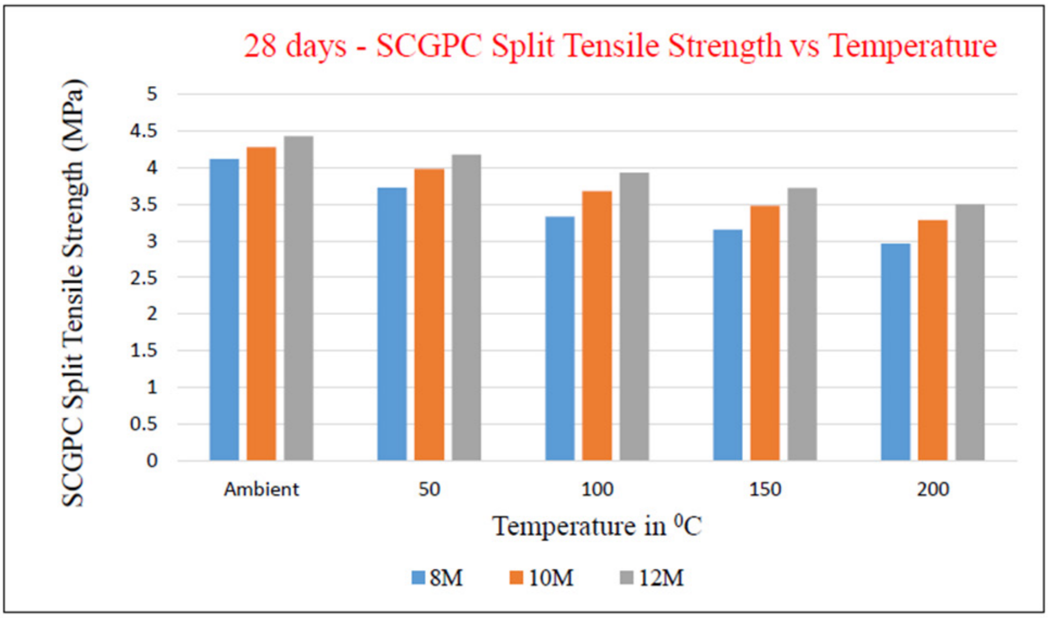

Figure 7. 28 days – SCGPC Split Tensile Strength vs temperature

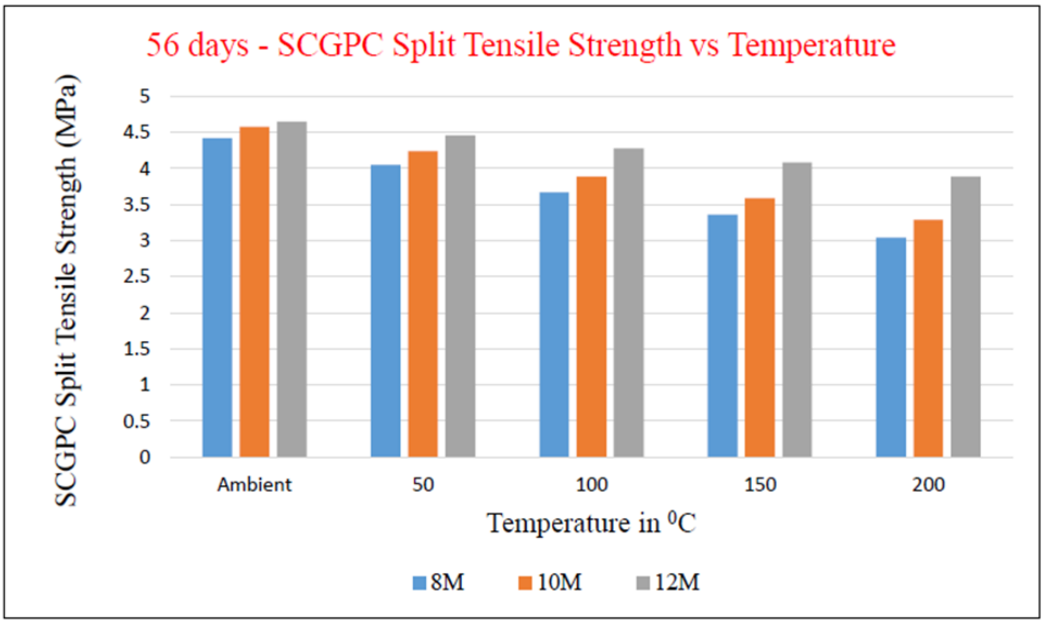

Figure 8. 56 days – SCGPC Split Tensile Strength vs temperature

For split tensile strength checking, 1 set of 3 cube specimens has been subjected to several raised temperatures in the range of ambient temperature to 200°C, with the increment range of 50°C, in a thermostat controlled electrical furnace. The SCGPC gains about 65-75% of the entire split tensile strength within 7 days. Figures 6, 7 and 8 show the chart presentation of split tensile strength vs temperature at 7, 28 and 56 days respectively.

The proposed work has been examined by conducting the experiment in SCGPC concrete with different grades and curing temperatures. First analyzed is the compressive strength of proposed concrete at 7, 28 and 56 days curing with ambient to 50°C constant increasing temperature. The testing results have been noted and presented via graph. Next analyzed is the Split Tensile strength of proposed concrete at 7, 28 and 56 days curing with ambient to 50°C constant increasing temperature. The testing results have been noted and presented via graph. Both the strength properties have been compared from the noted results. According to the compared results, it cleared that while ambient to increase of high level curing temperature, both the mechanical strength properties of proposed SCGPC has reduced. When compared to previous research of Geo Polymer concrete, the compressive strength of the proposed work has been improved.

4. Conclusions

The effects of several properties, specifically compressive and split tensile strength for proposed SCGPC by adding GGBS and fly ash has experimented. The proposed SCGPC (8M, 10M and 12M) has analyzed both compressive and split tensile strength in three sets (7, 28 and 56 days). At last, the analyzed mechanical properties of proposed SCGPC results were compared with conventional concrete. All the experimental results of new SCGPC have been given in the form of chart presentation. Based on the comparison, while the increase of curing temperature, the proposed SCGPC - split tensile and compressive strength has reduced. To reach extend action that the need of improving strength with different ecofriendly materials in concrete binding preparation will be the future action of this paper.

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