Utilization Of Industrial Waste For Production Of Self Compacting Geo-Polymer Concrete

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Abstract: Global warming is the major threat to the modern world. Cement industry contributes maximum heat to the atmosphere due to liberation of carbon dioxide during course of its preparation. Therefore researchers are trying to develop more and more eco-friendly materials. Self-compacting geo-polymer concrete (SCGC) is one of the eco-friendly material which is termed as green concrete. SCGC not only reduces pollution but also enhance the environmental and performance of concrete with respect to cement concrete. The advantages of development of SCGC are (a) consuming industrial waste and (b) self-consolidation without any vibration, towards better strength of concrete. This review paper critically analyses the various factors associated with the development of SCGC. The factors like concentration of sodium hydroxide, fly ash (FA) content, replacement of other industrial wastes, dosage of super plasticizer, ratio of sodium silicate to sodium hydroxide (alkali solution), ratio of alkali solution to fly ash, ratio of water to geo-polymer solid and curing condition on workability and mechanical properties of SCGC.

Index Terms: Alkali solution, Fly ash, Green concrete, Self-compacting geo-polymer concrete, Super plasticizer

1 INTRODUCTION

Now a days use of concrete is very indispensable in the infrastructure development. This requirement is very huge and said to be next to water but it has lot of environmental drawbacks. The cement industry produces approximately 6-7% of global CO_2 emission to the environment which contributes to global warming. Cement used in construction industry is the main cause of environmental pollution. This environmental threat forced the researchers to develop an alternative binding material of cement. Subsequently the researchers found geo-polymer concrete (GPC) as the alternate binding material to produce more environmental friendly concrete with respect to conventional cement concrete. This geo-polymer technology reduces approximately about 80% of CO_2 emission to the environment caused by cement industry [27], which is quite helpful to reduce global warming and therefore it is termed as green concrete. Davidovits introduced first geo-polymer in 1970 and stated that the three-dimensional alumino-silicates material in binder form is produced from the reaction of silicon and aluminium present in source materials with concentrated alkaline solution. The source materials are mainly the industrial waste like fly ash (FA), ground granulated blast furnace slag (GGBFS), silica fume (SF), rice husk (RH) and red mud. Sodium (Na), Potassium (K) based high alkaline liquids react with silicon and aluminium atoms present in the source materials such as FA, GGBFS and SF etc, to form a gel like materials which acts like a binder in geo-polymer concrete (GPC). This GPC have shown better results in both mechanical and durability properties. [27].

Fresh behaviour of GPC has a little concern on workability as it stiffens quicker due to early activation of source materials. This difficulties have been countered by adding some percentage of plasticizers with the geo-polymer concrete to make it workable. Self-compacting Geo-polymer concrete (SCGC) is an innovative method which makes the concrete not only workable but also flowable due to its own weight without any vibration for placing it even if in case of closely spaced reinforcement cage. In the developing world, the industrialization is increasing and as such the amount of waste material produced is also increasing. The disposal of these materials has become an ecological issue and need to be managed. Efforts are being taken to protect the environment by using more and more industrial wastes in the concrete and conserving the natural resource as well as to reduce the cost of construction materials. In this paper, the various industrial waste like FA, GGBFS, SF for making self-compacting geo-polymer concrete (SCGC) is reviewed. An extensive studies have been made in respect of various factors associated with the production of SCGC towards its performance on fresh and hardened behaviour of concrete.

2 LITERATURE REVIEW

2.1 Materials Used

Industrial waste like FA, GGBFS and SF, which are abundantly rich in alumina and silica are preferred to be used in production of SCGC. Annually, approximately 440–450 million tons and 310–370 million tons of FA and GGBFS waste products are being produced globally from thermal power plant and steel industries respectively. Out of which only 5-7% of the waste products are used in cement and concrete industries as of now [11]. Most of the authors have used low calcium fly ash singly [4,8-10,14,17,20,21,24]as source material, binary with GGBFS [5,11-15,18,22,23,28] or SF [6,19], tertiary with both GGBFS and SF [5,19]for the production of SCGC. Now-a-days self-compacting concrete is more popular because of smooth flow ability without any compaction at the time of casting. It not only enhances the strength as well as the durability properties but also reduces the time of casting, economy and sound pollution. Ordinary concrete while

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placing in the form requires vibration for proper compaction by elimination of entrapped air present in the concrete to get a homogenous mass without any honey-comb [4], but the result is not always satisfactory. By adding some percentages of super plasticizer the ordinary concrete becomes self-compacting concrete which can flow with its own weight without any vibration to the space available in the congested reinforcement. This makes the concrete more homogenous and their by more stronger without any external vibration [6].

Table 1 *Source materials used by various authors*

Source Materials	Fly Ash		GGBFS	SF
Ref. No.	3,7,11,15,22,28	4,6, 9, 10,19,23,24	7,11,15,22,27,28	6,19
Chemical Composition				
Oxides	Mass percentage			
SiO_2	60-72	40-51	30-38	90-97
Al_2O_3	20-30	26-30	14.5-19.5	0.4-0.82
Fe_2O_3	1.2-5	4.5-6	0.58-1.2	0.3-1.67
CaO	0.1-3.2	4.8-15	33.25-41.70	0.3-1.24
MgO	0.18-0.54	0-4	6.1-8.7	0.00
P_2O_5	0-1.6	1.60	0-0.16	0.00
SO_3	0.07-1.34	1.4-1.9	0.02-1.85	1.40
K_2O	0.03-0.81	1.56	0.07-0.82	4.02
Na_2O	0.03-1.36	-	0.16-1.35	-
TiO_2	0.13-1.4	0-0.67	0-0.24	-
LOI	0.29-0.8	0.29-7	0.04-2.1	-
Physical Properties				
Specific Gravity	2.13-2.36		2.4-2.9	2.22
Fineness (m^2/Kg)	340-390		400-700	12000-17000

The details of chemical compositions and physical properties of source materials used by various authors are mentioned in the table-1. In this table two categories of fly ash are used i.e low calcium (0.1 - 3.2%) but high percentages (60-72) of silica and, medium calcium percentages (5-15%) with (40-51%) of silica. The authors using low calcium fly ash have added GGBFS partially to achieve better mechanical properties [7, 11, 15, and 22].

Alkaline solution:
A mixture of $NaSiO_3$ / $KSiO_3$ and NaOH/ KOH to a particular proportion makes an ideal alkaline solution for geo-polymer reaction. Most of the authors adopted commercial grade of NaOH/ KOH in their research works [11]. Sodium silicate was supplied as a solution with around 50-60% water content, whereas sodium hydroxide flakes of 92-99% purity was dissolved to required concentration [3, 4, 11]. The different concentration NaOH solution were taken for experiment from 2M, 4M, 6M, 8M, 10M,12M, 14M and 16M in order to make 1 Kg of solution, 7.3%, 14.7%, 22.1%, 29.4%, 36.7%, 44.1% and 51.4% of pellets were added to the water respectively [4]. The most of the best results of SCGC were found out at 10M to 14M concentration of NaOH.

Superplasticizer (SP)
Most of the authors reported that at 12M of NaOH concentration, the SCGC did not have workability with 3%, 4%, and even at 5% addition of super plasticizer, but it showed good workability as well as maximum strength at 7% dosage of super plasticizer. At 6% SP result was also nearing to 7% dosage, hence the author adopted 6% of SP for economic point of view.

2.2 Mix Proportions
Different authors have suggested different mix designs for SCGC using various industrial waste as mentioned in table-2. Most of the researchers adopted 12 M NaOH concentration, 7% super plasticizer by weight of fly ash, ratio of sodium silicate to sodium hydroxide as 2.5, fly ash content varied from 400- 450 kg/ m³, proportion of fly ash to fine aggregate to coarse aggregate as 1: 2.125: 2.375, alkaline solution to fly ash ratio as 0.5, water to geo-polymer solid as 0.33, liquid to fly ash ratio as 0.69 with 12% extra water by weight of fly ash [4-6,8-10, 17, 20-21].

Table 2 *Mix proportions by previous authors*

Ref. No.	FA		F. Agg.	C. Agg.	Na OH	Na_2SiO_3	NS / NH	AS/ FA
	(Kg/ m³)							
[4] [5] [6] [8] [9] [10] [17] [20] [21]	FA	400	850	950	57	143	2.5	0.5
[5] [19]	FA	450	850	1000	57	143	2.5	0.44
	FA	405	850	1000	57	143	2.5	0.44
	GGBFS (10%)	45						
	FA	360	850	1000	57	143	2.5	0.44
	GGBFS (20%)	90						
	FA	315	850	1000	57	143	2.5	0.44
	GGBFS (30%)	135						
	FA	427.5	850	1000	57	143	2.5	0.44
	SF (5%)	22.5						
	FA	405	850	1000	57	143	2.5	0.44
	SF (10%)	45						
	FA	382.5	850	1000	57	143	2.5	0.44

	SF (15%)	67.5						

2.3 Fresh Properties
Fresh properties are the main criteria of SCGC. The fresh property consists of three characteristics such as filling ability (slum flow, T-50 cm slum flow, V-funnel), passing ability (L-box, U-box, fill box) and segregation resistance (V-funnel, T-5 min.). The purpose of mix design is to flow the concrete under self-weight without vibration and also flow through the closely spaced reinforced structures under its own weight. The results of fresh properties of previous authors have been given in the table- 3. The results of the fresh properties should be within European Guidelines i.e. FENARC limits [30] as mentioned below the table- 3.

Table 3 *Fresh properties by previous authors*

Ref. No.	Mix Sample	Slump flow	T-50 cm Slump flow	V-funnel flow	L- box (H2 /H1)	J-Ring	SP
		mm	sec	sec		mm	%
[4]	FA-100%	690	4.5	10	0.94	7	6
[6]	FA-100%	695	3.5	9	0.96	-	6
[8]	FA-100%	690	4.5	10	0.94	7	6
[9]	FA-100%	690	4.5	10	0.94	7	6
[10]	FA-100%	710	4	7	0.96	5	7
[17]	FA-100%	710	4	7	0.96	5	7
[20]	FA-100%	690	4.5	10	0.94	7	6
[21]	FA-100%	710	4	7	0.96	5	7
[5]	FA-100%	690	4.5	10	0.92	-	6
[19]	FA- 100%	650	4.5	14	0.88	-	6
	FA-95%, SF-5%	660	5	12	0.94	-	6
	FA-90%,SF -10%	670	5.5	11.5	0.96	-	6
	FA-85%, SF -15%	680	6.5	10.5	0.95	-	6
	FA-90%,GBFS -10%	660	5.9	9.3	0.89	-	6
	FA-80%,GGBFS -20%	680	5.6	9.5	0.92	-	6
	FA-70%,GGBFS -30%	690	4.7	11	0.96	-	6
EFNARC Limits [30]	Minimum	650	0	0	0.8	0	-
	Maximum	800	7	10	1	10	-

It is seen that by addition of SF and GGBFS the workability of SCGC is increased. The results obtained from the laboratory testing are within the EFNARC limitations. Some of the authors used different concentration of NaOH solution and found that the increase in molarity inversely proportional to the workability of the mix.

2.4 Curing:
The hot curing samples of SCGC give better strength than the ambient curing samples. The authors achieved better strength of SCGC replacing FA partially by GGBFS or SF [11]. It has been seen that [10] the curing temperature with 70^0 and curing period for 96 hours gives highest strength. Beyond 70^0 C the strength decreases [17] and the gain of strength is not encouraging after 48 hours of hot curing. 2.5 Hardened Properties: The compressive strength, flexural and split tensile strength are the main three properties of hardened concrete. In respect of hardened properties the results obtained by previous researchers are given in the table- 4 and table- 5.

Table 4 *Compressive strength results by previous authors*

Ref. No.	FA (Kg/m³)	Replacement (%)	Compressive Strength in MPa			
			1d	3d	7d	28d
[4] [8] [9] [20] [21]	400	0	47.83	48.52	49.44	51.52
[6]	400	0% SF	46.99	-	49.25	51.43
	400	5% SF	48.22	-	51.62	53.38
	400	10% SF	50.25		53.76	55.02
	400	15% SF	48.54		51.53	53.96
[10]	400	0				51.03
[5] [19]	450	0% GGBFS				34.67
	450	10% GGBFS				35.92
	450	20% GGBFS				36.26
	450	30% GGBFS				38.55
	450	5% SF				36
	450	10% SF				37.38
	450	15% SF				35.56

The compressive strength is optimized as 6% SP. Replacement of 10% fly ash by SF achieves the highest compressive strength. Similarly replacement of 30% Fly ash by GGBFS achieves the highest compressive strength. The strength of SCGC increases with the increase of molarity and alkali solution ratio. It has also been seen that rate of gain of strength after one day is not proportional. The rate of gain of strength is more in heat curing rather than ambient curing.

Table 5 *Flexural and split tensile strength results by previous authors*

Ref. No.	Replacement	Flexural Strength (MPa)			Split tensile strength (MPa)		
		1day	7days	28days	1day	7days	28days
[6]	0% SF	3.62	3.76	4.09	3.84	4.07	4.14
(SP=6 %,	5% SF	3.8	4.03	4.18	3.92	4.18	4.31

AS/FA = 0.5, NS/NH = 2.5)	10% SF	3.98	4.29	4.56	4.12	4.4	4.67
	15% SF	3.78	4.10	4.21	3.89	4.09	4.24
[5], [19] (SP= 6%, AS/FA = 0.44, NS/NH = 2.5)	0% GGBFS			4.20			4.20
	10% GGBFS			4.43			4.44
	20% GGBFS			4.63			4.56
	30% GGBFS			4.82			4.62
	5% SF			4.28			4.20
	10% SF			4.60			4.40
	15% SF			4.30			4.38

The split tensile strength & flexural strength are the highest when the SP= 6%, AS/FA= 0.5 and NS/NH = 2.5. When the Fly ash is replaced by 10% of SF the split tensile strength as well as the flexural strength both are at the highest level. Similarly when the Fly ash is replaced by 30% of GGBFS the split tensile strength and flexural strength both attains the highest level.

3 CONCLUSION

This critical study encounters various factors associated with the development of SCGC and summarizes the effects of molarity, alkaline activator ratio, water to geo-polymer solid, fly ash content, fly ash to fine aggregate to coarse aggregate of mix proportions, AS/ FA on workability and mechanical properties of SCGC under different curing temperature.

The following points have been studied and presented as below:

(i) The increase in the concentration of NaOH increases the strength but decreases the workability of SCGC.

(ii) Increase in the Na2SiO3 to NaOH ratio in matrix increases the workability but decreases the strength of concrete.

(iii) The optimum concentration NaOH is found out as 12 M and percentage of super plasticizer is 7% by weight of fly ash.

(iv)The favorable alkaline solution to fly ash ratio as 0.5, water to geo-polymer solid as 0.33, liquid to fly ash ratio as 0.69 and NS to NH ratio is 2.5.

(v) The addition of GGBFS up to 30% and SF up to 10% increases both the workability and strength of SCGC.

(vi)The strength of SCGC is enhanced by partial replacement of fly ash by GGBFS or SF at ambient temperature.

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