Sustainable Alternatives to Cement: Exploring Geopolymer Concrete and Industrial Byproducts in Construction

Himanshu Navneet[*1], Prof. Ujjwal Boora[*2]
[*1,2] *Dept. Of Civil PKG College Of Engineering & Technology Affiliated by Kurukshetra University, India*

A crucial component in building construction is cement, which serves as a binder. As a plaster or as a component in the production of concrete, cement is currently utilized in every construction project. India ranks as the second largest cement producer globally in terms of cement manufacturing. In 2017, India accounted for the production of 270,000 tonnes of cement [1]. According to the emission of approximately 0.94 metric tonnes of CO_2 is produced per tonnes of cement [2]. A substantial quantity of carbon dioxide (CO_2) is emitted and numerous earthen resources, which are essential base materialsfor cement production, are depleted as a result of increased cement usage in construction activities. In the construction industry, it is critical to find an alternative material that reduces cement usage in orderto mitigate the negative effects of cement production. The comparative merits of geopolymer concrete over cement concrete have been the subject of a multitude of studies. The concept of geopolymerization and geopolymer are widely acknowledged and embraced by scientists [3]. It has been demonstrated that geopolymer concrete has the second- lowest production costs, after wood, when comparing the production costs of various building materials using eco-taxes on energy or actual CO_2 emissions as assessing factors. The development of ultra-high performance geopolymer concretehas been the subject of recent research. The technical viability of incorporating copper refuse as fine aggregate in ultra-high-performance concrete [4-5]. The current utilization of geopolymer concrete asa substitute for cement concrete as a sustainable material is restricted on buildings and other structuralcomponents. This is primarily due to the absence of codal provisions governing the mix design procedure for geopolymer concrete, which is exacerbated by the insufficiency of information regarding its fresh and hardened properties [6]. Cement is an essential component of concrete, whichis the most important building material utilized in infrastructure development. It is anticipated that developing countries will experience a significant surge in demand for Ordinary Portland Cement in the future years. India ranks second globally in cement production. Cement's manufacturing process generates greenhouse gases, which contribute to the phenomenon of global warming. An estimated 3.4% of the world's carbon dioxide is produced through the utilization of fossil fuels and the manufacturing of cement [7]. As a result, cement consumption must be decreased in order to restrict the carbon footprint. Assuring the sustainability of concrete development requires the substitution of cement as a binder with naturally occurring supplementary cementations materials that are suitable. An environmentally friendly alternative to cement in the production of concrete is the utilization of industrial byproducts such as fly ash, wood ash; Ground Granulated Blast Furnace Slag (GGBS), metkaolin, and silica fume [8].

A portion of the increase in global warming can be attributed to the reduction in CO_2 emissions causedby the addition of these supplementary cementations materials [9]. Portland Pozzolana Cement and Portland Slag Cement have the capability to incorporate pozzolanic materials such as fly ash and GGBS as direct clinker substitutes. In an effort to develop concrete, Feret (1939) initially substituted debris for cement. They may also be incorporated as mineral admixtures into concrete. The inception of alkali activated concrete from slag can be attributed to Purdon in 1940. Subsequently, Glukhovsky (1959) designated it as alkaline cement. The utilization of pozzolanic materials such as granulated slagand fly ash as cement substitutes in concrete offers several benefits. These include cost reduction in concrete production, prevent the conversion of usable land to dump yards, and enable the utilization of refuse materials to develop sustainable concrete. Additionally, energy consumption is decreased during the extraction of basic materials and cement production.

Materials Used

Concrete is a solid material composed of cement and aggregates. Hydraulic cement along with water forms a binder in hydraulic concrete (ACI Committee 116).Density of concrete after oven-drying ranges between 2000 to 2600 kg/m^3 (as per BS EN 206-1:2000). From earlier investigations it is clear that the Tyre Rubber Aggregate Concrete (TRAC) shows lesser unit weight, workability while compared with ordinary cement concrete and possess good aesthetics.

Cement

The specific gravity, initial setting time and final setting time are 3.15, 85 minutes and 425 minutes respectively. Cements produced with these requirements can vary in their physical properties such as fineness and sometimes in their chemical composition. Usually the cementof same type may be different in their properties such as strengthand rheology when they areused in conjunction with super plasticisers and mineral admixtures.

Hence, the choice of the cement should be based on their fineness and the chemistry.Cement characteristic is listed in Table 1.1.

Table 1.1 Properties of OPC

Properties		Value
Physical Properties		
Specific Gravity		3.15
Surface Area, Blaine’s (cm^2/gm)		2749
Setting time	Initial (min)	85
	Final (min)	425
Chemical Properties		
SiO2 (%)		22.38
Al2O3(%)		6.73
Fe2O3(%)		4.72
CaO (%)		59.4
MgO (%)		1.02
SO3(%)		2.33
Na2O (%)		0.021
K2O (%)		0.36
Cl (%)		0.00
LOI (%)		2.31

Supplementary Cementitious Materials (SCMs)

Supplementary Cementitious Materials are fines that help in enhancing the propertiesthrough hydraulic or pozzolanic activity (CAN/CSA A3001, 2003). These materials are more beneficial since they enhance the durability properties.

because of the physical and chemical effects due to their microstructure. Supplementary cementing materials are classified as cementitious or pozzolanic or both based on their rolein hydration (Mindess et al. 2003). A limestone powder is less reactive, natural cement and hydraulic lime are cementitious, silica fume and are pozzolanic, and Class F fly ash and GGBS as possess both cementitious and pozzolanic SCMs. They can be natural or artificial depending upon their source.

Silica fume

It is a pozzolanic material and a by-product of silicon or ferro-silicon manufacturing industry which is highly reactive in nature. Silica fume particles are very fine with particle sizes abouthundred times smaller than those of average sizeof OPC particles. The specific gravity of silica fume used is 2.22. Silica fume is a very fine particle compared to cement about 1/100 times. The ASTM C 1240 code lays down the standard specifications for silica fume. Cement is normally replaced by silica fume by 5-12%. The properties of silica fume are given in Table 3.2. In general, it is resorted in the projects when there is requirement of higher strengthin concrete and with lesser porosity in the structure thereby reducing the permeability to water being major requirement.

Fine Aggregate

For the entire investigation, river sand of zone II as per IS 383- 2016 was used. Before mixing, it was sieved and dried to remove air. Its specific gravity andfineness modulus were 2.65 and 2.60, respectively. The particle size distribution of the river sand is presented in Figure 1.1. According to IS 383 – 2016, grading them into different zones is provided in Table 1.3. The particle size distribution of fine aggregate is given in Table 1.4

Table 1.2 Properties of silica fume used

Properties	Value provided byElkem	Sandvik and Gjørv (1992) [86]	Titherington and Hooton (2004) [87]	Yazici (2008) [88]
Physical Properties				
Specific Gravity	2.22	-	-	2.2
Chemical Properties				
SiO_2(%)	87.13	92.1	96.65	92.26
Al_2O_3(%)	1.96	0.5	0.23	0.89
Fe_2O_3(%)	1.13	1.4	0.07	1.97
CaO (%)	7.16	0.5	0.31	0.49
MgO (%)	0.33	0.3	0.04	0.96
SO_3(%)	0.12	-	0.17	0.33
Na_2O (%)	0.09	0.3	0.15	0.42
K_2O (%)	0.33	0.7	0.56	1.31
LOI (%)	1.52	2.8	2.27	-

Coarse Aggregate

Crushed stone aggregate of 10-12 mm sizes was used for the study to obtain a pumpable concrete. The coarse aggregate was obtained from the quarry at Vandalur nearer to the University. Based upon IS, the specific gravity and the absorbing capacity were determinedand the properties are given in Table 3.5. The particle size distribution of coarse aggregate is given in Figure 1.2.

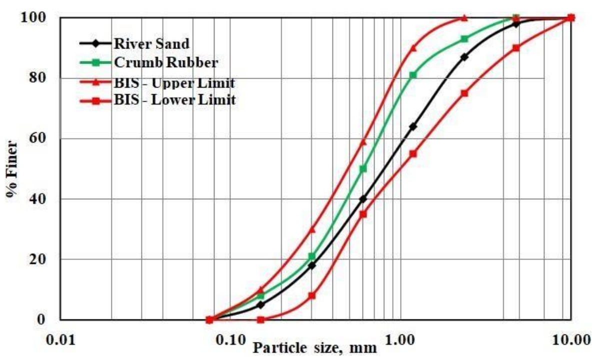

Figure 1.1 Particle size distribution of fine and crumb rubber aggregatewithupper and lower limits of BIS for Zone II

Compressive Strength of Foamed Concrete

The test on foamed concrete with the crumb rubber cube is carried out similar to the test onconcrete cube. The test results of compression of foamed concrete with crumb rubber is provided in Table 5.1 The test results show that the strength decreased from 12.4 MPa to 8.9MPa when there is a addition of crumb rubber by replacing fly ash at the end of 28 days. Similar results were also obtained for 7 and 14 days test results. The density of concrete is increased by the addition of crumb rubber in foamed concrete and it varied between 760 - 898 kg/m^3. The compressive strength reduction is due to poor bonding between crumb rubberand cementations content and due to the percentage increase in air content in concrete due to the increase in the rubber content and also due to the flexible porous on the crumb rubber content. The casting of foamed concrete with and with our crumb rubber in cubical specimens is shown in Figure 5.1.

Figurer2.1Casting of foamed concrete cube specimens with and withoutcrumb rubber

Split Tensile Strength of Foamed Concrete

Split tensile strength test on casted cylindrical specimen of foamed concrete with and withoutcrumb rubber is conducted similar to the conventional split tensile test on cylinders. The casting of foamed concrete cylinder with and without crumb rubber to study the tensile strength is shown in Figure 5.2. The test results of split tension specimen of foamed concretewith crumb rubber is provided in Table 5.2 The test results show that the strength decreasedfrom 1.15MPa to 0.72MPa when there is an addition of crumb rubber by replacing fly ash atthe end of 7 days. Similar results were also obtained for 14 and 28 days test results. The splittensile strength of the foamed concrete decreased by 34% when crumb rubber of 15% is added to the foamed concrete. The density of concrete is increased by the addition of crumbrubber in foamed concrete and it varied between 769– 907 kg/m^3.

Figure 2.2 Casting of crumb rubber foamed concrete cylindrical specimens. Table 2.2 Split tensile strength results of crumb rubber foamed concrete

Mix	Split Tensile Strength (N/mm^2)			AverageDensity (kg/m^3)
	7 days	14 days	28 days	
FC0	1.15	1.52	1.98	769
FC1	1.03	1.45	1.85	785
FC2	0.98	1.38	1.62	815
FC3	0.93	1.25	1.50	838
FC4	0.86	1.10	1.41	875
FC5	0.72	1.03	1.29	907

The relationship between compressive strength and split tensile strength of foamed concretewith crumb rubber shows a positive correlation in the mixture which shows that the strengthof concrete is decreased when there is an addition of rubber content as shown in Figure .

Compressive Strength

The stress required to rupture a material is called as strength. Compression with different batches with varying quantity of crumb rubber at 7, 14, 21 and 28 days for M30 and M40 is represented as Table 6.4.When fines are substituted from rubber crumbs(3%) compression is increased by 8% and the further increase by 6% the compressive strength remains same as the controlled concrete. By further increase in crumb rubber upto 9%, 12%and 15% the compressive strength is decreased by 8%, 14% & 19% respectively. This did not affect strength on the crumb rubber concrete but compression generally increases. At 28 days, there was reduction in compressive strength by 14%Pelisser et al when the replacement of 10% sand aggregate by using conventional recycled tire rubber and rubber modified using the alkaline activation and silica fume addition to improve the mechanical properties. It can interpret from the result that by adding crumb rubber in concrete by more than 6% by replacing fine aggregate reduces compression.

Table 3.1 Variation in compressive strength of concrete with replacement offine aggregate by crumb rubber

Mix Designation	Crumb rubber, %	Compressive Strength, MPa				% Variation in 28 daysstrength
		7 Days	14 Days	21 Days	28 Days	
CR30	0%	25.2	30.5	36.3	37.1	-
CR30-1	3%	26.5	31.3	37.4	40	8
CR30-2	6%	25.8	30.3	36.1	37.4	0.08
CR30-3	9%	25.3	29.3	33.2	35.3	-4.8
CR30-4	12%	23.6	25.4	27.4	29.3	-21
CR30-5	15%	20.2	22.3	25.5	27.5	-25.87
CR40	0%	30.3	43.1	45.2	46	-
CR40-1	3%	31.6	44.27	48	49.7	8.04

CONCLUSION

In conclusion, the pressing need to reduce cement usage in construction is underscored by the significant environmental impact of cement production, which contributes heavily to CO_2 emissions and resource depletion. Geopolymer concrete and the incorporation of industrial byproducts present promising alternatives that can help mitigate these effects. While research indicates that geopolymer concrete offers comparable performance and lower production costs, its adoption has been limited by the lack of established guidelines and comprehensive data on its properties. To promote sustainability in the construction industry, it is crucial to further investigate and develop these alternative materials, ensuring they are viable for widespread use. By embracing innovations in concrete technology and utilizing supplementary cementitious materials, the construction sector can make substantial strides toward reducing its carbon footprint and fostering a more sustainable future.

REFERENCES

[1] Andrew, R. M. (2018). Global CO 2 emissions from cement production. Earth System Science Data, 10(1), 195-217.

[2] Jena, S., & Panigrahi, R. (2019). Performance assessment of geopolymer concrete with partial replacement of ferrochrome slag as coarse aggregate. Construction and Building Materials, 220, 525-537.

[3] Davidovits, J. (1991). Geopolymers: inorganic polymeric new materials. Journal of Thermal Analysis and calorimetry, 37(8), 1633-1656.

[4] Ambily, P. S., Ravisankar, K., Umarani, C., Dattatreya, J. K., & Iyer, N. R. (2014). Development of ultra-high-performance geopolymer concrete. Magazine of Concrete Research, 66(2), 82-89.

[5] Ambily, P. S., Umarani, C., Ravisankar, K., Prem, P. R., Bharatkumar, B. H., & Iyer, N. R. (2015). Studies on ultra-high performance concrete incorporating copper slag as fine aggregate.Construction and Building Materials, 77, 233-240.

[6] Kumar, H., Prasad, R., Srivastava, A., Vashista, M., & Khan, M. Z. (2018). Utilisation of industrialwaste (Fly ash) in synthesis of copper based surface composite through friction stir processing route for wear applications. Journal of Cleaner Production, 196, 460-468.

[7] Hanle, L. J., Jayaraman, K. R., & Smith, J. S. (2004). CO2 emissions profile of the US cement industry. Washington DC: Environmental Protection Agency, 10.

[8] Cheah, C. B., & Ramli, M. (2012). Mechanical strength, durability and drying shrinkage of structural mortar containing HCWA as partial replacement of cement. Construction and BuildingMaterials, 30, 320-329.

[9] Turner, L. K., & Collins, F. G. (2013). Carbon dioxide equivalent (CO2-e) emissions: A

comparison between geopolymer and OPC cement concrete. Construction and building materials, 43, 125-130.

[10] van Deventer, J. S., Provis, J. L., Duxson, P., & Brice, D. G. (2010). Chemical research and climate change as drivers in the commercial adoption of alkali activated materials. Waste and Biomass Valorization, 1, 145-155.

[11] Davidovits, J. (1994, October). Properties of geopolymer cements. In First international conference on alkaline cements and concretes (Vol. 1, pp. 131-149).

[12] Hardjito, D., Wallah, S. E., Sumajouw, D. M., & Rangan, B. V. (2004). Factors influencing the compressive strength of fly ash-based geopolymer concrete. Civil engineering dimension, 6(2), 88-93.

[13] Dave, N., Misra, A. K., Srivastava, A., & Kaushik, S. K. (2017). Setting time and standard consistency of quaternary binders: The influence of cementitious material addition and mixing. International Journal of Sustainable Built Environment, 6(1), 30-36.

[14] Nedeljković, M., Li, Z., & Ye, G. (2018). Setting, strength, and autogenous shrinkage of alkali- activated fly ash and slag pastes: Effect of slag content. Materials, 11(11), 2121.

[15] Chang, J. J. (2003). A study on the setting characteristics of sodium silicate-activated slag pastes.

[16] Cement and Concrete Research, 33(7), 1005-1011.

[17] Duxson, P., Fernández-Jiménez, A., Provis, J. L., Lukey, G. C., Palomo, A., & van Deventer, J.

[18] S. (2007). Geopolymer technology: the current state of the art. Journal of materials science,42, 2917-2933.