Investigations on Ambient Cured Alkali-Activated One-Part Geopolymer Concrete

F. Stellamary and T. Ch. Madhavi

1 Introduction

Inorganic polymers are called as geopolymers. They are also called as alkali-activated materials (AAMs). They can be produced by using raw materials such as industrial waste materials in alkali activation reaction. They have advantages of achieving properties such as fire resistance, resistance against chemical corrosion, adequate mechanical strength, and exceptional durability. After 1980s, ordinary Portland cement (OPC) is replaced by GPC mainly because of their less CO_2 emissions and high performance comparing with OPC [1–5].

The processing technique of GP is a composite chemical reaction by developing dissolution of raw materials, conveyance, and polycondensation of the reaction products. If sodium silicate usage is avoided, two-part or traditional GP will be more energy efficient with a lower CO_2 emission. In addition to that current geopolymeric mixes could be affected from efflorescence because of the less utilization of alkaline silicates which are mixed at the time of processing in polymerisation mechanism [6–8]. The main drawback of GPC is the alkaline solution which is already corrosive in nature for activating aluminosilicate precursor in the two-part method and at the same time impedes their overall productivity.

So, the one-part GPC emerged in which solid alkaline activator and solid Al-Si precursor were prepared to improve their huge production and marketable potentiality. So, we need to get upgraded geopolymer mixes. It was first introduced by French scientist Joesph Davidovits and his team in 2007. The major factor exhorted to the advancement of one-part GP using solid activators in terms of safety concerns are solid activators replaces activating solutions.

F. Stellamary (✉) · T. Ch. Madhavi
Department of Civil Engineering, SRM Institute of Science and Technology, Ramapuram, Chennai, Tamil Nadu 600089, India
e-mail: sf9003@srmist.edu.in

Md. A. Mannan et al. (eds.), *Emerging Trends in Composite Structures*, Lecture Notes in Civil Engineering 387, https://doi.org/10.1007/978-981-99-6175-7_53

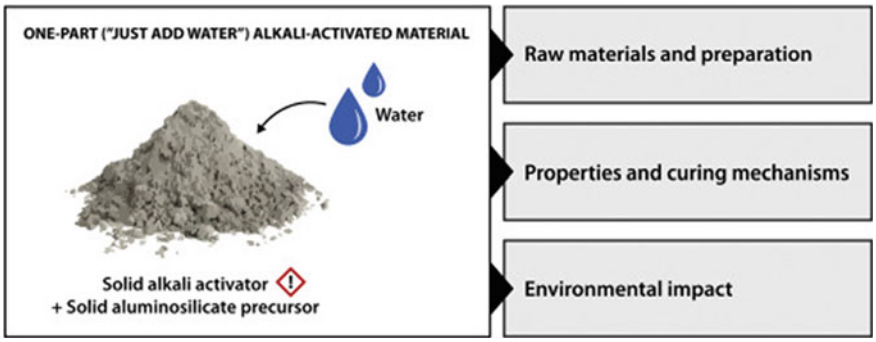

Fig. 1 One-part geopolymer concrete

1.1 What is One-part Geopolymer?

One-part (water added) GPC constitutes a blend of solid alkaline activator and Al-Si precursor, and it can be used same as conventional concrete. One-part GP is the mixture of dry powder and sufficient water Fig. 1.

1.2 Differentiation and Advantages Between Conventional Geopolymer and One-Part Geopolymer

See Table 1; Figs. 2 and 3 and 4.

Table 1 Differentiate between conventional and one-part geopolymer

S. No.	Two-part geopolymer	One-part geopolymer
1	Produced by reaction in between strenuous alkaline solution of first part: NaOH, Na_2CO_3, Na_2SiO_3, $NaAlO_2$, Na_2SO_4, and KOH and second part: solid rich in alumina and silica	Completely solid (powder form) + water added same as conventional OPC
2	Less potential for cast in situ	Greater potential for cast in situ
3	Difficult in handling, storage, and transportation	Easy to handle, storage, and transport
4	Less convenient mixing procedure	Convenient mixing procedure

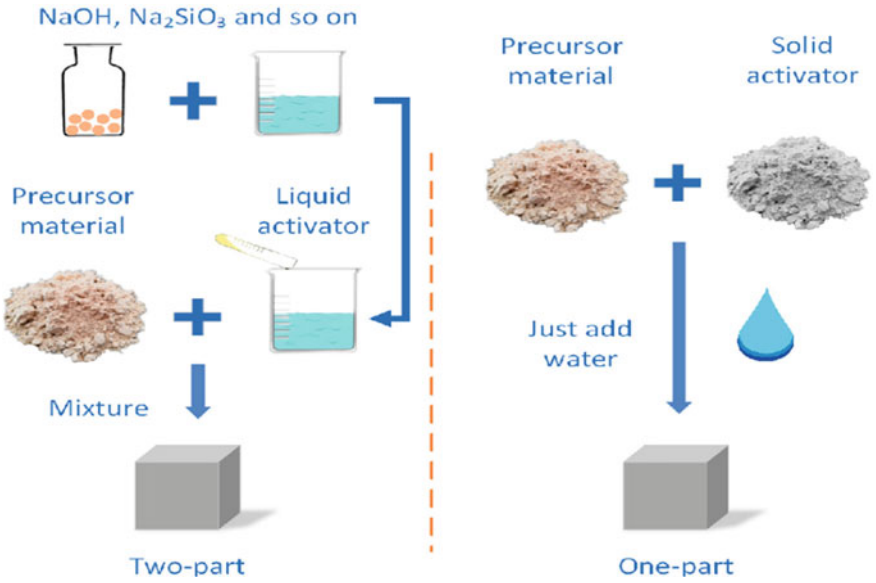

Fig. 2 Differentiation between one-part and two-part geopolymer

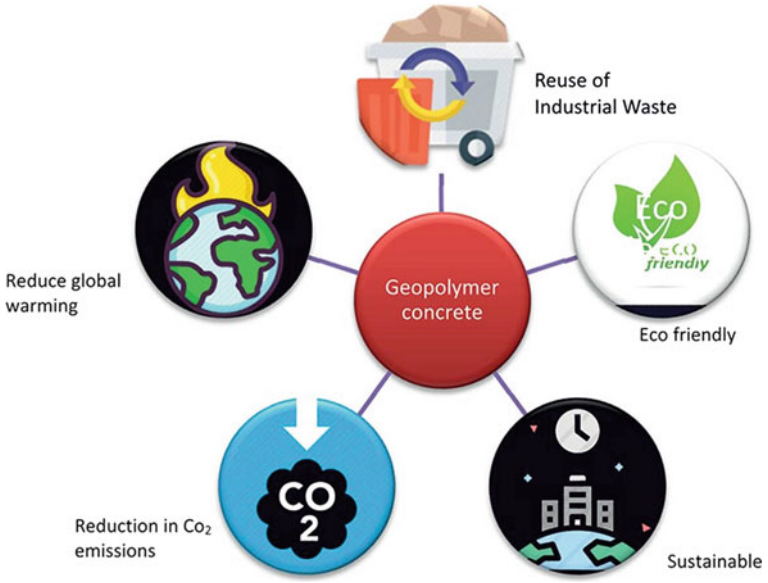

Fig. 3 Benefits of one-part geopolymer

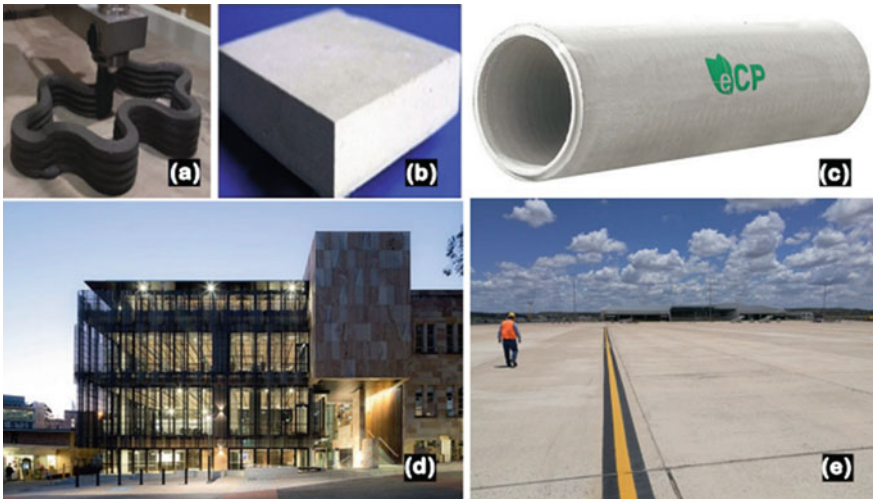

Fig. 4 **a** 3D printed geopolymer product **b** geopolymer foam **c** UG sewer pipes **d** Building: The University of Queensland's Global Change Institute **e** precast construction

1.3 Applications of One-Part Geopolymer

Geopolymer concrete can be utilized for construction of pavements/blocks, retaining walls, water tanks, precast bridge decks, and sewer pipe in infra works.

2 Materials or Precursor Used for One-Part Geopolymer Mix

2.1 Aluminosilicate Precursors

- Fly ash from coal combustion with class F (containing less calcium) as defined by ASTM standard C618. Fly ash with classification class C (containing high calcium) is rarely used as its quick setting and less availability [9].
- Blast furnace slag-GGBFS: high calcium content. It hardens at room temperature.
- Al-Si-rich materials such as silica fume, rice husk ash, Kaolin, Metakaolin, geothermal silica, red mud, natural zeolite, and many more [10].

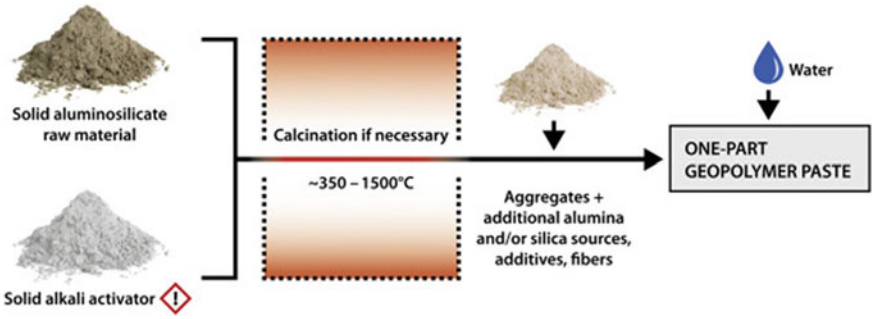

Fig. 5 Preparation method of one-part geopolymer.

2.2 Solid Activators

Activators can be consumed in the formation of GP mix such as solid NaOH, Na_2CO_3, Na_2SiO_3, $NaAlO_2$, Na_2SO_4, and KOH.

2.3 Curing Condition

The nature and the property of aluminosilicate precursor plays a major role in curing activity whether in ambient or in elevated temperatures for one-part GP [11].

The heat discharged from dissolving dry activator in solid precursor enhanced the early-ages compressive strength. GP samples are more advantageous as microcracks have been avoided while sealing and is helpful for mechanical aspects [12].

3 Preparation of One-Part Geopolymer

While preparing the GP mix, the water is added to the ingredients at the site itself whenever it is required. This is the method same as Portland cement as explained in Fig. 5. This means omitting alkaline solutions can contribute to the marketable promotion of GP.

4 Properties of One-Part Geopolymer Concrete

Factors deciding the properties are strength of the activator, precursor, and curing circumstances [13–15].

- Fresh one-part GP paste slump test value = 3.52–3.69.

- The setting time has been limited as 23–150 as initial and final 69–230 min, respectively. It has been found out that the setting time increases when fly ash content is included more.
- Also, it has been observed that when NaOH remains constant and quantity of blast furnace slag was added more, then setting time also increased. These are the statements from Nematollahi et al.
- Water absorption for blast furnace slag was 7–16%. (As curing time increased, water absorption reduced.)
- The PH value for the one-part GP pastes made up of residue from silica fume (activated by sodium aluminate) is 13.4–14.7.

5 Geopolymerization Process and Their Phases [16]

Following steps can be occurred after adding water into GP mixtures:

1. ion exchange
2. hydrolysis
3. network breakdown
4. release of Si and Al.

After completion of the above steps, the formation of one-part GP will be similar to two-part GP process as mentioned below:
(i) speciation (ii) consolidation (iii) restructuring (iv) polymerization.

6 Mechanical Properties of One-Part Geopolymer Concrete

See Table 2.

Table 2 Mechanical properties

Parameters	One -part geopolymer
Compressive strength	• Achieved 45 MPa by adding Al-Si along with Na_2SiO_3 at air curing • Resulted as 39 Mpa and 36 MPa by using Al-Si along with Na_2SiO_3 at air and heat curing, respectively • Reported as 66 MPa by including BFS along with sodium metasilicate at ambient curing
Split tensile strength	Recorded the results as 3.5, 3.1, and 4.75 MPa at water, air, and solar curing, respectively
Flexural strength	6, 5, 8.3, and 4.2 MPa at ambient, water, plastic, and air curing, respectively
Fire resistance	It has a good fire resistance

7 Durability Properties of One-Part Geopolymer [17]

The below factors affect the durability properties, namely

- Effect of chemical attack such as sulphate and chloride attack,
- Freeze/thaw cycles,
- Climatic conditions,
- Carbonation and efflorescence,
- Environmental changes and weathering actions.

8 Conclusion

The following is the summary of points discussed:

1. One-part GP is more eco-friendly than two-part GP. It is having a great influence on the products/project as it is added with water at the time of the usage such as cement with ample curing in ambient temperatures, and further, it has better attainable properties.
2. The major sources of Al-Si-based industrial by-products are preferred widely as they are easy available and meet the required properties while major activators such as sodium silicate, sodium metasilicate, sodium hydroxide, and sodium carbonate used to produce the GP mixtures.
3. As compared with OPC, the price of alkali activators is very high. But at the same time the price of industrial waste by-products is lesser as added advantage and affordable as a whole.
4. The compressive strength of one-part AAMs are up to 80 MPa values on 28th day. Also, it has been identified that value of compressive strength and elasticity has been increased, if SiO_2/Al_2O_3 molar ratio is increased. It also has been observed that porosity increases when SiO_2/Al_2O_3 ratios are low [14]
5. The environmental impact studies/analysis like life-cycle assessment analysis (LCA), global warming potential (GWP) of one-part GP showing the results are comparatively lower than that of two-part GP and OPC concrete. The mix design criteria are also a deciding factor in this. The quantity of activator added is also the major factor affecting environmental impact specifically. Thus, one-part geopolymers are sustainable and more eco-friendly [14].

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