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ORIGINAL RESEARCH PAPER

# Feasibility study of compost as a partial substitute for fine aggregate in concrete

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## ABSTRACT

In this study, vermicompost is replaced for fine aggregate in geopolymer concrete (GPC). Initially mix design is made for GPC and mix proportion is proposed. The vermicompost is replaced at 5%, 10%, 15% and 20% with M sand in GPC. Result indicates the 5% replacement with vermicompost based geopolymer concrete (GPVC) has the compressive strength of 32 N mm$^{-2}$ (M30 grade) whereas the compressive strength of control specimen made with GPC is 37 N mm$^{-2}$. Other replacement shows 21 N mm$^{-2}$, 14 N mm$^{-2}$ and 11 N mm$^{-2}$ respectively. The 5% replaced concrete cubes and control specimen are tested at an elevated temperature of 200°C, 400°C, 600°C and 800°C and compared with the control specimen. There is no significant difference observed in weight lost at control (GPC) and GPVC specimen. An elevated temperature, the weight loss is almost 4% at 200°C because of expulsion of water from the concrete. Afterwards only 2% weight loss is observed in remaining elevated temperature. The compressive strength loss is observed at an elevated temperature in GPC and GPVC specimen because of thermal incompatibility between aggregate and the binder. EDX results show M sand and compost contains Si, Al, C, Fe, Ca, Mg, Na and K and it is similar in the elemental composition and SEM image confirms vermicompost contains fine particles.

## KEYWORDS

Geopolymer concrete, Fine aggregate, vermicompost, compressive strength, elevated temperature

## 1. INTRODUCTION

Cement is an important building material in the world. Cement manufacturing emits almost 8% of the total carbon di oxide ($CO_2$) and affects the environment by releasing greenhouse emissions [1]. Geopolymer Concrete (GPC) is the alternative initiative to reduce the heat and $CO_2$ emissions [2, 3]. The water absorption and porosity of geopolymer concrete is lower than Ordinary Portland based Concrete (OPC) [4]. GPC is manufactured from sustainable material namely fly ash and Ground Granulated Blast Furnace Slag (GGBS). Fly ash and GGBS is the disposal of industrial waste product from coal based thermal power plant and steel plant. Alkaline Activator Solution (AAS) is commonly used in GPC, which is sodium or potassium based. Sodium based solution is the mixture of sodium hydroxide (NaOH) solution with sodium silicate ($Na_2SiO_3$). In recent past, cement is fully replaced with fly ash and alkaline activator solution. In the fly ash-based geopolymer binder, fly ash interacts with the alkaline solution and formed alumina-silicate binder providing strength to the concrete [5]. The cost of fly ash and GGBS is very low. At the same time, the cost of alkali activator solution is very high [6] in manufacturing of GPC. [7] found fly ash based GPC reduces 10–30% of the total cost than OPC. The costs of cement and other building materials are increasing at an alarming rate now. Geopolymer based concrete is the sustainable approach not only helpful for constructing buildings with minimum cost but also gives the solution for waste management. But so far there is no fixed mix design for GPC and is lacking up to date. Few researchers [6–8] suggested mix design for fly ash based geopolymer concrete. [7] used

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various mix ratios by trial and error for different grades of GPC. [6] found the cost of AAS is high in GPC and suggested economic mix design to minimize the cost of GPC. In many of the laboratory research works, alkali activators are wasted after preparation of concrete specimens. In this study the alkali activator is fixed and mix design is made.

Another challenge in the construction sector is the availability of river sand and it is very scarce now; manufactured sand (M sand) is replaced for river sand now. On the downside, solid waste management is the major challenge in towns and cities by the municipal the authorities [9]. There is a lot of initiatives undertaken by the government to manage the solid waste, still huge volumes of waste are unmanaged. The production of solid waste is mainly organic in nature. [9] found the elements present in the solid waste are based upon numerous factors namely lifestyle of the people, economic situation, waste management regulation and industrial structure. In India, almost 65–70% of the land are the rural areas and the major occupation is agriculture, which is organic in nature. In this study, an attempt is made to utilize decomposed solid waste (compost) for M Sand at different proportion in GPC. The mix design is developed for GPC with vermicompost as well as mix proportion is found for all the components used in concrete.

Many researchers replaced the waste material for fine aggregate. [10, 11] replaced saw dust for fine aggregate and it is found sawdust-cement-gravel-mix reduced 10% of weight floors above the structures and thereby it reduces the cost for providing thick columns. The sawdust reduced 56% of cost. Sawdust has unique characteristics and is a suitable material for fine aggregate and it is recommended to be used for interior walls. [12] found rice husk ash for fine aggregate. [13] used 5–10% of paper sludge for the replacement of fine aggregate and it is found the compressive and split tensile strength is decreasing with the percentage increment of paper sludge. [14] used cork for the replacing fine aggregate and reported that cork has special and unique characteristics, low thermal resistance and good sound absorption. [15] used ground nut shell at 0, 5, 15, 25, 50 and 75% replacement levels for the fine aggregate. [16] used compost and replaced in ordinary Portland cement concrete and reported concrete with compost is in par with the conventional concrete.[17] compared micro structural properties of red soil and compost and found compost is the suitable alternative material for red soil in brick manufacturing.

According to the authors' knowledge, no studies have been carried out to introduce compost for fine aggregate in geopolymer concrete. In this study, the following objectives are proposed: (i) mix proportion is made for vermicompost based geopolymer concrete by fixing alkali activation solution. (ii) an attempt is made by replacing M sand with 5%, 10%, 15% and 20% of vermicompost in geopolymer concrete and comparing the compressive strength with control specimen casted with geopolymer concrete. In control specimen of geopolymer concrete is casted with fly ash mixed with alkali activator solution (binder), fine aggregate (M Sand) and coarse aggregate. (iii) the casted cubes were kept under different temperature namely 200°C, 400°C, 600°C and 800°C to analyse the performance and behaviour against thermal characteristics.

## 2. MATERIALS AND METHODS

### 2.1. Physical properties of materials

Fly ash used in this work is smooth and ultra-fine. The specific gravity of fly ash is 2. The M sand is obtained from the local stone crushing factories. The specific gravity of M sand is 2.33 whereas the compost –1.76. The less specific gravity imposes the manufacture of light weight concrete. The fineness modulus of M sand and compost are 4.56 and 1.7, respectively. Less value of fineness modulus in compost helps in making fine paste making easier finish in concrete. The water absorption value of M Sand is 4.35% and compost is 2.7%. It is found that the water absorption value is very low for vermicompost. It is found that the vermicompost has good water resistant properties.

Coarse aggregates (CA) from the local quarry are obtained for this work. Coarse aggregate pieces used in this work are angular in shape and are clean and dry. The size of the coarse aggregate is passing through 13.5 mm and retaining in 22.4 mm. The specific gravity, fineness modulus and water absorption for coarse aggregate are 3.116, 2.985 and 0.81%, respectively.

***2.1.1. Preparation of alkali activator solution.*** Alkali activator solution is prepared by mixing sodium hydroxide with sodium silicate solution. In geopolymer concrete, AAS is acting as a binding agent. The preparation of alkaline activator is crucial. Sodium silicate solution is available directly in a chemical shop and hence can be weighed and used. Sodium silicate ($Na_2SiO_3$) is in semisolid (gel) state. It occupies the larger amount of alkaline solution. The specific gravity of $Na_2SiO_3$ is 1.4. The sodium hydroxide solution has been prepared in the laboratory by dissolving the calculated amount of NaOH pellets in distilled water based on the molarity. Sodium hydroxide is the part of alkaline solution. Utmost care should take while handling NaOH pellets as they cause irritation of the skin when exposed directly. It is prepared by dissolving sodium hydroxide pellets in distilled water for the required molarity. To obtain 13 molarity of sodium hydroxide solution, 520 g (40 g equivalent weight X 13 molarity) of pellets are dissolved in 1 L of distilled water. The molecular weight of sodium hydroxide is 40.

### 2.2. Chemical properties of materials

***2.2.1. Energy dispersive X ray (EDX) analysis.*** The elemental composition of M-sand and vermicompost was determined by Energy dispersive Xray (EDX) analysis. Figures 1a and 1b show elemental composition of M-sand and vermicompost, respectively. It is evident that the elements of C, Si, O, Al, Mg, Na, K, Fe are present in both the materials.

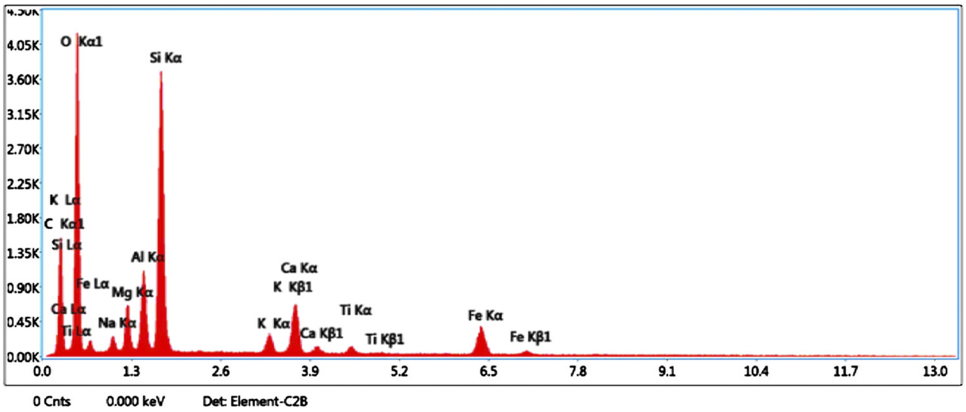

*Fig. 1a.* EDX image of M-sand

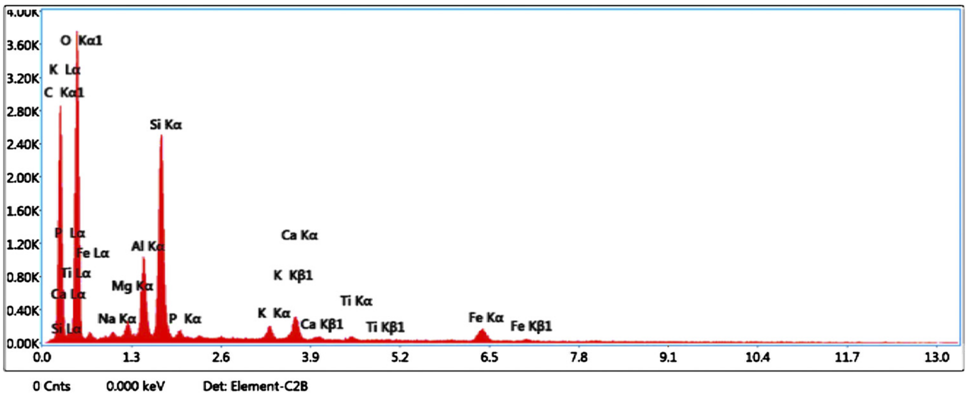

*Fig. 1b.* EDX image of vermicompost

***2.2.2. Scanning Electron Microscope (SEM) analysis.*** The Figs 2a and 2b shows Scanning Electron Microscope (SEM) image of M-sand and compost, respectively. The M-sand is elongated in shape with sharp edges; compost is angular in shape and forms very fine particles with a rough surface. It is observed that the different ranges of grains are present in both the materials. While mixing M-sand and compost, different shapes and different sizes of particles give good arrangement between the concrete matrix and act as a filler during compaction.

## 2.3. Mix proportion

There is no standard mix design of geopolymer concrete. Strength and durability attainment in concrete is because of the mix proportion. A concrete cube of compressive strength

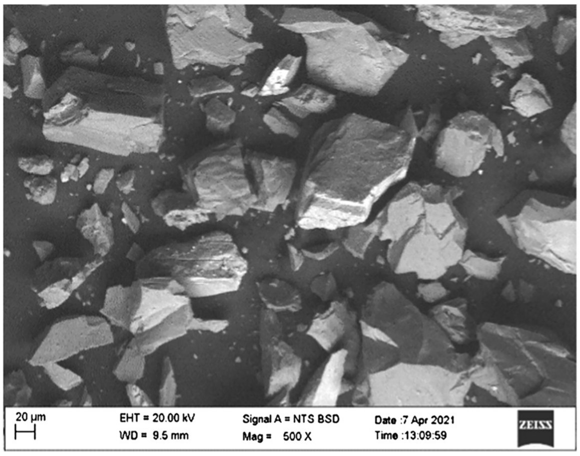

*Fig. 2a.* SEM image of M-sand

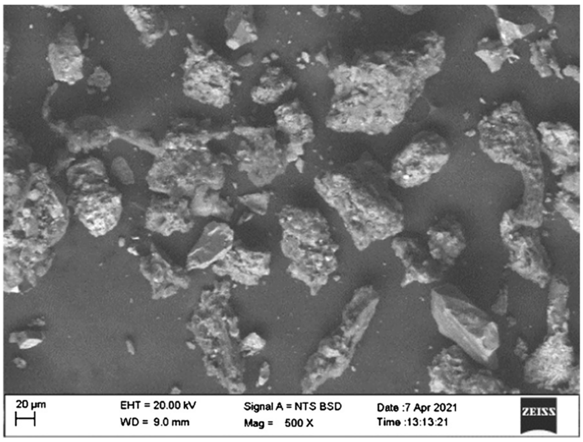

*Fig. 2b.* SEM image of compost

30 MPa is designed and proportioned for casting. The M 30 grade geopolymer concrete mix design is made with the reference to past literature [6]. Alkaline Activator Solution (AAS) is fixed and the amount of other materials used for concrete is quantified using standard mix design for the particular mix proportion. Further the proportioning of fly ash-based geo polymer concrete, M sand is replaced with compost at a percentage of 5%, 10%, 15% and 20%, respectively. Table 1 shows the mix proportion used for GPVC specimens.

The volume of NaOH is 80 kg $m^{-3}$ and volume of $Na_2SiO_3$ 120 kg $m^{-3}$ is mixed up before 24 h of casting. AAS should be prepared one day before the casting of specimens and it cannot be used for casting beyond 36 h.

## 2.4. Mixing casting and curing

***2.4.1. Preparation of concrete specimen.*** Fly ash and M-sand are mixed in a dry condition; coarse aggregate is added and mixed for 2–3 min after mixing it in dry state. The prepared alkaline activator solution is added and mixed thoroughly until homogeneous mix state. After mixing, the concrete mix is placed in a steel mould and it is well compacted. After demoulding, heat curing is done for GPC concrete. In geopolymer concrete cubes are more suitable for heat curing because it offers high compressive strength. In heat curing, demoulded concrete cubes are kept in an oven at a temperature of 100°C for one day. After one day, the cubes are kept in room temperature until the testing day is reached. The vermicompost is added at various percentages from 5 to 20 and the same GPC concrete preparation process is adopted for GPVC as per mix proportion in Table 1.

***2.4.2. Testing of specimen at an elevated temperature.*** It is a known fact that the compost is obtained from solid waste which is organic in nature. Although replacement of compost is a greener alternative, it was decided to study the behaviour of compost based concrete specimen at an elevated temperature. In this study, the prepared control specimens and with compost are kept at different temperature such as 200°C, 400°C, 600°C and 800°C for 2 h after reaching the desired temperature in a muffle furnace. Then samples are taken and left to reach ambient temperature. The loss of weight and loss of compressive strength is obtained. Eqs 1 and 2 are used for determining the loss of weight in (%) and loss of compressive strength (%).

$$\%\ \text{of weight loss} = \frac{\text{Initial weight of cube} - \text{final weight of cube}}{\text{Initial weight of the cube}} \times 100 \tag{1}$$

$$\%\ \text{loss of compressive strength} = \frac{\text{Initial compressive strength} - \text{final compressive strength}}{\text{Initial compressive strength}} \times 100 \tag{2}$$

*Table 1.* Mix Ratio of Geopolymer Concrete with vermicompost

| Flyash (kg $m^{-3}$) | Fine aggregate (kg $m^{-3}$) | Coarse aggregate (kg $m^{-3}$) | Vermicompost (kg $m^{-3}$) |
|---|---|---|---|
| 400 | 568.52 | 1237.052 | 0 |
| 400 | 540.09 | 1237.052 | 28.43 |
| 400 | 511.19 | 1237.052 | 56.90 |
| 400 | 483.22 | 1237.052 | 85.30 |
| 400 | 454.82 | 1237.052 | 113.7 |

## 3. RESULTS AND DISCUSSIONS

### 3.1. Results of Compressive strength

The compressive strength at 5%, 10%, 15% and 20% of vermicompost at 28 days are given in Table 2 and Fig. 3. From the results, it is found that the compressive strength of GPC (control specimen) is 37.5 N $mm^{-2}$ at 28 days, while introducing compost at 5%, 10%, 15% and 20%, the compressive strength is 32 N $mm^{-2}$, 21 N $mm^{-2}$, 14 N $mm^{-2}$ and 11 N $mm^{-2}$ respectively. It is evident that with the increasing percentage of compost, compressive strength is decreased. [15] reported compressive strength is decreased while replacing ground nut shell directly without making ash. This corroborates our findings. Among the replacements, 5% gives the compressive strength as 32 N $mm^{-2}$. This is good strength attainment for M30 grade concrete. The bulk density of the sample specimens is shown in Table 2. It is observed

*Table 2.* Compressive strength results of GPC and GPVC

| Percentage of vermicompost | Bulk density (kg $m^{-3}$) | Compressive strength N $mm^{-2}$ (28 days) |
|---|---|---|
| 0% | 2435 | 37.5 |
| 5% | 2430 | 32 |
| 10% | 2375 | 21 |
| 15% | 2385 | 14 |
| 20% | 2245 | 11 |

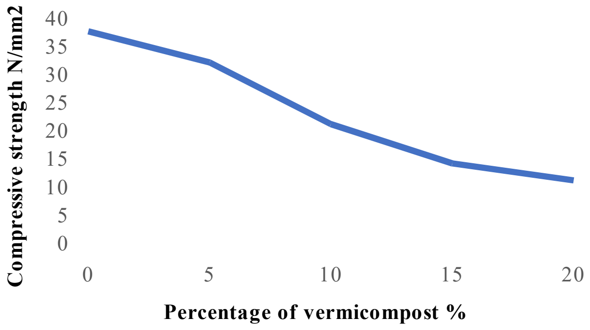

*Fig. 3.* Compressive strength results at 28 days by replacing vermicompost

that the bulk density decreases with the increment of vermicompost.

## 3.2. Effect of elevated temperature on loss of weight and strength

It was decided to study the effect of elevated temperature on compressive strength and weight loss in the GPC and GPVC specimens. In a GPVC specimen, only 5% replacement of compost concrete cubes are considered and have undergone the exposure to elevated temperature. Similarly, the control specimens are kept at an elevated temperature and the results are compared. From Table 3 and Fig. 4 it is understood that the weight loss of GPC at 200°C, 400°C, 600°C and 800°C are 4.3%, 5.4%, 5.6% and 6.1%, respectively. Similarly, the weight loss in GVPC at 5% replacement of compost is 4.0%, 4.2%, 4.8% and 4.8% respectively. It was observed that the weight loss occurred in GPC as well as GPVC at all the temperatures. But it is less than OPC. It is a known fact that the GPC is better than OPC in thermal behaviour because of less calcium hydroxide [18]. It is noted that no significant difference weight loss is observed between the 200–800°C. The initial loss of weight in concrete is because of evaporation of water expelled from the concrete pores [19]. Also, there is no significant difference in weight lost between GPC and GPVC based specimens (Fig. 3).

The % loss of compressive strength at different temperatures for controlled specimen (GPC) and vermicompost based concrete specimens (GPVC) are presented in Table 3. Figure 5 represents that the increase of temperature decreases the compressive strength. The loss of compressive strength at an elevated temperature is due to thermal mismatch between aggregate and geopolymer matrix [20]. It is understood that, at 200°C and 400°C, the loss of compressive strength in GPVC specimen is 1.8% and 11.3%, respectively, whereas GPC is 11.1% and 16.6%. It was determined that the loss of compressive strength is less at GPVC specimens than GPC specimens at 200°C and 400°C. The reason could be the combination of vermicompost and M-sand delaying the formation of micro cracks because of strong binding force between the aggregates in GPVC matrix [21]. However, the temperature is more than 600°C, the % loss of compressive strength in GVPC is suddenly increased

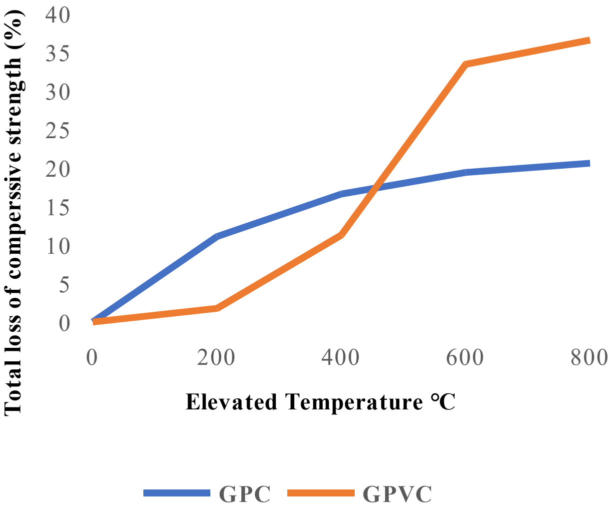

*Fig. 5.* Strength loss of GPC and GPVC at elevated temperature

*Table 3.* Comparison of GPC Vs GPVC

| | Total weight loss (%) | | Total loss of compressive strength (%) | |
|---|---|---|---|---|
| Temperature °C | GPC (CS) | GPVC replaced at 5% for fine aggregate | GPC (CS) | GPVC replaced at 5% for fine aggregate |
| 200°C | 4.3 | 4.0 | 11.1 | 1.80 |
| 400°C | 5.4 | 4.2 | 16.6 | 11.3 |
| 600°C | 5.6 | 4.8 | 19.4 | 33.4 |
| 800°C | 6.1 | 4.8 | 20.6 | 36.6 |

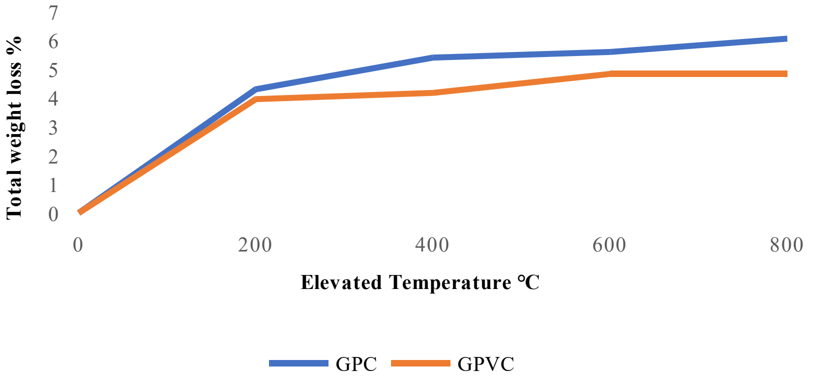

*Fig. 4.* Weight loss of GPC and GPVC at elevated temperature

to 33.4%. Similarly, the compressive strength loss is increased to 36.6% at 800°C. The reason could be the volatile solids in the compost of GPVC specimens may start to decompose at an elevated temperature. However, the weight loss observed in GPVC (4.8%) is smaller than in GPC specimen (6.1%). Hence, the exact behaviour is to be clearly studied in GPC and GPVC specimens by detailed investigation.

## 4. CONCLUSION

In this study, compost (decomposed solid waste) is introduced in fly ash based geopolymer concrete. The main limitation in GPC is the cost of alkaline activator solution. Hence the AAS content is fixed and mix design is made. Then compost is introduced in geopolymer concrete at various percentages such as 5%, 10%, 15% and 20%. Based upon the mix ratio, concrete cubes are casted with compost and the compressive strength results are compared with geopolymer based concrete at the age of 28 days. It was found that 5% replacement of compost is suitable in concrete. The loss of compressive strength is higher while replacing 15% and 20% of compost in GPVC specimen.

The casted geopolymer with vermicompost (GPVC) cubes and geopolymer concrete cubes (GPC) are kept at an elevated temperature such as 200°C, 400°C, 600°C and 800°C. Compressive strength is decreased with the increase of temperature. The loss of weight is higher at 200°C because of water escape from the specimens. After 200°C, no significant weight loss is observed in GPC and GPVC specimens. The loss of weight in GVPC and GPC is 4%–6% at all elevated temperatures.

The compressive strength loss is observed in GPC and GPVC specimens. This is because differential thermal expansion between aggregate and paste causes micro cracks in the concrete. The loss of compressive strength is higher in GPVC at higher temperature namely 600°C and 800°C because of volatile matter in compost may escape from the specimen. However, detailed investigation has to be carried out to analyse the behaviour of GPC and GPVC specimens at an elevated temperature.

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