Effect of Treated Domestic Wastewater Versus Potable Water on the Compressive Strength of Ambient Cured Geopolymer Mortar

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Abstract: The paper examines the relative effect of Treated Domestic Wastewater (TDW) and Potable Water (PW) on compressive strength of geopolymer mortar which is cured in air. With the construction industry in need of sustainable substitutions to traditional Portland cement, geopolymer technology is capable of providing a lower carbon footprint, and the use of wastewater would resolve the increasing water shortage in the world.A blend of sodium silicate (Na2Sio3) and sodium hydroxide (NaOH) was used as the alkaline activator. All the specimens were cured at ambient temperatures to represent real life conditions. The major variables considered are the chemical composition of mixing water and Fly Ash to GGBS ratio. The findings of this study are that TDW is a technically viable and environmentally friendly alternative of drinking water in the manufacture of high-strength, ambient-cured geopolymer mortars.

Index Terms – Geopolymer mortar, Treated domestic wastewater, Fly ash, GGBS, Water absorption, Sustainable construction

1. INTRODUCTION

The construction business is now under a twofold challenge of both the carbon footprint of conventional Portland cement and the diminishing amount of fresh water available to use in the manufacture of concrete. An alternative product is geopolymer mortar which is an environmentally friendly and innovative building material that uses industrial waste such as fly ash or slag to bind the mortar, thus cutting down on greenhouse gases to a considerable degree. Nevertheless, manufacturing of these eco-friendly materials requires large amounts of drinkable water to be mixed and cured, which is a sustainability paradox in water-deprived areas.

In India, the reuse of treated wastewater in construction is gaining importance due to water scarcity and environmental regulations. Authorities such as environmental agencies and pollution control boards encourage the reuse of treated wastewater for non-potable applications including construction activities.

This paper presents the feasibility of using treated domestic wastewater (TWW) instead of scarce potable water in production of geopolymer mortar. Through exploring the relationship between the chemical components and impurities of the treated effluent and the geopolymerization process i.e. under ambient curing conditions, this study will identify the effects on the main mechanical property of the material which is compressive strength. A comparison between the results of TWW-based geopolymer mortar performance and a control group of mixed mortar with potable water offers important clues in whether or not it is possible to close the loop on wastewater so as to produce a long-lasting and strong construction material without structural integrity being compromised**.**

2. OBJECTIVES

1. To test the ability of treated domestic wastewater to be used as a mixing medium in geopolymer mortar.
2. To compare the compressive strength of geopolymer mortar that had been prepared using treated wastewater and potable water.
3. To experiment on the effect of different Fly Ash-GGBS ratios on the development of strength.
4. To examine compressive strength of geopolymer mortar at various ages when it was cured at ambient conditions.
5. To encourage sustainable construction through the decreased use of freshwater.
6. To assess the binding nature of geopolymer mortar using strength and water absorption as indirect indicators.

3. MATERIALS USED

The constituents of preparation of geopolymers mortar are :

3.1 Fly ash :

Class F fly ash obtained from a thermal power plant was used as the primary alumino-silicate precursor.

3.2 Ground Granulated Blast Furnace Slag (GGBS) :

GGBS was incorporated to increase calcium content and enhance early strength development.

3.3 Fine Aggregate :

River sand conforming to **IS 383 specifications** was used as fine aggregate.

3.4 Alkaline Activator :

The alkaline activator consisted of:

- Sodium Hydroxide (NaOH)
- Sodium Silicate (Na_2SiO_3)

3.5 Water

Two types of mixing water were used:

- Potable Water (PW)
- Treated Domestic Wastewater (TDW)

The treated wastewater was collected from a municipal sewage treatment facility.Preparation of the alkaline activator solution was done through sodium hydroxide and sodium silicate which triggered the geopolymerization process.

4. METHODOLOGY

4.1 Mixing of Geopolymer Mortar

ASTM C305 -Mechanical Mixing of Hydraulic Cement Pastes and Mortars- Standard Practice.

4.2 Casting of Specimens

ASTM C109 / C109M- Standard Test Method of Compressive Strength of Hydraulic Cement Mortars (Cube specimens)

4.3 Curing of Specimens

None have got an individual geopolymer code.

As per general laboratory practice, ambient curing ensued.

4.4 Compressive Strength Test

ASTM C109 / C109M -Compressive Strength of Mortar Cubes.

4.5 Water Absorption Test

ASTM C642- Density, Absorption and Voids of Hardened Concrete.

4.6 Indirect Evaluation Characteristics (Indirect Evaluation) ASTM C109 / C109M strength based bonding assessment. ASTM C642- Porosity and absorption-based test.

5. MIX PROPORTIONS

This study was done using 4 combinations of Fly Ash and GGBS:

Mix ID	Flyash(%)	GGBS(%)
M1	50	50
M2	40	60
M3	30	70
M4	20	80

These mixes were prepared separately using treated domestic wastewater and potable water.

5. EXPERIMENTAL PROCEDURE

5.1 Casting of Specimens

In accordance with IS 4031 standards, mortar cubes measuring 70.6 mm by 70.6 mm by 70.6 mm were cast. The procedure involved:

1. Preparation of Alkaline Activator Solution (Using Potable Water and Treated Domestic Wastewater)

The alkaline activator solution of geopolymer mortar is made up of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) solutions. The procedure for preparing samples of potable water (PW) and treated domestic wastewater (TDW) is similar to each other.

Step 1: Preparation of Sodium Hydroxide Solution

Sodium hydroxide pellets are measured according to the required molarity (commonly 8M - 12M). The pellets are gradually dissolved in the required amount of water (either potable water or treated domestic wastewater) under constant stirring. The solution is allowed to cool down to room temperature because the heat is released during the dissolution process.

Step 2: Preparation of Alkaline Activator

After cooling the prepared sodium hydroxide solution is mixed with sodium silicate solution in required ration (commonly Na2SiO3: NaOH = 2 to 2.5 by weight). The mixture is well stirred in order to achieve a homogeneous alkaline activator solution.

Step 3: Resting Period

The combined alkaline activator solution is stored at room temperature for approximately 24 hours before it is used. This helps in getting complete dissolution and stabilization of activator solution.

Step 4: Application in Geopolymer Mortar

The prepared alkaline activator solution is then mixed with the fly ash - GGBS binder and fine aggregate to make geopolymer mortar. The same procedure of preparation is followed in case of both potable water and treated domestic wastewater so that there are chances to directly compare the effect of both the on the geopolymerization process.

Note: Care should be taken while handling sodium hydroxide solution as it is highly alkaline and can cause skin irritation. Protective gloves and safety equipment should be used when preparing.

2. Dry mixing of Fly ash, GGBS and fine aggregate
3. Mixing activator solution and mixing water
4. Casting in moulds, compaction
5. Surface finishing

5.2 Curing

All specimens were cured in ambient temperature conditions.

6. COMPRESSIVE STRENGTH RESULTS :

Mix ID	Fly Ash (%	GGBS(%)	3 Days (PW)	7 Days (PW)	28 Days (PW)	3 Days (TDW)	7 Days (TDW)	28 Days (TDW)
M1	50	50	19	27	35	18	26	34
M2	40	60	23	31	40	22	30	39
M3	30	70	27	36	46	26	35	45
M4	20	80	31	41	53	30	40	52

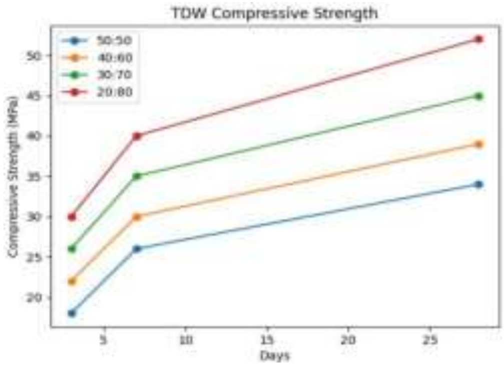

Fig 1 : Compressive Strength vs Age (TDW)

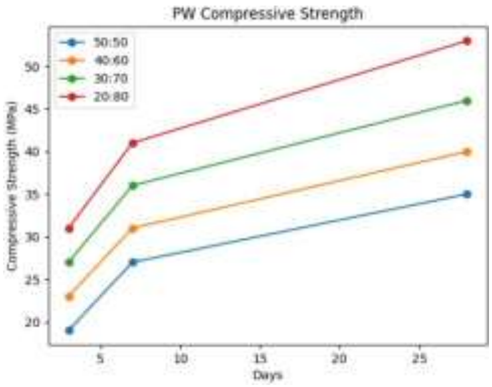

Fig 2 : Compressive strength vs Age (PW)

6.1 Compressive strength behaviour

The results of compressive strength show a gradual increase with age of curing for both of the mix proportions. At early ages (3 days) the mixes showed moderate strength, which significantly increased at 7 days and the highest values were reached at 28 days. This behavior is primarily attributed to the geopolymerization process, whereby the aluminosilicate materials react with the alkaline activators to create a strong binding matrix. Increase in GGBS content led to increase in compressive strength values. The mix with 80% GGBS (M4) had the highest strength at all the curing ages. This is because GGBS possesses higher calcium content which favour formation of dense calcium - alumino - silicate - hydrate (C - A - S - H) gel which result in better bonding between binder and aggregate particles. In contrast, mixes with higher fly ash content had slightly lower strength as a result of slowing geopolymerization under ambient curing conditions.

6.2 Effect mixing water type

The compressive strength of the geopolymer mortar made with potable water (PW) was marginally higher than that of the specimens made with treated domestic wastewater (TDW). The strength difference was generally within 2-4%, suggesting that the geopolymerization reaction was only slightly impacted by dissolved salts and other minor contaminants in treated wastewater. Therefore, treated domestic wastewater can be considered a viable alternative mixing water source for geopolymer mortar production, especially in regions facing freshwater scarcity

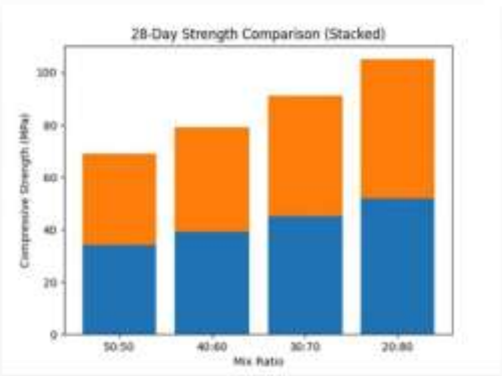

Fig 3 : 28-Day Strength comparision

6.3 TDW vs PW Performance

Difference in strength: = -1 MPa (negligible) TDW reduced slightly under impurities.
Nevertheless, salts can have the role of secondary activators.

Key finding: Compressive strength is not greatly influenced by treated wastewater.

7. WATER ABSORPTION & BINDING CHARACERISTICS

7.1 Water Absorption Test (ASTM C642) :

Sample (70.6 mm cubes) is dried in the oven at 105 o C in 24 hours. Record dry weight → W_1
Soak cubes in water 24 hours. Record saturated weight → W_2 **Formula :**

$$\text{Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100$$

7.2 Results :

Treated Domestic Wastewater (TDW)

Mix (FA:GGBS)	Water Absorption (%)
50:50	6.2
40:60	5.4
30:70	4.6
20:80	4.6

Potable Water (PW)

Mix (FA:GGBS)	Water Absorption
50:50	5.8
40:60	5.0
30:70	4.2
20:80	3.5

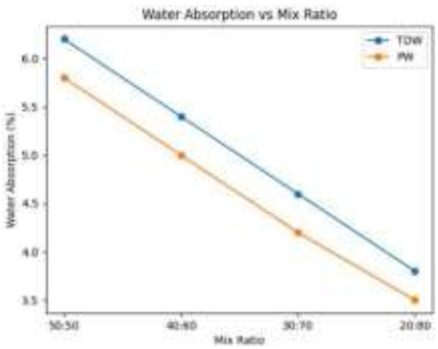

Fig 4 : WaterAbsorption Graph

7.3 Discussion

In both treated domestic wastewater (TDW) and potable water (PW) mixtures, absorption of geopolymer mortar in water was reduced with addition of GGBS. The mixes of TDW reduced to 6.2 to 3.8 and PW reduced to 5.8 to 3.5, which demonstrated that the densification issue and the geopolymer matrix binding is better. The decrease in water uptake is explained by the appearance of a dense microstructure because of the simultaneous existence of C-A-S-H and N-A-S-H gels that decrease the pore connectivity and increase durability.

TDW mixes had a marginally better water absorption (approximately 0.3-0.4 percent) than PW mixes, presumably because the dissolved salts created a small number of pores. Nonetheless, the disparity is minor, and the general trend is the same, which means that the binding properties of geopolymer mortar with treated domestic wastewater do not differ significantly with the binding properties with potable water.

7.4 Sustainability Analysis :

The benefits associated with the current study are that it exhibits a lot of sustainability by using both treated domestic wastewater (TDW) and industrial byproducts like fly ash and GGBS. A potential use of TDW in the place of potable water helps in conserving the freshwater resources, which is very paramount in areas where there is limited water supply. Also, the use of fly ash and GGBS minimizes the use of Ordinary Portland Cement which lowers the amount of carbon dioxide emitted in the production of cement.

Circular resource utilization and maintaining sustainable waste management practices also happen through reuse of wastewater that minimizes the environmental discharge and encourages recycling of wastewater. The similarity in performance of TDW-based geopolymer mortar is another corroborating fact that it is a viable construction material as an environmentally-friendly material. All in all, this strategy can help to achieve sustainable development because it incorporates the efficiency of resources, reduction of waste, and preservation of the environment.

8. CONCLUSION

The outcome of the conducted experimental study is the conclusion that compressive strength of geopolymer mortar rises with age of curing and GGBS contents. The FA:GGBS mix of 20:80 had the best performance in terms of strength and least water absorption.

The value of compressive strength of mortars made with treated domestic wastewater was similar to that made with potable water with small deviations. Further confirmation of the same was made by water absorption which showed that there is no significant impact made on the binding properties and stability of mortar based on TDW.

The paper confirms that treated domestic wastewater may be used as a good alternative to potable water in geopolymer mortar without affecting mechanical or strength characteristics. This enhances sustainable building methods such as the conservation of freshwater and the use of industrial by-products.

9. FUTURE SCOPE

Future studies can be carried out to test the long term durability performance of geopolymer mortar made with the help of treated domestic wastewater during aggressive environment like sulfate or chloride environment. Further investigations at the microstructural level by means of SEM and XRD may yield more information about the formation and bonding of gels.

There is also a possibility that further research can be carried out on the application of wastewater in geopolymer concrete and reinforced structural components. Large-scale applications and field implementation could be attempted to test laboratory results. Moreover, with the optimization of mix design and the degree of treatment of wastewater it is possible to improve the performance and increase the range of practical application.

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