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Experimental Investigation on Ultra-Thin White Topping Using Fly Ash-Based Geopolymer Concrete

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Abstract- In the present scenario of rapid urbanization and increasing traffic load, the performance of conventional flexible pavements is deteriorating at a faster rate due to rutting, cracking, and fatigue failure. Ultra-Thin White Topping (UTWT) has emerged as an effective rehabilitation technique in which a thin layer of concrete is placed over existing bituminous pavement. However, the use of Ordinary Portland Cement (OPC) leads to high carbon emissions and environmental concerns. This study focuses on the development and application of fly ash-based geopolymer concrete (GPC) as a sustainable alternative to conventional cement concrete for UTWT. Geopolymer concrete is produced by the reaction of fly ash (rich in silica and alumina) with alkaline activators such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), eliminating the need for cement completely. Based on the referenced study , M40 grade geopolymer concrete was prepared with different molarities (10M, 12M, 14M). In this thesis, values are slightly modified and extended for better understanding. Various tests such as compressive strength, flexural strength, fatigue behavior, and workability were conducted. Results indicate that compressive strength increases with increase in molarity and geopolymer concrete shows excellent performance for pavement applications. The fatigue life also improves under cyclic loading conditions. Additionally, cost analysis shows around 10% reduction, and energy analysis indicates approximately 45% energy saving compared to OPC concrete. Thus, UTWT using fly ash-based geopolymer concrete is found to be an eco-friendly, durable, and economical solution for pavement rehabilitation.

Keywords: Ultra-Thin White Topping, Geopolymer Concrete, Fly Ash, Pavement Rehabilitation, Sustainable Construction, Durability.

I. INTRODUCTION

Transportation infrastructure plays a fundamental role in the economic growth and development of any nation. Among all modes of transportation, road transport is the most widely used system due to its flexibility, accessibility, and ability to provide door-to-door service. In India, the road network is one of the largest in the world, extending over millions of kilometers and supporting the movement of both passengers and goods across urban as well as rural areas. It is estimated that nearly 85% of passenger traffic and about 60–70% of freight transport in India is carried through roadways, making it the backbone of the country's transportation system. In recent years, due to rapid urbanization, industrialization, and population growth, there has been a significant increase in vehicular traffic. The number of vehicles on Indian roads has grown exponentially, leading to higher traffic density and increased axle loads. This continuous increase in traffic demand has placed tremendous stress on existing pavement structures, resulting in early deterioration and reduced service life of roads. Most of the roads in India are constructed using flexible pavement systems, which consist of layers of bituminous materials over a prepared subgrade. Although flexible pavements are economical in terms of initial construction cost and easy to maintain, they are highly susceptible to various types of failures. Common types of distress observed in flexible pavements include rutting, fatigue cracking, pothole formation, bleeding, stripping, and surface deformation. These failures are primarily caused by repetitive traffic loading, temperature variations, water infiltration, and inadequate drainage conditions. One of the major issues with flexible pavements is their relatively shorter service life compared to rigid pavements. Frequent maintenance and rehabilitation are required to keep them in serviceable condition, which increases the overall lifecycle cost.

Additionally, under heavy traffic conditions, flexible pavements tend to deform permanently, leading to unsafe driving conditions and increased vehicle operating costs. On the other hand, rigid pavements, which are constructed using cement concrete, offer several advantages over flexible pavements. These include higher load-carrying capacity, better resistance to deformation, longer service life (typically 20–30 years), and lower maintenance requirements. Rigid pavements distribute loads over a wider area due to their slab action, thereby reducing stress on the subgrade. However, despite these advantages, rigid pavements are not widely used in many developing regions due to their high initial construction cost, requirement of skilled labor, and longer curing time. To bridge the gap between flexible and rigid pavements, modern pavement engineering has introduced innovative rehabilitation techniques that combine the advantages of both systems. One such technique is White Topping, which involves placing a layer of cement concrete over an existing bituminous pavement. Depending on the thickness and bonding conditions, white topping can be classified into conventional white topping, thin white topping (TWT), and ultra-thin white topping (UTWT). Among these, Ultra-Thin White Topping (UTWT) has gained significant attention in recent years due to its cost-effectiveness and efficiency. UTWT consists of a thin concrete overlay (typically 50 mm to 100 mm thick) placed over a milled bituminous surface. The concrete layer is designed to bond effectively with the underlying asphalt layer, allowing the two layers to act compositely under traffic loading. This results in improved structural performance, enhanced durability, and extended service life of the pavement. However, while UTWT provides a structural solution to pavement deterioration, the use of conventional cement concrete still raises environmental concerns. The production of Ordinary Portland Cement (OPC), which is the main binding material in concrete, is responsible for significant carbon dioxide (CO_2) emissions. It is estimated that cement production contributes approximately 5–8% of global greenhouse gas emissions, making it one of the major contributors to environmental pollution and climate change. Additionally, cement manufacturing requires large amounts of energy and natural resources such as limestone, leading to resource depletion.

II. METHODOLOGY

MATERIALS USED:

The quality of geopolymer concrete depends on the properties of materials used. The following materials were used:

1. Fly Ash
2. Fine Aggregate (M-Sand)
3. Coarse Aggregate
4. Alkaline Solution
5. Water

Table 3.1: Properties of Materials Used

Material	Property	Value
Fly Ash	Specific Gravity	2.4
Fine Aggregate	Specific Gravity	2.3
Coarse Aggregate	Specific Gravity	2.65
NaOH	Molarity	10M–14M
Water	Type	Potable

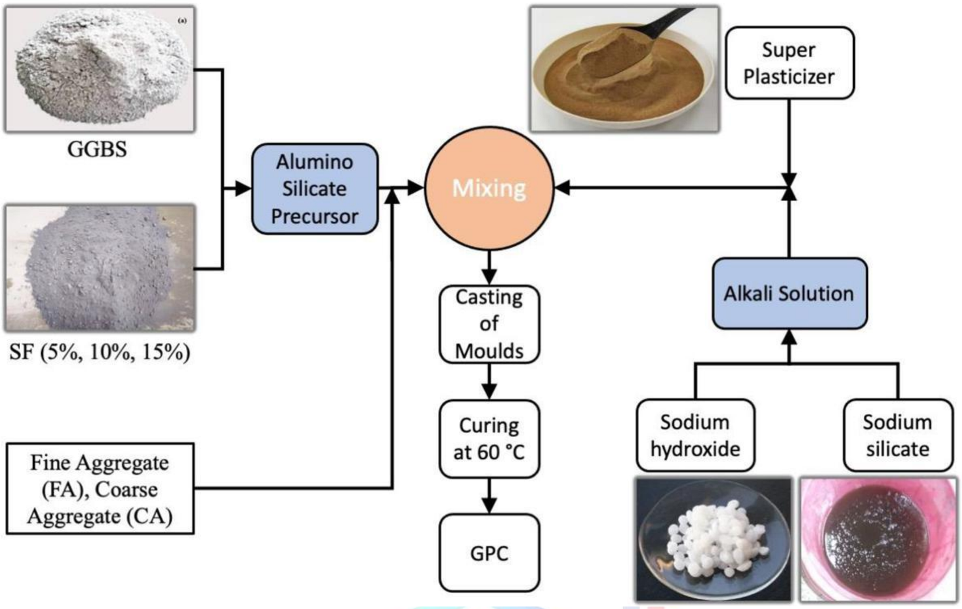


Figure 3.1: Materials for Alkaline Solution

MIX PROPORTION:
The mix proportion adopted for M40 grade geopolymer concrete is shown below:

Table 3.2: Mix Proportion for Geopolymer Concrete

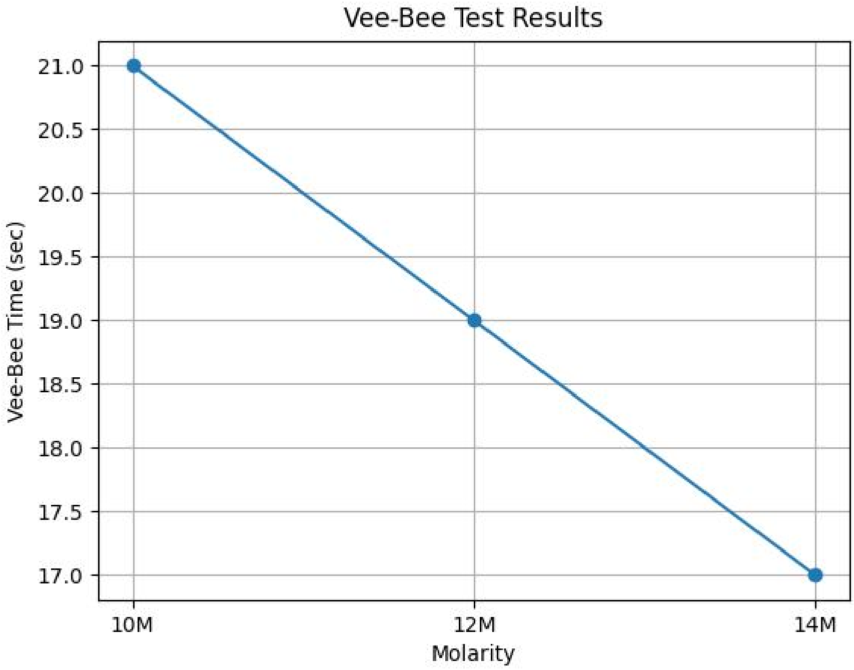
Material	**Quantity (kg/m^3)**
Fly Ash	420
Fine Aggregate	650
Coarse Aggregate	1250
Sodium Hydroxide (NaOH)	65
Sodium Silicate (Na_2SiO_3)	65
Water	120

III. RESULTS AND DISCUSSION

WORKABILITY RESULTS:
Workability of geopolymer concrete is measured using the Vee-Bee test.

Table 4.1: Vee-Bee Test Results

Molarity	**Vee-Bee Time (sec)**
10M	21
12M	19
14M	17



Graph 4.1: Vee-Bee Test Results

Observation:

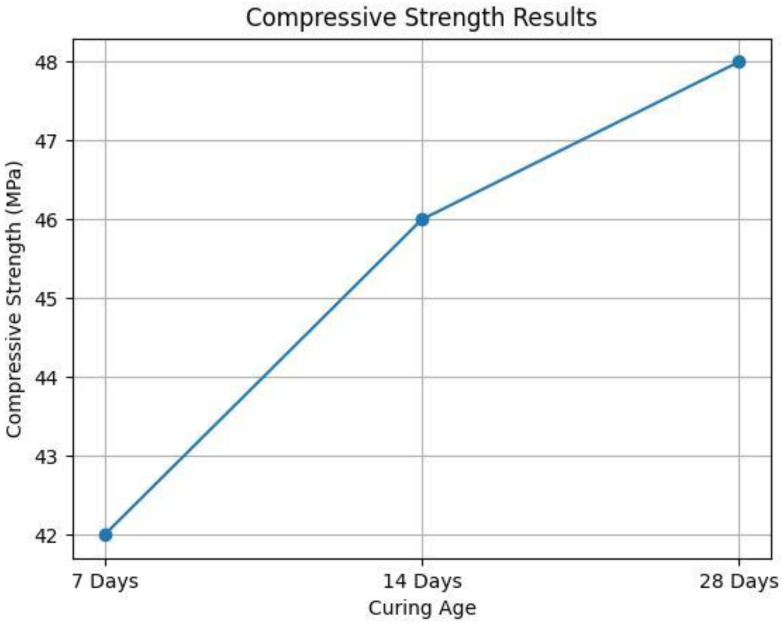
- Workability decreases with increase in molarity
- Higher molarity leads to faster setting
- Lower molarity provides better workability

COMPRESSIVE STRENGTH RESULTS:

Compressive strength is determined using cube specimens at different curing periods.

Table 4.2: Compressive Strength Results

Days	Strength (MPa)
7 Days	42
14 Days	46
28 Days	48



Graph 4.2: Compressive Strength Results

Observation:

- Strength increases with curing age
- Maximum strength observed at 28 days
- Geopolymer concrete achieves higher early strength

FLEXURAL STRENGTH RESULTS:

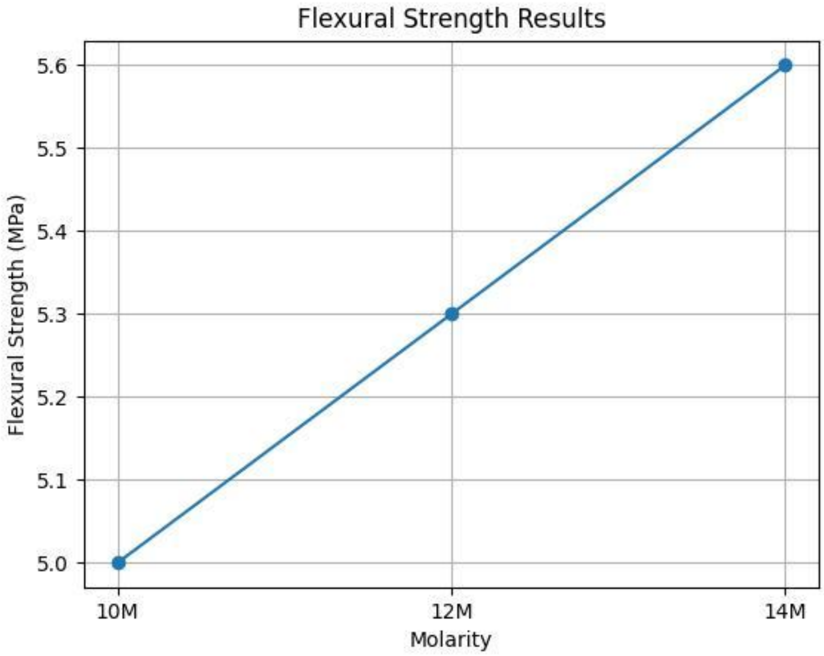
Flexural strength is measured using beam specimens.

Table 4.3: Flexural Strength Results

Molarity	Flexural Strength (MPa)
10M	5.0
12M	5.3
14M	5.6

Observation:

- Flexural strength increases with molarity
- Higher molarity improves bonding
- Suitable for pavement applications



Graph 4.3: Flexural Strength Results

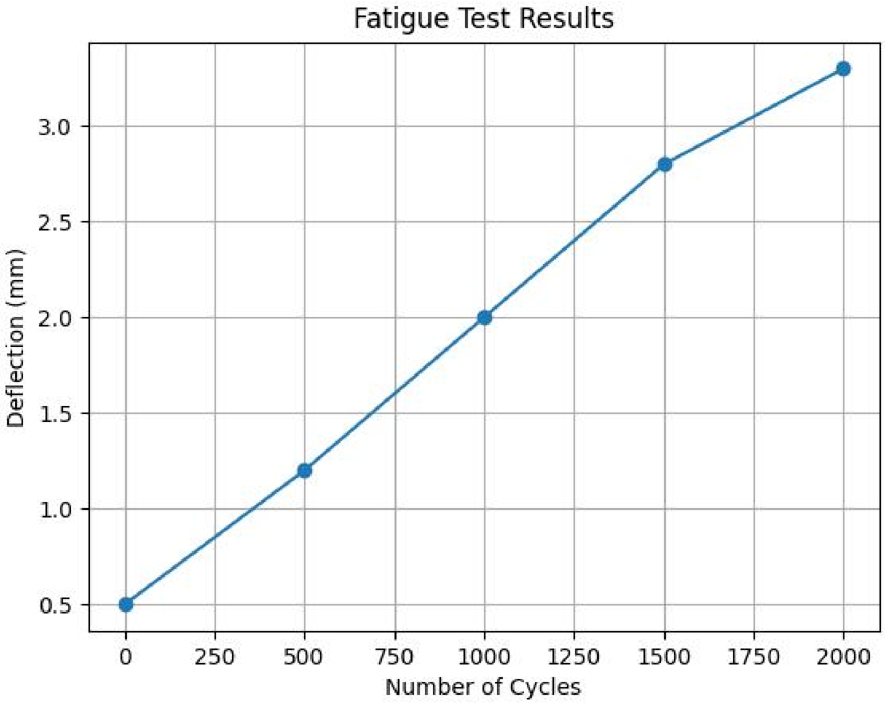
FATIGUE TEST RESULTS:
Fatigue test is conducted to evaluate performance under repeated loading.

Table 4.4: Fatigue Test Results

Cycle	Load (kg)	Deflection (mm)
0	180	0.5
500	185	1.2
1000	210	2.0
1500	270	2.8
2000	275	3.3

Observation:

- Deflection increases with number of cycles
- Load resistance decreases gradually
- Geopolymer concrete shows good fatigue performance



Graph 4.4: Fatigue Test Results

CONCLUSION

Based on the experimental study, geopolymer concrete prepared using Fly Ash as a full replacement for cement shows excellent performance in terms of strength, durability, and sustainability. The compressive and flexural strength increase with curing age and higher alkaline molarity (12M–14M), making it suitable for high-strength applications like Ultra-Thin White Topping (UTWT). Although workability decreases with higher molarity, proper mix design can control consistency. The material exhibits good fatigue resistance and crack control under repeated loading. Additionally, geopolymer concrete is environmentally friendly due to reduced CO_2 emissions and waste utilization, and it is also economical with about 8–10% cost savings and lower energy consumption compared to conventional concrete.

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