Experimental Study on Fresh and Mechanical Properties of Manufactured Sand and Recycled Aggregate Mixed Self-Compacting Concrete

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Abstract — The increasing generation of fly ash from thermal power plants has created significant challenges related to its disposal and environmental management. At the same time, the construction of pavement infrastructure requires large quantities of suitable materials for subgrade, sub-base, and base layers. The utilization of fly ash as a pavement construction material provides an opportunity to address both problems through sustainable engineering practices. However, the relatively low strength, high compressibility, and sensitivity of untreated fly ash restrict its direct application in structural pavement layers. The present study investigates the improvement of fly ash through stabilization with cement and reinforcement with fibers. Cement was incorporated to promote bonding and pozzolanic reactions, while discrete fibers were introduced to improve tensile resistance, crack control, ductility, and load-transfer characteristics. The engineering behavior of the stabilized and fiber-reinforced fly ash was evaluated using compaction, unconfined compressive strength (UCS), and California Bearing Ratio (CBR) tests. The experimental results indicate that cement stabilization significantly improves the strength characteristics of fly ash. Increasing cement content results in an increase in water demand because of cement hydration and particle interaction. The maximum dry density initially shows minor variation and subsequently increases with cement addition. The addition of fibers further enhances the mechanical performance by providing reinforcement and restricting crack propagation. The combined use of cement and fibers therefore offers considerable potential for converting fly ash into a value-added material for pavement structural layers. The study demonstrates that fiber-reinforced cement-stabilized fly ash can contribute to sustainable pavement construction while reducing dependence on conventional natural aggregates and providing an environmentally beneficial method for fly ash utilization.

Keywords: Fly ash, cement stabilization, fiber reinforcement, pavement structural layers, unconfined compressive strength, California Bearing Ratio, compaction, sustainable pavement construction

I. INTRODUCTION

The rapid development of transportation infrastructure has resulted in an increasing demand for naturally occurring materials such as soil, aggregates, and granular materials for pavement construction. At the same time, large quantities of industrial wastes are generated from various manufacturing and energy-producing activities. Fly ash is one of the major industrial by-products generated from coal-fired thermal power plants. Its large-scale production and improper disposal can create environmental problems such as air pollution, land degradation, and contamination of soil and groundwater.

Fly ash possesses several characteristics that make it potentially suitable for geotechnical and pavement applications. It generally consists of fine, predominantly spherical particles and contains significant quantities of silica, alumina, and iron oxides. Depending on its chemical composition, fly ash can exhibit pozzolanic and self-cementing behavior. However, untreated fly ash may have insufficient strength and durability for direct use in heavily loaded pavement structural layers.

Stabilization is an established technique for improving the engineering properties of weak or marginal materials. Cement stabilization is particularly effective because cement reacts with water and produces cementitious compounds that bind individual particles together. The resulting matrix can provide increased compressive strength, improved resistance to deformation, and enhanced durability.

Although cement stabilization substantially improves fly ash, brittle behavior and cracking may occur when the cement content becomes relatively high. The incorporation of discrete fibers can address this limitation. Fibers act as reinforcement within the stabilized matrix and help bridge developing cracks. They can improve post-cracking behavior, tensile resistance, toughness, and deformation characteristics.

Therefore, combining cement stabilization and fiber reinforcement may provide a technically effective and environmentally sustainable approach for utilizing fly ash in pavement structural layers. The present research experimentally investigates this combined stabilization technique and evaluates its suitability for pavement applications.

II. LITERATURE SURVEY & BACKGROUND

Kaya (2025), Kaya investigated hybrid fiber systems in cementitious materials. The study showed that combining different types of fibers improves multi-scale reinforcement. Hybrid systems provide better performance than single fiber systems.

Zhang et al. (2024), Zhang studied permeability and strength characteristics of stabilized fly ash mixtures. The study found that fly ash reduces permeability and enhances durability. Reduced permeability leads to improved resistance to moisture damage.

Singh et al. (2023) Singh conducted a recent study on fiber-reinforced cement-stabilized fly ash mixtures. The research focused on mechanical properties and durability under environmental conditions. The results showed significant improvement in UCS, flexural strength, and resistance to wet-dry cycles. The fiber-reinforced samples exhibited minimal cracking and better structural integrity.

The study also identified optimum fiber content, beyond which performance decreases due to poor dispersion. This study provides modern validation of combined stabilization techniques and highlights the importance of optimizing fiber content.

White et al. (2013) White conducted durability tests on stabilized soils under harsh environmental conditions. The study showed that cement stabilization improves resistance to moisture and temperature variations. Durability is critical for long-term pavement performance, and stabilization plays a key role in achieving it.

Wei et al. (2015) Wei studied the long-term performance of fly ash stabilized soils under cyclic loading and environmental conditions. The results indicated that fly ash contributes to long-term strength gain and improved durability. The study confirms that fly ash is beneficial for long-term performance but requires stabilization for early strength.

III. OBJECTIVE

1) To investigate the engineering properties of untreated fly ash for potential pavement applications.
2) To study the influence of cement stabilization on the compaction characteristics of fly ash.
3) To determine the effect of cement content on the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of fly ash.
4) To investigate the effect of cement stabilization on the Unconfined Compressive Strength (UCS) of fly ash.

IV. RESULT

A. Effect of cement and fiber on stabilized fly ash

The impact of cement on maximum dry density and optimum moisture content of fly ash, fly ash with 4% cement, fly ash with 6% cement and fly ash with 8% cement is presented in Figure,

The compaction characteristics of fly ash stabilized with different percentages of cement were investigated by determining the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). The results obtained from the laboratory investigation are presented in Table 4.2.

SN	Description	OMC (%)	MDD(%)
1	Fly ash + 0% Cement	16.4	1.35
2	Fly ash + 2 % Cement +	16.6	1.31
3	Fly ash + 4 % Cement	17	1.32
4	Fly ash + 6% Cement	17.1	1.34
5	Fly ash + 8% Cement	17.2	1.39

Table 1: Effect of cement percentage on MDD and OMC of stabilized fly ash without fiber

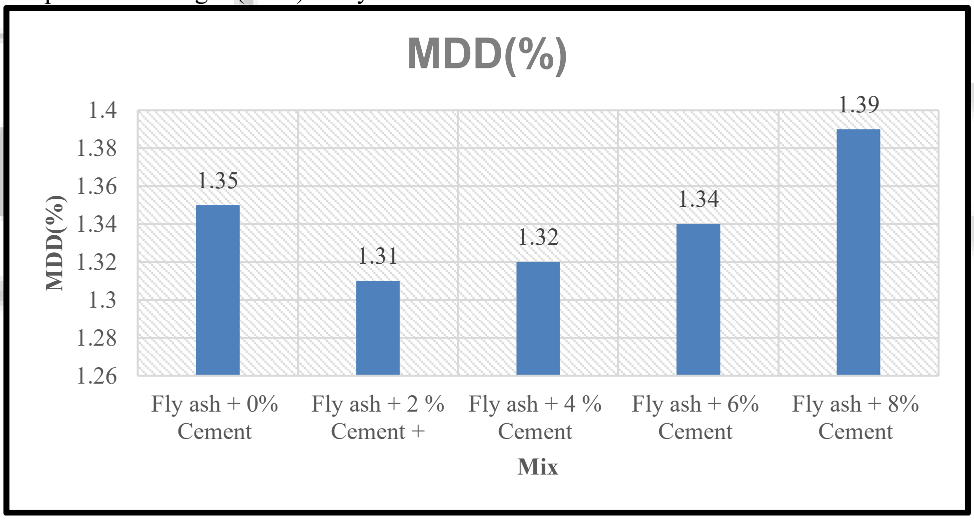

Fig. 1: Effect of cement percentage on MDD and OMC of stabilized fly ash without fiber

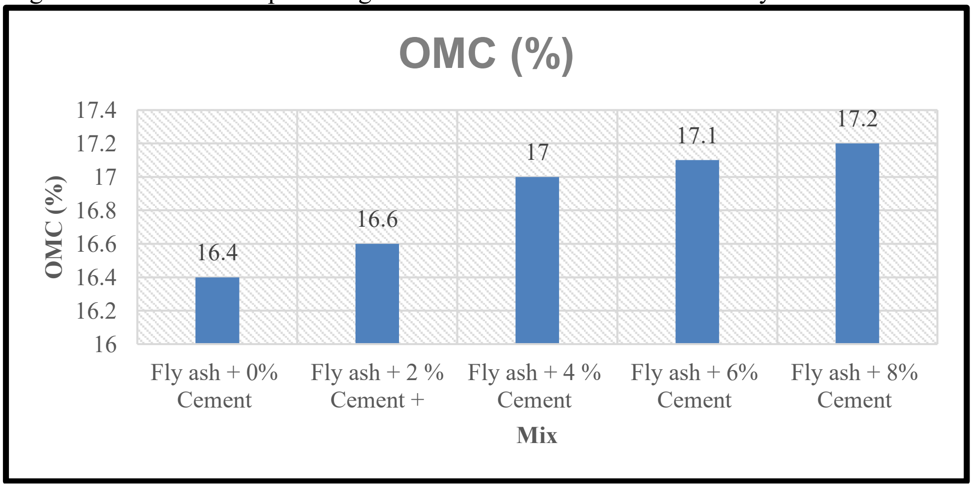

Fig. 2: Effect of cement percentage on MDD and OMC of stabilized fly ash without fiber

The OMC increased gradually from 16.4% to 17.2% as cement content increased from 0% to 8%. At 2% cement, MDD decreased from 1.35 to 1.31 g/cm³. With further cement addition, MDD gradually increased. The highest MDD of 1.39 g/cm³ was obtained at 8% cement content. The increase in OMC is mainly due to the higher water requirement for cement hydration. The increase in MDD at higher cement content indicates better particle packing and densification. Overall, 8% cement showed the best compaction performance, with an OMC of 17.2% and MDD of 1.39 g/cm³.

	Fly ash +2% cement	OMC (%)	MDD(%)
1	0% fiber	20.6	1.34
2	.25 % fiber	20	1.35
3	.35 % fiber	19.8	1.36
4	.45 % fiber	19	1.38
5	.5 % fiber	18.5	1.3

Table 2 Effect of Fly ash +4% Cement on MDD and OMC

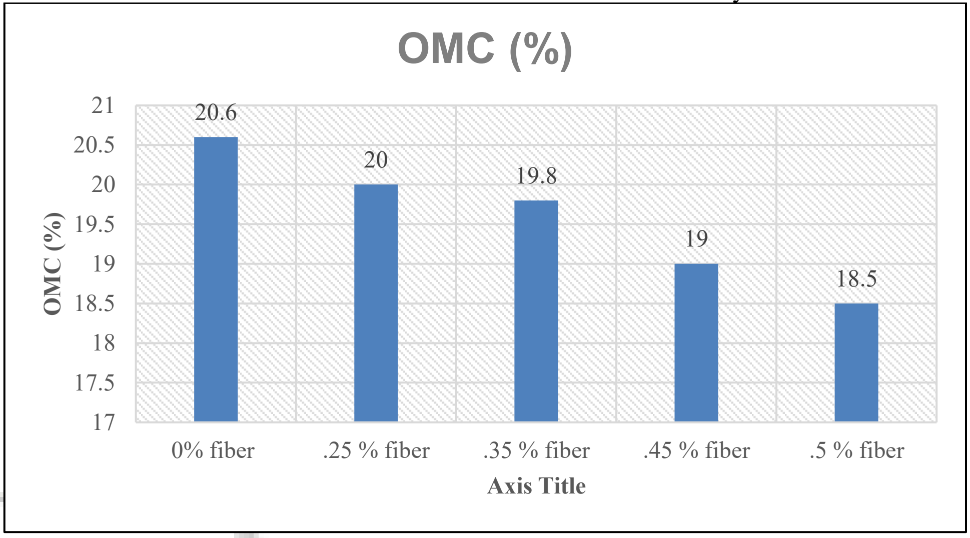

Fig. 3: Effect of cement percentage on MDD and OMC of stabilized fly ash with fiber

Fiber Content (%)	UCS at 28 Days – Cement 4% (MPa)	UCS at 28 Days – Cement 6% (MPa)	UCS at 28 Days – Cement 8% (MPa)
0	2.05	3.65	4.45
0.25	2.5	4.05	5.45
0.35	2.35	3.9	5.1
0.45	2.31	3.6	5
0.5	2.25	3.51	4.45

Table 3: UCS of fly ash stabilized with cement mixed with fiber at 28 Days

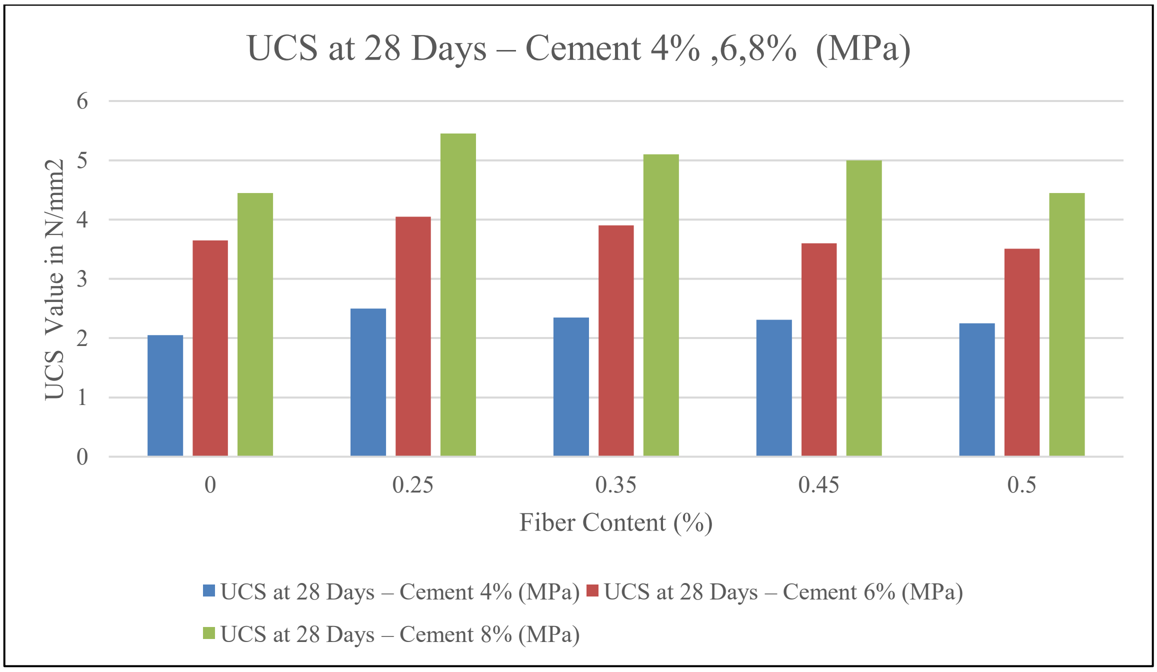

Fig. 4: UCS at 28 Days – Cement 4% ,6,8% (MPa)

- The UCS increased with curing period, and the 28-day values were higher than the corresponding 7-day strengths.
- For 4% cement, UCS increased from 2.05 MPa at 0% fiber to a maximum of 2.50 MPa at 0.25% fiber.
- For 6% cement, UCS increased from 3.65 MPa to 4.05 MPa with the addition of 0.25% fiber.
- For 8% cement, UCS showed the highest improvement, increasing from 4.45 MPa at 0% fiber to 5.45 MPa at 0.25% fiber.
- Beyond 0.25% fiber, UCS gradually decreased for all cement contents. At 0.5% fiber, UCS reduced to 2.25 MPa, 3.51 MPa, and 4.45 MPa for 4%, 6%, and 8% cement, respectively.
- The improvement at 0.25% fiber can be attributed to better fiber distribution, improved interparticle bonding, and effective control of crack development.
- The reduction in UCS at higher fiber contents may result from fiber clustering, increased voids, and reduced compact ability, which weaken the stabilized matrix.
- The highest 28-day UCS of 5.45 MPa was obtained for the combination of 8% cement + 0.25% fiber.
- Overall, the results demonstrate that cement content and curing age significantly improve UCS, while a moderate fiber content provides additional strength enhancement.
- Based on the 28-day UCS results, 0.25% fiber is identified as the optimum fiber content, while 8% cement + 0.25% fiber provides the best overall strength performance.

V. CONCLUSION

- Fly ash can be effectively utilized as an alternative pavement material when its engineering properties are improved through appropriate stabilization.
- The addition of cement significantly influences the compaction characteristics of fly ash. The OMC increases with cement content, primarily because of water consumption during cement hydration and cement-fly ash interactions.
- The MDD initially exhibits slight variation and subsequently increases with increasing cement content. A maximum MDD of approximately 1.39 g/cm³ was obtained at 8% cement in the investigated mix.
- Overall, the results demonstrate that cement content and curing age significantly improve UCS, while a moderate fiber content provides additional strength enhancement.
- Based on the 28-day UCS results, 0.25% fiber is identified as the optimum fiber content, while 8% cement + 0.25% fiber provides the best overall strength performance.

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