

PAPER • OPEN ACCESS

Mitigation of Greenhouse Gas Emissions by Fly Ash Stabilization and Sisal Fibre Reinforcement of Clay Subgrade for Road Construction

To cite this article: Vinod Kumar and Ravinder Singh Panwar 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **219** 012020

View the [article online](#) for updates and enhancements.

Mitigation of Greenhouse Gas Emissions by Fly Ash Stabilization and Sisal Fibre Reinforcement of Clay Subgrade for Road Construction

Vinod Kumar* and Ravinder Singh Panwar

Department of Civil Engineering, National Institute of Technical Teachers Training and Research, Sector 26, Chandigarh, 160019

*Corresponding author E-mail: vkmail1970@gmail.com

Abstract. Construction of bituminous pavements forms a major source of greenhouse gas emissions. In order to mitigate this effect, the research study proposes use of fly ash and sisal fibre in stabilization of clay soil for the pavement subgrade. The test specimens were impregnated with fly ash contents of 10%, 20%, 30% and 40% and fibre contents of 0.25%, 0.50%, 0.75% and 1.0% of the dry soil mass and different geotechnical characteristics of the stabilized soils namely maximum dry density (MDD), optimum moisture content (OMC), California bearing ratio (CBR) and unconfined compressive strength (UCS) values were determined. Additionally, scanning electron microscopy tests were also carried out on the stabilized soil samples to know their surface morphology. Bituminous pavements sections with stabilized and non-stabilized subgrades were designed for 50 million standard axles traffic intensity in accordance with the standard codal provisions. The greenhouse gas emissions associated with construction of bituminous pavements were evaluated using standard inventories of carbon coefficients for road materials. The results indicated that key strength parameters of soil subgrade i.e. CBR and UCS were significantly enhanced with the use of fly ash and sisal fibre. The soil stabilization treatment significantly reduced the layer thickness eventually leading to reduction in the associated greenhouse gas emissions for the designed pavements. The results obtained are indicative of the potential utilization of fly ash and sisal fibre in building sustainable and durable bituminous pavements with reduced greenhouse gas emissions.

1. Introduction

The quality of air in India is continuously deteriorating as an after effect of population eruption and its allied activities. India is the third largest generator of greenhouse gas emissions after China and the United States of America [1]. In 2014, the World Health Organization declared that, the capital of India- Delhi is the most polluted city in the world [2]. In the present era of catastrophic environmental degradation as a side effect to industrialization, urbanization and modernized manufacturing processes, the creative idea would be treating the waste products in a way beneficial for reuse and recycling. The enhanced mechanical strength of the subgrade soil of a pavement may lead to the reduction in the thickness of bituminous and granular layers and save natural resources bitumen and aggregates and hence reduce the carbon footprint of the pavement construction. Additionally, soil stabilization with waste is also a sustainable practice as their utilization would lower their land coverage with associated environmental implications. In the current study, fly ash which is construed



as a waste product from thermal industry and sisal fibre are tried as alternate materials for stabilizing clay and their potential to lower greenhouse gas emissions associated with road construction was evaluated.

2. Materials used

In the present study, fly ash, sisal fibre and clay soil were used.

2.1 Fly ash

Fly ash is a non-plastic material that possesses comparatively lower specific gravity than the normal soils. The size of fly ash was found comparable to silt. In this study class F fly ash collected from Panipat thermal power plant was used. Its scanning electron microscopy (SEM) image is shown in figure 1 A and index properties have been reported in Table 1.

Table 1. Index properties of fly ash

Specific gravity	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	MDD (g/cc)	OMC (%)	Permeability (cm/s)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
1.97	0	19.7	80.3	0	1.167	31.5	5.6×10^{-5}	-	-	-

2.2 Sisal fibre

Sisal fibre is a natural fibre derived from sisal plant, with characteristics such as small re-growth period and grows wild in the hedges of fields and railway tracks. In India Sisal plant was imported by the Portuguese in the fifteenth century and first time cultivated in Goa and later on in Orissa and now found throughout the country. Its SEM image is shown in figure 1B and physical properties have been reported in Table 2.

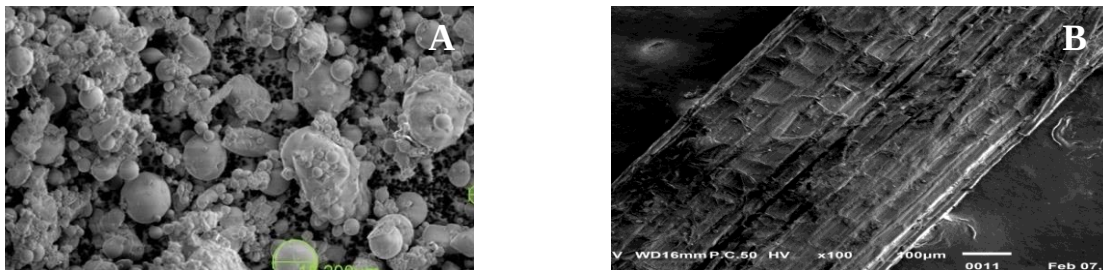


Figure 1. (A) SEM image of fly ash at 500x magnifications, (B) SEM image of sisal fibre at 100x magnification

Table 2. Physical properties of sisal fibre

Material type	Length	Diameter	Specific gravity	Tensile strength	Young's modulus
Natural	2.0 cm	0.8-1.2 mm	1.58	385 to 728 MPa	9 to 22 GPa

2.3 Soil

Clay soil used in the current study was obtained from Chandigarh, India. The clay soil was classified as clay with intermediate plasticity (CI) in accordance with the Indian soil classification system [3]. The index properties of soil as obtained in the laboratory are in table 3.

Table 3. Index properties the clay soil

Specific gravity	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
2.68	0.0	5.3	75.0	19.7	40.8	25.5	15.3

3. Study methodology

The study was carried out in two phases. In the first phase a number of laboratory tests were carried out on clay soil stabilized with fly ash and reinforced with sisal fibre. Fly ash in proportions of 0%, 10%, 20%, 30% and 40% replaced the clay soil. Clay with the optimized dosage of fly ash was further reinforced with sisal fibre content of 0.25%, 0.50%, 0.75% and 1.0% by the dry mass of clay-fly ash mix. Modified Proctor compaction tests for determining maximum dry density (MDD) and optimum moisture content (OMC), California bearing ratio (CBR) tests and unconfined compressive strength (UCS) tests were performed. The CBR samples were immersed in water for 96 hours prior to testing. In order to understand the mechanism of stabilization, SEM images of clay containing fly ash and sisal fibre were analyzed. This was followed by quantification of the greenhouse gas emissions emitted due to the construction of bituminous pavements with natural and stabilized subgrade. Embodied carbon dioxide (CO₂) value signifies the quantum of greenhouse gas emissions expressed in equivalent contents of CO₂ throughout the life cycle of the material. An exhaustive literature review reveals that the embodied CO₂ issued by the Auroville Earth Institute, India (AEI) [4] were found generally wide-ranging and appropriate. As the embodied CO₂ coefficient for bitumen was not determined in the research performed by AEI, literature from international source was consulted and is reported henceforth in table 4 [5].

Table 4. Embodied CO₂ of materials.

Material	Bitumen [5]	Coarse aggregates [4]	Fine aggregates [4]
Embodied CO ₂ (kg/kg material)	0.48	0.0216	0.002

As per the guidelines of the Ministry of Road Transport and Highways (MoRT&H) [6], a suitable mix design of bitumen and aggregates was done for pavement layers such as bituminous concrete (BC), dense bituminous macadam (DBM), wet mix macadam (WMM) and granular sub-base (GSB) and the details have been listed in table 5.

Table 5. Properties of the mix for different layers of bituminous pavements

Properties of the mix	BC	DBM	WMM	GSB
Density (kg/m ³)	2400	2300	2300	2300
Bitumen by mass (%)	5.5	4.5	0	0
Aggregates by mass (%)	94.5	95.5	100	100
Coarse fraction of total aggregates (%)	55	60	70	80
Fine fraction of total aggregates (%)	45	40	30	20

The embodied CO₂ was worked out mathematically by multiplying the relevant construction material quantity with its associated embodied CO₂ factor (table 4), the embodied CO₂ associated with the different layers of bituminous pavement were worked out and are shown in table 6.

Table 6. Embodied CO₂ for different pavement layers (kg/ cu.m. of pavement layer)

BC	DBM	WMM	GSB
92.4	79.9	36.2	40.7

4. Results and discussion

4.1 Modified Proctor compaction test results

Figure 2 shows the outcome of Modified Proctor compaction tests performed to determine the behaviour of fly ash and sisal fibre on the MDD and OMC of clay. The MDD falls with the rise in

fly ash dosage due to the substitution of soil granules with fly ash particles that possess lesser specific gravity. The OMC increased with the increase in fly ash contents due to the presence of non-burnt carbon in it. The clay with 30% fly ash content was reinforced with varying content of sisal fibre. Reinforcement with the fibre further decreased the MDD and increased the OMC.

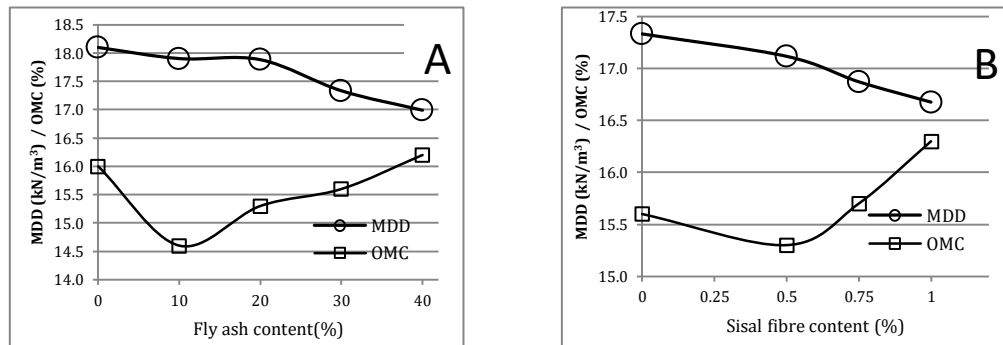


Figure 2. Variation of MDD and OMC: (A) clay soil with varying fly ash content; (B) clay containing 30% fly ash and varying sisal fibre content.

4.2 CBR and UCS tests results

Figure 3 and Figure 4 shows the change in CBR with varying dosage of fly ash and sisal fibre where it was observed that with the increasing contents of fly ash, the CBR and UCS values rises upto its optimum content of 30% is reached, following which there was fall in the CBR and UCS. The improvement in the strength could be due to replacement the plastic soil particles with non-plastic fly ash particles. Sisal fibre further increased the CBR and UCS of clay containing 30% fly ash. The highest benefit of fibre reinforcement was obtained at 0.5% fibre content.

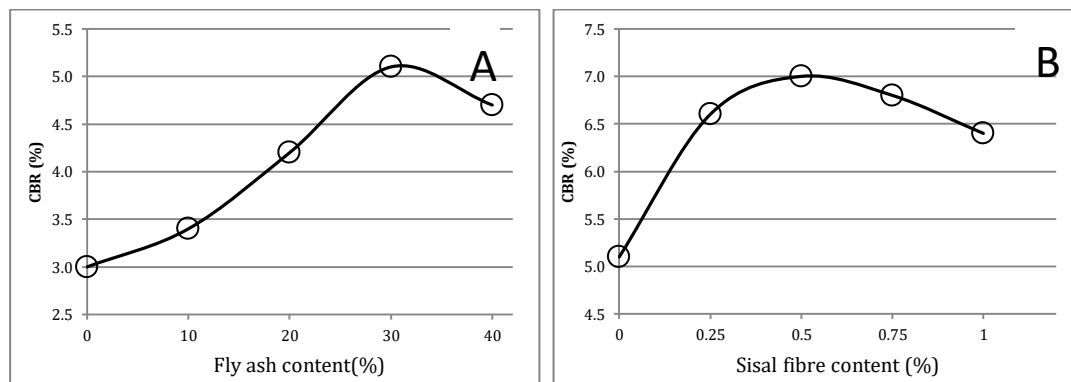


Figure 3. Variation of CBR: (A) clay soil with varying fly ash content; (B) clay containing 30% fly ash and varying sisal fibre content.

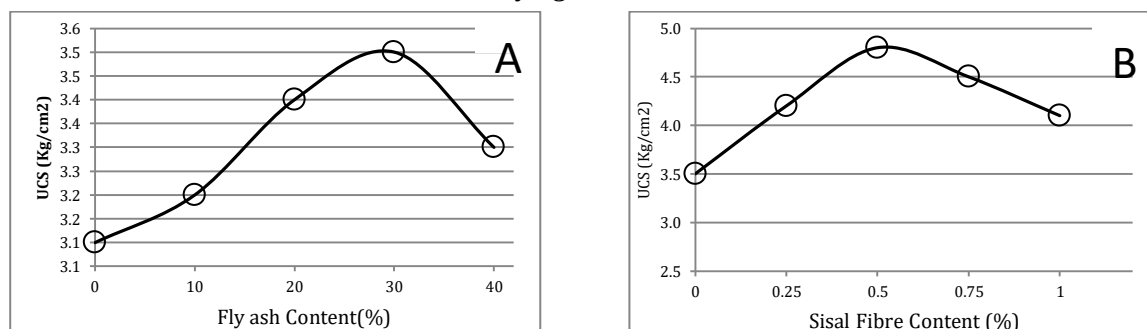


Figure 4. Variation of UCS: (A) clay soil with varying fly ash content; (B) clay containing 30% fly ash and varying sisal fibre content.

4.3 SEM results

Figure 5 shows SEM images of plain and stabilized clay. It was seen that fly ash was effective in improving the gradation of clay particles due addition of silt size particles in clay. The fibre reinforced soil images show that extensive clay-fly ash matrix got closely bonded with the fibre surface hence increased the strength at the interface of fibre-reinforced fly ash soil.

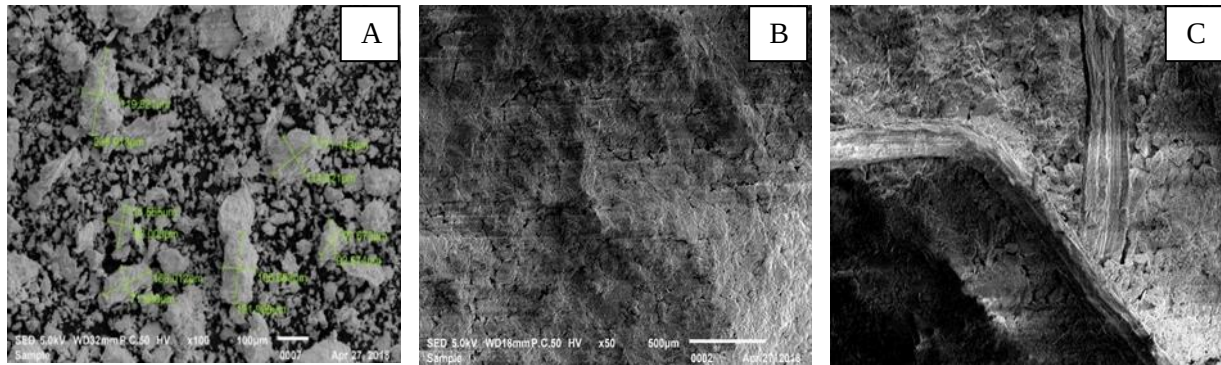


Figure 5. SEM images: (A) clay; (B) clay stabilized with 30% fly ash; (C) clay stabilized with 30% fly ash and reinforced with 0.5% sisal fibre.

4.4 Estimation of greenhouse gas emissions for bituminous pavements

Bituminous pavements with natural and stabilized subgrade were designed as per the procedure laid down by the Indian road congress and shown in figure 6A [7].

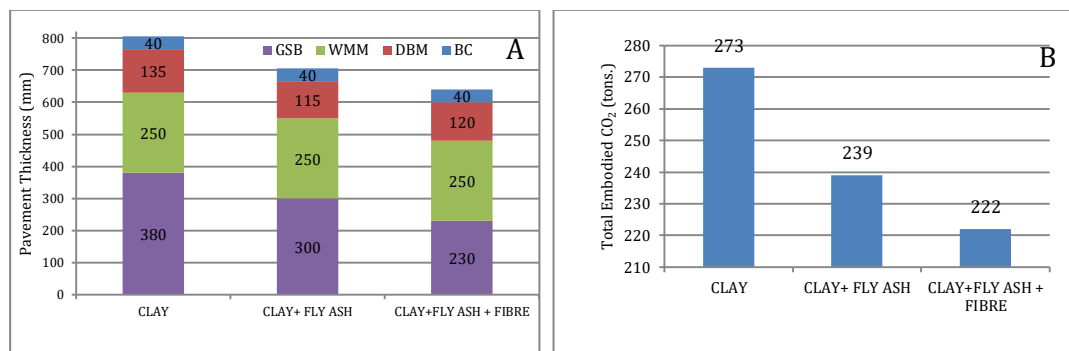


Figure 6. (A) Pavement thickness with natural and stabilized clay, (B) Total embodied CO₂ released

The road section designed in the current study possessed 7 metre width i.e. two lanes with 3.5 metre width each and a unit km length. The road sections were designed to cater 50 million standard axles of traffic intensity. Significant reductions in thickness of pavements were obtained with un-reinforced fly ash and fibre-reinforced fly ash stabilized clay subgrade. Figure 6B represents the greenhouse gas emitted due to the utilization of construction materials. Results show that stabilizing the clay soil with un-reinforced fly ash and fibre-reinforced fly ash significantly reduced the greenhouse gas emissions due to lower material requirements where fibre-reinforced fly ash resulted in the higher CO₂ reduction than for un-reinforced fly ash clay subgrade.

4.5 Carbon credits-A green approach for subgrade stabilization

Kyoto Protocol was signed by a number of countries focusing towards enacting methodologies to trim down their CO₂ emissions [8]. Mitigation of a unit tonne of CO₂ earns them one carbon credit that is considered globally as universal dealing money possessing an equal intercontinental worth of 24 Euros [9]. 12.5% and 18.7% CO₂ emissions were reduced and 34 and 51 carbon credits were earned with un-reinforced fly ash and fibre-reinforced fly ash stabilization respectively as can be inferred from figure 7 A and 7 B respectively.

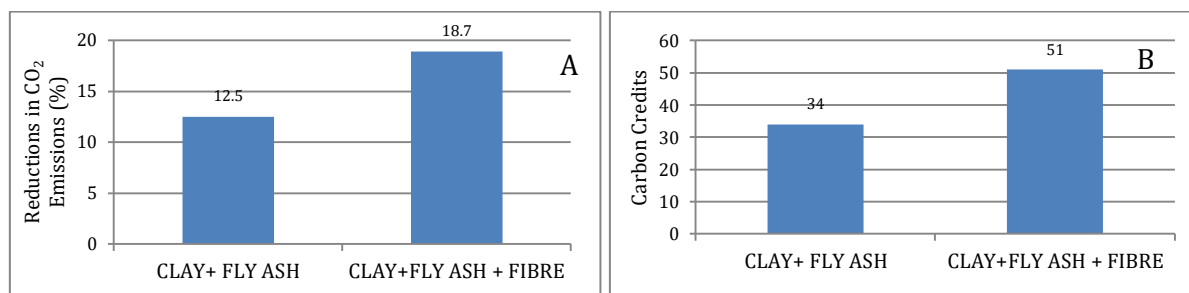


Figure 7. (A) percentage reduction in CO₂ emissions; (B) Carbon credits earned due to fly ash stabilization and sisal fibre reinforcement

5. Conclusion

In the present study, fly ash and sisal fibre were made use for lowering greenhouse gas emissions generated due to construction of bituminous pavements. Results show that with increase in the contents of fly ash and sisal fibre decreased the MDD, increased the OMC and enhanced the CBR and UCS of clay soil where fibre-reinforced fly ash-clay performed better than un-reinforced fly ash clay. 12.5% and 18.7% CO₂ emissions were reduced and 34 and 51 carbon credits were earned with un-reinforced fly ash and fibre-reinforced fly ash stabilization respectively. The utilization of fly ash and sisal fibre in pavement construction is a sustainable practice leading to mitigation of greenhouse gas emissions eventually resulting in amassing of carbon credits and pave way towards building a sustainable environment.

References

- [1] World Resource Institute 2014, Climate analysis indicators tool, Version 2.0 available online. <http://www.wri.org/resources/data-sets/cait-historical-emissions-data-countries-us-states-unfccc>. (Accessed 05 June, 2018)
- [2] Report: Ambient Air Pollution Database-Update (2014), (online), Available: http://www.who.int/phe/health_topics/outdoorair/databases/AAP_database_results_2014.pdf, (accessed 7 June, 2018).
- [3] IS 1498 1970 Classification and identification of soils. Bureau of Indian Standards.
- [4] Maini S and Thautam V 2009 Embodied energy of various materials and technologies. Auroville Earth Institute. Auroville. Tamil Nadu. India.
- [5] Hammond G, Jones C, Lowrie F, and Tse P 2008 Inventory of carbon & energy: ICE (Vol. 5). Bath: Sustainable Energy Research Team, Department of Mechanical Engineering, University of Bath. U.K.
- [6] Ministry of Road Transport & Highways (MoRT&H) 2013 Specifications for road and bridge works, 5th revision, India.
- [7] IRC 37 2012 Guidelines for the design of flexible pavements. Indian Road Congress, New Delhi, India.
- [8] Protocol K. 1997 United Nations framework convention on climate change. Kyoto Protocol, Kyoto, 19.
- [9] Shende B R, and Jadhao R S. 2014 Carbon credit science and business. Scientific Reviews and Chemical Communications, 4(2), pp 1-11.