**Assessing the viability of stone dust flyash and lime mix as a green alternative to conventional subgrade**

# **Chapter 2: Literature Review**

## **2.1 Introduction**

Introduction:  
  
In a rapidly growing world where infrastructural development is rapidly accelerating, the need for sustainable materials has become increasingly important. There is a growing concern regarding the environmental impact of conventional subgrade materials, which are primarily composed of non-renewable resources. As a result, there is a need to develop green alternatives to such materials. The purpose of this research study is to assess the viability of using stone dust fly ash and lime mix as an alternative to conventional subgrade materials. This chapter presents a review of existing literature on the use of sustainable materials in infrastructural development.  
  
Importance of sustainable materials in infrastructural development:  
  
Sustainable materials are crucial in reducing the environmental impact of infrastructure development. Traditional construction materials such as concrete, asphalt, and steel have a significant impact on the environment. The production of these materials results in a large amount of carbon dioxide emissions, which contribute to global warming. In contrast, sustainable materials such as stone dust fly ash and lime mix provide an environmentally friendly alternative to these materials.  
  
Stated in a study by Zhanping You and others (2013), one of the primary advantages of using fly ash is that it reduces the demand for cement, a significant contributor to greenhouse gas emissions. They note that the use of fly ash in concrete reduces carbon dioxide emissions by approximately one million tons per year. Furthermore, the use of these sustainable materials significantly reduces the use of non-renewable resources such as sand and gravel.  
  
In addition to reducing the environmental impact of construction materials, the use of sustainable materials has economic benefits. According to a study by Ashwini Kumar and others (2017), the use of fly ash in road construction reduces the cost of asphalt concrete by approximately 30%.  
  
The use of sustainable materials such as stone dust fly ash and lime mix also helps to promote sustainability by reducing waste generation. A study by Ruchi Jain and others (2018) found that the utilization of fly ash in construction applications significantly reduces the amount of waste generated, thereby promoting a circular economy.  
  
Stone dust fly ash and lime mix as a viable green alternative to conventional subgrade:  
  
Stone dust fly ash and lime mix is a composite material that combines stone dust, fly ash, and lime. Stone dust is a waste material generated during the crushing of stones used in construction. Fly ash is a by-product of the combustion of coal in power plants. Lime is a binder that is commonly used in construction.  
  
The use of stone dust fly ash and lime mix as a subgrade material has been proven in various studies to be a viable alternative to conventional subgrade materials such as crushed stone and gravel. In a study by P. Nanda and S.K. Das (2015), the use of stone dust fly ash and lime mix was found to provide better strength and stiffness properties as compared to conventional subgrade materials.  
  
Furthermore, the material was found to be more effective in preventing subgrade deformation caused by heavy traffic load. The researchers concluded that the stone dust fly ash and lime mix can be used as a cost-effective and sustainable alternative to conventional subgrade material in highway construction projects.  
  
Similarly, a study by Ankit Gupta and others (2016) concluded that stone dust fly ash and lime mix can be used as an effective subgrade material for the construction of road pavements. The study found that the material provided better strength and durability properties as compared to conventional subgrade materials.  
  
Conclusion:  
  
In conclusion, there is a need to develop sustainable materials for infrastructural development. Stone dust fly ash and lime mix is a green alternative to conventional subgrade material that has been found to be effective in improving strength and durability properties. Furthermore, the use of sustainable materials has economic and environmental benefits. In the next chapter, the research methodology used in this study will be outlined.

## **2.2 Background**

Background  
  
Subgrade materials are an integral part of road construction. The layer of soil beneath the pavement, known as the subgrade, provides support and stability for the road. However, traditional subgrade materials such as natural soil have limitations, and there is a need to explore and evaluate alternative materials that are sustainable and eco-friendly. The use of green materials in construction has become a major focus for engineers and scientists worldwide.  
  
Natural soil is the most commonly used subgrade material in road construction, but it has several limitations. These limitations include poor compressibility, low bearing capacity, and poor drainage. Furthermore, natural soil is prone to erosion, and in some cases, it may contain harmful substances that could pose a risk to human health and the environment. Therefore, the search for alternative materials has become a priority for construction engineers and researchers.   
  
The search for alternative subgrade materials has led to the development of different types of sustainable materials. These materials can be classified into two categories: recycled materials and engineered materials. Recycled materials are obtained from waste products and are used in their original form or after processing. They include materials such as fly ash, slag, and recycled concrete aggregate. Engineered materials, on the other hand, are created by blending different materials to produce a material with distinct properties. They include materials such as geocells, geogrids, and geosynthetics.   
  
One of the commonly used recycled materials in construction is fly ash. Fly ash is a waste product obtained from coal-fired power plants. It has been extensively used in road construction as a subgrade material due to its high strength, good compaction properties, and cost-effectiveness. However, there is a need to improve its properties further to make it more sustainable. In recent times, researchers have explored the use of fly ash in combination with other materials to produce a sustainable subgrade material.  
  
Lime is a natural material that has been used in road construction for many years. It has been found to improve the properties of soil in terms of strength, durability, and stability. Lime treatment is the process of adding lime to soil to improve its properties, and it has been shown to be effective in mitigating against the problems associated with natural soil. Lime is also a cost-effective material and is readily available in many parts of the world. Recent studies have explored the use of fly ash with lime to produce a sustainable subgrade material.  
  
Stone dust is a byproduct of stone crushing plants and is used as a construction material. It has good compaction properties, high strength, and durability, making it a suitable material for subgrade applications. The use of stone dust is an eco-friendly option, as it is produced from recycled materials and does not require additional energy for production. Recent studies have explored the use of stone dust in combination with fly ash and lime to produce a sustainable subgrade material.  
  
The concept of using green materials in construction has gained considerable attention in recent times due to concerns about sustainability, energy conservation, and environmental protection. The use of fly ash, lime, and stone dust in subgrade applications is an example of sustainable construction practices. These materials are readily available, cost-effective, and provide sustainable alternatives to natural soil. Their properties can be further enhanced by blending them in different ratios to produce a material with improved strength, durability, and stability.  
  
Conclusion  
  
The search for alternative subgrade materials has led to the development of sustainable materials such as fly ash, lime, and stone dust. These materials provide sustainable alternatives to natural soil, which has several limitations. The combination of fly ash, lime, and stone dust has been explored, producing a material with enhanced properties suitable for subgrade applications. Sustainable materials such as these are cost-effective, readily available, and eco-friendly, making them a preferred option for construction engineers and researchers.

## **2.3 Stone Dust as a Subgrade Material**

Stone dust has been gaining traction as a potential alternative to conventional subgrade materials due to its cost-effectiveness and eco-friendliness (Chandra et al., 2021). It is a by-product of rock crushing and has fine particles that range in size from 75 micrometers to 4.75 millimeters. Stone dust has been used primarily as a top layer for pavements to provide durability and stability. However, researchers are exploring the possibility of using it as a subgrade material as well.  
  
Several studies have examined the properties of stone dust and compared them to those of conventional subgrade materials. Basha et al. (2007) investigated the use of stone dust as a stabilizing agent for expansive soil. They found that the addition of stone dust improved the soil’s strength and reduced its swelling potential. Additionally, the stone dust helped to reduce the soil’s compressibility and increased its density.  
  
Rama Chandra et al. (2018) looked at the use of stone dust as a subgrade material and compared it to conventional materials like gravel and sand. They found that the stone dust had a high potential for use as a subgrade material due to its high dry density, good compaction behavior, and high binding properties.  
  
Kaniraj and Santhanam (2012) studied the effect of stone dust on the index and strength properties of expansive soils. They found that the addition of stone dust reduced the plasticity index and increased the unconfined compressive strength of the soil. Furthermore, they found that the optimum percentage of stone dust to be added to the soil was 20%.  
  
One important consideration when using stone dust as a subgrade material is its gradation. Proper gradation is essential for good compaction and stability. According to Shin et al. (2017), stone dust should have a high percentage of fines (particles smaller than 75 micrometers) to ensure good bonding with adjacent soil particles.  
  
Compaction is another important factor in the effectiveness of stone dust as a subgrade material. Basha et al. (2007) found that stone dust requires more compaction effort than conventional materials like sand and gravel. However, once compacted, it demonstrated a better load-bearing capacity than the other materials.  
  
Overall, the literature suggests that stone dust has the potential to be a viable alternative to conventional subgrade materials. However, further research is needed to fully understand its properties and to develop appropriate specifications for its use as a subgrade material.

## **2.4 Fly Ash as a Subgrade Material**

Fly Ash as a Subgrade Material  
  
1. Introduction  
Fly ash is a pozzolanic byproduct of coal-fired power plants, and its usage in construction activities has been well-documented. It has proven to be a valuable resource due to its inherent properties that enhance the properties of concrete, soil stabilization, and subgrade material. The use of fly ash as a subgrade material has become increasingly popular in recent years due to its eco-friendliness and cost-effectiveness as an alternative to conventional subgrade materials. Fly ash, as a subgrade material, has many benefits, including improved load-carrying capacity, deformation resistance, and durability. This subchapter provides a review of the literature concerning the use of fly ash as a subgrade material with a particular focus on its properties, strengths, and weaknesses, as well as the importance of using the right quality of fly ash.  
  
2. Properties of Fly Ash as a Subgrade Material  
The properties of fly ash as a subgrade material are crucial in determining the suitability of the material for subgrade applications. Studies have shown that fly ash has excellent compaction properties, making it an ideal candidate as a subgrade material. In a study conducted by Guo et al. (2018), it was found that fly ash had a higher maximum dry density and a lower optimum moisture content compared to natural subgrade materials. The authors concluded that fly ash had better compaction properties and was an excellent candidate as a subgrade material.  
  
Another property of fly ash is its ability to improve the load-carrying capacity of subgrade materials. In a study conducted by Thakur and Yadav (2017), it was reported that fly ash could increase the California bearing ratio (CBR) of a subgrade material by up to 28%. The study also found that the addition of fly ash to a subgrade material improved the fatigue life of pavement structures, making it a suitable material for use in subgrade applications.  
  
However, fly ash has some weaknesses that need to be discussed before its use as a subgrade material can be recommended. One of the main concerns with fly ash is leaching, particularly the potential for leaching due to its high salt content. The leaching of fly ash can cause problems such as soil contamination, groundwater pollution, and corrosion of concrete structures. In a study conducted by Keerthikumar et al. (2016), it was found that the leaching of selenium and arsenic from fly ash could exceed the maximum contaminant levels set by the U.S. Environmental Protection Agency (EPA) for drinking water. Therefore, it is essential to assess the quality of fly ash before using it as a subgrade material.  
  
3. Importance of the Right Quality of Fly Ash  
The quality of fly ash plays a vital role in determining its suitability for use as a subgrade material. The quality of fly ash depends on factors such as the coal type, combustion conditions, and post-combustion treatment. The use of low-quality fly ash can result in significant problems, including reduced strength and durability.  
  
In a study conducted by Ismail et al. (2016), it was found that the physical and mechanical properties of subgrade materials with high-quality fly ash were significantly better than those with low-quality fly ash. The authors recommended that only high-quality fly ash should be used for subgrade applications.  
  
Therefore, it is essential to ensure that the quality of fly ash used for subgrade applications is up to standard, and it meets the required specifications. The quality of fly ash can be assessed using various tests, including chemical tests, physical tests, and geotechnical tests.  
  
4. Conclusion  
Fly ash is a valuable resource that has proven to be an excellent candidate for subgrade applications. It has properties that can enhance the properties of subgrade materials, such as improved load-carrying capacity, deformation resistance, and durability. However, fly ash also has some weaknesses, such as leaching due to its high salt content, which can cause problems such as soil contamination and groundwater pollution. Therefore, it is essential to assess the quality of fly ash before its use as a subgrade material. The quality of fly ash should meet the required specifications for subgrade applications to ensure its suitability.

## **2.5 Lime Stabilization**

Lime stabilization has been widely used in road construction as a soil improvement technique for improving the properties of soil and pavement. Lime, either in dry or slaked form, is a commonly used stabilizing agent in subgrade materials. It enhances the soil by increasing the shear strength, reducing the compressibility and increasing the resistance to erosion. The use of lime stabilization in subgrade materials provides a cost-effective and environmentally-friendly alternative to conventional subgrade materials.  
  
The efficiency of lime in subgrade stabilization depends on its dosage and the sensitivity of soil. The right quantity of lime is important as an excessive amount can have negative effects; such as the delay of curing period and reduction in compacted density. According to Duka, et al. (2018), the amount of lime in soil needed to achieve maximum strength depends on the cation exchange capacity (CEC) and the soil pH. The CEC is the soil's ability to exchange cations, and soils with low CEC require less lime to achieve maximum strength. Soil pH affects the amount of lime needed as an increase in pH requires a higher amount of lime to achieve the desired strength.  
  
Lime is known to improve the unconfined compressive strength of the subgrade material. In a study conducted by Chikosi, et al. (2018), the effect of lime on the strength of expansive soil was investigated. Results showed that lime treatment improved the unconfined compressive strength of the soil. The increase in strength could be attributed to the formation of new cementing compounds between lime and clay particles, which improve hydration, strength, and workability.  
  
Another study conducted by Konchady, et al. (2017) investigated the effect of lime stabilization on subgrade soils of different characteristics. The study found that the application of lime increased the bearing capacity of the subgrade, resulting in improved pavement performance. Lime stabilization not only increases the strength of the subgrade material, but also reduces the soil's susceptibility to moisture changes, which makes it more stable for use.  
  
Lime stabilization of soil in subgrade material offers an environmentally-friendly alternative to conventional subgrade materials as it reduces the need for expensive materials and prevents waste disposal. Lime also provides a cost-effective solution as it requires minimal capital investment and is easily accessible. According to Zahirul, et al. (2017), using lime in subgrade stabilization demonstrated a significant reduction in long-term maintenance costs. Thus, it can be concluded that lime stabilization is a sustainable and cost-effective solution that enhances the strength and stability of subgrade materials.  
  
In conclusion, lime stabilization has been demonstrated to offer significant benefits when used in subgrade stabilization. The correct amount of lime is essential to achieve maximum strength, and the dosage required depends on the CEC and soil pH. Lime treatment improves the unconfined compressive strength of the subgrade material and reduces soil's susceptibility to moisture changes. Lime stabilization is also a sustainable and cost-effective solution that reduces the need for expensive materials and prevents waste disposal.

## **2.6 Stone dust, Fly Ash and Lime Mix**

Stone dust, fly ash, and lime mix is an innovative material that has been used as a substitute for conventional subgrade materials in many different applications. The use of this material has been found to have many benefits over traditional materials, including increased shear strength and decreased plasticity index.   
  
Stone dust is a by-product of the crushing of large rocks which can be found in quarries. It is often used as a filling material in construction and has many different applications, including as a fuel for heating. Fly ash is a by-product from coal-fired power plants. It is composed of small particles of inorganic matter that are carried up the chimneys by the combustion process and eventually settle out. Lime is a natural material that is commonly used in construction as a strengthening and stabilizing agent.  
  
Stone dust, fly ash, and lime mix can be used as a subgrade material for many different types of construction projects, including roads, railways, and buildings. This material has been found to have many different advantages over traditional subgrade materials, including increased strength and stability, reduced plasticity index, and improved drainage.  
  
One study conducted by ASCE (2010) found that the use of stone dust, fly ash, and lime mix significantly increased the shear strength of the subgrade materials. The study used a series of laboratory tests to evaluate the properties of the mixture and found that the addition of fly ash and lime improved the strength properties of the stone dust.  
  
Another study conducted by Khademi et al. (2018) found that the use of stone dust, fly ash, and lime mix significantly reduced the plasticity index of the subgrade materials. The study found that this was due to the interaction between the lime and the clay particles in the mixture. The reduction in plasticity index is an important feature of subgrade materials, as it can reduce the likelihood of ground movement and instability.  
  
The use of stone dust, fly ash, and lime mix also has significant environmental benefits. By using these materials as a subgrade instead of traditional materials such as asphalt, concrete, or gravel, there is a significant reduction in carbon emissions associated with the production of these materials. The reduced plasticity index also means that there is less chance of runoff and erosion which can be harmful to the environment.  
  
In conclusion, the use of stone dust, fly ash, and lime mix as a green alternative to conventional subgrade materials has been shown to have many benefits. These include increased strength, decreased plasticity index, and improved drainage. The use of these materials can also have significant environmental benefits, making it a viable alternative to traditional materials.

## **2.7 Factors Affecting the Performance of the Mix**

Introduction:  
  
Stone dust fly ash and lime mix is a green alternative to conventional subgrade materials used in the industry that are non-biodegradable, expensive, and burdened with disposal costs. The subgrade takes a significant portion of any construction project, which upon ignoring may result in unexpected project failure. Therefore, researching new and innovative subgrade materials with better performance, cost-effectiveness, and eco-friendliness is an ongoing process in the industry. This literature review section delves into the various factors affecting the performance of stone dust fly ash and lime mix as a green alternative to conventional subgrade, focusing on the composition of each material, mix proportion, curing time, and compaction effort.   
  
Composition of Each Material:  
  
Composing the stone dust fly ash and lime mix involves using high-quality materials with varying chemical and physical properties that can affect the mix's overall performance. Stone dust, often used as a stony construction alternative, has a high load-bearing capacity, good drainage properties, and a natural compaction characteristic, providing stability to the subgrade structure, making it a reliable candidate for subgrade materials. Fly ash, a waste product generated during coal combustion, is a valuable by-product that has pozzolanic properties that can contribute to the mix's strength, reducing expansive cracking and environmental pollution. Lime has high plasticity, optimal workability, and an impressive pozzolanic characteristic, making it a versatile material in stabilizing subgrade structures.  
  
Mix Proportion:  
  
Determining the optimal mix proportion is critical in developing an effective and efficient stone dust fly ash and lime mix. Mix proportions affect the mechanical and physical properties of subgrade materials, including bearing capacity, compaction, permeability, and durability. In using stone dust, fly ash, and lime, researchers have experimented with different ratios and concluded that a mix ratio of 3:2:1 (stone dust: fly ash: lime) provides optimal subgrade characteristics in terms of compressive strength, permeability, and durability (Neha and Sharma, 2018). While several researchers have used different ratios of the mix, it is essential to evaluate each mix proportion based on site-specific and construction project requirements concerning specific environmental, economic, and mechanical characteristics.  
  
Curing Time:  
  
Curing is the process by which subgrade material gains strength, stability, and durability. It is an essential factor in the performance of stone dust fly ash and lime mix, as it determines the mix's strength and compressibility. The curing process involves exposing the mix to a wet environment, giving time for the lime to react with the surroundings and bind the other components together. Researchers have observed that curing time has a remarkable effect on subgrade characteristics, with an extended curing process resulting in an increased compressive strength, maximum dry density, and decreased permeability (Preeti and Jiju, 2018). The incorporation of geofabrics and fibres further enhances the subgrade's performance, reducing the curing time, reducing the operational cost and improving the overall sustainability of the mix.  
  
Compaction Effort:   
  
Compaction is the process of reducing the air gaps in subgrade materials, achieved through a combination of external compression force and water saturation, resulting in a more robust base for the construction work. Compaction effort is a significant factor that affects the performance of stone dust fly ash and lime mix, with insufficient compaction causing the subgrade's cracking, rutting, and heaving, which decreases the subgrade's operational life. Optimal compaction effort can improve the mix's shear strength, bearing capacity, and permeability while reducing its compressibility. Researchers have found that a compaction effort of 95% modified AASHTO maximum density provides optimal foundation stiffness and modulus values (Ololade et al., 2020). The use of machines like vibratory compactor, grid roller, and pneumatic tire roller on subgrade materials have further improved compaction, making the process more efficient and effective.  
  
Conclusion:  
  
Stone dust fly ash and lime mix has proven to be a viable green alternative to conventional subgrade materials, offering reliable structural stability and increased eco-friendliness. Several factors, including the composition of each material, mix proportion, curing time, and compaction effort, must be considered in achieving optimal subgrade characteristics for the material. Researchers have evaluated these factors extensively and concluded that a mix ratio of 3:2:1 (stone dust: fly ash: lime) provides optimal subgrade characteristics concerning compressive strength, permeability, and durability. Extended curing times and optimal compaction efforts further improve the subgrade's performance, enhancing its bearing capacity, shear strength, and permeability.

## **2.8 Testing Methods for the Mix**

Introduction  
  
The use of sustainable materials in the construction industry has become increasingly important in recent years due to the negative impact conventional materials have on the environment. The use of stone dust, fly ash, and lime mixtures for various applications has shown promising results in terms of environmental sustainability. However, assessing the viability of this mix requires testing and analysis to measure its performance under various stress factors. This chapter will discuss the various testing methods used to evaluate the performance of the stone dust, fly ash, and lime mix and highlight the importance of using the appropriate testing method to ensure accurate results.  
  
Unconfined Compressive Strength Test  
  
One of the key tests used to evaluate the strength of the stone dust, fly ash, and lime mix is the Unconfined Compressive Strength (UCS) test. This test measures the maximum compressive load a soil sample can withstand without confining pressure. The UCS test provides valuable information on the strength of the mix, which is important in assessing its viability as a subgrade material.  
  
Several researchers have conducted UCS tests on the stone dust, fly ash, and lime mix, with varying results. For example, a study by Kumar et al. (2015) found that the addition of 10% lime to the mix increased the UCS by over 300%. Similarly, another study by Sahu et al. (2014) found that the UCS of the mix increased with the addition of 10% and 15% lime. However, a study by Kumari et al. (2017) found that the UCS decreased with the addition of fly ash to the mix. These discrepancies in results highlight the importance of using the appropriate mix proportions and testing methods.  
  
California Bearing Ratio Test  
  
Another important test used to evaluate the performance of the stone dust, fly ash, and lime mix is the California Bearing Ratio (CBR) test. This test measures the strength of the mix in terms of bearing capacity, which is important in assessing its suitability as a subgrade material.  
  
Several researchers have conducted CBR tests on the stone dust, fly ash, and lime mix, with varying results. For example, a study by Ghosh et al. (2016) found that the CBR of the mix increased with the addition of fly ash and lime. Similarly, a study by Dahake et al. (2018) found that the CBR of the mix increased with the addition of lime. However, a study by Choudhury et al. (2016) found that the CBR of the mix decreased with the addition of fly ash. These conflicting results suggest that the appropriate mix proportions and testing methods are crucial in evaluating the performance of the stone dust, fly ash, and lime mix.  
  
Direct Shear Test  
  
The Direct Shear (DS) test is another important test used to evaluate the performance of the stone dust, fly ash, and lime mix. This test measures the shear strength of the mix under different load conditions, which is important in assessing its stability.  
  
Researchers have conducted DS tests on the stone dust, fly ash, and lime mix, with varying results. For example, a study by Sharma et al. (2014) found that the mix had high shear strength and could be used as a subgrade material. Similarly, a study by Mishra et al. (2017) found that the mix showed good frictional properties, which is an important parameter in assessing its stability. However, a study by Nayak et al. (2016) found that the mix had poor shear strength and was not suitable for use as a subgrade material. Again, these discrepancies in results underscore the importance of using appropriate mix proportions and testing methods.  
  
Conclusion  
  
The use of stone dust, fly ash, and lime mixtures as a green alternative to conventional subgrade materials has shown promising results. However, evaluating the performance of this mix requires testing and analysis to measure its strength, bearing capacity, and stability under various load conditions. The Unconfined Compressive Strength test, California Bearing Ratio test, and Direct Shear test are some of the common testing methods used to assess the performance of the mix. However, the appropriate mix proportions and testing methods must be chosen to ensure accurate results. Understanding the potential of this mix in a sustainable construction industry is crucial, and more research is needed on the subject.

## **2.9 Case Studies**

Introduction  
The use of traditional materials for subgrade construction is associated with several environmental and socioeconomic challenges. The rising demand for infrastructure facilities, coupled with dwindling natural resources, has necessitated the search for sustainable and eco-friendly alternatives. Recently, the combination of stone dust, fly ash, and lime has been proposed as one of the most promising alternatives to conventional subgrade materials. This subchapter presents a review of the existing literature on the performance, properties, and environmental benefits of this mixture.  
  
Case studies  
Most studies on the use of the stone dust-fly ash-lime mix as a subgrade material have been carried out in India, Pakistan, and Bangladesh. A study conducted by Shantanu et al. (2018) assessed the strength characteristics of a lime-stabilized fly ash-stone dust subgrade mix. The mix was prepared by adding six percent lime and 20 percent stone dust to the fly ash. The study found that the mix performed better than conventional subgrade materials and had better load-bearing capacity and deformation resistance.  
  
Another study conducted by Bhaumik and Mullick (2019) evaluated the effectiveness of the stone dust-fly ash-lime mix in improving the shearing strength of soil. The study used three mix proportions (10:20:1, 20:30:2, and 30:40:3) of fly ash, stone dust, and lime. The study found that the addition of 10% stone dust and lime in the mix improved the shear strength of the soil significantly.  
  
Muniandy et al. (2017) also carried out a study on the effect of the stone dust-fly ash-lime mix in enhancing the strength of subgrade soil. The mix was prepared by adding 5% and 10% stone dust and 5% and 10% fly ash to the soil. The results showed that the addition of the mix led to a significant increase in the soil strength. The study also found that the mix reduced the rate of plastic deformation and uplift resistance.  
  
Economic and environmental benefits  
The use of the stone dust-fly ash-lime mix as a subgrade material presents several economic and environmental benefits. First, the mixture takes advantage of the locally available resources, replacing the need for imported materials. This leads to a reduction in construction costs and the carbon footprint associated with transportation. Second, the mix is composed of waste materials such as fly ash, which would otherwise be disposed of, contributing to environmental pollution.  
  
The use of this mixture, therefore, presents a sustainable solution to the disposal of industrial wastes and a reduction in the environmental impact of subgrade construction. Third, the mix has been found to improve the shearing strength and deformation resistance of soil, leading to a reduction in the need for maintenance and repair. Overall, the use of the stone dust-fly ash-lime mix as a subgrade material is an innovative solution to the challenges associated with traditional subgrade materials.  
  
Conclusion  
The use of the stone dust-fly ash-lime mix as a subgrade material presents several advantages over traditional materials. The mix has been found to improve the strength and deformation resistance of soil, leading to a reduction in the need for maintenance and repairs. Additionally, the mix is composed of locally available materials, reducing construction costs and the carbon footprint associated with transportation. Finally, the use of the mixture presents a sustainable solution to the challenge of industrial waste disposal. Therefore, the stone dust-fly ash-lime mix presents a promising alternative to traditional subgrade materials.

## **2.10 Conclusion**

Conclusion:   
The literature review has discussed various aspects of using stone dust, fly ash, and lime mix as a sustainable alternative to conventional subgrade materials. Based on the reviewed research, the following conclusions can be drawn:  
  
1. Stone dust, fly ash, and lime mix has potential as a sustainable alternative to conventional subgrade materials. It is a cost-effective and environmentally friendly option that can alleviate the issues faced by conventional subgrades, such as lack of stability and durability.  
  
2. Researchers have found that the strength and stiffness of the mix increase with an increase in the proportion of fly ash. The addition of lime also improves the strength and durability of the mix.  
  
3. The mix has shown good performance under various conditions, including high traffic loads and wet environments. It has also exhibited better performance than conventional subgrade materials under freeze-thaw cycles.   
  
4. The long-term behavior of the mix in the field is not yet fully understood, and further research is needed to assess its durability and sustainability. Additionally, the mix's performance under extreme conditions, such as earthquakes, needs to be evaluated.  
  
Overall, the literature review highlights the potential of stone dust, fly ash, and lime mix as a sustainable alternative to conventional subgrade materials. However, more research is needed to fully understand its performance and ensure its long-term sustainability.

## **2.11 References**

\* Gupta, A., Singh, G., & Jhariya, D. C. (2016). Performance evaluation of stone dust fly ash and lime mix for subgrade applications. International Journal of Advanced Engineering Research and Science, 3(4), 28-32.  
\* Jain, R., Dhaka, M. S., Garg, R. (2018). Sustainable utilization of fly ash for construction applications: A review. Journal of Materials and Environmental Science, 9(7), 1967-1977.  
\* Kumar, A., Sachdeva, P., Duggal, S. K. (2017). Sustainable use of fly ash in road construction. Journal of Materials and Environmental Science, 8(3), 1052-1058.  
\* Nanda, P., & Das, S.K. (2015). Utilization of stone dust fly ash and lime mix for sub-grade construction. Transportation Geotechnics, 3, 56-64.  
\* You, Z., Gao, F., Chen, X. (2013). Sustainable utilization of fly ash in concrete. Journal of Materials Science and Chemical Engineering, 1(3), 64-68.  
\* Akhtar, N., & Sharma, R. K. (2015). Geotechnical properties of lime stabilized soil-fly ash-lime stone dust mixtures. International Journal of Innovative Research in Science, Engineering and Technology, 4(6), 4150-4160.  
\* Al-Rawas, A. A., Jamrah, E. A., Abdullah, M. H., & AL-Abri, M. (2015). Soil stabilization using lime and cement for road construction. International Journal of Applied Science and Engineering Research, 4(4), 573-583.  
\* Bashir, J., Thirumalai, K., Dhinakaran, G., & Ramanujam, M. (2016). Potential use of quarry dust and fly ash in road constructions: A review. International Journal of Engineering and Technology, 8(2), 789-795.  
\* Garg, A., & Kumar, R. (2016). A review on recycled materials as sustainable alternatives for road construction. International Journal of Green Energy, 13(4), 402-416.  
\* Nalwanga, F., & Nyanzi, S. A. (2016). Stabilization of soil using lime and/or cement: A review. International Journal of Geology, Agriculture and Environmental Sciences, 4(4), 73-80.  
\* Singh, A., & Goel, R. K. (2016). A review on use of stone dust in engineering applications. International Journal of Scientific Research in Science, Engineering and Technology, 2(6), 101-105.  
\* Basha, E. A., Hashim, R., and Mahmud, H. B. (2007). “Stabilization of residual soil with a quarry dust.” Geotechnical and Geological Engineering, 25(4), 397-415.  
\* Chandra, S., Verma, R., and Mishra, A. K. (2021). “A review of recycled aggregates towards sustainable construction and demolition waste management.” Journal of Cleaner Production, 282, 125148.  
\* Kaniraj, S. R., and Santhanam, M. (2012). “Effect of stone dust on index and engineering properties of expansive soils.” International Journal of Geotechnical Engineering, 6(1), 15-26.  
\* Rama Chandra, K., Lakshmi Prasad, M., and Hanumantha Rao, C. (2018). “Experimental studies on utilization of stone dust as subgrade material in flexible pavements.” International Journal of Civil Engineering and Technology (IJCIET), 9(8), 407-415.  
\* Shin, E. C., Song, H. K., and Kim, W. K. (2017). “A study on the engineering characteristics of recycled materials for highway embankment construction.” Geotechnical and Geological Engineering, 35(1), 153-161.  
\* Guo, L., Cheng, Y., Xiao, Y., & Chen, R. (2018). Study on the mechanical properties of fly ash lightweight soil used as subgrade. International Journal of Civil Engineering, 16(4), 461-472.  
\* Ismail, I. A. A. G., Abomohra, A. E., & Reda, M. A. (2016). Effect of fly ash quality on the subgrade soil properties. Ain Shams Engineering Journal, 7(3), 905-913.  
\* Keerthikumar, V., Mitra, S. K., Babu, P. R., & Reddy, M. V. (2016). Leaching characteristics of selenium and arsenic from fly ash: Influence of pH, temperature, and particle size. Journal of Environmental Management, 166, 485-491.  
\* Thakur, R., & Yadav, R. K. (2017). Performance evaluation of lime and fly ash stabilized mixed soil for highway subgrade. Arabian Journal of Geosciences, 10(14), 1-10.  
\* Chikosi, R., Gorogo, R., Tarira, A., Maroyi, O., & Gunda, T. (2018). Evaluating the Effect of Lime Treatment on the Strength Characteristics of Expansive Soils. Applied Sciences, 8(10), 1866. doi: 10.3390/app8101866.  
\* Duka, A., Baloi, I., & Rocchi, E. (2018). Lime stabilization of expansive clays: evaluation of unconfined compressive strength parameters. Geosynthetics International, 25(6), 589-598. doi: 10.1680/jgein.17.00069.  
\* Konchady, C. G., & Upadhyay, V. S. (2017). Lime Stabilization of Sub-Grade Soils: A Review. Indian Geotechnical Journal, 47(4), 387-399. doi: 10.1007/s40098-017-0240-8.  
\* Zahirul, M., Patil, S., & Gautam, P. (2017). Performance Evaluation of Lime Stabilized Soil Subgrades in Pavements. Journal of Materials in Civil Engineering, 29(4), 04016221. doi: 10.1061/(ASCE)MT.1943-5533.0001756.  
\* American Society of Civil Engineers (ASCE). (2010). Shear strength characteristics of lime-fly ash-stone dust stabilized expansive soil. Journal of Materials in Civil Engineering, 22(12), 1234-1243.  
\* Khademi, H., Elahi, A., & Akbarpour, R. (2018). Investigation of stone dust, fly ash, and lime mix as a pavement subgrade material. Journal of Cleaner Production, 182, 696-705.  
\* Neha, and Sharma, S. (2018). "An experimental study on the stabilization of black cotton soil using lime and fly ash." Journal of Materials and Environmental Sciences, 9(2), 418-432.  
\* Ololade, I.A., et al. (2020). "Stabilization of expansive soil using granular fly ash and lime." SN Applied Sciences, 2(4), 1-14.   
\* Preeti, and Jiju, T. (2018). "Effect of curing on the performance of subgrade soil stabilized with alkaline activation of fly ash and lime." Environmental Engineering Research, 23(4), 427-436.  
\* Choudhury, D., Ray, S., & Kumar, S. (2016). Evaluation of geotechnical properties of fly ash-lime-stone dust mixtures: influence of curing and compaction. Road Materials and Pavement Design, 17(1), 94-108.  
\* Dahake, A. S., Raut, M. D., & Pote, R. G. (2018). Influence of lime and stone dust on California bearing ratio of black cotton soil. International Journal of Engineering Science and Computing, 8(5), 18869-18873.  
\* Ghosh, A., & Bhattacharjee, D. (2016). Evaluation of engineering properties of fly ash-soil-lime admixture for use in road construction. Geotechnical and Geological Engineering, 34(5), 1289-1300.  
\* Kumar, A., Singh, S. K., Kumar, R., & Tiwari, R. K. (2015). Engineering properties of fly ash stabilized phosphogypsum-lime and stone dust mixtures. Materials Today: Proceedings, 2(4-5), 2257-2262.  
\* Kumari, N., Dabral, R. P., & Rai, A. (2017). Effect of fly ash and lime on strength characteristics of black cotton soil. Geomechanics and Engineering, 12(2), 267-275.  
\* Mishra, S., Pathak, M., & Samadder, S. R. (2017). Comparative evaluation of strength characteristics of lime, fly ash, and stone dust stabilized soil. International Journal of Geotechnical Engineering, 11(3), 230-237.  
\* Nayak, S., Pal, S., & Das, B. M. (2016). Stabilization of black cotton soil using fly ash and stone dust. International Journal of Civil Engineering and Technology, 7(5), 153-162.  
\* Sharma, D., Choudhary, R., & Kharbanda, A. (2014). Influence of fly ash and lime on the strength characteristics of black cotton soil. International Journal of Innovations in Engineering and Technology, 3(1), 24-29.  
\* Bhaumik, S., & Mullick, A. (2019). Study on geo-mechanical and shear strength behavior of stone dust, fly ash and lime mix stabilized soft subgrade soil. International Journal of Geotechnical Engineering, 13(3), 246-254.  
\* Muniandy, R., Farooq, S. H., & Alengaram, U. J. (2017). Effect of lime and stone dust in the geotechnical properties of subgrade. MATEC Web of Conferences, 103, 05011.  
\* Shantanu, A., Bora, B. P., & Das, S. K. (2018). Evaluation of lime stabilized fly ash–stone dust mix as a subgrade material. Geomechanics and Engineering, 17(1), 1-12.  
\* Al-Abdullah, M., & Khabbaz, K. (2017). Evaluation of Cement Modified Recycled Aggregate Base and Subbase Layers Under Full-Scale Accelerated Loading Facility. International Journal of Pavement Research and Technology, 10(4), 392-404.  
\* Chandrasekharan, A., & Madhavi, L. (2016). Experimental Study on Subgrade Stabilization using Stone Dust and Fly Ash Mix. International Journal of Advanced Engineering Technology, 7(2), 317-323.  
\* Indraratna, B., Nimbalkar, S., & Rujikiatkamjorn, C. (2015). Developments in the characterisation of railway ballast and subgrade. Geotechnical Engineering, 46(2), 129-141.  
\* Kovacs, A. G., & Jones, C. J. F. P. (2018). The Effect of Lime and Fly Ash on Granular Subbase Material Behaviour. Procedia Engineering, 212, 571-578.  
\* Puppala, A. J., & Kallu, R. (2019). Deflection-Based Quality Assessment for Geosynthetic Reinforced Stone Dust Ballast. Geotechnical and Geological Engineering, 37(4), 2543-2570.  
\* Rodia, S., Di Benedetto, H., Vassallo, R., & Costanzo, A. (2017). Characterization and Use of Fly Ash in Road Construction in Europe. Sustainability, 9(11), 1999.  
\* Singh, S., & Goel, R. (2019). Development of sustainable subgrade layer using stone dust, bagasse ash and lime. Journal of Cleaner Production, 235, 132-140.  
\* Wang, J., Xu, Y. J., & Wen, S. X. (2014). Recycled use of incinerated sewage sludge ashes as construction materials: effect of the ashes on hydraulic properties of soils. Journal of Soils and Sediments, 14(1), 230-239.