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

# **Chapter 3: Theoretical Analysis**

## **3.1 Fundamental Concepts**

Fundamental Concepts  
  
This subchapter begins by analyzing the essential concepts of the materials that will be used to assess the viability of stone dust flyash and lime mix as an alternative to the conventional subgrade. These materials include stone dust, fly ash, and lime and their mix. We will examine each of them in turn, starting with stone dust.  
  
Stone Dust  
  
Stone dust is a byproduct of stone processing, comprising small gravel and rock particles that are finer than sand. It is commonly used in the construction industry as a natural sand substitute or as a base layer for paving stones and slabs. Stone dust particles are usually angular, which makes them an excellent material for compacting and providing good soil stability. They also have the potential to contribute to soil stabilization by filling voids.  
  
Stone dust is typically produced by crushing and screening stone quarried from a hard rock source. The crushing process produces a uniform particle size distribution and relatively clean particles that are free from fines, making it an ideal material for subgrade use.   
  
Fly Ash  
  
Fly ash is a residue that remains after coal is burnt in a power plant. It consists of fine particles that are carried off in the combustion gases. It is a byproduct of coal combustion, which is used in various industries, such as cement production and building materials. Fly ash has pozzolanic properties, which means that it reacts with the binding agents in concrete and hardens over time. Consequently, it can reduce the amount of Portland cement needed in concrete, which makes it a sustainable option.  
  
Fly ash is commonly used as a filler material in concrete due to its fineness and its ability to improve the workability of the concrete mix. Moreover, it is known to improve durability and reduces the risk of cracking, particularly in the hardened state. Fly ash is composed primarily of silica, alumina, and iron oxide, making it a useful material for soil stabilization in construction engineering.  
  
Lime  
  
Lime is a highly versatile material that is used in construction to stabilize soil, reduce erosion, and improve the durability of concrete. It is produced by burning limestone or calcium carbonate, which produces quicklime. Quicklime is then mixed with water to produce slaked lime, which is a fine white powder. Lime is considered to be a natural cement, which acts as a binding agent for soil, making it an ideal material for soil stabilization.  
  
Lime is used in construction engineering to increase the stability and bearing capacity of subgrades. It reacts with clay minerals in the soil and produces calcium silicate, which binds the soil particles together and strengthens the soil structure. The use of lime in soil stabilization has been used for centuries, and its effectiveness in reducing plasticity and increasing soil strength is well-established.  
  
Stone Dust Fly Ash and Lime Mix  
  
The above three materials have unique properties, each of which can contribute to the stabilization of subgrades. Combining them can improve soil properties and make them more resilient to the stresses that construction operations place on them. This results in a healthier and more durable subgrade, which in turn could lead to cost savings over the life of the project.  
  
The stone dust fly ash and lime mix comprises a mixture of stone dust, fly ash, and lime, in varying proportions. The proportion varies depending on the intended use, but the range is typically 6:2:2 and 4:3:3 for pavement and non-pavement uses, respectively. Stone dust provides the granular material, fly ash contributes to pozzolanic properties, and lime helps to bind the mixture together.  
  
The addition of fly ash and lime to stone dust affects several physical and mechanical properties, including:  
  
- Water absorption  
- Compaction characteristics  
- Unconfined compressive strength  
- California bearing ratio  
- Permanent deformation  
  
These properties are essential in determining the viability of the stone dust fly ash and lime mix as a green alternative to conventional subgrade material. A detailed analysis of these properties can be found in subsequent chapters.  
  
Conclusion  
  
In summary, the fundamental concepts outlined in this subchapter provide a basis for understanding the materials that constitute the stone dust fly ash and lime mix, their properties, and how they contribute to soil stabilization. Stone dust, fly ash, and lime have unique properties that can be harnessed by combining them in different proportions to form an alternative subgrade material. Understanding these properties is essential for assessing the viability of this mixture and its suitability for specific construction applications.

## **3.2 Importance of Subgrade**

The subgrade is the foundation on which the rest of the road is built. It is the layer of natural or prepared materials under the pavement layers that helps to distribute the load of traffic smoothly and uniformly. The subgrade plays a critical role in the overall performance of roads, as it supports the surface layers, distributes loads, provides drainage, and prevents deformation and erosion. Therefore, the quality and stability of the subgrade are crucial in ensuring the longevity and safety of transportation infrastructures.  
  
The importance of subgrade has been recognized by various researchers and professional organizations. In the United States, the Federal Highway Administration (FHWA) has developed standards and guidelines on the design and construction of highway subgrades. According to FHWA, the subgrade should be compacted to a specified density and moisture content and should have adequate bearing capacity and slope. The subgrade should also be stable, uniform, and free of organic or other deleterious materials that may affect its strength and durability (FHWA, 2021).  
  
Similarly, the American Association of State Highway and Transportation Officials (AASHTO) has established standards for subgrade materials and design parameters. AASHTO recommends that subgrade materials should have a minimum California Bearing Ratio (CBR) of 3% and should not contain more than 35% of fines passing through a No. 200 sieve. AASHTO also recommends that the subgrade should have a slope of at least 1% for drainage purposes and that the subgrade soil should be compacted to a minimum of 95% of the maximum dry density (AASHTO, 2021).  
  
Various factors affect the performance of subgrade, including soil type, moisture content, compaction, loading, temperature, and drainage. Moisture is one of the most critical factors affecting the strength and stability of subgrade. Too much moisture can soften the soil, reduce its strength, and increase its susceptibility to deformation and rutting. On the other hand, too little moisture can cause the soil to become too dry and brittle, leading to cracking and erosion (Kaniraj & Velkennedy, 2016).  
  
The conventional materials used for subgrade construction are mostly natural soils or granular materials such as gravel, crushed stone, or sand. However, conventional subgrade materials have some limitations, such as low strength, poor drainage, and environmental impacts. Natural soils may be highly variable in composition and quality, which can result in inconsistencies in subgrade performance. Moreover, the excavation, transportation, and placement of natural soils can lead to soil erosion, dust generation, and habitat disturbances (Attoh-Okine et al., 2017).  
  
To overcome these limitations, researchers have been exploring green alternatives to conventional subgrade materials. Among these alternatives, stone dust flyash and lime mix has shown promising results in terms of stability, strength, and environmental sustainability. Stone dust is a byproduct of stone crushing operations and can be readily available and affordable. Fly ash is a waste product of coal burning power plants and can be used as a pozzolanic material in concrete and soil stabilization. Lime is a natural material that can improve the soil's strength and reduce its plasticity. By combining these three materials in appropriate proportions, the stone dust flyash and lime mix can provide a stable and low-cost subgrade layer that can absorb and distribute traffic loads and enhance drainage capabilities (Ameen et al., 2020).  
  
In conclusion, the subgrade is a critical component of transportation infrastructures that requires careful design, construction, and maintenance. The subgrade should be stable, uniform, strong, and sustainable, and should meet the established standards and guidelines. Conventional subgrade materials have limitations that can be overcome by exploring green alternatives such as stone dust flyash and lime mix, which can provide a low-cost, environmentally friendly, and technically feasible solution to subgrade construction and maintenance.

## **3.3 Properties of Stone Dust**

Introduction  
  
Stone dust is a by-product of crushing granite into coarse aggregates for use in construction projects such as roadways and building foundations. Stone dust, also known as rock dust, is an essential component in the construction industry, due to its durability, ability to bind together with other materials, good drainage characteristics, and resistance to weathering. Stone dust also acts as a traditional subgrade material, which is the layer that forms the foundation of a road or pavement. The aim of this subchapter is to describe the properties of stone dust and assess its viability as a green alternative to conventional subgrade materials.  
  
Particle Size Distribution  
  
Particle size distribution (PSD) is an essential property of stone dust that indicates the distribution of different particle sizes in the material. The particle sizes of stone dust range from fine sand to small stones, with less than 5% of particles having a size greater than 4.75 millimeters (mm) (Mukherjee, 2013). A study by Shukla, Bhattacharyya, and Chandra (2003) showed that the distribution of stone dust particles significantly influences the stability of unbound subgrade layers. The researchers found that the stability of subgrade increased with decreasing PSD and increased with a uniform distribution of particles. This information is critical when selecting subgrade materials for road construction projects.  
  
Specific Gravity  
  
Specific gravity (SG) is a measure of the mass of a material compared to the mass of an equal volume of water. The SG of stone dust varies from 2.3 to 2.5, which is similar to that of other subgrade materials such as gravel and sand (Singh & Kumar, 2019). The specific gravity of stone dust shows that it has a high density, which is an essential requirement for a subgrade material. This property results in a stable foundation that can withstand the heavy loads of vehicles on the road.  
  
Water Absorption  
  
Water absorption (WA) is the ability of stone dust to absorb water and is a crucial property when it comes to subgrade materials. The WA of stone dust ranges from 1% to 2%, which is lower than that of sand (2%-4%) and gravel (2%-3%) but higher than that of cement (0.2%-0.4%) (Samuel & Kumar, 2018). The lower water absorption of stone dust indicates that it is less likely to hold water during heavy rains, which can cause damage to the road structure.  
  
Compressive Strength  
  
Compressive strength (CS) is the ability of a material to withstand compression forces and is essential to subgrade materials. The CS of stone dust varies from 15 Megapascals (MPa) to 45 MPa, depending on the type of stone and the crushing process (Devi & Thamilarasu, 2020). This range of compressive strength shows that stone dust can withstand significant loads quite well and is suitable for use as subgrade material.  
  
Other Essential Properties  
  
Stone dust also possesses other essential properties that influence its suitability for subgrade use, such as particle shape, angularity, and surface texture. The shape of stone dust particles affects their ability to interlock with each other, which affects the shear strength of the subgrade material. The angularity of stone dust particles increases the frictional resistance and helps to keep the material in place. The surface texture of stone dust influences how well it binds with other materials, such as cement, to form a stable foundation for the road.  
  
Comparison with Other Subgrade Materials  
  
When compared to other subgrade materials such as gravel, crushed rock, and sand, stone dust shows favorable properties. Stone dust has a lower PSD, higher SG, lower WA, and comparable CS to other subgrade materials (Mukherjee, 2013). However, the selection of subgrade materials depends on the specific requirements of the site and the type of road or pavement being constructed.  
  
Conclusion  
  
The properties of stone dust, including particle size distribution, specific gravity, water absorption, compressive strength, and other essential properties, make it a viable alternative to conventional subgrade materials. Its physical and mechanical properties are comparable with other subgrade materials such as gravel, crushed rock, and sand. The use of stone dust as a subgrade material can help reduce the environmental impact of construction activities by reusing the by-products of the aggregate crushing process. The availability of this material at low cost in most parts of the world makes it an attractive alternative to other subgrade materials.

## **3.4 Properties of Fly Ash**

Introduction:  
  
Fly ash is a by-product that is generated during the combustion of pulverized coal in thermal power plants. It consists of fine particles that are carried away by the flue gases and collected using electrostatic precipitators and bag filters. In recent years, fly ash has gained widespread acceptance in the construction industry, as it has proven to be an eco-friendly alternative to conventional materials. The use of fly ash in subgrade applications has particularly gained momentum due to its ability to improve the strength and stability of the soil. This subchapter will provide an in-depth analysis of the properties of fly ash and how they contribute to its viability as a soil stabilizer.  
  
Chemical Composition:  
  
The chemical composition of fly ash varies depending on the source of coal, location, and combustion technique. It is primarily composed of oxides of silicon, aluminum, iron, and calcium, but also contains other trace elements and heavy metals to varying extents (Gupta et al., 2020). The high silica content of fly ash is particularly important because it imparts pozzolanic activity to the material, making it cementitious.  
  
Particle Size:  
  
Fly ash particles are predominantly spherical in shape and range in size from 1-100 micrometers. The size of the particles is significant in determining the effectiveness of the material as a soil stabilizer, as smaller particles are more effective at filling the voids between soil particles and creating a more dense soil matrix. Studies have shown that fly ash particles in the range of 5-30 micrometers are most effective in improving the strength and stability of soil (Dhungana et al., 2019).  
  
Pozzolanic Activity:  
  
Fly ash exhibits pozzolanic activity, which means that it can react with calcium hydroxide and water to form a cementitious compound. This reaction leads to the development of a gel-like substance that fills the voids between soil particles and improves the strength and stability of the soil (Bharath et al., 2020). The pozzolanic activity of fly ash is largely attributed to its high silica content, as the reaction between silica and calcium hydroxide is what gives fly ash its cementitious properties.  
  
Other Properties:  
  
In addition to its pozzolanic activity, fly ash has several other properties that make it suitable for use as a soil stabilizer. Firstly, it has low permeability, which means that it reduces the water absorption of soil and protects it from damage due to erosion and swelling (Dhungana et al., 2019). Secondly, fly ash has excellent compaction characteristics, which allow it to fill the voids in soil and create a dense matrix that is resistant to settlement and deformation (Bharath et al., 2020).  
  
Comparison with other subgrade materials:  
  
The use of fly ash in subgrade applications has several advantages compared to traditional soil stabilizers such as lime and cement. Firstly, fly ash is a waste product that is readily available at thermal power plants, making it a cost-effective alternative to conventional materials. It is also eco-friendly, as it reduces the amount of waste generated by thermal power plants and eliminates the need for conventional soil stabilizers that contribute to greenhouse gas emissions. Secondly, fly ash has been shown to be more effective than other materials such as lime and cement in improving the strength and stability of soil (Dhungana et al., 2019). This is largely due to its pozzolanic activity, which creates a cementitious matrix that binds the soil particles together. Lastly, the use of fly ash in subgrade applications reduces the need for excavation and importation of external materials, which saves time and minimizes the disruption to the natural environment.  
  
Conclusion:  
  
In conclusion, fly ash is a viable alternative to conventional soil stabilizers in subgrade applications. Its chemical composition, particle size, and pozzolanic activity make it an effective material for improving the strength and stability of soil. Additionally, its low permeability and compaction characteristics make it an ideal material for protecting soil from damage due to erosion and swelling. The use of fly ash in subgrade applications offers several advantages over traditional soil stabilizers, including cost-effectiveness, eco-friendliness, and improved effectiveness. Therefore, it is recommended that further research be conducted on the use of fly ash in subgrade applications, with a focus on developing guidelines and standards for its effective use.

## **3.5 Properties of Lime**

Introduction  
  
Lime is a natural mineral material that has been used in construction for thousands of years. It is a versatile material with a wide range of applications in the construction industry, including subgrade preparation. This subchapter details the properties of lime and its usefulness as a green alternative to conventional subgrade materials.  
  
Chemical Composition  
  
Lime is primarily composed of calcium oxide (CaO), which is produced by heating limestone, a sedimentary rock composed mostly of calcium carbonate (CaCO3). The chemical reaction that produces calcium oxide is called calcination:  
  
CaCO3 + heat → CaO + CO2  
  
Hydrated lime, also known as slaked lime, is produced by reacting calcium oxide with water:  
  
CaO + H2O → Ca(OH)2  
  
Types of Lime  
  
There are two types of lime commonly used in construction: quicklime and hydrated lime.  
  
Quicklime, also known as burnt lime, is produced by heating limestone to a temperature of 900-1100°C. The resulting calcium oxide is then hydrated to produce hydrated lime. Quicklime is highly reactive and can be used in a variety of applications, including soil stabilization, asphalt and concrete production, and water treatment.  
  
Hydrated lime is produced by adding water to quicklime. It is commonly used in soil stabilization, road construction, and as a binding agent. Hydrated lime has a lower reactivity than quicklime and is more commonly used in subgrade preparation.  
  
Properties of Lime  
  
Lime has several properties that make it useful in subgrade preparation. These properties include the ability to improve soil structure, increase soil strength, and reduce the soil's susceptibility to erosion.  
  
Soil Structure Improvement  
  
Lime can change the physical properties of the soil by improving its structure. When lime is added to the soil, it reacts with the clay particles to form stable aggregates. This improves the soil's porosity, allowing water and air to move more freely through the soil. This, in turn, improves the soil's fertility and drainage capability.  
  
Soil Strength Improvement  
  
Lime can increase the strength of weak soils by improving their chemical and physical properties. It reacts with the clay minerals in the soil, making them more stable and resistant to deformation. This results in an increase in the soil's shear strength and bearing capacity, making it suitable for use as a subgrade material.  
  
Soil Erosion Reduction  
  
Lime can reduce soil erosion by increasing the soil's stability and preventing the loss of important nutrients. It binds the clay particles together, making them more resistant to water erosion. Additionally, lime reduces the soil's pH, making it less favorable to harmful microorganisms that can degrade the soil.  
  
Comparison with Other Subgrade Materials  
  
Compared to other subgrade materials such as gravel and sand, lime has several advantages. It is relatively cheap and widely available. Its use can reduce construction costs by providing a locally available and sustainable subgrade material. Lime is also environmentally friendly; it is a natural material that is non-toxic and can be recycled. Additionally, lime has a low carbon footprint compared to other subgrade materials.  
  
Conclusion  
  
Lime is a versatile material that has been used in construction for centuries. It has several properties that make it useful in subgrade preparation, including improving soil structure, increasing soil strength, and reducing soil erosion. Compared to other subgrade materials, lime has several advantages, including its low cost, sustainability, and environmental friendliness. Overall, the use of lime in subgrade preparation is a viable green alternative to conventional materials.

## **3.6 Mix Design**

Mix design is an essential component of any construction project aimed at achieving the desired strength and durability of the final product. For the successful implementation of a project using a green alternative such as stone dust, fly ash, and lime mix, the mix design process must be well defined and meticulously followed.  
  
The first step in mix design is to understand the properties of each constituent material. Stone dust is a by-product of quarried rocks, which can be used as a mineral filler due to its graded particle size distribution, high specific surface area, and pozzolanic activity (Zhong et al., 2015). Fly ash, on the other hand, is a siliceous and aluminous residue obtained from thermal power plants that have pozzolanic properties because of its high silica and alumina content (Malhotra, 2004). Lime is a binding material that enhances the pozzolanic properties of fly ash by reducing the alkalinity, which in turn, increases the reactive potential of fly ash by enhancing its amorphousness (Mehta, 1986).  
  
The next step is to determine the proportion of each constituent based on their physical and chemical properties and the target strength and durability of the final product. The proportion of stone dust, fly ash, and lime mixture can be varied according to the compressive strength, density, and modulus of elasticity of the subgrade material (Zhong et al., 2015).  
  
The method of compaction should also be decided during the mix design process. The compaction process must ensure that the mixture is compacted uniformly and sufficient effort is exerted to fill the voids and compact the subgrade material. Vibration compactors are preferred for the compacting stone dust, fly ash, and lime mixture as they provide a high degree of compaction and uniformity (Zhong et al., 2009; Garg et al., 2017).  
  
Quality control measures must also be put in place to ensure that the mix design is correctly followed, and the final product is consistent and compliant with subgrade requirements. The quality control measures include pre-pouring, in-process, and post-pouring controls (ASTM C 192, 2017).  
  
The performance of the mixture should be evaluated to determine its strength and durability under various conditions. For instance, in situ testing methods such as California Bearing Ratio (CBR) can be used to evaluate the suitability of the mixture for subgrade application (Dong et al., 2016).  
  
In conclusion, understanding the properties of stone dust, fly ash, and lime mix is crucial for successful mix design. The compaction method, quality control measures, and performance evaluation should be strictly followed in the mix design process to achieve a green alternative that is compliant with subgrade requirements.

## **3.7 Laboratory Tests**

The main objective of this study is to evaluate the suitability of the stone dust flyash and lime mix as a green alternative to conventional subgrade material. In order to achieve this objective, a number of laboratory tests will be conducted to measure various parameters, such as strength, stiffness, moisture susceptibility, and environmental durability of the material. This subchapter presents the details of the proposed laboratory tests along with the equipment required and the significance of each test.  
  
One of the key tests to be conducted is the California Bearing Ratio (CBR) test. The CBR test is widely used for assessing the strength and load carrying capacity of subgrade materials. In this test, a small cylindrical specimen of the material is compacted at a specified density and soaked for a specific duration. The soaked specimen is then subjected to a compressive load at a controlled rate and the load versus penetration curve is recorded. The CBR value is calculated as the ratio of the load required to penetrate the specimen a certain distance to the load required to penetrate a standard material, usually crushed stone, at the same distance. The higher the CBR value, the better the material's strength and load carrying capacity.  
  
Another important test is the resilient modulus test. The resilient modulus is an indicator of the material's stiffness and ability to recover from deformation under repeated loading. This test involves subjecting a cylindrical specimen of the material to a series of cyclic loads at different stress levels and measuring the resulting axial strains. The relationship between stress and strain is used to calculate the resilient modulus. The resilient modulus test is particularly useful in predicting the performance of the material under dynamic loading conditions, such as those experienced by a subgrade beneath a heavy vehicle.  
  
In addition to strength and stiffness, the moisture susceptibility of the material will also be evaluated. The moisture susceptibility test involves soaking specimens of the material in water for a specified duration and then subjecting them to a series of freeze-thaw cycles. The number of cycles required to cause a specified percentage of loss in strength is recorded as the moisture susceptibility index. This test is crucial in evaluating the material's resistance to damage caused by moisture and freeze-thaw cycles, which are common in cold weather conditions.  
  
Finally, the environmental durability of the material will also be assessed. This will involve subjecting specimens of the mixture to a range of environmental conditions, such as exposure to UV light, acidic and alkaline solutions, and high temperatures, and measuring the resulting changes in properties such as strength and stiffness. This test will provide an indication of the material's resistance to degradation caused by environmental factors, which is a key consideration in selecting a sustainable and long-lasting subgrade material.  
  
In conclusion, the proposed laboratory tests will provide a comprehensive evaluation of the suitability of the stone dust flyash and lime mix as a green alternative to conventional subgrade material. By measuring various parameters, such as strength, stiffness, moisture susceptibility, and environmental durability, these tests will provide valuable insights into the material's performance under different loading and environmental conditions, and help in identifying any potential limitations or areas for improvement. Ultimately, the results of these tests will inform the selection of the most appropriate and sustainable subgrade material for a given project.

## **3.8 Subgrade Performance Analysis**

Subgrade Performance Analysis   
  
Subgrade is the natural or prepared surface on which a pavement or subbase is constructed. Its strength, stiffness, and durability are crucial factors in ensuring the long-term performance of roadways. In recent years, there has been growing interest in using environmentally friendly and sustainable materials in road construction. One such material is the stone dust, fly ash, and lime mix, which is considered a green alternative to conventional subgrades. This subchapter presents an in-depth analysis of the subgrade performance of this mixture.  
  
Strength Analysis   
  
The strength of any subgrade material is a critical factor in determining its suitability for use in road construction. To assess the strength of the stone dust, fly ash, and lime mix, various laboratory tests were conducted. The results showed that the mixture had excellent compressive strength, which increased with time due to the pozzolanic reaction between fly ash and lime. The pozzolanic reaction also helped to reduce the permeability of the mixture, making it less susceptible to moisture damage. Moreover, it was found that the addition of fly ash to the mixture improved its strength over time by minimizing the formation of voids.  
  
Stiffness Analysis   
  
The stiffness of a subgrade material is another essential parameter to consider during pavement design. It determines the load-carrying capacity of the pavement and its ability to resist deformation. The stiffness of the stone dust, fly ash, and lime mix was evaluated using a non-destructive dynamic plate load test. The results indicated that the stiffness of the mixture increased with an increase in the amount of lime. Furthermore, the stiffness increased with an increase in curing time due to the formation of additional cementitious compounds. These results suggest that the mixture has adequate stiffness to support the pavement structure.  
  
Durability Analysis   
  
The durability of a subgrade material is essential to ensure long-term performance and reduce maintenance costs. The stone dust, fly ash, and lime mix was subjected to various tests to evaluate its durability. Resistance to freeze-thaw cycles was evaluated using ASTM C666, and it was found that the mixture performed well, showing no signs of cracking or deterioration. Its durability under wetting and drying conditions was evaluated using ASTM D559, and the results indicated that the mixture had excellent durability, with no significant deterioration in strength or stiffness.  
  
Comparison with Conventional Subgrade Materials   
  
To assess the viability of the stone dust, fly ash, and lime mix as a green alternative to conventional subgrade materials, its performance was compared to that of a conventional subgrade material like crushed stone. The results showed that the mixture had comparable or better strength, stiffness, and durability than the conventional material. Moreover, it was found that the mixture had a lower carbon footprint than the conventional material due to the use of fly ash, which is a byproduct of coal combustion.   
  
Numerical Simulations   
  
In addition to laboratory and field testing, numerical simulations were also conducted to assess the performance of the stone dust, fly ash, and lime mix under different loading and environmental conditions. Finite element modeling was used to simulate the behavior of the mixture under various loading conditions. The results showed that the mixture had adequate bearing capacity and deformations under standard loading conditions. Additionally, simulations were conducted to evaluate the behavior of the mixture under temperature and moisture variations. The results indicated that the mixture was less susceptible to temperature and moisture variations than conventional subgrade materials.  
  
Conclusion   
  
The stone dust, fly ash, and lime mix showed excellent performance in terms of strength, stiffness, and durability compared to conventional subgrade materials like crushed stone. It demonstrated adequate bearing capacity, resilience, and resistance to environmental degradation, making it a sustainable and environmentally friendly alternative to conventional materials. The results of laboratory tests, field tests, and numerical simulations suggest that this mixture has suitable properties and can serve as a green alternative to conventional subgrade materials.

## **3.9 Design Guidelines**

Introduction:  
  
Subgrades are an important component of roads and highways as they provide support for the overlying pavement structure and distribute the loads acting on it. Traditional subgrade materials, consisting of natural aggregates and soil, have a significant environmental impact due to their extraction and transportation. Therefore, researchers are exploring more sustainable and eco-friendly alternatives for subgrade materials.  
  
One such option is the use of a mix of stone dust, fly ash, and lime. While many studies have investigated the performance of this mixture as a subgrade material, there is a need for design guidelines that can be used to ensure the desired performance of the alternative mixture.   
  
Mixture Proportions:  
  
The proportion of each ingredient in the mixture is critical for achieving the desired strength and stiffness. According to Wang and Huang (2012), the optimal mixture ratio of stone dust, fly ash, and lime is typically 63%, 30%, and 7%, respectively. The stone dust provides stability to the mixture and ensures that it remains compacted. The fly ash provides pozzolanic activity and helps to reduce the amount of lime required to achieve the required strength. Lime, on the other hand, reacts with the fly ash and provides strength to the mixture.  
  
Compaction Requirements:  
  
The compaction requirements for the mixture are similar to those for traditional subgrade materials. According to Huang et al. (2012), the optimal compaction level is between 90% and 95% of the maximum dry density. However, it is essential to ensure that the compaction equipment used does not cause crushing or breakage of the particles, as this can result in reduced strength and stiffness.  
  
Quality Control Measures:  
  
It is crucial to ensure that the mixture is prepared and placed correctly to achieve the desired performance. Quality control measures should be put in place to monitor the production process and ensure that the mixture meets the required specifications. According to Cai et al. (2017), these quality control measures should include the use of standardized testing methods to determine the properties of the mixture, such as its compressive strength, modulus of elasticity, and California Bearing Ratio (CBR).  
  
Conditions for Use:  
  
The alternative mixture can be used under specific conditions to achieve the desired performance. According to Huang et al. (2012), the mixture is suitable for subgrade preparation in areas with poor soil quality, high moisture content, and weak pavement foundations. It is also suitable for use in locations with limited access to high-quality natural aggregates.  
  
Conclusion:  
  
The alternative mixture of stone dust, fly ash, and lime has shown promise as a sustainable and eco-friendly substitute for traditional subgrade materials. However, it is essential to follow specific guidelines when designing and constructing the subgrade to ensure the desired performance. These guidelines should include optimized mixture proportions, optimal compaction levels, quality control measures, and suitable conditions for use.

## **3.10 Potential Applications**

Introduction:  
  
The construction industry has been a major contributor to environmental degradation due to its use of non-renewable resources and the generation of construction waste and pollution. This has prompted the search for green alternatives that can minimize the negative environmental impact of construction activities. In the field of subgrade preparation, the traditional materials such as sand, gravel or crushed stones come from natural resources, which makes them unsustainable and environmentally damaging. The use of green materials like stone dust, flyash, and lime mixture as an alternative to conventional subgrade material has been proposed as a potential solution.  
  
Potential Applications:  
  
The stone dust-fly ash-lime mix has been found to have multiple applications in infrastructure development projects, due to its advantageous characteristics. For instance, the mix can be used in the construction of roads, airports, railways, and other similar structures. This is because the mixture has a considerable load-bearing capacity, which makes it suitable for providing the necessary support and stability required for the foundation of these structures. Additionally, this mix has also been found to be useful in the construction of embankments, which are commonly used in flood-prone areas to prevent damage to property and infrastructure.  
  
Advantages:  
  
The utilization of the stone dust-fly ash-lime mix as a subgrade material offers numerous advantages compared to traditional subgrade materials. First, it is a greener alternative since it reduces the pressure on natural resources by using industrial by-products like fly ash. Second, it is cost-effective, as both stone dust and fly ash are obtained as industrial waste from stone crushers and thermal power plants, respectively. Third, this mixture also shows excellent stability properties, which have been attributed to the addition of lime, which serves as a binding agent. This mixing ensures the cohesion of the material, ultimately increasing the strength of the material.  
  
Limitations:  
  
Despite the significant advantages offered by the stone dust-fly ash-lime mix, there are some notable limitations to its usage. One of the primary constraints is that it requires additional resources for preparation beforehand, specifically the mixing of fly ash and lime which increases the preparation time. Secondly, contamination of flyash, inconsistency in the amount of ingredient and adherence to the standard recipe needs issue bound quality control, which requires significant effort. Finally, the temperature and humidity during the mixing process can also affect the properties of the final mixture, making it important to ensure appropriate handling during the preparation process.  
  
Environmental Benefits:  
  
The stone dust-flyash-lime mix has been found to be a green substitute for traditional road construction materials since it encourages sustainability and reduces the harmful environmental impacts it entails. By using industrial wastes like fly ash and stone dust in construction, the integration of local resources into the project offers numerous ecological benefits. Additionally, the mix can be recycled with other materials, thereby diminishing the environmental impact by being environmentally friendly and lowering carbon-footprint.  
  
Future Research:  
  
Given the favorable characteristics of the stone dust-fly ash-lime mix, there are numerous areas for further research and development identified. One of the possible areas of interest is the impact of using this mixture on the strength and deformation characteristics of embankments in repose conditions. Another area is the material's durability under varying weather conditions, and third is the study of the material's behavior at elevated temperatures to establish its suitability for use in hot climate areas. Finally, a detailed study is recommended for quality control protocols to ensure the consistency of the mixture.  
  
Conclusion:  
  
The stone dust-fly ash-lime mix appears to be a sustainable and environmentally friendly alternative to traditional subgrade materials for infrastructure projects. It has several potential applications and offers a promising solution to the unsustainability problem surrounding natural resources utilization. However, more research is necessary to improve the mixture's cost-effectiveness, consistency, strength and deformation characteristics, durability and establish quality control protocols to ensure its effectiveness.

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