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In-situ Fine Basalt Soil Reinforced by Cement Combined with Additive DZ33 to Construct Rural Roads in Gia Lai Province, Vietnam

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ABSTRACT

Today, the use of additives to enhance the load-bearing capacity of the soil has been applied to some rural roads in a number of provinces in Viet Nam, proving the outstanding advantages. This paper presents the results of research work and techno-application to rural road construction with on-spot fine basalt soil combined with adhesives including cement PCB40 and additive DZ33. The experimental results show that additive DZ33 has made it possible to increase the hydration ability with cement when effectively reacting with soil particles to reduce construction costs and environmental harms, improve the intensity of reinforced soil mix such as Elastic modulus of reinforced soil (E_s), splitting tensile strength (f'_{st}), compressive strength (f'_s) and California Bearing Ratio (CBR). Successful application of additive DZ33 combined with cement in soil reinforcement to build rural transport works not only brings about economic efficiency but also, makes use of in-situ fine basalt soil to create a new material for the construction industry, humbly contributing to the study of rural road development in Gia Lai mountainous province in particular and Vietnamese transport infrastructures in general.

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1. INTRODUCTION

Towards creating materials that reduce construction costs and environmental harms, there have been researches using natural pozzolan to strengthen the soil. This topic has been successfully studied and applied in the world. Some researchers have fruitfully studied the use of natural pozzolan combined with lime to reinforce weak clay, cohesive soil, etc. For instance, Harichane et al. [1], Harichane et al. [2], Harichane et al. [3], Malisa et al. [4], Al-Swaidani et al. [5], Mfinanga et al. (2008) [6] conducted experiments to find out the proper ratio of mixing natural pozzolan and lime with the soil for building foundation and pavement. The study result was soil mixed with 10-30% pozzolan (by weight) and 2% lime. Gypsum if added will significantly increase the compressive strength. Sharpe et al. [7] made a report on the use of natural puzolan for building the low strength roadbed and pavement. Regarding the stabilized fine-grained soils, Javdanian [8] evaluated the compressive strength of fly ash and blast furnace slag based geopolymer clayey soil based on a large database and the results showed that the variation trends of the proposed UCS model are in reasonable agreement with the experimental result.

Rural roads play an important factor, constituting a high percentage of investment capital in practice of the criteria for new countryside in Viet Nam. Currently, most of the rural roads are made of cement concrete. However, the concrete road is limited by fracture due to its low compressive and tensile strength. Also, the continued exploitation and use of traditional materials will soon deplete the natural resources, affecting the environment. Using additive DZ33 to reinforce the soil is an option that contributes to reducing the total

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construction cost of the building by allowing utilization of the local materials, lessening the need for aggregate materials and decreasing the total cost of road materials in general. Additive DZ33 is commonly used in construction of roadbeds with and without pavement, roads and shoulders, public roads, temporary roads into construction works, car parks with and without pavement, works foundation, farm roads, access to mines, foundation of airport runways, rural roads, and wherever technical improvement of road materials is in need. Additive DZ33 is capable of changing the physical and mechanical properties of the soil, thereby reducing the elasticity and permeability, increasing compactness and the load-bearing capacity of the soil.

The study of using local materials to replace traditional materials like sand, stone, etc. to build roads is extremely necessary and of high scientific significance. In this article, the authors would like to present the experimental results on effects of the ratio between cement and additive DZ33 on the soil hardening technology, those experiments done in laboratory and the practical application in a rural road section in Pleiop village, Hoa Lu ward, Pleiku city, Gia Lai province, Viet Nam.

2. MATERIALS USED

2. 1. Portland Cement Blended

Portland cement Blended (Cement PCB) is commercially manufactured in Viet Nam. Cement PCB of grade 40 was used as a binder in this study. The specific gravity is 3.10 and specific surface area is 3550 cm^2/g [9]. The chemical composition and basic physical properties of cement are presented in Tables 1 and 2, respectively.

TABLE 1. Chemical composition of cement PCB 40

Component	Cement PCB (in weight %)
C_3S	52.19
C_2S	29.37
C_3A	6.36
C_4AF	10.62

TABLE 2. Physical properties of PCB

Component	Unit	Cement PCB
Specific gravity	g/cm^3	3.10
Fineness	(cm^2/g)	3550
Loss on ignition	(%)	0.90
Insolubility	(%)	0.10
Alkali content	(%)	0.54
Initial setting time	(min.)	142
Final setting time	(min.)	400

2. 2. Mechanism for Forming the Strength of Cement-reinforced Soil

Chemical process: This is the hydration process of cement particles, the ion exchange process of the double electric layer of clay and ions in the environment to make clay hard with a crystalline structure. The equation for the reaction is as follows:

$$SiO_2 + xCa(OH)_2 + nH_2O \rightarrow xCaOSiO_2(n+1)H_2O \tag{1}$$

$$Al_2O_3 + xCa(OH)_2 + nH_2O \rightarrow xCaOAl_2O_3(n+1)H_2O \tag{2}$$

The silicate calcification process and the aluminate calcification process above are very important in soil reinforcement, creating the crystalline structure for the soil and also enabling the particles in the soil to well bind. These processes slowly occur in the reinforced soil, hence cement, lime or fly ash must be well compacted and retain the best moisture for a given time.

Physical and chemical process: This is the process of exchanging ions between clay and ions in the environment, the absorption of molecules of substances from the liquids on the surface separating the phases, the coagulation of clay particles and colloidal particles, which creates stronger and more solid soil.

Physicochemical and mechanical process: Loosening the soil plays an important role to create gradation between soil, cement, lime or fly ash in the condition of compacting at the best moisture_ the smaller the soil particle, the more the particle surface is exposed to the binders, which increases linkability, thereby enhancing compaction and stability of the reinforced soil. Therefore, construction equipment that well loosens the soil plays a key role in the effectiveness of the reinforced soil.

2. 3. Additive DZ33

Additive DZ33 was supplied by MTV New Technology Application and Tourism Ltd Company (Newtatco), Vietnam. Additive DZ33 is a multi-Enzyme product specially developed as an effective aid to the workability, mix-ability, binding and compaction of soil. Also, additive DZ33 significantly improved stability in construction of roads and other infrastructure constructions. Especially, DZ33 has ionic actions, which bind dust particles together and cause dust-free environment. The physical and chemical properties are not provided by supplier due to a commercial and exclusive product.

Presence of additive DZ33 in the cement and soil mix enables water to penetrate farther into the cement particle core, which makes the reaction process of minerals C_3S and C_2S more thorough. During the reaction process, crystal lattices will be formed. These crystals penetrate and grow in the soil pores, which reduces permeability and increases intensity of the soil-cement mix. Pore reduction by increasing the number of structural crystals will increase the compressive strength, elasticity and destruction resistance of the reinforced soil.

2. 4. Principle of Strength Formation in Reinforcing Basalt by Cement Combined with Additive DZ33 The working mechanism of additive DZ33 consists of the following steps [10].

3. CONSTRUCTION OF RURAL ROADS WHIT IN-SITU BASALT REINFORCED BY ADDITIVE DZ33

3. 1. Introduction of the Works The road of Pleiop village, Hoa Lu ward, Pleiku city, Gia Lai province, Viet Nam has a cross-section of 3 meters and a total length of 1100 meters. The current state of the road pavement is seriously deteriorating, so transportation activities in the area face many difficulties.

3. 2. Content of the Experiment The experimental samples must meet the requirements for eliminating rough errors. Therefore, the uniformity, sample height, sample maintenance, and casting pattern were followed by the Vietnamese standard. Generally, the performance was carried out in principle:

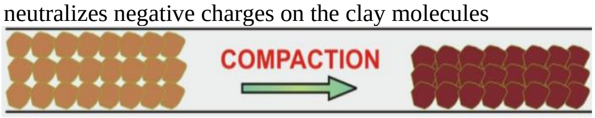
- Each group consists of 06 samples;
- Samples were cast on the automatic compactor;
- Test results were tested at curing age of 7, 14 and 28 days in two curing conditions: Moisturizing and water saturation. The specimens firstly were cured at room temperature and above 80% relative humidity for hydration to take place. For moisturizing condition, samples were tested after reaching sufficient days of moisturizing for moisturizing. For water saturation, samples were tested after reaching sufficient days of moisturizing and being soaked continuously for 48 hours. Survey criteria were tested as:

+ Elastic modulus E_s, (MPa);
+ Compressive strength R_n, (MPa);
+ Splitting strength f'_{st}, (MPa);
+ California bearing capacity, CBR, (%).

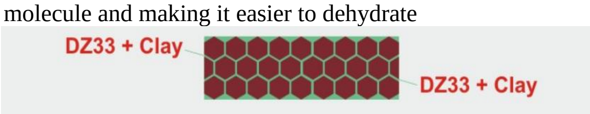
- The cement content varied from 6%, 8% and 10%, respectively, by the dry soil weight. Additive DZ33 was mixed with water, performed at the moisturizing step to enable the reinforced soil mix to achieve the optimum moisture of W_{DZ33}. The mixing ratio is 1 liter of DZ33 for 30m^3 of compacted soil. This is also the recommended dosage according to the guidance of supplier. When experimenting, all samples had control samples for comparison. The reinforced soil was cast as survey samples in two forms:

+ Form 1: Reinforced basalt (cement + DZ33);
+ Form 2: Cement-reinforced basalt as reference sample.

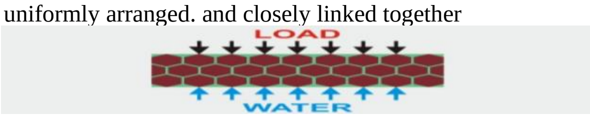
Step 1. DZ33 introduces organic cations into the soil and neutralizes negative charges on the clay molecules



Step 2. The ionic reaction occurs by the participation of DZ33, weakening the molecular bonds between the naturally formed water film layer that envelops the clay molecule and making it easier to dehydrate



Step 3. Through the compaction process, the 'polymerization' between the soil molecules appears, pushing water and gas molecules present in the soil out, allowing the soil molecules reinforced with DZ33 to be uniformly arranged. and closely linked together



Step 4. Multilateral bonding of the soil molecules forms a strong solid structure, greatly improving the load-bearing capacity and permeability coefficient of the material

3. 3. Experimenting Methods Within the study scope, the researchers aim to use basalt in pavement construction, so first of all, it is necessary to test the physical and mechanical properties of the local basalt, including the particle composition test by TCVN 4198:1995 [11], the plasticity index by TCVN 4197:1995 [12], the load-bearing capacity index CBR by ASTM D1883-16 [13], the standard compaction to determine the maximum dry unit weight and optimum moisture content by 22 TCN 59-84 [14].

3. 4. Experiment Results

3. 4. 1. Physical Mechanical Properties of Basalt Soil The fundamental physical properties of basalt in the western region, southwest of Gia Lai Province, Viet Nam,are illustrated in Item 3.5 for the selected section of Pleiop village road, Hoa Lu ward, Pleiku city, Gia Lai province, Viet Nam. The soil sample is dark brown as shown in Figure 1.

Figure 1. Basalt soil sample

* The tested properties of basalt soil are collected as follows.

+ Maximum dry unit weight: γ_{kmax} = 1.371 g/cm^3;
+ Optimum water content: W_{opt} = 30.52 %;
+ Liquid limit: W_L = 64.20 %;
+ Plastic limit: W_P = 40.64 %;
+ Plasticity index: I_p = 23.56;
+ CBR index at compact K = 0.98, CBR = 13.924 %;
+ CBR index at compact K = 0.95, CBR = 11.125 %;
+ Natural moisture: W = 31.47 %.

3. 4. 2. Elastic Modulus of the Reinforced Soil Es (MPa) The reinforced basalt (cement+DZ33) gains E_s increasing by 6%, 8% and 10% cement in both states of moisturizing and water saturation, illustrated in Figures 2-4.

*** Remarks:** The control basalt soil reinforced with 6%, 8% and 10% cement, all yield lower elastic modulus than the reinforced soil with cement + DZ33. In detail,

+ 22.90% lower in the sample reinforced with 6% cement, moisturizing on curing age of 28 days, 26.15% lower in the saturated sample;
+ 20.86% lower in the sample reinforced with 8% cement, moisturizing on curing age of 28 days, 25.61% lower in the saturated sample;
+ 20.31% lower in the sample reinforced with 10% cement, moisturizing on curing age of 28 days, 19.61% lower in the saturated sample. Looking the data presented in Figures 3-4, an increase in elastic modulus with adding additive DZ33 was to be found. The results also can be explained by the mechanism of additive DZ33 as presented in previous part and be described in the guidance of supplier.

Figure 2. Elastic modulus test apparatus

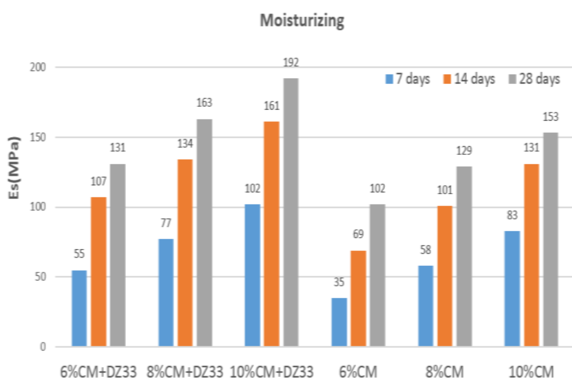


Figure 3. Elastic modulus of moisturizing sample

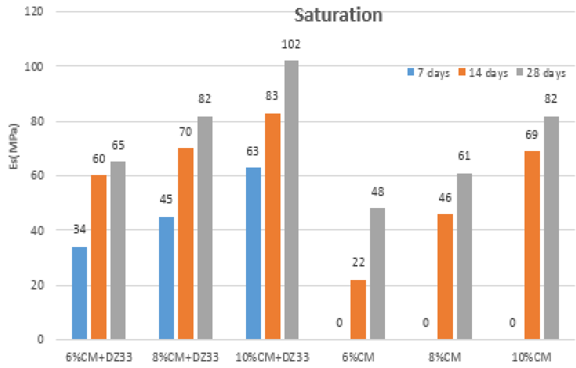


Figure 4. Elastic modulus of saturation sample

3. 4. 3. Splitting Strength of the Reinforced Soil f'st (MPa) This is an important norm of reinforced materials, indicating the ability to resist structural cracking of the road background in unfavorable conditions. There is forced basalt (cement+DZ33) gains f'st (MPa) increasing by 6%, 8% and 10% cement in both states of moisturizing and water saturation, illustrated in Figure 5 as experimental test setup and in Figures 6-7 as obtained results.

*** Remarks:** The control basaltic soil reinforced with 6%, 8% and 10% cement, all yield lower splitting strength than the reinforced soil with cement + DZ33. In detail,

+ 20.60% lower in the sample reinforced with 6% cement, moisturizing on Day 28, 29.71% lower in the saturated sample;
+ 17.15% lower in the sample reinforced with 8% cement, moisturizing on Day 28, 39.94% lower in the saturated sample;

Figure 5. Splitting test apparatus

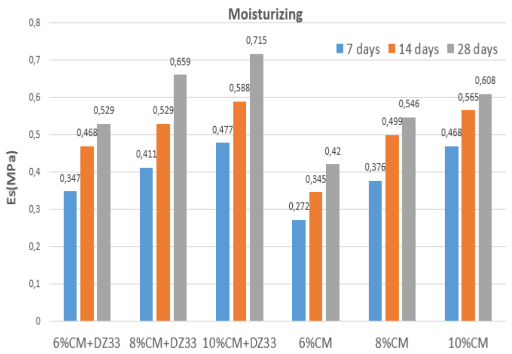


Figure 6. Splitting strength of moisturizing sample

Figure 8. Compressive strength test apparatus

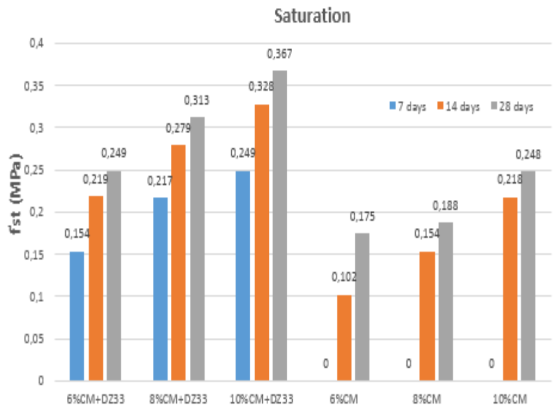


Figure 7. Splitting strength of saturation sample

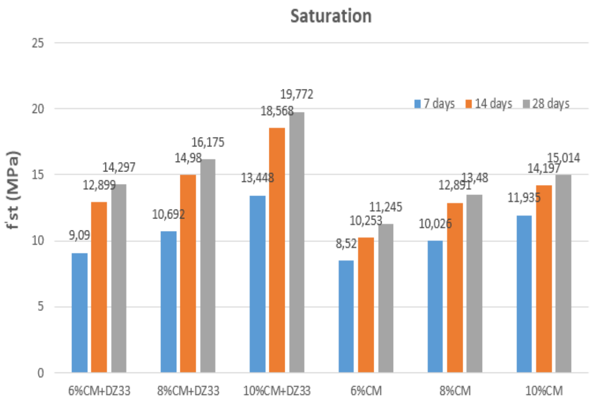


Figure 9. Compressive strength of moisturizing sample

+ 14.96% lower in the sample reinforced with 10% cement, moisturizing on Day 28, 32.43% lower in the saturated sample.

3. 4. 4. Compressive Strength of the Reinforced Soil f'$_{st}$ (Mpa) The reinforced basalt (cement+DZ33) gains f'$_{st}$ (MPa) increasing by 6%, 8% and 10% cement in both states of moisturizing and water saturation, illustrated in Figure 8 as experimental test setup and in Figures 9-10 as obtained results.

*** Remarks:** The control basaltic soil reinforced with 6%, 8% and 10% cement, all yield lower compressive strength than the reinforced soil with cement + DZ33. In detail,

+ 21.34% lower in the sample reinforced with 6% cement, moisturizing on day 28, 38.48% lower in the saturated sample;

+ 16.66% lower in the sample reinforced with 8% cement, moisturizing on day 28, 30.22% lower in the saturated sample;

+ 24.06% lower in the sample reinforced with 10% cement, moisturizing on day 28, 38.80% lower in the saturated sample. As seen in Figures 9-10, adding

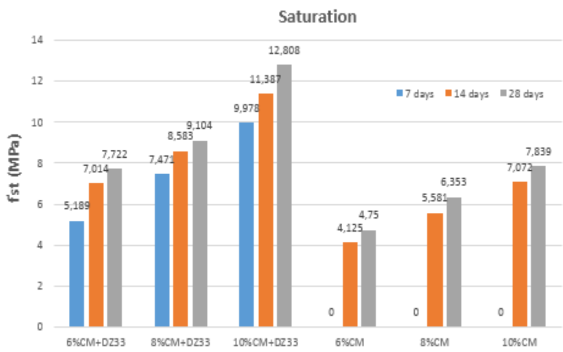


Figure 10. Compressive strength of saturation sample

additive DZ33 increased the compressive strength of the reinforced soil. This phenomenon can be explained by the way that the additive DZ33 allowed soil materials to become more easily wet and more densely compacted. Also, it improved the chemical bonding that helped to link the soil particles together and created a more permanent structure which increased the compressive strength of reinforced soil.

3. 4. 5. Load-bearing Index CBR The test on the in-situ soil reinforced with 6% cement + DZ33 15cm thick in the subbase clearly shows improved effectiveness and enhanced load-bearing capacity of the substrate via CBR index. Test equipments are shown in Figure 11. The results were obtained as at compaction of K=0.98 with CBR=13.924 %, increasing to 23.37%; at a compaction K=0.95 with CBR=11.125 %, increasing to 17.72%. This finding is the same tendency with the research of Tolleson et al. [15] who studied the Enzyme Catalyst and indicated that CBR significantly increased with adding this Enzyme to the soil. This process is probably involved providing a surface for materials in the soil, which in this case is the enzyme, onto which they can easily be adsorbed, brought into closer proximity of each other and hence bind more easily.

Figure 11. CBR test apparatus

3. 5. Application in Rural Road Reinforcement

The road Pleiop village, Hoa Lu ward, Pleiku city, Gia Lai province, Viet Nam is calculated for the single axle of 10 tons and the traffic flow in 24 hours on a single lane is not high. Elastic modulus is required at E_{yc}= 91 MPa for rural roads according to current Vietnamese standard. Based on the experimental data such as compressive strength, elastic modulus, CBR value, and splitting strength, a recommended pavement structure is presented as follows, as shown in Figures 12-13.

+ Surface layer: Covered with asphalt mortar, h=3cm;
+ Base layer: In-situ soil reinforced with 6% cement and DZ33, with the thickness of 12cm;
+ Subbase layer: In-situ soil reinforced with 6% cement and DZ33, with a thickness of 15cm.

In site, to investigate the strength of pavement structure, the Benkelman beam deflection test was used in this project. The general modulus of base layer was obtained in range of 90-110 MPa in the site. These results indicated that the chosen thickness of layers was satisfied the requirement of rural roads according to current Vietnamese standard. Investigating the surface in site indicated that the hardened basalt after in-situ reinforcement does not disintegrate in water, opening new possibilities for soil reinforcement with cement and DZ33. For instance,

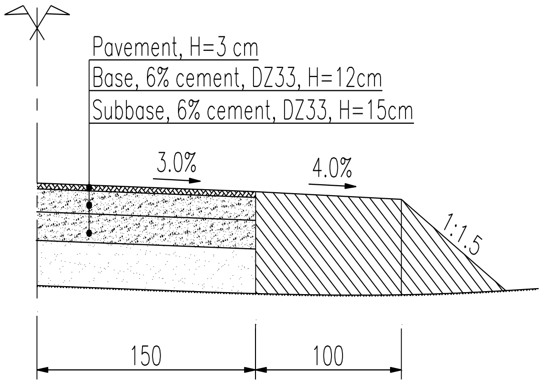


Figure 12. A half of cross-section

Figure 13. The road after covering the surface layer

+ Apart from making rural roads, such technology can be applied for construction of residential roads, green parks, parking areas, etc. ;
+ Building the foundation of national highways, provincial highways, water grooves, reinforced margins;
+ Taking advantage of local materials in some other rural areas of Vietnam's territory.

3. 6. Method of Reinforcing In-situ Fine Basalt with Cement and Additive DZ33

3. 6. 1. Ground Making

- Step 1: Levelling the Existing The soil to be reinforced for the substrate construction is required to be leveled at 3.5m wide and 15cm thick after compaction. The sponge coefficient for the soil is 1.4, illustrated in Figure 14.

- Step 2: Fine Milling the Soil to be Reinforced Using the agricultural milling machine of greater 30 horsepower for fine milling. The milling rig has a cover to ensure dust-proof and flat ground, illustrated in Figure 15.

- Step 3: Spreading Cement PCB40 String stretching to determine the boundary of the road substrate; Manual cement spreading; Weight conversion is 50 kg/bag; Allocating the bags by across and lengthwise distance, corresponding to the construction area, illustrated in Figure 16.

Figure 14. Bulldozer leveling the ground

Figure 15. Plowing machine stirring the soil

Figure 16. Spreading cement PCB40

- Step 4: Mixing Basaltic Soil with Cement PCB40 Using the agricultural milling machine to turn up cement PCB40 and the soil downward. Setting the slow milling speed for turning (2-3 turns/spot), then increasing the speed. Checking the even mixing level by taking a shovel of soil from a groove across the reinforced layer and then making comments on the color of cement PCB40 with the soil distributed on the vertical walls of that horizontal groove. Testing to determine the moisture and uniformity of cement PCB40 according to the reinforcement ratio, illustrated in Figure 17.

- Step 5: Watering with Additive DZ33 Added and Wet Mixing Determining the amount of water needed for one cubic meter of reinforced compacted soil; Preparing enough water in a truck or drum; Adding additive DZ33to water and stirring up; Also spraying and mixing up 2-3 times /spot by a milling machine; Testing the moisture content of the soil reinforced by spraying additive DZ33, illustrated in Figure 18.

- Step 6: Levelling the Surface of the Reinforced Lane Using a dump truck to re-level the reinforced lane on the vertical and horizontal slopes according to the design requirements, illustrated in Figure 19.

- Step 7: Mixed Compacting the Reinforced Soil Using a hard wheel roller or a vibrating roller of >10 tons to roll from outside to the center with the later streak overlapping 30cm the former. Rolling starts about 30 cm from the margin. The number of rolls of about12-18 times/spot meets the required compactness K. Testing to determine the compactness after rolling ($K \geq 0.95$), illustrated in Figure 20.

Figure 17. Milling machine to mix cement CB40 with basalt

Figure 18. Watering with additive DZ33 added

Figure 19. Leveling

Figure 20. Rolling

- Step 8: Stapling Stones to Create Adhesion After compaction rolling, spreading stones (2x4cm) on the reinforced lane, then using a hard wheel roller to press them into the surface for ‘sticky feet’ creation. The stone spreading area is 3.20m wide, 10cm larger than the road surface in each side, illustrated in Figure 21.

3. 6. 2. Making the Asphalt Mortar Surface

- Step 1: Making the Link Layer

+ Watering the asphalt emulsion over the surface the first time and spreading stones (1.0x2.0) cm and then well compacting the layer by a 10-ton hard wheel roller.

Figure 21. Stapling stones to create adhesion

+ Watering the asphalt emulsion over the layer the second time and spreading stones (0.5x1.0) cm and then well compacting it by a 10-ton hard wheel roller

+ The link layer should be 3.20m wide on the surface.

- Step 2: Making the Asphalt Mortar Layer

+ String stretching to determine the boundary of the road surface of 3.00m wide;

+ Making asphalt mortar of a group of aggregates, including stones (0.5x1.0) cm, dust stone and sand mixed with asphalt emulsion by a concrete mixer;

+ The formula for the mortar is adjusted corresponding to the aggregates arriving at site;

+ Placing the navigation bar and pouring the mortar mixture onto the site. Using a mortar wiper and a trowel to create flatness for the mortar mix following the navigation bar and then compacting with a vibration compactor;

+ Performing the same process, moving two navigation bars along the string that determines the boundary of the road surface to make the asphalt mortar layer.

- After the asphalt mortar layer making comes rolling for maintenance. Using a 10-ton static roller to roll about (3-5) times/spot, illustrated in Figure 22.

Figure 22. Making the asphalt mortar layer

4. CONCLUSIONS

The road surface making technology using in-situ fine basalt combined with cement + additive DZ33 soil has proved suitable for rural roads because local materials are taken advantage of. This method makes use of farm equipment and road construction machines available in the locality, so the investment costs are low, which is a good message to help localities implement the asphalt covering of rural roads, reduce the need for aggregate materials and lessen the total cost of materials for road construction.

Chemical additives used in soil reinforcement are capable of changing the physical and mechanical properties of soil, thereby reducing elasticity, permeability while increasing compactness and the load-bearing capacity of the soil.

The introduction of chemical additives soil reinforcement chemicals and their advantages as analyzed has opened up many hopes for beautiful, durable and clean rural roads, contributing to the renewal of rural appearance particularly in Pleiop village, Hoa Lu ward, Pleiku city, Gia Lai province and generally in Vietnam's territory on the motto "the State

and the people work together" in the context of extremely difficult budget capital today.

Through this study/ article, the researchers/ authors also wish that the relevant and related agencies and industries promulgate properties, unit prices, technical standards and encourage localities to widely apply the study results to contribute to completing the infrastructures at minimal costs, succeeding the cause of national industrialization and modernization, creating rich people, a powerful country and a democratic, fair and civilized society.

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Persian Abstract

چکیده

امروزه استفاده از مواد افزودنی برای افزایش ظرفیت تحمل بار خاک در برخی از راههای روستایی تعدادی از استانهای ویتنام اعمال شده است و این مزایای برجسته را اثبات می کند. در این مقاله نتایج کار تحقیقاتی و کاربردهای فنی برای ساخت جاده های روستایی با خاک ریز بازالت درجا همراه با چسب از جمله سیمان PCB40 و افزودنی DZ33 ارائه شده است. نتایج تجربی نشان می دهد که ماده افزودنی DZ33 امکان افزایش توانایی هیدراتاسیون با سیمان را در هنگام واکنش موثر با ذرات خاک برای کاهش هزینه های ساخت و ساز و آسیب های محیطی ، بهبود شدت مخلوط خاک تقویت شده مانند مدول الاستیک خاک تقویت شده فراهم کرده است. شکافتن مقاومت کششی ، مقاومت فشاری و ضریب تحمل کالیفرنیا .(CBR) استفاده موفقیت آمیز از افزودنی DZ33 همراه با سیمان در تقویت خاک برای ساخت کارهای حمل و نقل روستایی نه تنها باعث بهره وری اقتصادی می شود بلکه از خاک بازالت خوب درجا برای ایجاد ماده جدیدی برای صنعت ساخت ، فروتنانه به مطالعه توسعه جاده های روستایی در استان کوهستانی جیا لای به طور خاص و زیرساخت های حمل و نقل ویتنام به طور کلی استفاده گردید.