



Journal of Materials and Engineering Structures

Research Paper

Experimental Study of Using Paper Production Industry Waste as Soil Stabilizer for Road Construction in Vietnam

Nguyen Trong Hiep ^{a,*}, Pham Huy Khang ^a

^a University of Transport and Communications / UTC, Hanoi, Vietnam

ARTICLE INFO

Article history:

Received : 15 November 2022

Revised : 24 December 2022

Accepted : 28 December 2022

Keywords:

Soil Stabilizer

Paper Industry Waste

Construction Material

Lignosulfonate

DBS-06

ABSTRACT

The solution of using organic and inorganic chemical agents to strengthen loading capacity of soil for base, subbase or surface layers in unpaved road pavement has been applied for a long time in the world. In Vietnam, the method has been applied with conventional such as lime, cement, fly ash, or bitumen. Since the years of 2000s, the new soil stabilizers have been introduced to Vietnam. However, the price of the imported admixtures is still the barrier for practical applications. DBS-06 is a domestic lignosulfonate soil stabilizer synthesized from the paper industry waste, which was collected from the HoaBinh paper factory located in Ky Son District, HoaBinh Province. The study program was conducted to investigate the main mechanical properties of the soil specimens stabilized by DBS-06 intending for used in road construction. The test results showed that the soil treated with DBS-06 was significantly improved the strength of compression, split tensile and elastic modulus, the three critical indicators representing for load bearing capacity of the material, in both normal and water saturated conditions.

F. ASMA & H. HAMMOUM (Eds.) special issue, 4th International Conference on Sustainability in Civil Engineering ICSC2022, Hanoi, Vietnam, J. Mater. Eng. Struct. 9(4) (2022)

1 Introduction

In road construction, the use of local or in-situ materials is the most fundamental and important principle, which allows us to utilize favourable conditions to minimize construction cost. The common rule is worldwide applied not only in developing or new emerging economies, but in the developed world. The in-situ available soil is always a good material resource for pavement construction. One of the main directions for utilization of the material is to use the chemical admixtures (organic or inorganic) to improve the soil properties to increase its strength, durability, stability to satisfying the requirements for using in base, subbase or even surface courses of pavement structure [1]. Along with well-known traditional soil admixtures such as lime, cement, fly ash, bitumen, ... lignosulfonate is a lignin-based polymeric soil stabilizer, which has

* Corresponding author. Tel.: +84 0972336548.

E-mail address: nguyentronghiep@utc.edu.vn

attracted much attention from scholars due to advanced features bringing about high technical efficiency and environmental friendliness. The stabilizing mechanism of the compound is classified into the electro-chemical method in that the water existing in soil acts as carriers of chemical ions affecting the electrostatic bonding of the soil. Therefore, the admixture can break the water membrane of the clay content of the soil, then creating the convenient condition for soil hydration [2-6].

In Vietnam, some commercial soil admixtures have been introduced since the first half of the 2000s such as Con-Aid (South Africa) CONSOLID (Switzerland); Dustex (Australia), and the most well-known products were applied in small scale pilot projects. The first one is Raynolds Roadpacker 2-3-5 Special RRP-S, denoted RRP, developed from Germany. When mixed RRP, a liquid (sulfurized oil) soluble in water, soil will change the physicochemical properties. As the result, it has higher density and strength after compaction, and not being an expensive underwater effect. RRR has been applied for some rural road pilot projects in the countryside and road of the military barracks, the efficiency of the new agent is under monitoring. However, the main disadvantage of this admixture is high price, which leads to the construction cost nearly equal to that of the crushed aggregate.

The most well-known admixture is SA44/LS40, a product Dallas Roadway Products Inc., licensed by the licensed by the US Department of Transportation since 1990 and has been used in over 50 countries around the world. The advantages of SA44/LS40 over the other stabilizers presented in high strength and stability in adverse conditions of treated soil helped it to be approved by the Ministry of Transport for application. However, the high price has been the main barrier for expanding the product in practice. The domination of the compound over the other stabilizers is because of its good performance in real condition, bringing about high strength and stability in adverse conditions for treated soil.

The initial applications of using new admixtures for soil stabilization in Vietnam revealed that the stabilizers, especially SA44/LS40, can be completely used for roadway pavement construction. The current conditions of construction technology also allow the stabilizers to be widely used. However, the high price is the main barrier for expanding the product in Vietnam. Therefore, the problem is how to make use of domestic materials and favorable conditions to produce a soil admixture which has equivalent features, at a reasonable price for Vietnam conditions [7].

The soil stabilizer DBS-06 is a variation of lignosulfonatesoil stabilizer, synthesized from paper industry waste. It was developed as the applied product of the research project launched by the University of Transport and sponsored by the Ministry of Transport. The paper presents the investigation of the most important mechanical properties of soil treated with DBS-06. The test results will be compared to the limits required in current specifications of Vietnam.

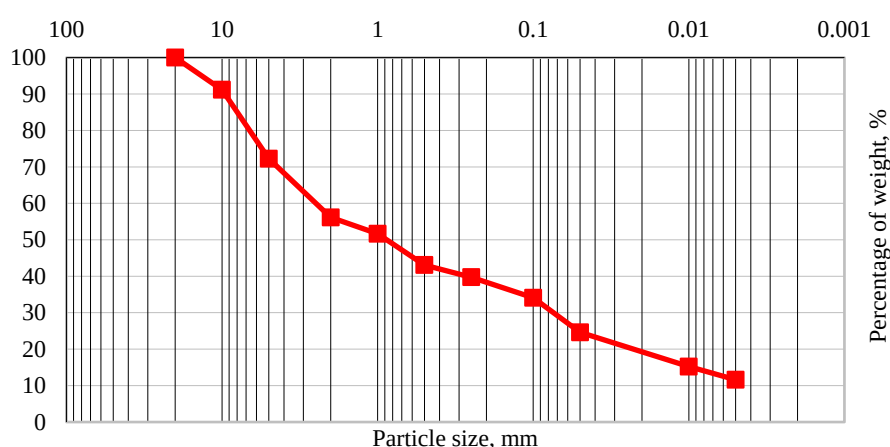


Fig. 1 – Particle size distribution of the tested soil

2 Material

2.1 Soil

The soil used for stabilizing in the experimental test is dusty clay, taken in TucTranh Commune, Phu Luong District, Thai Nguyen province, Vietnam. In order to prepare for use in experiment program, the main physical and chemical properties of the soil were test including particle size composition, liquid limit and plasticity index, organic content, pH [8].

2.1.1 Particle size analysis

The particle composition of the soil was determined according to the provisions of the current standard on the particle size analysis in the laboratory [9]. The particle size composition of the tested soil is presented in terms of accumulation percentage graph shown in Figure 1.

From the particle composition chart in Figure 1, compared with the soil classification standard, the test soil is clayey gravel and sand, classified in group A-2-5 [10].

2.1.2 Compaction

The compaction test was conducted to find out maximum dry unit weight and the optimum water content (O.M.C.) of the soil. The test was implemented following the current specification for soil compaction [11].

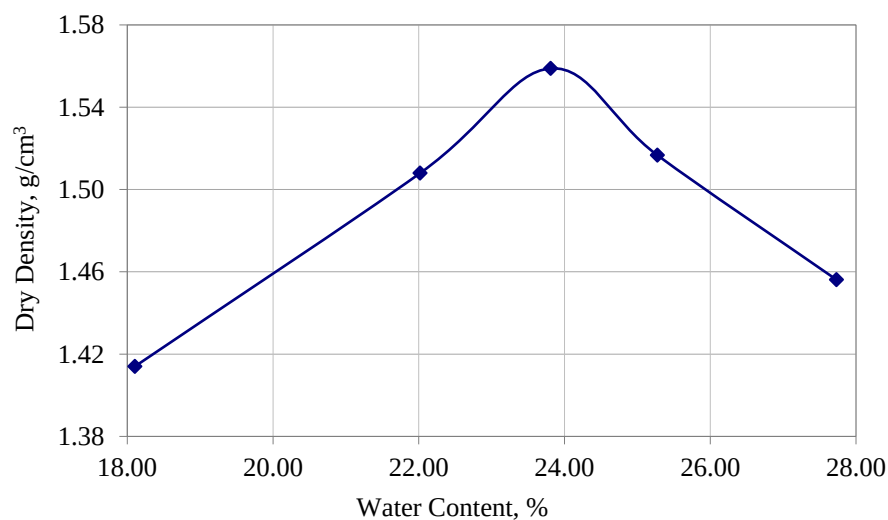


Fig. 2 – The optimum moisture content of stabilized soil

The compaction test showed that the soil has a dry density of 1.56 g/cm³, achieved at the optimum moisture content of 23.81%. The main physical and chemical properties of the soil used for the experiment are shown in Table 1.

Table 1 – Physical and chemical properties of tested soil

Characteristics	Values	Specification required
Dry density (g/cm ³)	1.56	-
Liquid limit (%)	28.5	≤ 55
Plasticity index (%)	10.3	≥ 4
Organic content (%)	8.4	
pH	3.8	

According to the requirements for soils which is recommended for stabilization with lime or chemicals, the soils met the requirements in accordance to the in force standard [8].

2.2 Lime

The lime itself was a conventional admixture utilized for soil strength improvement in road construction. In the research, it also plays the role of active gradient for admixtures DBS-06. The lime used in the experiment is powdered lime Grade 1, which is well preserved before use to prevent the reaction between lime and water existing in the air to form Ca(OH)₂. The main characteristics of lime are shown in Table 2.

Table 2 – Main characteristics of lime used in the experiment

Characteristics	Description	Specification Limits [8]
CaO and MgO content (%)	92	≥ 90
Passing Sieve 2mm (%)	100	100
Passing Sieve 0.1 (%)	85.7	≥ 80

The ratio of lime added into the mixture was determined at 4% of dry weight of soil in the whole specimens which will be used for tests.

2.3 Soil stabilizer DBS-06

The soil stabilizer DBS-06 used in the experiment was synthesized from the paper production waste of the HoaBinh Paper Factory, located in Ky Son District, HoaBinh Province. The main physical characteristics of DBS-06 is shown in Table 3 [2].

Table 3 - Main characteristics of DBS-06

DBS-06 Features	Description	Note
Color	Glossary Black	
Odor	Pungent aroma	
Density	1104 (g/l)	
pH	11-12	Adjusted

In usage, at first, DBS-06 was mixed with water at the volume ratio of DBS-06/Water be 8/100 for standard dosage. For extension dosage, the volume ratio of DBS-06/Water was 16/100. After mixed with water, DBS-06 solution would be mixed with soil. The ratio of DBS-06/Soil was 1 liter/10 kilogram.

2.4 Water

Water used to mix with DBS-06 and to add into the soil mixtures for compaction is the domestic tap water, which meets the requirements for standard of water for concrete and mortar [5].

Table 4 – Sample test design

Type of Test	Condition		Admixtures	
	Normal (Sampling)	Saturated	Lime	DBS-06
S-L	✓	✓	✓	✗
S-L-DBS06-1	✓	✓	✓	✓
S-L-DBS06-2	✓	✓	✓	✓✓

3 Experimental Program

3.1 Test program

The experimental program was designed to investigate the behavior of soils treated with stabilizer DSB-06 under laboratory conditions, according to three basic mechanical indicators commonly used to evaluate the strength and working capacity of road construction material, namely compressive strength, split compressive strength and elastic modulus. The types of samples test were grouped by: (1) Soil admixture, which is the type of stabilizer or combination of stabilizers used in sampling; (2) Dosage of DBS-06 stabilizer added into the tested soil; and (3) Conditions of tested specimen, which means

the specimens are tested at the sampling or normal maintenance condition, and fully soaked in water in 96 hours before tested as saturated condition. In this experiment program, the ages of specimens were 28-day;

The sampled soil was mixed with the fixed lime at ratio of 4% of weight for all tested specimens. Without any other stabilizer, this type of test specimen was denoted “S-L”, means soil only mixed with lime. The mechanical properties of “S-L” specimens were the benchmark indicators for other added stabilizers. The stabilizer DBS-06 was added to “S-L” soil to make the specimen with “lime and DBS-06”, which is denoted as “S-L-DBS06-1” for the standard dosage, and “S-L-DBS06-2” with double dosage. The test specimen characteristics in molding process are shown in the Table 4.

3.2 Test method

To prepare the test material mixture for experiment, first determine the test soil mass and mix it with lime at the design ratio (4% dry weight of the soil). A sufficient portion of the soil and lime mixture to be used for the “S-L” samples is kept separate. The remaining soil and lime mixture was further divided into two equal parts, and DBS-06 stabilizer was added at the specified ratios (standard dose and extension dose). The mixtures were placed in separate sealed containers to incubate for 2 hours at 25 ± 1 °C.

After incubation, the soil mixtures were used to make specimens. All test specimens were the same cylindrical in shape, made by using the modified compaction molds, which have dimensions of 152 mm in diameter and 117 mm in height. The specimen molding procedure followed the current compaction testing standards [11, 12]. The detailed experimental test indicators and corresponding specimen size, quantity and test methods are summarized and shown in Table 5.

Table 5 – Test method

Test Indicators	Specimen Size	Number of Specimens	Test Standards
Particle size Analysis	Clay soil	200 kg	TCVN 4196:2014
Compaction test	Cylinder D152, H117	5x1	TCVN 12790:2020
Compression test	Cylinder D152, H117	3x3x1	ASTM D1633
Split Tensile	Cylinder D152, H117	3x3x2	TCVN 8862:2011
Elastic Modulus	Cylinder D152, H117	3x3x2	TCVN 9843:2013

4 Result and Discussion

4.1 Compressive strength

The compression specimens were made at optimum moisture content with best dry bulk density, and then regularly maintained by moisturizing until to be tested. Specimens must be soaked in water saturation for 3 days and nights (in the first day, soaked 1/3 of the height; in the 2 days later, soaked at full height), then tested to determine the compressive strength in accordance with the method specified in relevant standard [13].

The compressive strength test results of the specimens at the age of 28-day presented in Figure 3 show that at normal condition, the strength of the specimens increases as the ratio of DBS-06 increases. The average compression strength of specimens made by soil treated with only lime “S-L” was 0.93 MPa. For the specimen made by soil, lime and standard dose of DBS-06 “S-L-DBS06-1”, the average compression strength was 1.27 MPa, 37.1% comparing to the “S-L” group. For specimens made with extension DBS-06 dose “S-L-DBS06-2”, the compression strength was 2.08 MPa, recording the increments of 124.6% comparing with “S-L” group and “S-L-DBS06-2” group. Regarding specimens at saturated condition, the corresponding compressive strength measurements of “S-L”, “S-L-BDS06-1” and “S-L-DBS06-2” were 0.68 MPa, 1.10 MPa, and 1.62 MPa, respectively. The improvements of compressive strength at saturated condition between “S-L-BDS06-1” and “S-L” was 61.2%; between “S-L-BDS06-2” and “S-L” was 138.6%, and between “S-L-BDS06-2” and “S-L” was 48.0%. Thus, the values of compressive strength of all specimen groups at saturated condition decreased in comparing to the normal condition. However, the increment tendency with the DBS-06 content was kept.

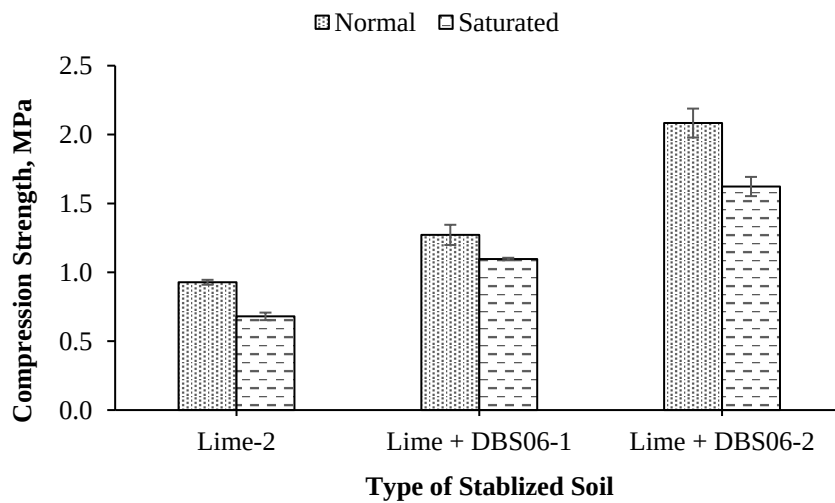


Fig. 3 – Compression Strength

4.2 Split tensile strength

The specimens for split tensile strength were also made and maintained similarly to the compression specimens, then tested to determine the split tensile strength according to the relevant standard [14].

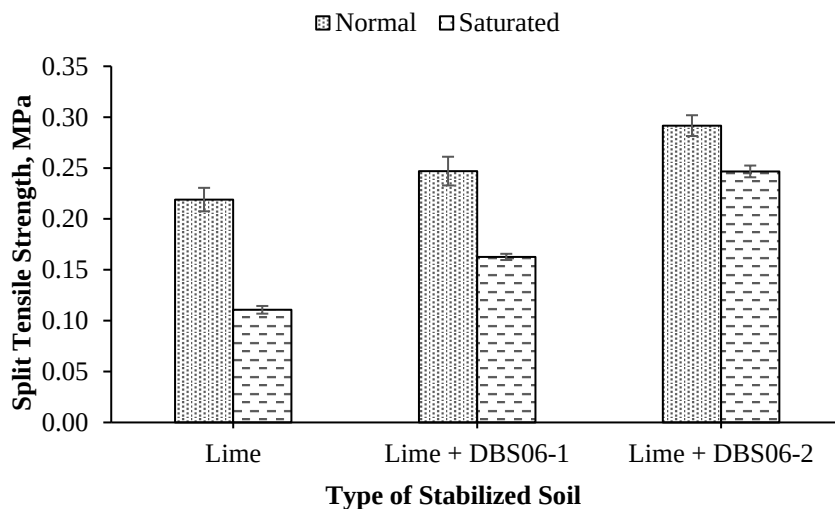


Fig. 4 – Split Tensile Strength

The split tensile strength test results at 28-day age are presented in Figure 4. The graph show that at normal condition, the strength of the specimens gradually increases while the content of DBS-06 increases. However, the gaps between split tensile at different DBS-06 ratios were minor in term of absolute values. Concretely, for the soil treated with only lime “S-L”, the split strength was 0.22 MPa, the soil with lime and standard DBS-06 dose “S-L-DBS06-1” was 0.25 MPa, and double DBS-06 dose “S-L-DBS06-2” was 0.29 MPa. The increment in term of percentage between the two groups of “S-L-DBS06-1”, “S-L-DBS06-2” and “S-L” were 12.8% and 33.2%. Regarding the groups of specimens at water saturated condition, the compressive strengths of “S-L”, “S-L-DBS06-1” and “S-L-DBS06-2” were 0.11 MPa, 0.16 MPa, and 0.25 MPa, respectively, corresponding to 47.0% and 122.9%. It means that the increasing tendency of split tensile strength of treated soil in saturated condition was kept significantly between the “without DBS-06 group” and “with DBS-06 groups”. Comparing to the specimen groups at normal condition, the split tensile indicator was declined at all DBS-06 ratios.

4.3 Elastic Modulus

The specimens for elastic modulus test has the same dimensions as for the compressive and split strength specimens. However, these were cured for 21 days and fully soaked in water for 7 days, and then tested for elastic modulus at 28-day age as specified according to relevant standard [15].

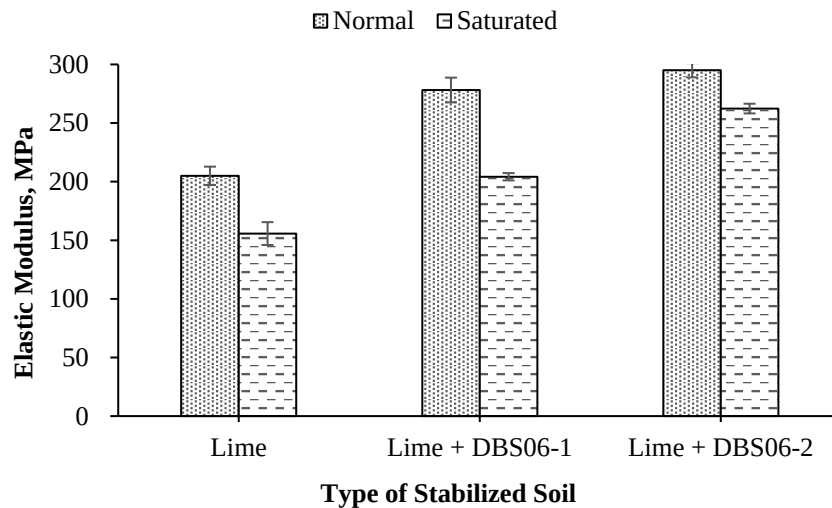


Fig. 5 – Elastic Modulus

The elastic modulus test results presented in Figure 5 show that at normal condition, the modulus of treated soil also increases as the ratio of DBS-06 increases. For the soil treated with lime “S-L” specimens, the average modulus was 204.99 MPa. For the specimens stabilized with lime and standard DSB-06 dose “S-L-DBS06-1” and lime and double dose of DSB-06 “S-L-DBS06-2” were 278.21 MPa and 295.06 MPa, respectively. Regarding the water saturated groups, the elastic modulus values of “S-L”, “S-L-DBS06-1” and “S-L-DBS06-2” were 155.71 MPa, 204.18 MPa, and 262.37 MPa, respectively. From the graph, the modulus measurements of these groups steadily increase along with DBS-06 ratios.

4.4 Discussion

According to the provisions of the current standard for soil reinforced with inorganic binders and chemicals for road works [8], the soil after stabilization with lime and admixture is evaluated and graded based on considering 3 indicators: elastic modulus, compressive strength and split tensile strength of specimens at 28-day age and water saturated conditions. For stabilized soil at Grade 1, the test values of compressive strength, split tensile strength and elastic modulus must not be less than 3.0 MPa, 1.2 MPa and 400 MPa, respectively. For Grade 2, the corresponding limits are 2.0 MPa, 0.8 MPa, and 350 MPa, respectively. For Grade 3, only required compressive strength no less than 1.0 MPa and elastic modulus not less than 200 MPa.

Comparing the test results with the corresponding regulations, it can be found that the test soil treated with only lime “S-L” did not meet the requirements to be graded at all 3 indicators. For the soil stabilized with lime and DBS-06, at both standard and strengthening dosages, the stabilized soil attained the Grade 3.

5 Conclusion and Recommendation

The study results on the characteristics of the soil treated with lignosulfonate soil stabilizer DBS-06 synthesized from paper industry waste in Vietnam show that the three critical mechanical indicators of compressive strength, split tensile and elastic modulus of the stabilized soil increases as DBS-06 content increase. The increment between “without DBS-06” and “with DBS-06” were significant for all indicators. The soil stabilizer DBS-06 can be used for stabilizing the soil in subgrade or pavement of road, airport or other transportation infrastructure constructions located in rural or shortage of traditional material areas or soft soil areas.

The lignosulfonate DBS-06 soil admixture is an advanced and environmentally-friendly stabilizer, which can be produced domestically and at a reasonable production cost. Therefore, it can contribute to reduce construction costs, ensuring ecological safety for surrounding the construction sites. It also helps to reduce the chemical pollution situation at industrial paper factories.

The study can be expanded by It is necessary to continue to study and experiment with soils with different soils in different regions to assess the scope of application in different areas in Vietnam. Along with research activities, the development of legal corridors such as technical specifications, construction norms should be implemented to promote the application of DBS-06 on large scale projects.

REFERENCES

- [1]- N. Q. Chieu, P.H. Khang, Highway Pavement Construction. 2nd ed. Hanoi: Transport Publishing House, 2006.
- [2]- M.Y. Trushinskii, Electrochemical soil stabilization method. *Soil Mechanics and Foundation Engineering*, 30(2) (1993) 61-65. doi:10.1007/BF01782910.
- [3]- J. Vinod, M.A. Mahamud, B. Indraratna. Elastic modules of soils treated with lignosulfonate. in *Conference on Geomechanics: Ground Engineering in a Changing World*. Australia: Engineers Australia. (2012), 487-492.
- [4]- J.S. Vinod, B. Indraratna, M.A.A. Mahamud, Stabilisation of an erodible soil using a chemical admixture. *Proceedings of the Institution of Civil Engineers - Ground Improvement*, 163(1) (2010) 43-51. doi:10.1680/grim.2010.163.1.43.
- [5]- A.D. Pere, V.J. S, I. Buddhima, H. Ana, Potential use of lignosulfonate for expansive soil stabilisation. *Environmental Geotechnics*, 6(7) (2019) 480-488. doi:10.1680/jenge.17.00051.
- [6]- R. Vaiana, C. Oliviero Rossi, G. Perri, An Eco-Sustainable Stabilization of Clayey Road Subgrades by Lignin Treatment: An Overview and a Comparative Experimental Investigation. *Applied Sciences*, 11(24) (2021) 11720. doi:10.3390/app112411720.
- [7]- P.H. Khang, Research on using construction waste in Hanoi for base and surface courses of road pavement. *Research Project, Final Report*. (2003).
- [8]- TCVN, 10379:2014, Soils stabilized with inorganic adhesive substances, chemical agent or reinforced composite for road construction - Construction and quality control, Ministry of Science and Technology Vietnam. (2014).
- [9]- TCVN, 4198:2014, Soils – Laboratory methods for particle - size analysis, Ministry of Science and Technology Vietnam. (2014).
- [10]- A. M145-91, Standard Specification for Classification of soils and Soil Aggregate Mixtures for Highway Construction Purpose, American Association of State Highway and Transportation Officials Washington, DC. (1995).
- [11]- TCVN, 12790:2020, Soils, Aggregate Mixtures for Transport Infrastructure – Proctor Compaction Test, Ministry of Science and Technology Vietnam. (2020).
- [12]- TCVN, 4506:2012, Water for concrete and mortar - Technical specification, Ministry of Science and Technology Vietnam. (2012).
- [13]- ASTM, D1633, Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders, ASTM International West Conshohocken, USA. (2000).
- [14]- TCVN, 8862:2011, Standard test method for splitting tensile strength of aggregate material bonded by adhesive binders, Ministry of Science and Technology Vietnam. (2011).
- [15]- TCVN, 9843:2013, Standard test method in the laboratory for resilient modulus of nonorganic adhesive substance stabilized aggregate material, Ministry of Science and Technology Vietnam. (2013).