MINISTRY OF EDUCATION AND TRAINING
UNIVERSITY OF TRANSPORT AND COMMUNICATIONS

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RESEARCH ON SOME MAIN PROPERTIES OF FLY ASH BASED- GEOPOLYMER CONCRETE USING TOTALLY STEEL SLAG AGGREGATE IN CONSTRUCTION OF HIGHWAY PAVEMENT IN VIETNAM

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INTRODUCTION

1. Research background

As the development of construction industry, the demand for aggregates increases. However, at the same time, the natural aggregate resource is becoming scarce. Thus, the use of artificial materials to replace natural mineral aggregates is an inevitable trend. Obviuosly, industrial waste rises significantly leading to many environmental issue in the case of not being properly treatet. In Vietnam, for example, an estimated 1.5 million tons of steel slag is discharged and mainly landfilled each year. It wastes land, resources, energy, pollutes the environment and is harmful to human health due to its high heavy metal content. With some outstanding properties such as sharp, angular, roughness, large porosity, rough surface can be interlocked, high stability if be well compacted; low organic component and flatten particles, high abrasion and compression, steel slag (waste of the steel making process) can be used as a substitute for crushed stone aggregate. In the world, steel slag has been studied and used as the aggregate of hot mixed asphalt concrete (HMA) in the highway construction in many countries such as the US, Russia, China ... However, steel slag is less used as aggregate in cement concrete (OPC). Because many studies show that the hydration process causes volume expansion for concrete using steel slag aggregate [49].

Geopolymer concrete (GPC) is considered as a new material friendly to the environment due to the utility of fly ash (waste from thermal power plants) and without cement. GPC has the potential for construction applications in the future due to its outstanding advantages, such as high strength, good corrosion resistance, high thermal stability, low shrinkage and magnetization ... [40, 45, 46] . According to the research results of Ashadi H.W [68], Nitendra Palanka [83], M.S.H. Khan [77] has shown that in geopolymer concrete strength development process is polymerization of inorganic compounds in which is less chemical reaction between CaO and metal oxide causing volume expansion. Therefore, steel slag can be used as a substitute for aggregate of traditional crushed stone and sand. This minimizes the environmental impacts from the river sand and crushed stone exploitation process (avoid erosion of river bank, quarry blasting ...), also effectively use of industrial waste to reduce environmental pollution. GPC and the use of steel slag as coarse aggregate for GPC have been studied and applied in Vietnam and over the world [13, 17, 18, 25, 68, 77, 83]. However, the use of steel slag to totally replace even fine aggregate (sand) to fabricate

GPC has not been made. Therefore, the thesis "*Research on some main properties of fly ash based- geopolymer concrete using totally steel slag aggregate in construction of highway pavement in Vietnam*" is nessesary and has scientific and practical contributions.

2. Research Objective

The objective of the thesis is to study the use of steel slag as the aggregate to replace both coarse aggregate (crushed stone) and fine aggregate (sand) to produce geopolymer concrete for construction applications in general and pavement in particular, as follows:

Determining the mechanical properties and chemical-mineral composition of electric arc furnace (EAF) steel slag aggregate from Thai Nguyen iron and steel plant, and assessing the suitability of steel slag aggregate in fly ash based geoplymer concrete;

Determining of the mixture composition of fly ash based geopolymer concrete with steel slag aggregates that can be used in rigid pavement structures;

Identify and clarify main properties of fresh and rigiden fly ash based-geopolymer concrete using steel slag aggregate with specific compressive strength 25, 30, 35 MPa including: Workability, setting time, microstructure, compressive strength, flexural strength, elasticity modulus, Poisson's coefficient, abrasion, shrinkage and thermal expansion coefficient. At the same time, comparing with traditional cement concrete and fly ash based geopolymer concrete using natural aggregate.

Determining of typical rigid pavement structures using fly ash based geopolymer concrete with steel slag aggregates, applicable in Vietnam.

3. Research scope

The thesis focuses on researching some basic properties of the fresh mixture and fly ash based geopolymer concrete using aggregate of steel slag on samples prepared and conducted in the laboratory.

4. Research methodology

Combining between theoretical and experimental methods.

5. Scientific and practical contributions

Clarify the scientific basis of the combination between fly ash based geopolymer binder and steel slag aggregate through microstructure, reaction mechanism.

Analysis and clarify of the properties and composition of steel slag then propose the mixture design method of fly ash based geopolymer concrete using steel slag aggregate.

Clarify the main properties of fly ash based geopolymer concrete with steel slag aggregate to serve the design calculation and construction of highway pavement in Vietnam.

Analysis, calculating and proposing the application of several typical rigid pavement structures using fly ash geopolymer concrete with steel slag aggregate.

Contribute to the realization of the policy of saving natural resources, protecting the environment and utilizing recycled materials, contributing to the development of a new eco-friendly building material.

6. Research outline

The thesis includes Introduction, 4 chapters, conclusion, recommendation, research orientation, reference and Appendix.

Chapter 1. LITERATURE REVIEW

1.1. Fly ash based geopolymer using steel slag aggregate

Fly ash based-geopolymer concrete is an artificial stone obtained after mixed, moulded, compacted and cured from a reasonably selected mixture consisting of a fly ash based geopolymer binder, aggregate (crushed stone, and sand), activated alkali solution (including: liquid glass-Na_2SiO_3; anhydrous soda-NaOH and water). After hardening, fly ash based geopolymer concrete has properties at least similar to that of traditional concrete. Fly ash based geopolymer concrete that uses steel slag as an alternative aggregate to crushed stone and sand is called fly ash based geopolymer concrete with steel slag aggregate.

1.2. Main properties of materials in rigid pavement construction in Vietnam

Due to the working conditions, pavement concrete is directly subjected to vehicle load and environmental impact (hydrothermal process). Therefore, the concrete material applied as a surface or foundation must meet certain requirements in terms of mechanical and physical properties. In order to calculate the bearing capacity of the pavement, it is necessary to determine the following main parameters of the materials, including: Compressive strength, flexural strength, elasticity modulus, Poisson's coefficient, shrinkage, coefficient of thermal expansion (CTE), abrasion and workability.

1.3. The research results on the main properties of fly ash based geopolymer concrete using steel slag aggregate in pavement construction in Vietnam and in the world

The use of steel slag aggregate to replace the traditional crushed stone aggregates in geopolymer concrete is a relatively new issue. Geopolymer concrete using steel slag aggregate has been studied since 2014, but only in the initial research on some mechanical properties and microstructure by authors such as Ashadi HW. [68], Nitendra Palanka [83], MSH Khan [77] ... The researches of the authors only focus on the use of steel slag as a coarse aggregate to replace natural aggregates (crushed stone, gravel) in the total aggregate. Up to now, this issue is being studied continuously and has obtained certain achievements.

In Vietnam, there are some major studies on geopolymer concrete such as Dao Van Dong [13], [14], Tran Viet Hung [18], Phan Duc Hung [17], Pham Duc Thien [25] ... The authors has focused on researching and fabricating mixtures of mortar and geopolymer concrete (using crushed stone and river sand), and some of their mechanical properties. The above research results show that the mechanical properties of fly ash based geopolymer concrete are as good as OPC, but geopolymer concrete has outstanding durability under chemical and high temperature conditions. However, the study of using steel slag aggregate to replace the crushed stone and river sand in the fabrication of fly ash based geopolymer concrete is the first time in Vietnam and also over the world. This is one of the new points and contributions of this thesis.

1.4. Problem statement

In Vietnam, the source of fly ash and steel slag from coal-fired thermal power plants and steel mills has increased rapidly. However, the recycling these by-products is still very limited. Meanwhile, the demand of aggregate and concrete in the pavement construction in particular and civil construction in general grows. From the above issues, within the thesis scope, the topic will focus on solving the following 4 main problems:

Study on the mechanical and chemical properties of Thai Nguyen steel slag as the aggregate for pavement concrete;

Research on mixture design and fabrication of fly ash based geopolymer concrete using steel slag aggregate in the pavement construction in Vietnam;

Research on some basic properties of fly ash based geopolymer concrete using steel slag aggregate in calculating pavement structure in Vietnam;

Propose pavement structures using fly ash based geopolymer concrete with steel slag aggregate in Vietnam.

Chapter 2. EXPERIMENTAL STUDY ON SOME PROPERITES OF THAI NGUYEN STEEL SLAG AGGREGATE AND DESIGN MIXTURE OF FLY ASH BASED GEOPOLYMER CONCRETE USING STEEL SLAG

The experimental plan of Chapter 2 can be shown through a map as in Figure 2.1.

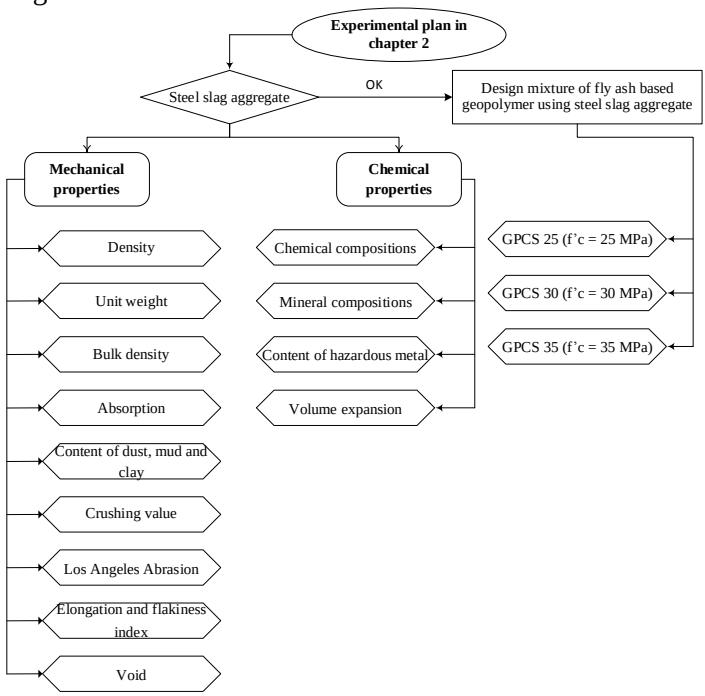


Figure 2.1. Experimental plan

2.1. Experimental study on some properites of Thai Nguyen steel slag aggregate

2.1.1. Mechanical properties of Thai Nguyen steel slag

The mechanical properties of steel slag aggregate studied are similar to some research results done in Vietnam and in the world, which completely meeting the requirements of materials to make rigid pavement according to Decision 1951-2012 [3].

2.1.2. Chemical composition of Thai Nguyen steel slag.

The steel slag's chemical composition was tested at the Institute of Chemistry (belongs to Vietnam Academy of Science and Technology) according to the XRF method. Experimental results are shown in Figure 2.7

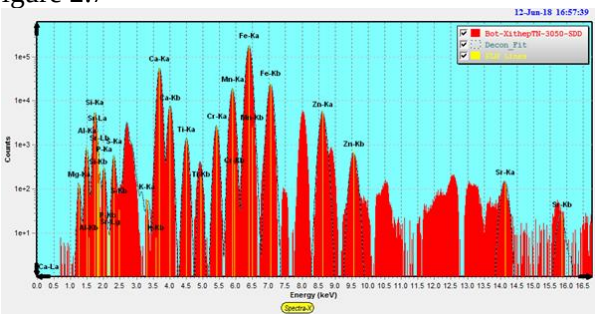


Figure 2.7. Chemical compositions of Thai Nguyen steel slag

The main chemical composition of steel slag (EAF) samples from Thai Nguyen iron and steel factory, including: CaO, SiO_2, Al_2O_3 and Fe_2O_3 accounting for 84.55% weight of steel slag, in which Fe_2O_3 (33.22%), CaO (25.26%), SiO_2 (19.94%), Al_2O_3 (6.13%).

2.1.3. Mineral composition of Thai Nguyen steel slag

The mineral composition of steel slag was tested at the Institute of Chemistry (Vietnam Academy of Science and Technology) according to the XRD method. The mineral composition analysis results are shown in Figure 2.8

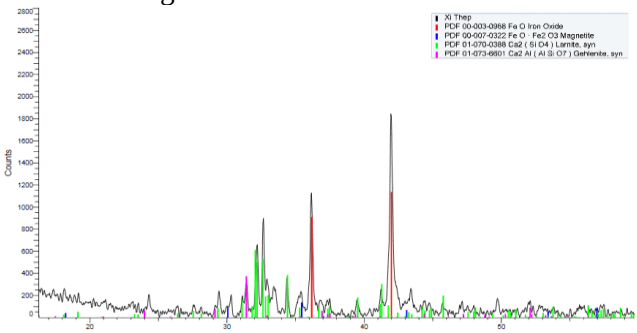


Figure 2.8. Mineral compositions of Thai Nguyen steel slag

The mineral composition of the studied steel slag samples mainly consists of two main components: Wuestite (FeO), and Larnite (Ca_2SiO_4). The highest peak in the X-ray diffraction patterns of a steel slag (EAF) sample was observed as FeO. The remaining ingredients are Magnetile ($FeO.Fe_2O_3$), Gehlanite Ca_2Al ($AlSiO_7$).

2.1.4. Content of hazardous components of Thai Nguyen steel slag aggregate

The results showed that the studied steel slag did not contain hazardous metals, or contained hazardous metals with the allowable content meeting the environmental requirements according to QCVN 07: 2009/BTNMT.

2.1.5. Study on volume expansion of Thai Nguyen steel slag aggregate

The study results showed that the volume expansion on Thai Nguyen steel slag aggregate after 7 days reached the average value of 0.198% and the specific c value of 0.2112%. These values are 0.5% less than the maximum required expansion for natural aggregates according to ASTMD4792 at 7-day age.

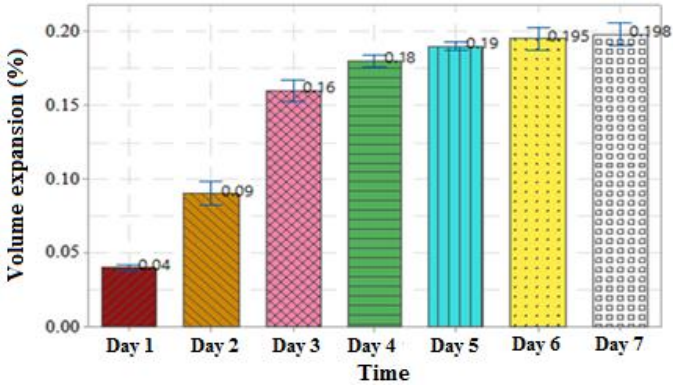


Figure 2.10. Volume expansion of steel slag with 95% confidential of mean value

2.2. Study on design mixture of fly ash geopolymer concrete using steel slag aggregate

Using design of experiment method to design mixture of fly ash based geopolymer using steel slag aggregate (GPCS).

$$Y = f(X_1, X_2, X_3) \quad (2.3)$$

Where: Y is the compressive strength GPCS at 28 days; X_1 is the molar concentration of the NaOH alkaline solution; X_2 is the mass ratio of activated alkali/fly ash (AAS/FA); X_3 is the mass ratio of the Na_2SiO_3 solution and the NaOH solution (SS/SH).

Table 2.16. Value and range of input variables

Variable	X_1	X_2	X_3
Range	$10M \le X_1 \le 14M$	$0.4 \le X_2 \le 0.5$	$2 \le X_3 \le 3$
Distance point	2M	0.05	0.5

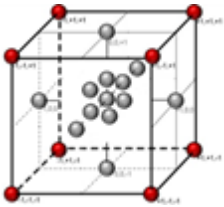


Figure 2.21. Center Composite Design model

Figure 2.22. Cylinder (150 mm by 300 mm);

The number of experimental points N = 2k + 2k + n_o = 20 (k is the number of experimental variables) with the number of experiments at center n_o = 6 is selected. Each experimental point has different values of X_1, X_2, X_3. Then it is proceed with 6 replicates. Total number of samples is 20*6 = 120 cylindrical samples with dimension of 150*300 mm.

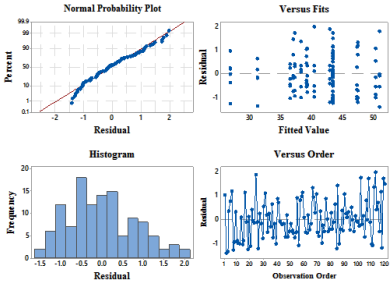


Figure 2.23. Residual assessments

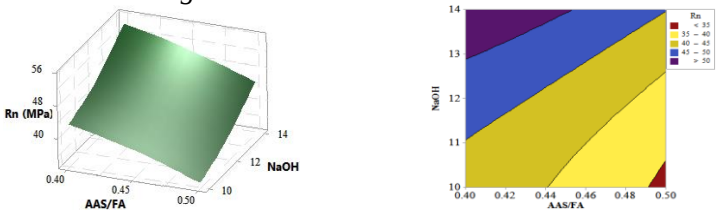


Figure 2.24. Response Surface graphs and counter lines of NaOH; AAS/FA variables and compressive strength relationships

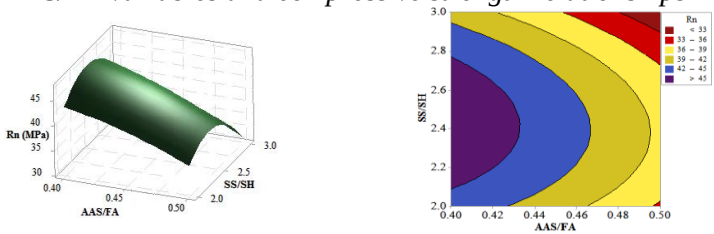


Figure 2.25. Response Surface graphs and counter lines of AAS/FA; SS/SH variables and compressive strength relationships

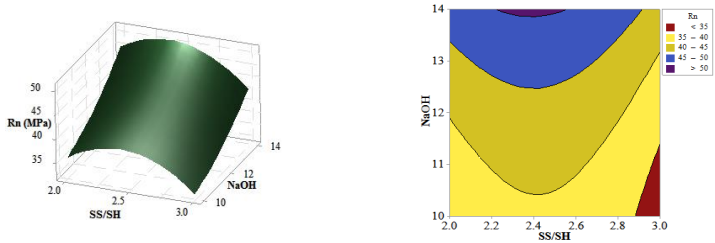


Figure 2.26. Response Surface graphs and counter lines of SS/SH; NaOH variables and compressive strength relationships

The regression equation of GPCS's compressive strength has been identified as following:

$$R_n = -103.4 - 4.6\text{NaOH} + 198.3\frac{\text{AAS}}{FA} + 110.77\frac{SS}{SH} + 0.3402(\text{NaOH})^2 - 261.7(\frac{\text{AAS}}{FA})^2 - 20.237(\frac{SS}{SH})^2$$
$$- 0.318\,\text{NaOH}\frac{SS}{SH} - 21.47\frac{\text{AAS}}{FA}\frac{SS}{SH}$$

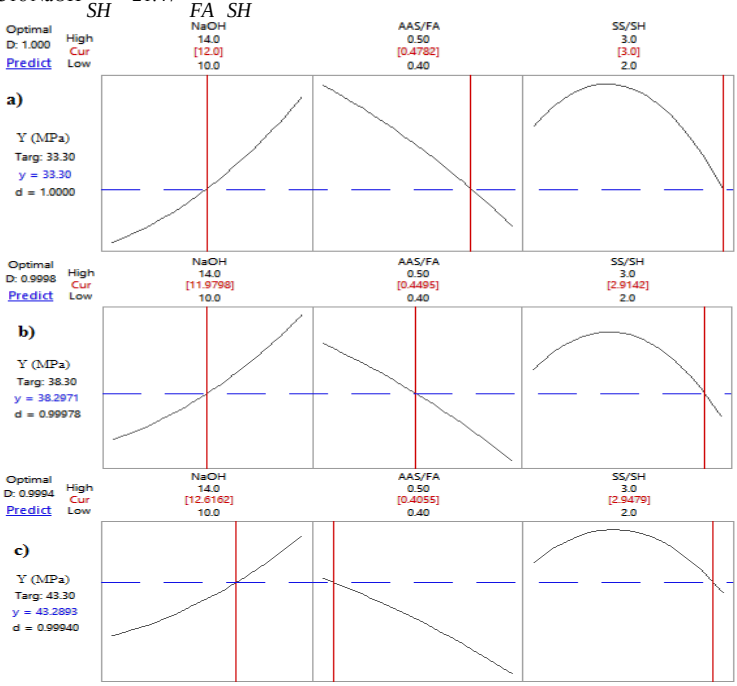


Figure 2.27. Estimated results for GPCs with the required compressive strength of 33.3 MPa (a), 38.3 MPa (b), 43.3 MPa (c)

Table 2.26. Compositions of GPCS mixtures of 25, 30, 35 MPa

GPC mixture	GPCS 25	GPCS 30	GPCS 35
Fly ash (kg)	482.34	491.89	507.29
Coarse aggregate (kg) 4.75-19 mm	1670.90	1670.90	1670.90
Fine aggregate (kg) 0.15-4.75 mm	716.10	716.10	716.10
Mass of NaOH solution (kg)	57.67	56.50	52.12
Molar concentration of NaOH	12 M	11.97 M	12.61M
Mass of Na_2SiO_3 solution (kg)	172.99	164.62	153.59
Ratio of Na_2SiO_3/NaOH	3.0	2.91	2.95
Ratio of AAS/FA	0.48	0.45	0.40

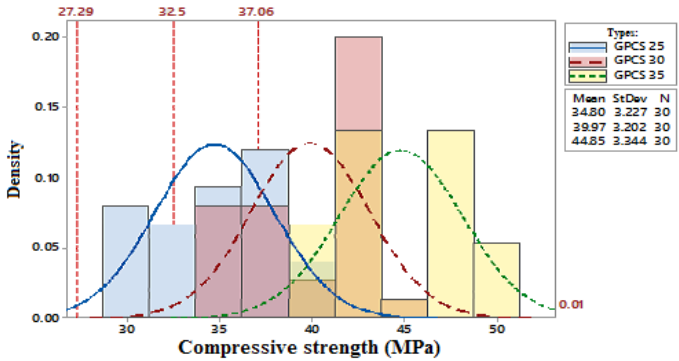


Figure 2.30. Probability density function and specific compressive strength of GPCS

The experiment results determined that the volume density of the mixture of fly ash based geopolymer with steel slag aggregate was 2990 kg/m^3 to 3133 kg/m^3. Thus, it can be confirmed that the design mixes meet the requirements of the initial selected volume desity of of 3100 kg/m^3.

2.3. Conclusion of chapter 2

The mechanical and chemical properties of Thai Nguyen steel slag aggregate are similar to some research results done domestically and internationally, completely meeting the requirements to make geopolymer concrete materials for rigid pavement according to Decision 1951-2012.

The thesis designed the mixture of fly ash based geopolymer concrete using steel slag aggregate with specific compressive strength of 25, 30, 35 MPa by design of experiment method.

The price of geopolymer concrete using steel slag aggregate is about 3% more expensive than that of OPC with the same compressive strength.

The fabrication technology of fly ash based geopolymer concrete using steel slag aggregate in the laboratory is almost similar to OPC, including using machinery, mixing, casting, compacting, moulding.

Chapter 3. LABORATORY EXPERIMENTAL STUDY ON SOME BASIC PROPERTIES OF FLY ASH BASED GEOPOLYMER CONCRETE USING STEEL SLAG AGGREGATE IN CALCULATION OF PAVEMENT STRUCTURE IN VIETNAM

3.1. Experimental plan

The experimental plan of Chapter 3 is shown in Figure 3.1.

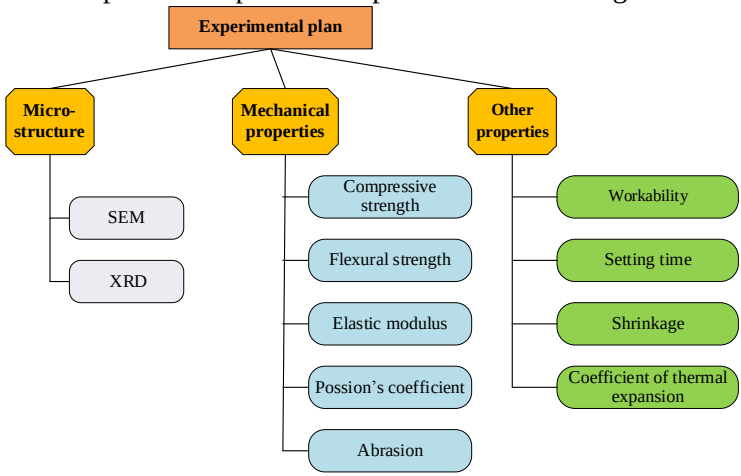


Figure 3.1. Experimental plan

3.2. Composition of the studied mixtures

Based on the research results in Chapter 2, the thesis has proposed 3 mixtures of fly ash based geopolymer concrete using steel slag aggregate with specific compressive strength of 25, 30, 35 MPa are shown in Table 2.26. These used to prepare experimental samples for the determination of major properties. The mixture compositions of the compared samples (OPCS 30, GPC 30, OPC 30) are shown in Table 3.2.

Table 3.2. Mixture compositions of comparing samples

Mixture	OPCS 30	GPC 30	OPC 30
Cement PC30 (kg)	388	-	361.45
Crushed stone- Hoa Binh (kg)	-	1256.64	1016.62
Sand - Red river (kg)	620.8	591.36	886.43
Water (kg)	175	26.30	167.92
NaOH (kg)	-	14.51	-
Na_2SiO_3 solution (kg)	-	122.45	-
Fly ash (kg)	-	388.73	-
Steel slag- coarse aggregate 4.75-19 mm (kg)	1662	-	-
Steel slag- fine aggregate 0.15-4.75 mm (kg)	-	-	-

3.3. Micro-structure of fly ash geopolymer concrete using steel slag aggregate

Small continuous cracks in the transition zone between cement and steel slag aggregate make their bond quite porous and weak.

The transition zone between gepolymer and basalt rock aggregate does not appear microcracks, but the boundary of the transition zone is quite clear. This can be seen on the surface of the basalt rock aggregate which is almost inert. It can be implied that there is no chemical interaction occurs with the component of the binder geopolymer.

No micro cracks appear and do not distinguish the scope and boundary of the transition zone between steel slag aggregate and geopolymer structure matrix.

At the same level of resolution and curing conditions, spherical fly ash particles have not yet reacted completely in the structure of geopolymer concrete samples using natural aggregates (basalt rock, natural sand). However, with fly ash based geopolymer concrete using steel slag aggregate, the fly ash particles have been geopolymerized almost completely.

For geopolymer concrete using completely steel slag aggregate, the mineralization product created is mostly Quart with the highest diffraction peak. This shows that there is a chemical interaction between the steel slag aggregate surface and the geopolymer matrix

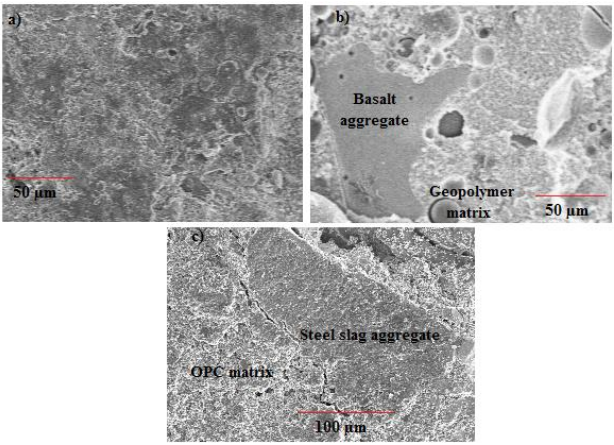


Figure 3.4. SEM micrographs at transition zone of fly ash based geopolymer concrete using steel slag aggregate- GPCS 30 (a); fly ash based geopolymer concrete using natural aggregate - GPC 30 (b); Cement concrete using steel slag as coarse aggregate - OPCS 30 (c)

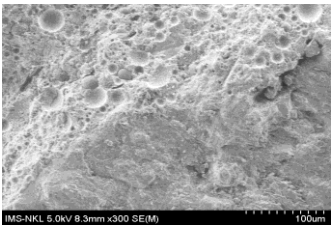


Figure 3.5. SEM result of GPC 30 sample

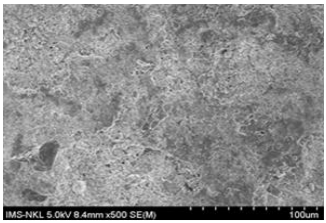


Figure 3.6. SEM result of GPCS 30

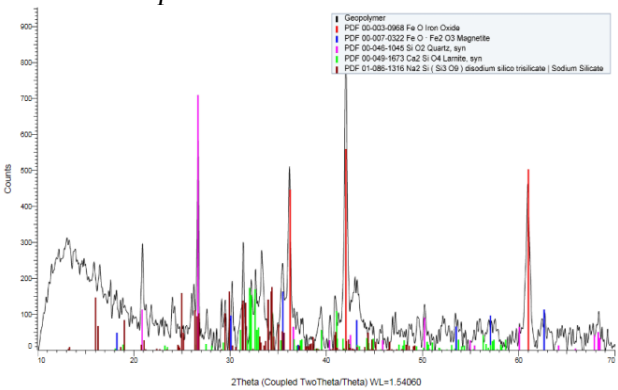


Figure 3.7. Mineral analysis result of fly ash based geopolymer concrete using steel slag aggregate by XRD

3.4. Workability

The results showed that the slump of the mixture decreased as the specific compressive strength of the mixture increased. The slump of all 3 GPCS mixtures satisfies requirements to ensure workability in pavement construction according to ACI 211.91 [43].

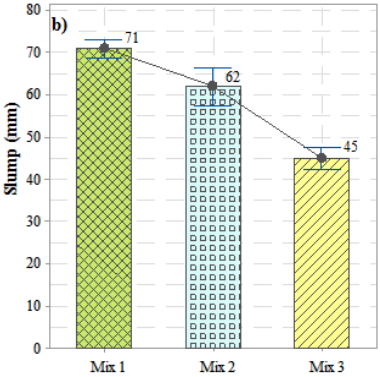


Figure 3.9. Workability results

3.5. Setting time

The results in Figure 3.12 and Table 7 (Appendix) show that the setting time (start; finish) of the mixture of fly ash based geopolymer concrete using steel slag aggregate (GPCS); using natural aggregate (GPC) and traditional concrete without using superplasticizer (OPC) are (8 hours; 15 hours), (12 hours; 43 hours), (4.5 hours; 6 hours) respectively. They are recorded from the start of wet mixing until the penetration resistance reaching 3.5 MPa; 27.6 MPa, corresponding to setting time (start; end).

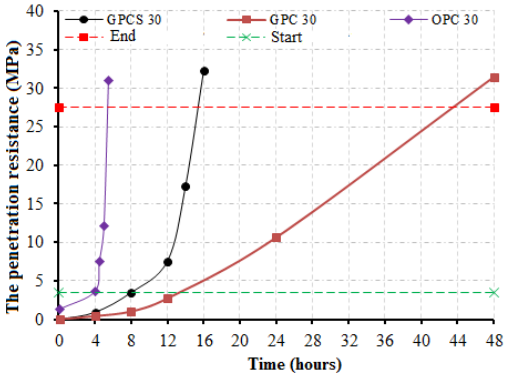


Figure 3.12. Diagram of the relationship between the penetration resistance over time of the fresh concrete mixtures

3.6. Main properties of fly ash based geopolymer concrete using steel slag aggregate

3.6.1. Compressive strength

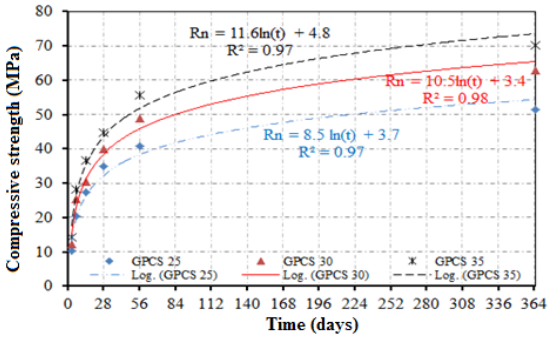


Figure 3.13. Diagram of compressive strength of GPCS over time

The regression equations of GPCS's strength over time within 365 days with the corresponding grades of 25, 30, 35 MPa are drawn as follows:

GPCS 25: $R_n = 8.5 \ln(t) + 3.7$ (MPa); $R^2 = 0.97$ (3.1)

GPCS 30: $R_n = 10.5 \ln(t) + 3.4$ (MPa); $R^2 = 0.98$ (3.2)

GPCS 35: $R_n = 11.6 \ln(t) + 4.8$ (MPa); $R^2 = 0.97$ (3.3)

In the compressive behavior, destructive forms of fly ash geopolymer concrete using steel slag aggregate at 365 days are almost the same as the standard failure forms for high-strength concrete. The cracks do not pass through transition zone and distinguise mortar and aggregate zone.

3.6.2. Flexural strength

Based on the distribution chart of the cumulative flexural strength of GPCS shown in Figure 3.20.

It can be determined the specific flexural strength of GPCS with a confidential probability of 99% for each concrete type GPCS 25, GPCS 30, GPCS 35 is 3.90 respectively; 4.35; 5.16 (MPa)

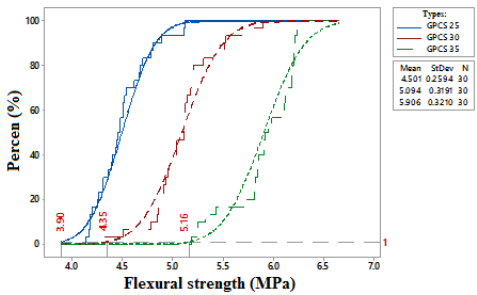


Figure 3.20. Cumulative distribution and specific flexural strength of GPCS

The comparison results in Figure 3.21 show that the flexural strength of GPCS 25, GPCS 30, GPCS 35 obtained from experiment is greater than calculated flexural strength of OPC with the same compressive strength calculated according to ACI 318 -11.

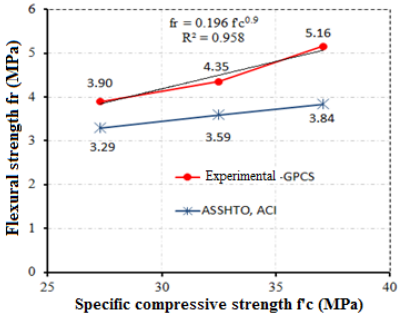


Figure 3.21. Relationship between compressive and flexural strength of GPCS

The experimental regression function of compressive strength and flexural strength of GPCS is propsed:

$$f_r = 0.196f'^{0.9}_c \text{ với } R^2 = 0.958 \qquad (3.4)$$

3.6.3. Elastic modulus and poisson coefficient

Based on the cumulative modulus distribution chart of GPCS shown in Figure 3.24, from there, the specific elastic modulus of GPCS is determined with a 99% confidential for each type of concrete GPCS 25, GPCS 30, GPCS 35 are 27.43 respectively; 28.16; 31.13 (GPa)

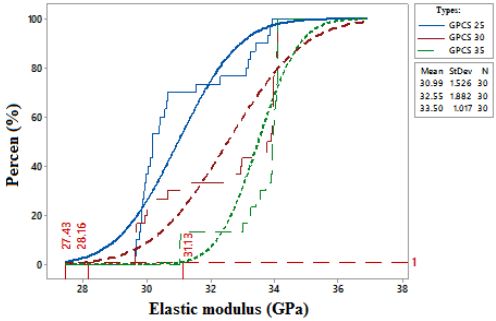


Figure 3.24. Cumulative distribution and specific elastic modulus of GPCS

The comparison results in Figure 3.25 show that the elastic modulus of GPCS has a smaller value than the elastic modulus of OPC at the same level, which is calculated according to AASHTO 2012 standard [42].

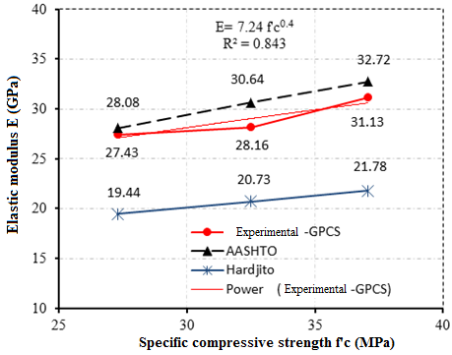


Figure 3.25. Relationship between compressive and elastic modulus of GPCS

Proposing experimental regression function of elastic modulus and compressive strength of GPCS:

$$E = 7.24\ f'^{0.4}_{c} \text{ với } R^2 = 0.843 \quad (3.9)$$

Poisson's coefficients of fly ash geopolymer concrete using steel slag aggregates corresponding to grades of 25, 30, 35 MPa are 0.177, 0.165, and 0.151 respectively.

3.6.4. Abrasion

As GPCS has a higher grade, the abrasion resistance is better. GPCS35 has the lowest abrasion value (0.11g/cm^2) while GPCS25 has the highest abrasion value of 0.19 (g/cm^2). When compared with OPC and GPC at the same specific compressive strength of 30MPa, the results show that GPCS has the highest abrasion resistance due to having the lowest abrasion value. This is also agreement consistent with some studies that have demonstrated the abrasion resistance of geopolymer material better than conventional OPC [51].

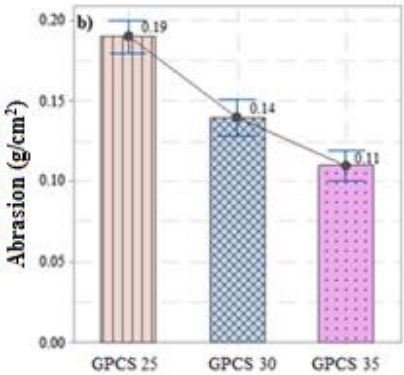


Figure 3.27. Abrasion of GPCS 25, GPCS 30, GPCS 35

3.7. Dry shrinkage

From the results in Figure 3.29, Figure 3.30 shows the change in sample length of geopolymer concrete samples including GPCS 25, GPCS 30, GPCS 35. There is not much difference among them. However, it can be seen that the general trend of the shrinkage develops strongly in the first 21 days and then gradually decreases. In addition, the results also showed that GPCS35 has a lower degree of dry shrinkage than GPCS25. From the above experimental results, the regression function (within 90 days) is proposed:

GPCS 25: $\varepsilon_t = -48.59 \ln(t) + 5.37$ với $R^2 = 0.966$ (3.12)

GPCS 30: $\varepsilon_t = -47.1 \ln(t) + 11.09$ với $R^2 = 0.961$ (3.13)

GPCS 35: $\varepsilon_t = -42.83 \ln(t) + 7.33$ với $R^2 = 0.955$ (3.14)

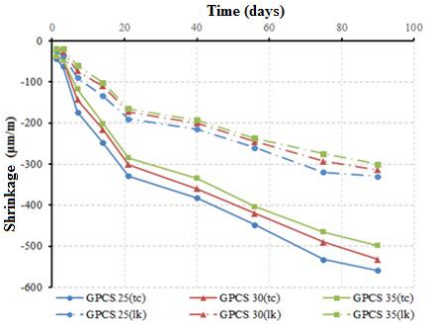


Figure 3.29. Total shrinkage and Chemical-Autogeneous shrinkage of GPCS 25, GPCS 30, GPCS 35

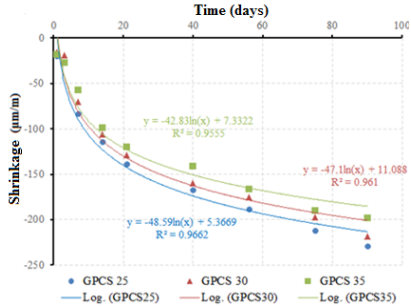


Figure 3.30. Drying shrinkage of GPCS 25, GPCS 30, GPCS 35

Where: "tc"is total shrinkage; "lk" is Chemical-Autogeneous shrinkage

The results showed that sample length changes of GPC and GPCS lower than that of OPC (Figure 3.31, Figure 3.32).

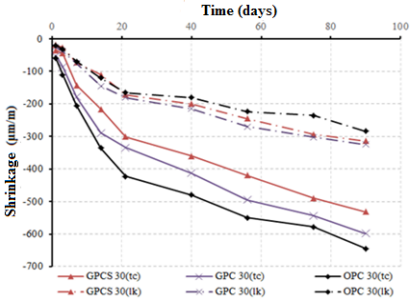


Figure 3.31. Total shrinkage and Chemical-Autogeneous shrinkage of GPCS 30, GPC 30, OPC 30

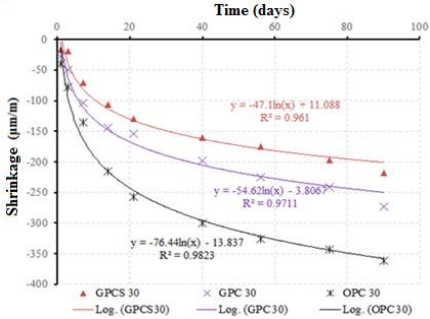


Figure 3.32. Drying shrinkage of GPCS 30, GPC 30, OPC 30

In the above experimental mixture, the 90-day dry shrinkage of GPCS30 was 218µm/m and that of GPC 30 was 273µm/m, OPC 30 was 361µm/m and the shrinkage was not completely finished. According to Neville [81], [80], [82] after three months, the shrinkage of the sample also reaches about (40 - 80)% compared with the shrinkage at 20 years old. From the above experimental results, the regression function is proposed:

OPC 30: $\varepsilon_t = -76.44 \ln(t) - 13.84$ với $R^2 = 0.982$ (3.15)

GPC 30: $\varepsilon_t = -54.62 \ln(t) - 3.807$ với $R^2 = 0.971$ (3.16)

3.8. Coefficient of thermal expansion

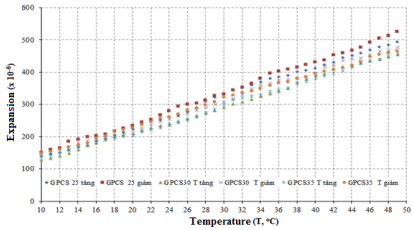


Figure 3.35. Temperature - expansion of GPCS 25, GPCS 30, GPCS 35

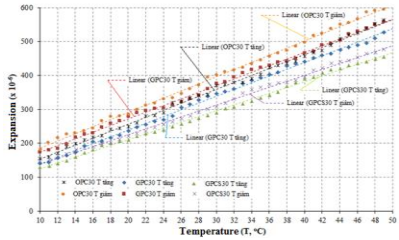


Figure 3.37. Temperature - expansion of GPCS 30, GPC 30, OPC 30

With 3 geopolymer concrete mixtures being considered including GPCS25, GPCS30, GPCS35, the CTE results are obtained in the range 8.34 to 9.53 με/°C.

CTE results of GPCS 30 using steel slag aggregate reached the lowest value of 8.65 με/°C. CTE of OPC 30 and GPC 30 using conventional aggregates were 10.42 and 9.91 με/°C, respectively. The reason may be due to the use of steel slag aggregate that reduces the expansion.

Experimental regression equation between coefficient of thermal expansion (CTE) with experimental specific compressive strength of GPCS 25; GPCS 30; GPCS 35 is shown as Equation (3-18) and Figure 3.36.

$$CTE = 40.51f'_c\text{-}0.44 \text{ with } R^2 = 0.7137 \quad (3.18)$$

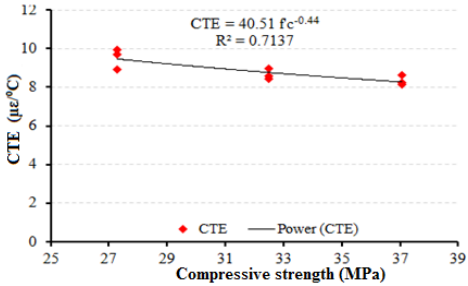


Figure 3.36. Diagram of CTE and compressive strength of GPCS

3.6. Conclusion of chapter 3

- Analysis results of SEM show that there are no transition zone between steel slag aggregate and geopolymer motar; on the contrary, there is a clear transition and micro-cracks between the cement motar and the steel slag aggregate. This can be considered as a justification for restricting the use of steel slag aggregate in the cement concrete;

• Workability of fly-ash based geopolymer concrete using steel slag aggregate to meet technical requirements for rigid pavement construction according to ACI 211.91 [43];

• Regression functions are drawn including: compressive strength over time; dry shrinkage over time, the relationship between compressive strength and flexural strength; between elastic modulus and compressive strength;

• Poisson's coefficient; abrasion; coefficient of thermal expansion (CTE); dry shrinkage of GPCS are identified and compared with OPC; GPC each other

Chapter 4. RESEARCH PROPOSAL FOR PAVEMENT STRUCTURES USING FLY ASH BASED GEOPOLYMER CONCRETE USING STEEL SLAG AGGREGATE

4.1. Overview of conventional cement concrete pavement design

Currently, there are many different methods of designing rigid pavement in the world. The methods used are suitable for the actual conditions of each country.

4.2. Overall of design, constrction and exploitation of geopolymer concrete pavement

Recentlty, many applications of geopolymer concrete for rigid pavement structures for highway, airports and harbors in the world. Construction technology of geopolymer concrete pavement mainly includes prefabricated slab and in-situ pavement. For on-site geopolymer concrete pavement, the basic construction stage is similar to that of traditional concrete.

4.3. Chosing parameters for rigid pavement

According to the 3230/QD-BGTVT for design rigid pavement structure, the main mechanical features of concrete for rigid pavement include: compressive strength, flexural strength, elastic modulus, Poisson's coefficients, the coefficient of thermal expansion. Based on the experimental results in chapters 2 and 3, it shows that geopolymer concrete can completely meet the requirements to calculate for rigid pavement structures. Reference from 3230/QD-BGTVT, and actual construction experence of rigid pavement in Vietnam, as well as research and application of geopolymer pavement in Australia, slab dimension is chosen: 5x4 (m).

In the thesis scope, a mechanical model which is a single-slab model on a multi-layer elastic foundation is selected to apply on the case of geopolymer concrete using completely steel slag aggregate as a slab set on the base layer of the steel slag (without binder). The light and

medium of traffic volume is chosen, applicable to the new pavement of grade IV or lower according to TCVN 4054: 2005 or rural pavement according to TCVN 10380: 2014.

4.4. Proposing pavement structure of fly ash based geopolymer concrete with steel slag aggreagte

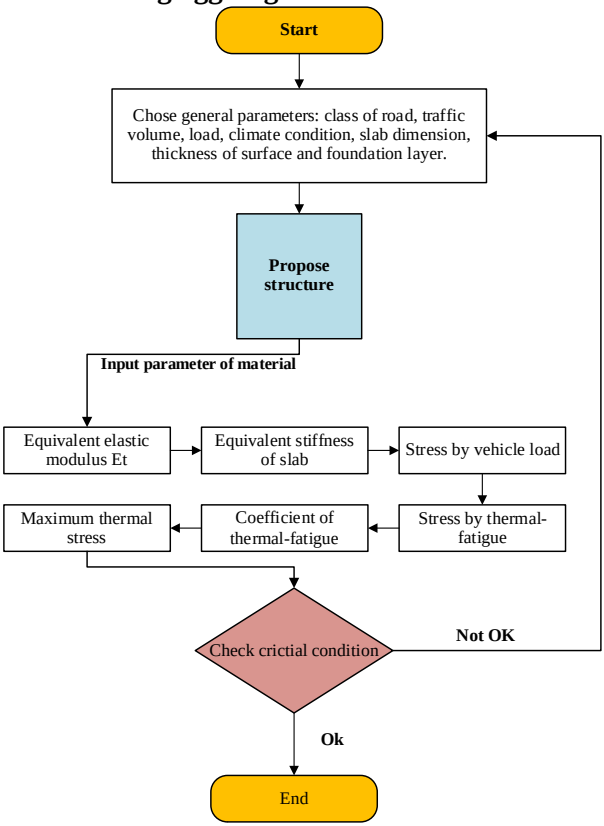
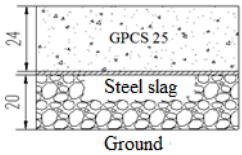
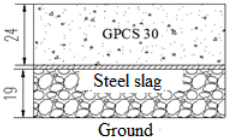
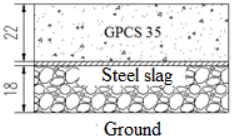


Figure 4.2. Calculating and checking of the proposed pavement structure according to the Decision 3230/QĐ-BGTVT

On the basis of experimental studies on the properties of fly ash based geopolymer concrete using steel slag aggregate combined with assumed loading conditions, foundation, weather conditions and chosen layer dimension. Typical pavement structures proposed in Table 4.5 are checked and confirmed according to Decision 3230/QD-BGTVT with the summarazie process shown as Figure 4.2. The results show that, the proposed structures satisfy the requirements of Decision 3230/QD-BGTVT (details are shown in Appendix 2).

Table 4.5. Proposed pavement structures

Structure	Parameters			Traffic volume
	Layer	**Thickness, cm**	**Describe**	
 KC1	GPCS 25	*24*	R_{ku}= 4.08 (MPa); $E_{đh}$= 28.49 (GPa); μ_c=0.197; α_c=9.53$\mu\varepsilon/^oC$ Slab dimension 4x5 m	Light < 3.10^4 to 1.10^6 (axle /lane)
	Separation layer	*1÷3*	Water-proofing geotextile	
	Steel slag	*20*	E = 248.2 (MPa);	
	Ground		E_0=40 (MPa)	
 KC2	GPCS 30	*24*	R_{ku}= 4.57 (MPa); $E_{đh}$= 29.46 (GPa); μ_c=0.184; α_c=8.65$\mu\varepsilon/^oC$ Slab dimension 4x5 m	Medium: 3.10^4 to 1.10^6 (axle /lane)
	Separation layer	*1÷3*	Water-proofing geotextile	
	Steel slag	*19*	E = 248.2 (MPa);	
	Ground		E_0=40 (MPa)	
 KC3	GPCS 35	*22*	R_{ku}= 5.38 (MPa); $E_{đh}$= 31.83 (GPa); μ_c=0.164; α_c=8.34$\mu\varepsilon/^oC$ Slab dimension 4x5 m	Medium: 3.10^4 to 1.10^6 (axle /lane)
	Separation layer	*1÷3*	Water-proofing geotextile	
	Steel slag	*18*	E = 248.2 (MPa);	
	Ground		E_0=40 (MPa)	

4.6. Conclusion of chapter 4

Three typical rigid pavement structures (KC1, KC2, KC3) using geopolymer concrete with steel slag as the surface layer and the steel slag aggregate as the foundation layer are propsed. Through the checking of selected GPCS slab on foundations for pavement road of grade IV or lower, all critical requirement are sastified according to TCVN 4054: 2005 or rural roads in accordance with TCVN 10380:

2014, corresponding to medium and light traffic volume suitable to conditions in Vietnam.

CONCLUSION AND RECOMMENDATION

1. Conclusion

Through the results of theoretical and laboratory experimental studies on some key properties of fly ash based geopolymer concrete with steel slag aggregate in the pavement construction in Vietnam, the following conclusions can be obtained:

1. Determined the mechanical and chemical properties of steel slag aggregate from Thai Nguyen iron and steel plant. The results show that steel slag meets the technical requirements to substitute for natural aggregates in the fabrication of geopolymer concrete.

2. Proposed the mixture design method of fly ash based geopolymer concrete aggregate using Thai Nguyen steel slag aggregate in the pavement construction.

3. Proposed the mixture formula for fabrication of fly ash based geopolymer concrete using Thai Nguyen steel slag aggregate with specific compressive strength of 25, 30, 35 MPa, to ensure technical requirements for pavement materials.

4. Identified and clarified the main properties of fly ash based geopolymer concrete using steel slag aggregate (GPCS), including (microstructure; workability; setting time; compressive strength; flexural strength; elastic modulus; Poisson's coefficient; abrasion; thermal shrinkage and expansion coefficient) for the calculation of design and construction of rigid pavement in Vietnam and for reference with OPC samples and GPC samples using crushed stone and natural sand, as following:

4.1. Analysis results (SEM) show that there is no transition zone between steel slag aggregate and geopolymer motar; on the contrary, there is a clear transition and micro-cracks between the cement motar and the steel slag aggregate. This can be considered as a justification for restricting the use of steel slag aggregate in the cement concrete.

4.2. Workability of fly ash based geopolymer concrete using steel slag aggregate meets technical requirements for construction of rigid pavement according to ACI 211.91 [43];

4.3. Found some experimental regression functions:

i) Compressive strength over time (within 365 days)

$$\text{GPCS 25: } R_n = 8.5 \ln(t) + 3.7 \text{ (MPa)}; R^2 = 0.97$$

$$\text{GPCS 30: } R_n = 10.5 \ln(t) + 3.4 \text{ (MPa)}; R^2 = 0.98$$

GPCS 35: $R_n = 11.6 \ln(t) + 4.8$ (MPa); $R^2 = 0.97$

ii) Relationship between compressive strength and flexural strength

$f_r = 0.196 f'_c 0.9$ where $R^2 = 0.958$

iii) Relationship between elasticity modulus and compressive strength:

$E = 7.24 f'_c 0.4$ where $R^2 = 0.843$

4.4. Poisson's coefficient of fly ash based geopolymer concrete using steel slag aggregates corresponding to grades of 25, 30, 35 MPa is 0.177, 0.165, 0.151, respectively;

4.5. The abrasion of fly ash based geopolymer concrete using steel slag aggregates corresponds to grades of 25, 30, and 35 MPa respectively 0.19; 0.14; 0.11 (g/cm^2);

4.6. Proposed a regression function of dry shrinkage over time (within 90 days) of GPCS 25, 30, 35, GPC30 and OPC30.

GPCS 25: $\varepsilon_t = -48.59 \ln(t) + 5.37$ with $R^2 = 0.966$

GPCS 30: $\varepsilon_t = -47.1 \ln(t) + 11.09$ where $R^2 = 0.961$

GPCS 35: $\varepsilon_t = -42.83 \ln(t) + 7.33$ where $R^2 = 0.955$

OPC 30: $\varepsilon_t = -76.44 \ln(t) - 13.84$ where $R^2 = 0.982$

GPC 30: $\varepsilon_t = -54.62 \ln(t) - 3.807$ where $R^2 = 0.971$

4.7. Fly ash geopolymer concrete using steel slag aggregate (GPCS) has an average thermal expansion coefficient (CTE) from (8.34 $\mu\varepsilon/^oC$ - 9.53 $\mu\varepsilon/^oC$) similar to OPC (10.42 $\mu\varepsilon/^oC$) and GPC (9.91 $\mu\varepsilon/^oC$).

5. Initially proposed 03 rigid pavement structures using fly ash based geopolymer concrete with steel slag aggregate for roads of grade IV or lower according to TCVN 4054: 2005 or rural road according to TCVN 10380: 2014, respectively for medium and light traffic volume suitable for conditions in Vietnam.

2. Research Orientation

Based on the results of the thesis, continue to research and test on a practical trial road using fly ash based geopolymer concrete with steel slag aggregate.

Study of long-term behaviors such as creep; fatigue and durability of fly ash based geopolymer concrete with steel slag aggregate.

Study on technology of geopolymer with steel slag aggregate roller compacted concrete.

It is necessary to continue to study the application of fly ash based geopolymer using steel slag aggregate with different steel slag sources in different regions and especially with treated and untreated fly ash.

PUBLISHCATIONS

1. Dao Van Dong, Trinh Hoang Son, Patent "Method of fabricating geopolymers concrete using completely steel slag aggregate and geopolyme concrete obtained by this method". Application number 2-2019-00367. (Accreditation decision of the Intellectual Property Department, Ministry of Science and Technology, No. 11189w/QD-SHTT July 31, 2020)
2. Dao Van Dong, Trinh Hoang Son, ‘Study, manufacture fly ash based geopolymer concrete totally using steel slag aggregate”. Win second prize at 7th Vinh Phuc Technical Creation Contest 2018-2019.
3. Dong Van Dao; Son Hoang Trinh; Hai-Bang Ly; Binh Thai Pham: Prediction of Compressive Strength of Geopolymer Concrete Using Entirely Steel Slag Aggregates: Novel Hybrid Artificial Intelligence Approaches (3/2019). MDPI Journal of Applied Sciences, Special Issue Soft Computing Techniques in Structural Engineering and Materials, Vol 9. SCIE, IF 2.217. ISI Journal.
4. Dong Van Dao, Hai-Bang Ly, Son Hoang Trinh, Tien-Thinh Le and Binh Thai Pham: Artificial Intelligence Approaches for Prediction of Compressive Strength of Geopolymer Concrete (3/2019). MDPI Journal of Materials, Special Issue New Advances in Self-Compacting Concrete and Geopolymer Concrete, Vol 12. SCIE, IF 2.217. ISI Journal.
5. Dong Van Dao, Son Hoang Trinh: Mechanical properties of fly ash based geopolymer concrete using only steel slag as aggregate (2019). Springer Nature Singapore Pte Ltd. 2020; C. Ha-Minh et al. (eds.), CIGOS 2019, Innovation for Sustainable Infrastructure, Lecture Notes in Civil Engineering 54. Scopus Index.
6. Dong Van Dao, Son Hoang Trinh: Design method for optimizing geopolymer concrete proportions utilising entirely steel slag aggregates (2019). Springer Nature Singapore Pte Ltd. 2020; C. Ha-Minh et al. (eds.), CIGOS 2019, Innovation

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